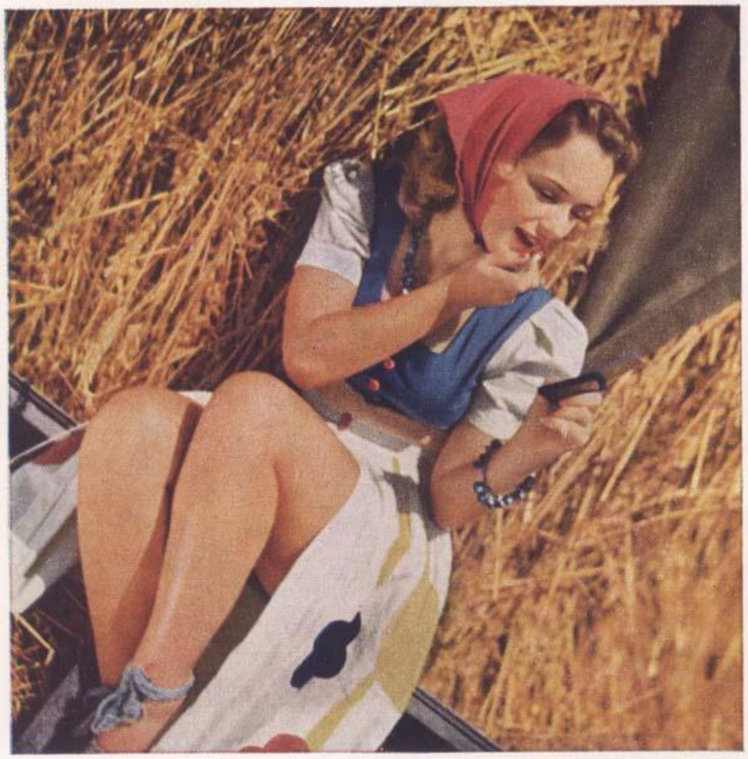
HAZELTINE'S COLORFUL DAYS

by B

(a)

(b)



(c)

Courtesy of Evans, Introduction to Color

Demonstration that low-definition color added to a high-definition black-and-white picture gives good color reproduction. Note high-detail black-and-white view (*a*), to which addition of low-detail color (*b*) gives high-grade color view (*c*).

HAZELTINE'S COLORFUL DAYS

By

Bernard D. Loughlin

June 24, 1988

HAZELTINE'S COLORFUL DAYS

TABLE OF CONTENTS

APPENDICES:

A A SUPPLEMENT TO THE EARLY HISTORY OF COMPATIBLE COLOR TELEVISION

B F.C.C. CRITERIA FOR COLOR TELEVISION

C HISTORY OF HAZELTINE RESEARCH, INC., - PEOPLE, PLACES AND PERSPECTIVES

D HAZELTINE SERVICE CORPORATION REPORT NO. 1157W - A PHASE CURVE TRACER FOR TELEVISION

E HAZELTINE CORPORATION REPORT 7116 - RECENT IMPROVEMENTS IN BAND-SHARED SIMULTANEOUS COLOR TELEVISION SYSTEMS

1

INTRODUCTION AND SPECIAL ACKNOWLEDGMENT

INTRODUCTION

This story centers around that colorful period of 1949 through 1955 during which Hazeltine Corporation was a leader in color television systems development. Hazeltine became known throughout the engineering world not only for its technical contributions to color television but also for its outstanding teaching demonstrations of color television principles. I was right in the middle of those COLORFUL DAYS, working hard on both the demonstrations and in making technical contributions. It was a most exhilarating period; we had an excellent leader, Arthur V. Loughren, and an outstanding supporting staff including such members as William F. Bailey, Charles J. Hirsch, R. Page Burr, just to name a few in these introductory remarks. Many patents came out of that period and a number are still used in all color television receivers and transmitters. Of course, most of these patents have expired many years ago.

During the major part of my career at Hazeltine, I have been involved with the consumer-electronics activities (i.e., radio and television) in which the pay-off was by royalties on patents. Important and strong patents were essential, and I contributed significantly to Hazeltine's group of color television patents. In many ways the story about Hazeltine's efforts in color television is related to my personal career; so I plan to discuss those parts of my career that have some bearing, either direct or indirect, upon this color TV story.

Hazeltine started as a small engineering/patent company in the radio field (now called the consumer-electronics field). Except for a brief hiatus during World War II, Hazeltine has had a continuing activity in this consumer-electronics field with patent royalty income. This activity is now again very small. But there was a great pinnacle of effort and accomplishment - those COLORFUL DAYS - when Hazeltine was a leader (second only to RCA) in contributing to the development of compatible color television. Although that period was over 35 years ago, we are still collecting some small patent royalties on that color TV effort. That income is expected to continue until the turn of the century.

I will try to treat both the pre-pinnacle days leading up to those COLORFUL DAYS, and the post-pinnacle days with its many varied facets. These include such items as: projection color TV, color film analyzer, antitrust suit, technical papers, and awards. But I will start with my story prior to arrival at Hazeltine's door.

For convenience, in this treatise, I will use the name Hazeltine to refer to Hazeltine Corporation and its subsidiaries, except where further description is needed for clarity.

SPECIAL ACKNOWLEDGMENT

Hazeltine's Colorful Days would not have happened except for the foresight and leadership of Arthur V. (Art) Loughren. He convinced Hazeltine management to invest in Color TV R&D at the right time. Then Art provided excellent leadership to Hazeltine's color television activities. After we had accomplished some really worthwhile results, he then broadcast the technical news to the television industry and to the governmental agencies. As a crowning step, Art provided leadership within the Second (Color) NTSC (National Television Systems Committee); particularly through leadership of NTSC's Panel 13, which recommended the standards for the complete video signal which the FCC (Federal Communications Commission) finally accepted as the Color Television System of USA.

2

PROLOGUE AND FORESHADOWINGS

2.1 Some Family Background Before BDL

In the late 1700's, a Bernard Loughlin came from Ireland; I have reason to believe from the County of Donnegal[1]. He came through the port of Philadelphia. The sketchy information we have indicates that the family line stayed in the Philadelphia and Southern New Jersey area. My grandfather, Dunlevy Loughlin, raised his family in the general area of Williamstown, New Jersey, and environs. Dunlevy had two sons, Bernard (my father), and Stanley (my uncle). My grandfather was a hard working and happy carpenter and gardener. My father was a very methodical railway mail clerk and my Uncle Stanley was a printer, having a complete printing press and accessories in my grandfather's basement.

My father left Williamstown, New Jersey, and went to New York City for a railway mail clerk job in 1914. Somewhere before May 1916 he met a sweet young girl, Hazel Hawley, at a church affair. He eventually persuaded her to marry him. Now enters another family member who had a very profound effect upon my career development. Hazel Hawley had a sister, Edna, who had married Charles A. Wingardner. This completes the close-knit "family circle," into which I was born on May 19, 1917, in Harlem, New York City. My parents named me Bernard Dunlevy Loughlin in honor of both my father and grandfather.

2.2 The Move To Philadelphia

In 1919, my father took on a new railway mail clerk job in Philadelphia, and we moved to 6038 Regent Street, a row house in West Philadelphia. Now we meet a young girl eventually to become the most important person in my life: Dorothy Turner. There were two Turner brothers, immigrants from Britain, who lived at the end of the block and

1. Unfortunately, early documented data on arrivals at the port of Philadelphia were destroyed in a fire early in the 1800's. But the fact that it was a Bernard Loughlin who emigrated to Philadelphia was verbally passed down through the family. Also the family recollections seemed unclear as to whether an "O'" or a "Mc'" prefix was on the Loughlin name. Additionally, the family story was that he came from Cork, but this may merely have been the port of embarkation.

   In September 1977, Dorothy and I vacationed in Ireland. We were on a planned tour without time for "family-tracing". But I did have an opportunity to look through the telephone directory for all of Ireland (about 3/8" thick!) and found: 1) no Bernard Loughlins; 2) no Bernard O'Loughlins; 3) many Bernard McLoughlins (with differing middle initials), up in County Donnegal. Also our tour took us through the town of Donnegal - there was a store by the name of Dunlevy's. In addition, a Family Name map has McLoughlin and McDunlevy near each other in County Donnegal.

across the street from each other. Alf Turner and his wife, Emma, had two daughters, Ethel and Edith. Bill Turner and Laura had one daughter, Dorothy, somewhat late in life.

The two Turner families and the Loughlin family remained friends for the rest of their lives, and all of us kids referring to the other parents as aunts or uncles. We have two classic pictures taken on the small front lawn on June 25, 1922, one with all three girls and me, and one of just Dorothy and me. I was obviously very disturbed: the girls were in bare feet, but my mother would not let me take off my shoes!

Dorothy and I were of the same age and when school started, Hazel and Laura took turns in walking the two of us to school, across those dangerous trolley tracks.

Before leaving Philadelphia, I must recall the Gallagher sisters, two maiden teachers who lived between us and the Alfred Turners. They spent a lot of time with me, teaching me to both read and to use a typewriter, before I started Kindergarten. The reading was important but the typewriter was not of much value in Kindergarten.

Some time in 1923 my father took a "real" railway mail clerk job, that is, sorting mail in a traveling train (all his other jobs were "terminal" jobs). This new position was on a train between Camden, New Jersey, (which is just across the Delaware River from Philadelphia) and, as I recall, Millville, New Jersey. He decided to settle in a little town between Camden and Millville; a town called Woodbury Heights. My grandfather built the house for us, finishing it in 4 months.

2.3 Woodbury Heights and Some Foreshadowings

We stayed in Woodbury Heights from 1923 until 1928 and more foreshadowings of the future showed up. On one Christmas, my father gave me a Lionel train set mounted on a board setting on the floor. It had two home-made train stations. One was made by my father and the other by my grandfather. The larger station had the name "Barneyville" on it which pleased me no end. I believe the train set was my starting experience with electricity.

One birthday, my father bought (in Philadelphia) two small books which I read many times. One was on astronomy and the other on electricity, including X-rays. Astronomy is now one of my hobbies; electricity and electronics became a hobby and then my business.

My father bought a radio and put up a long high outside antenna. Of all things, the receiver was a Neutrodyne. I often puzzled about those two big coils in the inside back of the cabinet. I recall the unusual situations when I was allowed to stay up late and we (my father and I) occasionally heard KDKA in Pittsburgh and KOA in Denver (real DX).

My father played the organ at the little church down the street, and he also played the piano that we had at home. Frequently, when my Uncle Charlie and my father got together, they played duets, my uncle on the violin and my father on the piano. My mother tried to send me for piano lessons, but I preferred to play with my erector set!

This seems like a good place to make it known that my Uncle Charlie was an electrical engineer by profession, working at Bell Telephone Laboratories on at 463 West Street in New York City. He graduated from Cooper Union in 1919 from night school. This was quite a long grind for him to pull himself into a profession; taking six years at night school; having a family and a daytime job with the Edison Power Company.

The next interesting foreshadowing while we lived at Woodbury Heights was during a trip to the Sesquicentennial Exhibition in Philadelphia. One popular and crowded exhibit was TV. I can recall my father lifting me up to see over the crowd, and at the other end of the room was a neon colored image about two inches by two inches. This was 1926 and the TV set used a whirling disk with a spiral set of holes, in front of the flat neon tube, to produce the scanning (probably 60 lines). The transmission was probably from the Jenkins experimental TV station, broadcasting just above the broadcast band, where the present 160 meter amateur band exists.

On December 4, 1926, my sister, Vivian Marie, was born. At first, she seemed rather sickly until my parents found the correct formula and then she blossomed out. The 9 1/2 years difference in ages almost put us in different generations. But with progressing years the significance of the age difference disappears.

An additional item before leaving Woodbury Heights. I won my first two awards early in 1928; one was 1st prize in a manual training contest (shop); the other was 2nd prize in a music appreciation contest. These skills were probably inherited from my grandfather and father, respectively.

So if one were to believe in foreshadowings, while at Woodbury Heights one might see: "Hazeltine" (the Neutrodyne); "DX Radio"; "Television"; and "Awards" as things to come.

2.4 Back To Philadelphia

In those days, a railway mail clerk on the train was required to wear a loaded gun. This eventually affected my father's gut, giving him stomach ulcers. He was required to get off the train and get another job in a terminal.

My father found a terminal job at the Sears and Roebuck main catalog warehouse in Philadelphia. In September 1928 we "swapped houses" with another family at 7028 Gillespie Street, Tacony, Philadelphia. This was a "twin" house, i.e., attached to an adjacent house on one side only. At this time, Vivian was just under 2 years old and I was just over 11 years old.

Soon, I had taken over my electric trains; that is, I did not need my father's help. For a year or so, the trains consumed my interest, particularly around Christmas time when I put them up in the living room. When my Uncle Charlie and family would visit, I would ask him how an electric motor worked. I remember getting some puzzling answers, including "back emf"! This was the start of a regular dialogue and learning session for me whenever Uncle Charlie came.

My train set had 2 engines, a crossing and 2 switches. I had constructed a makeshift relay system (from the electro-magnets of several electric bells) so that the two trains could run at the same time; automatically stopping at switches and crossings; waiting until the other train went by; and then starting up again. I recall being very proud of that set-up and quite willing to demonstrate how long the two trains could run around the same set of tracks without a crack-up[2].

During the mid '20's, my Uncle Stanley became interested in building his own radios (it was the thing to do then) and had collected a lot of radio parts. In the late '20's, he gave up that hobby and sometime before 1930 he gave me a large sturdy wood box (an old WWI ammunition box) all full of radio parts and some radio magazines. That started me playing around with radio.

My first effort was a neat little crystal set that I built in a small box (about 5" x 2 1/2" x 1 1/2"), using a small tuning capacitor (probably intended for fine tuning or neutralization use), a small inductor that I had wound on a thread spool, plus crystal and by-

---

2. While being quite proud of what I had done (with the train set-up), I was also quite shy. I recall one Christmas when Dorothy and family visited us. I gladly showed-off the train set, but never spoke a word to her until about 2 minutes before they were to leave. This dichotomy between pride in specifics of what I had accomplished and general bashfulness stayed with me throughout much of my life. But age has helped the battle!

pass across headphones. It was a complete flop; I didn't hear a thing. Soon though, I went to the library; got a copy of Morecroft; and tried to learn about inductance, capacitance and resonant frequency. It took quite a while to sink in before I realized I was not tuned anywhere near the broadcast band.

The next experiments were with regenerative receivers using larger variable condensers from the ammunition box, plus various of the variometers. These were more successful and I did much listening on the AM broadcast band.

One receiver I built, from parts in the ammunition box, used a unique design of variable capacitor (made by Remler) in which both sides of the capacitor varied in such a way as to permit a very low capacitance on the low C end. One day, while listening with the receiver, I heard a very unusual buzzing noise at the high frequency end of the AM broadcast band. Eventually the buzz stopped and they announced that they were broadcasting experimental television from the Jenkins station.

The above experience suddenly made me aware that short waves existed and I started short-wave DX listening. Eventually, I got a QSL card made up by my Uncle Stanley, and I was in the short-wave listening business, listening to both broadcast and amateur short wave radio, with a simple regenerative receiver with plug-in coils to change bands. Of course, I had to learn how many turns should go on the coils that I made, and I used what I now know was Harold Wheeler's short formula for inductances.

Eventually, I got a friend, William A. Blum, who lived a half block away, interested in short waves. As I remember, I helped him build a simple regenerative receiver with plug-in coils. It wasn't long before we were practicing code, sending to each other by keying the receiver when in an oscillating condition. In the summer of 1933 we both obtained our Amateur Radio licenses; Bill's call was W3EAV*; mine was W3EAL. My station license was listed as Williamstown, New Jersey, because I received the license during a summer which I spent at my grandparents' house.

Now to backtrack a little - the first 2 years in Tacony I finished 7th and 8th grade at a school just several blocks away. Then on to high school at Frankford High, a trolley ride away. My curriculum at Frankford High was an excellent one, intended specifically for someone expecting to go on to an engineering college (although I had no idea how I could manage college). At Frankford High, I participated in the Engineers Club, the Chess Club, and the Radio Club. I have group pictures to prove it - but I don't remember

---

* Bill had a stroke in 1982 and died in 1987.

any names except for Bill Blum in the Radio Club. I recall one time putting together a special breadboard to illustrate certain specific types of circuits and then demonstrating them at one of the Radio Club meetings.

Just in passing, I received another award in high school called the Stehl Memorial, but I can't remember what it was for, nor when. There is no date on the newspaper clipping that my mother kept.

In the meantime, over a period that I believe included 1931 through 1933, my mother had several operations, and these were extremely painful. In early 1933, the pain from these operations affected her mental capability and she was never the same after this. At times during 1933, she actually had violent periods. During some of these periods, Vivian stayed with my Aunt Edna and Uncle Charlie in Chatham, New Jersey, and during the summer I stayed with my grandparents in Williamstown, New Jersey. My mother insisted that she wanted to leave Philadelphia and go to live in North Jersey near her sisters. My father finally gave in, found another railway mail clerk job in Hoboken, New Jersey. We moved to Jersey City, New Jersey, in September 1933. In addition, this was a period in which houses were not selling, and so my father had to "walk-away" from the house in Tacony, losing all his equity in the house - never to own a house again.

There was a significant and lasting change in my mother's personality. She was normally very pleasant and extremely tolerant about things that we did. However, now it seemed as if my mother was no longer truly my father's wife[3].

2.5 North Jersey

During the next 6 years we moved around 6 times, I believe mainly due to my mother's discontent. The first place was an apartment (4th floor) in Jersey City near Journal Square. Second was a two-family house on Highland Avenue in Jersey City, and the remaining places were all two-family houses. Next was Davis Avenue in East Orange, then Union Street in Jersey City, then 17th Street in East Orange, and finally on September 1, 1939, as Hitler marched into Poland, we moved into New Street, East

3. My mother frequently developed an adversary relation against my father. I was 16 and thoroughly involved in radio and eventually engineering college. So the situation was one that I "tolerated" but tried to talk over with my mother many times with no success. The effect upon my father was obviously devastating and also very significant upon my sister who was only 7 years old at the time things started. My mother and father stayed together until their deaths in 1972, within 2 weeks of each other. At my mother's casket, my father said "I guess I did the best I could for her."

Orange. By this time, my mother was "calming down" and my parents stayed at New Street long after my sister and I left home.

This move to North Jersey had both positive and negative effects upon my education. When I left Frankford High, I had 3 1/2 years of credits of value toward a further engineering education. But in Jersey City High, they had no equivalent course. I lost credit for some of the courses I had in Frankford and had to take two sophomore courses in my senior year. I just made enough credits to graduate in 1934. But on the positive side, we were now near New York City, and an attempt to get into Cooper Union made sense. If I could make it, Cooper Union was very attractive for me since tuition was free, entrance being by competitive exam (about 1 out of 10 making it).

Luck was with me and I made it into Cooper Union. My parents agreed to handle the cost of books, transportation, and my living at home. My mother was very strong against my working to make money, even during the summer, and my parents agreed that I should go to CU day school (instead of CU night like my Uncle Charlie had done). In 1934, many people were without a job or only working part-time. Even Bell Labs had a part-time arrangement (in place of firing) so even my Uncle Charlie was only working part-time. On the other hand, my father had a civil-service job and, relative to the average public, was doing well.

2.6 Professional Development

During the 6 mobile years mentioned above, most of my time not spent on school work was spent on radio and eventually TV experimentation, in addition to operating my amateur rig (mainly on CW (code)). My parents gave me a small weekly allowance which went into radio parts, frequently from the Courtland Street area of New York City.

Most of my time on the air was in 1934, 1935, and 1936, and a lesser amount in 1937. My log for late 1936 and most of 1937 indicates I was very busy with school and also did not have a good transmitting antenna. During the summer of 1937, I recall getting my SW3 receiver to work up to 40 MHz. This permitted me to listen to both Armstrong's experimental FM transmissions (received by side-tuning) and NBC and ABC's experimental AM transmissions in the same general frequency band.

My log also indicates that during the periods of 1934 through 1936 I spent many hours on the air; I also spent many hours experimenting with various transmitter arrangements of tubes, power supplies, electronic keying "bugs", and the like[4].

In passing, I might mention that sometime during 1938 ±1 year I saw a very impressive demonstration at Bell Telephone Labs in New York City. They had constructed a 6 foot long CRT which permitted a very flat and very linear picture of about 1 foot in size. This was a precision tool for testing TV via inter-city coax cable. The subject matter of the demonstration was a "March of Time" including a shot of the Hindenberg disaster (of May 1937). The resolution and grey scale were good enough to make the subjective effect be very dramatic, and unforgettable.

By the summer of 1938, we were at 17^{th} Street, East Orange, and my log shows limited time spent on 5 meters and 10 meters. This was a critical summer for me. I had failed German twice and if I did NOT pass the re-exam I would be kicked out of Cooper Union. My father located a friend who would tutor me in German for the summer. The German course at CU was crazy! First, it was a one-year course and required for graduation. Second, during the year we studied kids' stories, and then the final exam was one page of semi-technical German!

The first time through I flunked with an F and couldn't take the re-exam. I had to take the course a second time. This time, I got a "conditional" failure which permitted taking the re-exam. When my tutor heard the story, she went over to Barnes and Noble and got a book of short ("one page") semi-technical stories. As we approached the end of the summer session, I recognized two of the stories as being ones I had failed. Then, by a pure stroke of luck, the last lesson we studied turned out to be the final re-exam given by CU's German teacher. This time, I passed with an A!

This above situation resulted in stretching out my studies to five years instead of four. With some foresight, I finished all of my electrical subjects in the first four years, so during the fifth year I not only had some spare time, but I had my EE subjects behind me.

2.7 My Entry Into TV Engineering

But backtracking a little, I celebrated my 21^{st} birthday in 1938 by having an operation removing all four wisdom teeth. I think my parents felt sorry for me and gave me an "extra special" birthday present - enough money to buy a 902 - a 2" cathode-ray tube. Before this, I had been following two sets of articles that intrigued me. One was by Don

4. My favorite transmitter arrangement had a push-pull pair of 46's (Class B tubes) with the second grid connected as a "partial" screen grid.

Fink in "Electronics", on how to build a TV set. The other was by (Prof.) Jesse B. Sherman of RCA (and later CU staff) in "QST" on circuits for TV.

Using the information in both of these articles, I first built scanning circuits for the 902 to make an oscilloscope. Then I built a so-called wide-band IF amplifier to use in a TV set. None of the articles told me what to do for the IF transformers, so I took HAW's simplified inductance formula and calculated what the self and mutual inductances would be between a set of coils wound end to end - in terms of the length/diameter ratio. This, in conjunction with the input and output capacitance of the IF amplifier tube, permitted me to construct a reasonable wide band amplifier without test equipment to measure it.

Just before the 1938 hurricane, I got the TV set working and saw several transmissions from NBC. Then I invited several of the CU-EE Department professors over to take a look, but NBC did not come on - they had "pulled the switch" to make a series of upgrades (including scanning rates) prior to the 1939 World's Fair. Incidentally, the day of the invitation turned out to be the day of the hurricane (September 21, 1938) which devastated much of eastern Long Island!

During the winter of 1938-1939, I worked with Jesse Sherman, at CU, designing and building a CRT oscilloscope for use in the EE Lab. Also during that winter, I had a TV set (at home), switchable to be mainly an oscilloscope, but NO TV transmissions. I had gotten the German problem out of the way and had made a little money with a night-time, part-time job at ESSO in the RCA Building, during August 1938. The subject of how to display swept phase characteristics on a CRT started to intrigue me.

Actually, I wanted some kind of display of both amplitude and phase vs. frequency, so I first constructed a frequency-modulatable oscillator and drove the CRT horizontal plates with the same sawtooth source that modulated the oscillator. I used a broadcast AM receiver IF as a "test circuit" and drove the CRT vertical plates with the output signal of the IF after amplification through a wide-band (i.e., flat) amplifier. This gave a varying amplitude sine wave whose envelope showed the amplitude response of the IF vs. frequency.

To display the effect of phase, I generated a short pulse from the sine wave input to the "test circuit". The short pulse was applied to the control grid of the CRT to brighten the trace at the time of the peak of the input sine wave - the position of the brighter pulse along the vertical sweep representing the phase shift through the circuit. This system I dubbed as a "Vector-Response Indicator", and its operation should be clarified by the attached set of figures[5].

I decided to present this system at the 13th annual AIEE students convention hosted by Cooper Union and held on April 27, 1939. Photographs of the system block diagram and of patterns on the CRT were taken with my father's "folding camera". Then we developed the film; made lantern slides; prepared the text for the technical paper; presented the paper in the Great Hall of CU; and won first prize.

The World's Fair opened on April 30, 1939. On my 2" picture tube (902), I saw President Roosevelt and Grover Whalen at the opening ceremonies. From then on, NBC's W2XBS was on regularly with good live programs and demonstration periods for the World's Fair audience with short "March of Time" films.

This was my background when I went looking for a job. First priority was Bell Labs, following my Uncle Charlie's footsteps. But at Bell Labs I was told: "We have enough Cooper engineers." - I was crushed!

Then I decided to drop in at every radio plant I could find in New York City, asking to see the Chief Engineer. These were the days when radio engineering was done in New York City! Of course, I stressed my interest in TV. The standard response was either, "not interested", or no response at all. That is, until I reached Emerson Radio, where the Chief Engineer, Dorm Isreal, came out and talked with me. He said that the New York City radio manufacturers were far from being interested in TV and suggested two places around New York City that were doing TV research: one was RCA License Lab and the other was Hazeltine, and he gave me the names of the persons to whom I should write. Of course, I knew about RCA's interest in TV but didn't know who or where to contact. Hazeltine, I knew practically nothing about them. Letters were sent out on May 31, 1939. Hazeltine answered right away and promptly set up an appointment. Dan Harnett, Les Curtis and Harold Wheeler interviewed me on June 6, 1939. The first two interviews were mainly technical questioning to see what I knew about radio and TV. Harold Wheeler's interview was mainly a discussion of my "Vector-Response Indicator" with strong encouragement to prepare it for publication. Wheeler reports in his writings that all three were sufficiently impressed to hire me before I left the lab that day[6].

The 80th Annual Commencement of CU was held June 8, 1939, in the Great Hall of Cooper Union. I started work at Hazeltine on June 19, 1939, just one month after my 22nd birthday, and about 2 months after the Little Neck Lab was opened. Thus entered Hazeltine into my life.

---

5. See Photos 1 and 2 at end of this section.
6. See HAW's book, "The Early Days of Wheeler and Hazeltine Corporation", page 154.

Incidentally, a letter was also sent out to the RCA License Laboratory in New York City at the same time I sent out the inquiry to Hazeltine. But I was already working at Hazeltine before I even received a response from RCA!

Historically, in June 1939, the starting salary for a new engineering graduate was $25 per week at Hazeltine. If I had a Master's Degree, I would have received $27.50 per week. Of course, this was the end of the depression and salaries had not "taken off" as yet. Actually, the per hour $'s from my office boy job at ESSO in 1938 were somewhat more than the $'s per hour from Hazeltine. In a few years, inflation during WWII soon rectified that situation.

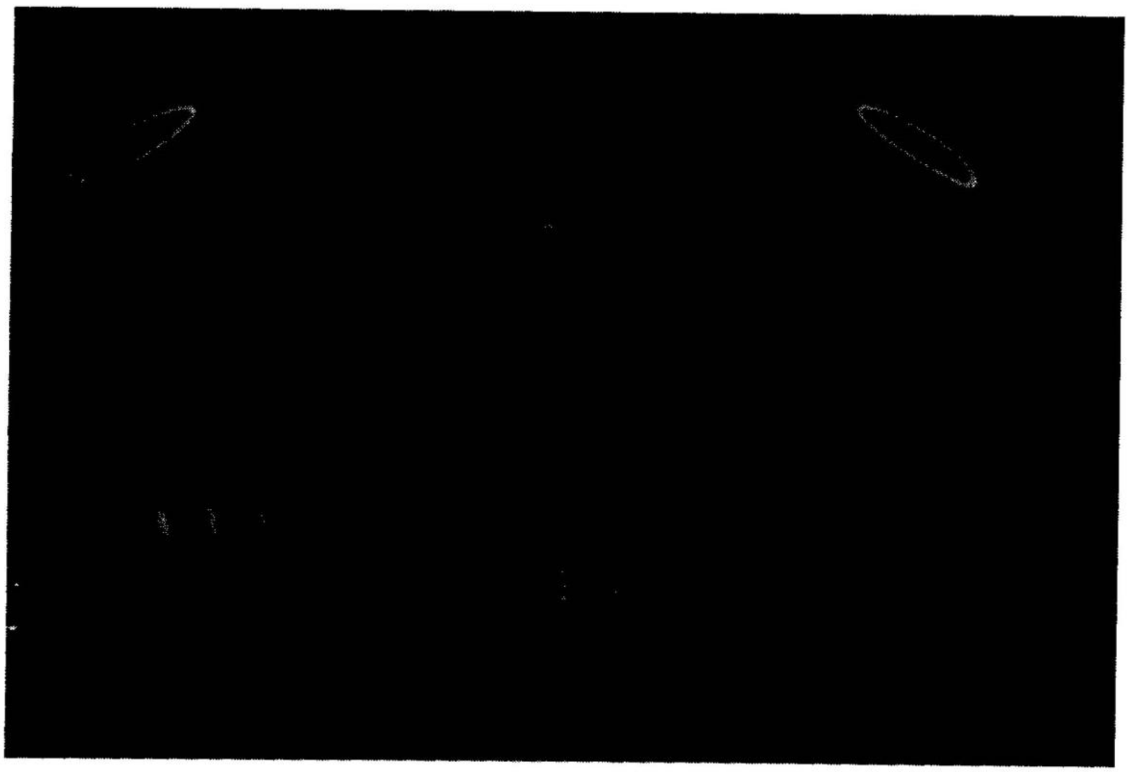


Photo 1. Comparison between elliptical-trace and reference-point methods of phase-angle measurement.

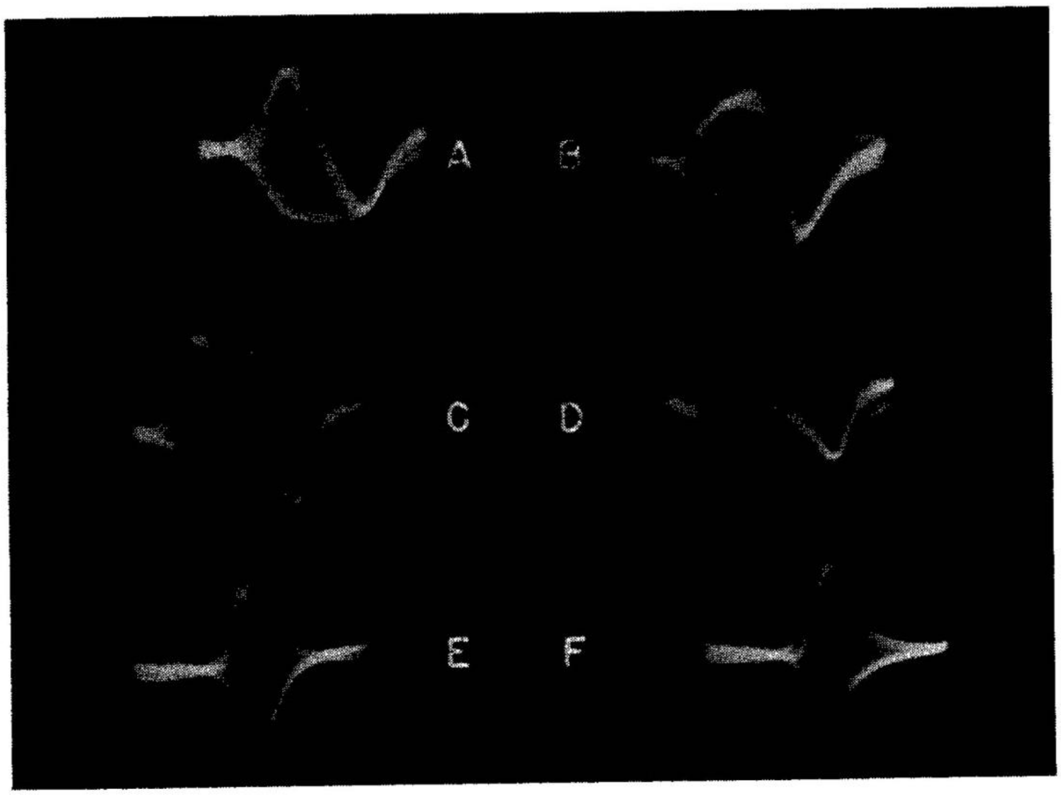


Photo 2. Vector response patterns for a band-pass amplifier with a double-tuned input circuit and a single-tuned output. (A) Proper adjustment of all circuits; (B) Similar to A with single-tuned circuit tuned above mid-band frequency; (C) Insufficient loading in double-tuned circuit; (D) Similar to C with single-tuned circuit tuned below mid-band frequency; (E) Less than critical coupling in double-tuned circuit; and (F) Similar to E with single-tuned circuit tuned above mid-band frequency.

3

TV AT HAZELTINE BEFORE JUNE, 1939

Hazeltine had been working on TV since 1932 and the activity was intense preparatory to the opening of the 1939 World's Fair in April. Some highlights of the activity were:

1. The construction of a camera tube by Dr. Hergenrother (starting in 1935) to provide a live test signal - useful when RCA was off the air.

2. A continuing series of TV receiver models with various improvements. When I arrived, Model 18 was just being completed, using a 45 degree mirror to view a long 12" CRT mounted vertically.

3. Wheeler and Loughren had made several fundamental studies regarding the scanning process and resolution.

4. A series of educational lectures had been conducted for the Hazeltine engineering staff starting late in 1936.

This series of TV efforts are detailed in Section 7, Television, of HAW's book "The Early Days of Wheeler and Hazeltine Corp." Selected portions of Section 7.1, TV 1932-41, are included below, but the reader is referred to HAW's book for the complete story.

3.1 The Start In TV

Our activities in television (TV) started under Harold M. Lewis in the Bayside Lab in 1932. He perceived the future of TV and was naturally motivated to explore this new field. He chose Madison Cawein as his assistant. From this autonomous group, the television work grew to be utilizing most of our expanding staff at the end of the decade. The staff was integrated under Dan Harnett when he took charge of Bayside late in 1936.

Before 1932, TV had progressed to the stage of mechanical scanning in the transmitter with electronic scanning in the receiver. The 1932 experimental transmissions by RCA were characterized by 120 lines for electronic scanning in the receiver (on a cathode-ray oscilloscope used as the picture tube). About 1933, the RCA image-storage tube (the Zworykin "iconoscope") enabled efficient electronic scanning in the camera tube and thereby set the future course for all-electronic scanning. By 1938, the line frequency had progressed to 441.

Lewis and Cawein were the prime movers in our TV program from the beginning in 1932 until late in 1936, when Harnett was given the overall responsibility of the Bayside Lab. They were joined in 1935 by Hergenrother who made the camera tube we needed for a complete system demonstration. To these three men goes the primary credit for the timely launching of our expanding TV activities.

Early in 1932, Lewis and Cawein planned and made an elementary receiver for the TV signals then being broadcast by RCA on an experimental basis. They brought to this project some recent experience with short-wave receivers in our labs. This TV receiver was demonstrated and another one was made for Philco. Late in that year, Lewis made a plan for TV development in the Bayside Lab.

From 1933, there was one line of development of the various kinds of test equipment needed for TV receivers. Furthermore, we needed a camera tube for generating a video signal to be used for picture reception.

3.2 The Camera Tube

The camera tube which we made in the Bayside Lab in 1936 was one of the principal achievements in our TV program. It was remarkable for its planning and its successful execution. It was essential to the complete demonstration we were assembling in our lab. Among other things, we recognized the need for a camera tube in order to test and to demonstrate our TV receivers without relying on the RCA programs from the Empire State Building. They used the Zworykin "iconoscope" which was not available outside RCA. Therefore we would have to make one. It was one of the most sophisticated of electronic devices up to that time. We had no background or competence in making a vacuum tube of any kind. A fortunate set of circumstances led to a solution of our problem.

Madison Cawein had been a member of our engineering staff for 5 years and was then working with Lewis in the main line of our TV program. He had become acquainted with Rudolph C. Hergenrother, and their friendship grew while they were later both employed at Westinghouse in Bloomfield, N. J. In 1935, Dr. Hergenrother had been working on TV tubes in Farnsworth Television Labs. Cawein invited him to join our staff, and we employed him to make the camera tube we needed. Hergie brought to us a powerful blend of all the education and skills that would be required. Those ranged from a Ph.D. in Physics at Cal. Tech. to practical experience in glass blowing.

Starting from scratch in the old Bayside Lab, Hergenrother equipped a tube laboratory for the processes needed to make a camera tube patterned after the RCA model. In 1936, he made such a tube with excellent performance. It placed us in the position of being the only lab outside RCA to have an equivalent camera tube. At that time, other labs outside RCA had to use a stationary pattern in a simulated camera tube ("monoscope") for modulation in a signal generator. We were unique in capability and were established as the leader outside RCA.

3.3 The Main Line of TV Development

The main line of TV development was a series of receivers embodying improvements as time went on (1936-40). This occupied an increasing number of our staff, mostly at Bayside and later Little Neck but also in New York. HAW's active participation in the TV program began with the design of RF, IF, and VF (video-frequency) circuits with the first receiver in this series. It was his introduction to the circuit problems peculiar to picture reproduction as distinguished from sound. This led to his intensive studies on these and other topics in TV.

Each receiver in this series was planned to meet a particular need and/or to demonstrate some features. One of our more recent models was usually installed in MacDonald's office in the New York Lab for showing to visitors. Some were operated in our homes for a while to gain experience.

The earlier receivers contained picture tubes with rather small screens for close viewing. With the advent of larger screens, the tubes became longer so the customary horizontal axis required excessive depth behind the receiver cabinet. Then two alternatives were needed: the mounting of a long tube with vertical axis, adapted for horizontal viewing in a 45^{o} mirror above the cabinet; or the design of a "short" tube for horizontal mounting and direct viewing.

During this period we benefited greatly from the addition of three brilliant and experienced engineers to our staff: Arthur V. Loughren from GE and RCA, John C. Wilson from CBS and previously Baird in England, and Leonard R. Malling also from Baird.

Jack Wilson had just published the first textbook on television engineering. It was a scholarly presentation based on his experience in Baird Television, Ltd., the pioneering company in England. He was familiar with analytical concepts related to TV and introduced them in our lab. A friend of his at Baird was Leonard Malling, who came to the U.S. later. Malling's genius was practical applications of new ideas.

Art Loughren and HAW were much interested in the basic relations in a TV picture. They developed some concepts which were related to the reproduction of a pictorial image by the scanning process. Their joint 1938 IRE paper on this topic became one of the basic references on this subject. It related the vertical and horizontal fineness of resolution as limited by the number of lines and the frequency bandwidth of light variations along the line.

One defect was the widening of a vertical line and fringing effects in its image. Some widening was unavoidable with a restriction of the frequency bandwidth. This was simply seen as a blurring of the image. Further visible distortion appeared as ripples either side of the line. These were identified with amplitude and/or phase ripples in the frequency response in the wideband circuits of the transmitter and receiver. The amplitude and phase distortion in the circuits was interrelated so its interpretation was complicated. HAW perceived a formula for independent interpretation in terms of "paired echoes". His IRE talk in 1938 was the first publication of this formula and attracted much attention in the profession.

Wideband amplifiers present one of the principal problems in the design of TV circuits. We had known that the shunt capacitance in a vacuum tube imposed a bandwidth limitation by virtue of its charging time. About 1937, HAW perceived that there was a simple rule for stating the upper limit of level amplification that could be obtained from one tube over a specified bandwidth. HAW was the first to publish this limitation, in his talk to the IRE Annual Convention in New York on June 18, 1938. It was entitled, "Wideband amplifiers for television". These three IRE papers, relating to TV, established HAW's status as a leader in the field. They were a suitable subject for the Morris Liebmann Memorial Prize awarded annually by IRE.

3.4 Classes

It was our custom to hold a series of classes about once a year. Its purpose was continuing education and reporting on current developments. The classes were scheduled during working hours. One of HAW's principal functions was organizing each series and conducting some or all of the classes. On the subject of television, we held six series, although the last was curtailed by the priority of war work.

a. December 8, 1936 - January 20, 1937, Bayside, eight classes conducted by HAW. They were attended by all the Bayside engineers and a few from New York, a total of about 16. They were directed mainly to wideband circuit design.

b. September 23 - December 14, 1937, Bayside, eleven classes at Bayside except the last which was demonstration in New York Lab. The first was conducted by Harnett and Cawein.

c. March 8 - May 24, 1938, Bayside, eight classes. The first was conducted by Loughren and the second by Curtis and Freeman. HAW conducted the remaining six. This was the first presentation of his new concepts of paired echoes, wide-band amplifiers and feedback filters. They aroused much interest and the attendance was most of our growing television staff.

d. October 3 - December 5, 1939, Little Neck, nine classes, of which HAW conducted five. He spoke on sawtooth-current circuits for magnetic scanning.

e. January 9 - March 5, 1940, Little Neck, seven classes. The speakers and their topics were:

    Sturm, the antenna impedance meter.
    Tyson, the antenna circuit of a TV receiver.
    Loughlin, the phase-curve tracer for TV.
    Malling, an economical TV receiver.
    Curtis (2), frequency modulation.
    Rado, a curve tracer for TV.

f. October 22 - 29, 1940, Little Neck, only two classes. Loughlin spoke on his phase-curve tracer and HAW spoke on shortcuts in computation (the reactance chart and the sliderule).

These 45 classes in a period of four years contributed very much to the development of our engineering staff and to the result of our leadership in television outside RCA. Concurrently with these classes, we prepared a cumulative textbook entitled, "Television Principles". It was written in 1938-40 by Dr. Charles E. Dean, who was experienced and talented in technical writing. He used material from our classes and other sources. He wrote 13 chapters in the form of laboratory reports which were serially printed and distributed to our engineers and our licensees. Then the work was terminated in favor of war work. HAW prepared the drafts for the last three chapters, relating to magnetic scanning. Other principal contributors were Harnett, Hergenrother, Loughren, Bailey and Wilson. In 1944, the collection was published in a bound volume for complimentary distribution to our staff and licensees. The result was a valuable collection of timely information, much of which has not been published elsewhere.

4

JUNE, 1939, THROUGH 1941

4.1 My First Job at Hazeltine: The Model B Oscilloscope

This was a very special TV oscilloscope designed, I believe, by Arthur V. Loughren and William F. Bailey. It was to have full and flat response up to 4 MHz with identical H and V amps to permit phase measurement. The Vert deflection input had 3 identical attenuator and input stages with their outputs summed. Besides the usual sweep and sync circuits, the model B had a so-called mono-line sweep. This consisted of a trapezoidal sweep derived from a 60 cycle input which was adjustable in amplitude and phase (shiftable through approximately 360^{o}). This sine wave was limited and the slope between bottom and top of the trapezoid were used as the sweep. NOTE: At that time, all TV signals were locked to the 60 cycle power line, making this reasonably feasible. One of the slopes was blanked out by applying a differential sweep signal to the CRT grid. Then the odd and even fields were separated by adding a synchronized 30 cycle square wave to the V deflection. This arrangement permitted view of a single line, with interleaved lines per field separated.

The design was complete, but not all items had been constructed and aligned. I was working with Morton Peter Duffy, supervised by W. F. Bailey. One of our first major tasks was to align the wide band Low-Pass HAW filters. HAW filters were used to get the maximum impedance (and then deflection) with desired flatness and bandwidth. We found it necessary to be able to adjust the output and input capacitance (with trimmers) as well as the inductance. The job had to be done with a point by point measurement of response (we didn't have a suitable sweep generator). We had to take about 10 or 12 measurements to get one curve and then guess how much each C and L should be tweaked, and then repeat the curve taking again. This was very painstaking. So I analyzed the type of effect of changes in each element, and then we had a guideline of what to vary. Even with the guideline, the tweaking was very long and laborious.

4.2 Next The Phase Curve Tracer For TV

After the Model B oscilloscope first unit had been aligned and met spec., I started the phase curve tracer and Duffy continued with further units of the Model B. During the work on the first Model B, I was commuting each day from East Orange to New York City to Little Neck and back again to New York City and East Orange at night. During these long train rides I did the preliminary planning for the Phase Curve Tracer. Bob (R.B.J.B.) Brunn gave me lots of help as we jointly traveled the same train on the way home. After Penn Terminal, he went on to Brooklyn, and I went on to East Orange.

The first major design decision was that the indicator CRT should basically operate at a constant frequency, like the i.f. in a superhet receiver. A compromise of 50 KHz was selected which is high enough to permit a real time swept display and low enough to permit a sawtooth vertical deflection of CRT upon which to display the phase curve and reference marks upon a linear scale. Reference markers at 90^{o} and 10^{o} were set as the goal, and these required short pulses with repetition rates of 4 x 50 KHz = 200 KHz and 9 x 200 KHz = 1.8 MHz, respectively. These short pulses as well as the phase marker pulse were derived from sine waves. This required large amplification, clipping (to a square wave), differentiation (to pulses), and a final clipping to select just one polarity of the differentiation pulses. All of the reference pulses could come from fixed amplitude sine waves. But the phase indicating pulse as a goal had to accommodate as much as 40 dB change in level with a minimum change in position from the actual intercept of the original sine wave. This was a difficult design job.

Another design goal was to sweep the circuit being tested up to 5 MHz. This required a very special signal generator. A first fixed oscillator at 10.00 MHz was used with a variable frequency oscillator sweeping from 10.1 to 15 MHz. The difference between these was obtained from a double balanced modulator. Another fixed oscillator, a 10 MHz - 50 KHz = 9.95 MHz was used to beat with the swept oscillator to give a tracking signal going from .15 to 5.05 MHz as a reference. Then two more balanced modulators were used to get two 50 KHz signals, one representing the input signal to the circuit under test and the other representing the output signal from the circuit under test. For stabilization, the reference 50 KHz signal was applied to a 50 KHz frequency discriminator to develop a control for the frequency of the 9.95 MHz oscillator to be 50 KHz away from the 10.00 MHz oscillator. This rather complicated signal generator permitted a swept signal from 0.1 MHz to 5.0 MHz to be applied to the network under test and then to derive two fixed frequency signals representing the input and output respectively of the circuit under test.

Another significant design problem was the horizontal (frequency) sweep for the CRT together with frequency markers. To make the horizontal sweep be proportional to frequency even though the swept frequency might not be linearly proportional with time was my goal. I did this by applying the constant amplitude swept signal to a differentiating filter followed by a peak to peak detector. This did a good job, permitting me to use motor-driven condenser to sweep the 10.1 to 15 MHz oscillator without needing to have special shaped plates.

For frequency markers I used a pulse derived from a separate 1 MHz oscillator and the 200 KHz pulses used to get the 90 degree phase markers. For further details on the design, I refer you to Appendix D, A Phase Curve Tracer for Television, a copy of HSC Report 1157W.*

When finished, this Phase Curve Tracer became a show piece of the lab, and I was regularly called upon to demonstrate the unit. Bell Telephone Labs even learned about the Phase Curve Tracer and various** distinguished Bell Lab engineers saw demonstrations on three dates: January 29, 1940, September 19, 1940, and December 6, 1940 - they were quite impressed. But early in '39, they "had enough engineers from Cooper Union"!

I gave my first paper on the Phase Curve Tracer on November 11, 1940, at the Rochester Fall Meeting of IRE and RMA. This also was the occasion for my first ride in an airplane. While I was presenting the paper and mentioned the number of tubes (67), a sound of surprise went through the audience. Today we can get thousands of transistors on a very small chip routinely!

4.3 Now Pre-War "War Work"

Sometime in 1940 we started "war work", seriously. Little by little most of the lab got off of just plain consumer related TV and radio. I am not positive of the order in which I was assigned to the following list of jobs: 1 - secrecy communication system; 2 - first model of rotating VHF direction finder; 3 - exploratory model of TV bomb sight; 4 - second model of rotating direction finder; 5 - Phase Curve Tracer for Signal Corps.

4.3.1 Secrecy Communication System

I believe this was an idea of Art Loughren's (but I am not positive). The concept was to use a pseudo random square wave to randomly invert the polarity of speech. The pseudo random square wave was to be recorded on film which was in front of a scanned TV raster. Various random patterns were to be the "code of the day" and were to be read-out with a synchronized raster at the receiving end. This re-established square wave would then be used to re-establish the original speech waveform.

---

* Jack McComsey and his father were invaluable in providing chassis and special mechanical pieces needed to build this unit.
** See HAW second book, page 387.

Before spending much time on the random-signal transport system, we decided to test the system with a square wave generated from random noise which was available both for encoding and decoding. This arrangement, after getting delays equalized, was able to do a good overall job on reconstructing an undistorted copy of the original speech.

However, we found the secrecy of the encoded signal was not good enough. In particular, the syllabic rate was not suppressed and much intelligence remained in the intended secrecy signal. This made it apparent that a much more complex encoding system was required. I soon got moved to another job. I do not remember whether any additional work was done on the secrecy communication system.

4.3.2 First Model Of A Continuously Rotating VHF Direction Finder

Earlier, Hazeltine had built several advanced models of an "Adcock" VHF direction finder which were manually rotated to put the received signal in a null. This arrangement, while quite accurate, had a number of disadvantages: 1 - the time to find the null; 2 - the signal in the null had poor signal-to-noise ratio; and 3 - the null was bi-directional. What was wanted was a very rapid indication of direction with improved accuracy, such as might be obtained by using the signal at a strong signal strength. Hazeltine's solution was to use a rotating parabolic reflector; to trace the signal strength vs. rotation on a CRT; and then to show a split pattern (± a few degrees) and use the cross-over of the split patterns as an accurate indication of direction.

My part in this job was the indicator system. I designed a low impedance precision goniometer* to develop x and y deflection signals for the CRT. The crossed goniometer coils were fed in-phase and quadrature signal at (as I remember) about 50 KHz. The goniometer was connected to the antenna rotating system, and dc signals representing sine and cosine of the rotation angle were developed by comparing the goniometer output 50 KHz with the in-phase and quadrature goniometer input 50 KHz components. We designed equal x and y dc deflection coils for the CRT. By using a square type deflection iron core with paper wound coils of many turns on the opposite legs, we obtained a very accurate angular deflection of CRT spot vs. antenna rotation.

To trace the antenna pattern, it was necessary to modulate the x and y deflections by the same percentage, such as might be done by modulating the signal obtained (or applied to) the rotating goniometer element. Actually, I have forgotten whether the

* The help of Merv Decker and Jack McComsey was invaluable in constructing these precision goniometers.

rotating coil was used as the input or output from the goniometer. The system can be designed either way.

The remaining feature of the system was to rotate the image ± a few degrees. At the moment, I have forgotten how we did this. Also, I believe this first model had a mechanical angular scale in front of the CRT, but again I am not positive. A later and more sophisticated model was made of the VHF Direction Finder and, at the present, I am confused as to how far we went on the first job.

4.3.3 Exploratory Model Of TV Bomb Sight

It seemed appropriate that Hazeltine attempt to more directly apply its TV knowledge to war needs. I don't know who instigated this project, but I wouldn't be surprised if it was Art Loughren.

John A. Hansen and I were given the job of a small TV camera and transmitter such as might be put in the front of a bomb plus a receiver such as might be in an airplane remotely controlling the bomb. Of course, the camera had to be battery powered. As I recall, I did most of the camera side and John did most of the receiver side.

As I recall, the transmission frequency was about 120 MHz, just above where the present FM band exists. A vibrator power supply was used to get the necessary higher voltages from the battery supply. RCA had just made a 2 or 3 inch camera tube available and we eventually got them to enscript a set of crosshair lines right on the camera sensitive surface.

Slow scan rate was chosen to permit reduced bandwidth in the RF link. The receiver CRT had a long decay red phosphor. As I recall, in order to get an appropriate RF power level, we used receiving tubes, larger than acorn tubes, and removed the base in order to get the leads short and get up to around 120 MHz.

The most memorable thing about this project was the many demonstrations that we gave to interest the military. A scene of several small warships was put on the ground just in the back of Building 1 (Little Neck Building 1). A rope and pulley system was arranged to let the camera drop slowly from the roof level of the building down to just above the warships, illustrating the dropping of a bomb from an airplane. This simulation on a small scale required optical refocusing of the camera lens as the camera approached the ground. A separate rope arrangement accomplished this refocusing.

One of our service personnel was generally called upon to carefully lower the camera to simulate a dropping bomb. This was all done from the roof of Building 1. And, many times, at a moment's notice, we had to "man the demonstration" whenever a potentially interested military personnel showed up.

Eventually we interested the military so that we received a contract to make several high resolution units for real testing. I was not involved in this follow-on work, which was done by Bill Bailey and John A. Hansen under direction of Art Loughren. A number of successful drops of this higher resolution model were performed. But in the end, RCA got the job that eventually went into production.

4.3.4 Second Model of Rotating VHF Direction Finder

This model had a series of improvements over the first model, and again I got involved mainly in the CRT indicator system. Gil Larson was overall in charge of this job, as well as having direct involvement with the receiver and antenna with its drive mechanics. Johnny Gray worked with him. Jim Craib worked with me on the indicator system.

I don't recall all of the receiver system improvements, except possibly in the area of AGC control by the unidirection antenna on top of the rotating reflector unit. This time, Nick Fedotoff, our special mechanical designer, got involved with a stronger pedestal, larger motor drive and better reflector construction. This unit really went faster, was known as the "whirling bird cage", and even "walked across the parking lot"!

The indicator unit was quite different than the first unit, particularly since the indication was to be monitored at least 50 miles away with the information going over a standard telephone line. This was accomplished using a set of audio subcarriers suitably amplitude, phase, and frequency modulated. In addition the angle markers were directly on the CRT; the main CRT corresponded to 90° of sweep and a small CRT presented 360° to resolve any ambiguity. For final testing we rented a round trip loop from the telephone company.

During the time we worked on this second unit, we were working extra hours to get the load of work done, and we worked 1/2 day on Saturday. I was still courting Dorothy who was finishing her nurse's training in Camden, New Jersey. So each Saturday I left sharply at Noon and "ran for the train". I usually carried engineering reading material with me, so on one Saturday I got on the train and found a large "SECRET" envelope in my brief case. When I peeked inside, I found a brick stamped SECRET. It obviously came from the bricks being used for our new Building 3 in Little Neck. It also was obvious to me that Johnny Gray* had done it. When I got to Camden (where I was leaving my car to save gas), I put the brick in the back of the car and never mentioned it to Johnny, nor removed it from the car, until about 5 years later. He was very upset that I wasn't upset when I came back to work on Monday.

4.3.5 Phase Curve Tracer For The Signal Corps

Ralph Cole, in charge of engineering at the Signal Corps in Fort Monmouth, New Jersey, had seen the original Phase Curve Tracer and decided he wanted one for the Signal Corps Labs. Pete Duffy was put in charge of this job and my only involvement was to assist in the original design and help in the all-night trouble-shooting just before delivery. We were still "fixing things" at 4 AM of the morning it was shipped!

Pete did a nice job on this unit. It used a larger CRT, had an electronic frequency sweep instead of a motor driven capacitor, and also had a two terminal measuring capability at the end of a 50 foot cable. This latter item was to measure antennas (below 5 MHz).

This Signal Corps unit, without the two terminal probe, was the basis for several units that the test equipment lab built for our color TV work in the early 50's.

4.3.6 Pearl Harbor

The two rotating direction finders and the Phase Curve Tracer went to Fort Monmouth. While I was helping in delivering one of these units (I don't remember which one right now), I found what active war does to security. On the Friday before the Sunday of December 7, 1941, I was at Fort Monmouth and security was very lax. When I came back on Monday, the place was tight as a drum, and it required quite a bit of effort to get back in and finish the delivery. From then on until August '45, it was obvious to the public that we were in a war. Of course, Hazeltine had been building up government work for more than a year before Pearl Harbor.

---

* Johnny and I became good friends and he became my "best man" when Dorothy and I wed in May, 1943.

5

1942 THROUGH END OF WWII

Much could be written about Hazeltine activities during WWII, but that is not the purpose of this opus. Harold Wheeler was working on this general subject for his next book, but for a number of reasons never finished the project. I intend to mention, in the main part of this opus, the projects that I was involved with during the period. However, HAW's preliminary work should not be lost, so I will pass on to Randy Cope HAW's list of projects, plus drafts of those which he had left in various stages.*

5.1 IFF - Identification Friend or Foe, Mark III

Before Pearl Harbor, a very secret project got started, behind locked doors - which puzzled some of us. Eventually, though, practically our entire staff became involved in that project - IFF. IFF was developed in Britain, and the early units used a superregenerative receiver which, upon reception of a radar pulse on a particular frequency, answered with a coded transmission on the same frequency. The same tube acted first as a receiver and then, upon a suitable level pulse, acted as a transmitter of a short pulse. One of the early models that Hazeltine became involved with was the ABK. The "A" meant airborne, so this was a transponder intended to identify an aircraft carrying the unit as a friend. The ABK had a motor driven frequency sweep to cover the radar band of 157 to 187 MHz. I did not get involved with the ABK since I had remaining work on some of the jobs mentioned in section 4.

At the beginning of our work with IFF, we did not have adequate production facilities to make and test the large number of units needed. So we acted as the design center and had someone else, generally a former licensee, do the production work, under our guidance.

My first job in IFF was with the APX-1 and APX-2. As I remember, both Jim Craib and I worked for Bob Brunn, at first, on these units. When we started, we had a most unusual display of memory. Bob Brunn sat at the work bench with a complete set of parts spread all over the bench and in relative few hours put together a unit with<u>out</u> ever consulting a circuit diagram!

As I remember, the APX-1 & 2 had a plug-in RF unit in addition to the swept RF unit. One plug-in unit was fix-tuned (but adjustable) to the G band (near 200 MHz) and another plug-in unit was to be designed for the B band (near 515 MHz). Also, as I remember, these units worked in cooperation with the swept unit so an answering response was only given when pulses were synchronously received on both the fixed frequency unit

---

* Preliminary Drafts of: "Hazeltine Corporation in World War II" by Harold A. Wheeler.

(either G or B depending upon which unit was being used) and the swept IFF band. This was for some level of security to minimize enemy use of our IFF to direct their aircraft fire. I believe that Jim and I worked together on the G band plug-in unit first, and then later I designed the B band unit (also called the "Rooster" unit).

There were some unusual requirements put upon the "Rooster" unit which made its design differ from the YJ. First it had to work with a relatively long cable between the unit and the antenna, and it had to respond to very short radar pulses without missing any. The short pulse requirement meant that the quench rate of the superregenerator had to be 1 MHz. The high quench rate combined with the long antenna cable meant that the superregenerator had to be isolated from the antenna. And all of this had to be accomplished at 500 MHz! We eventually succeeded, but only after we got a new design of grounded grid tube (6J4) with 3 grid pins, to provide a good grounded grid RF amplifier at B band.

The team on this job included Al Schneider, Don Richman and myself. Don joined us right out of college in 1943 and was rather "green" when it came to experimental work. At first, he didn't know which end of the solder iron was hot. But Don's real expertise developed in a few years, which was analytic work. At this, he was a genius.

The work on the B band unit was done in a small room in the Northeast corner of Building 2, a temporary all-wood building in back of Little Neck Building 1. Because of secrecy requirements, the windows were covered with iron bars, and there was only one way out for us in case of fire, and that was through a long hall common to three other rooms. Not the safest of conditions!

5.2 Mark V IFF

While I was still struggling with the B band unit and its special problems, a new IFF system (Mark V) got started. The basic concepts and some breadboard models had been developed at CRG (Combined Research Group) in Washington, D.C., Navy Department Labs. Hazeltine was to make production designs of the many units needed for the new system and was to have engineers, from the various outfits that would do the production, work directly with us on Long Island. This was a very big undertaking. We took over the Glen Oak Country Club, just a short distance from our Little Neck Lab, and just South of Northern State Parkway.

Mark V involved some new technologies for us. First, the RF band was around 1 GHz, specifically 950 to 1150 MHz. Second, the system was complete in itself using interrogators and transponders communicating with spaced pulses representing a certain code. Third, a quality delay line was needed for decoding and generation of the spaced pulses.

By the time I finished with the B band unit, most of the Mark V units were under way and Glen Oak's main buildings were full. I was put in charge of a remaining unit, the PPN-8 Paratrooper Beacon. The space remaining for our group was in the hangar. This hangar was used for barrage balloons, early in the war, when there was a scare over airplane attacks. A German sub had been spotted off Long Island, but where airplanes would have been based to attack us, I don't know! The working conditions in the hangar during the Winter of '44-'45 were far from the best. Space heaters were used. The floor was concrete, so after much effort we got plywood under each desk and in front of each work bench. But still the conditions were much better than on the front lines.

Jim Craib was my "chief" engineer, and we had a fair-sized group when you included the licensee engineers, technicians, "product" people and secretaries.

It is my recollection that our unit was the only unit of Mark V still using superregeneration, but I am not positive now that we did use superregeneration. Jim Craib would have been a good choice to lead our engineering of the PPN-8 if we had used superregeneration because he and Wheeler developed theory for the bandwidth of superregenerators while on Mark III.

On August 15, 1945 (VJ Day), the war was over, and some of us were rather promptly transferred back to Building 1 and patent-oriented TV and FM R&D, which had been the source of Hazeltine income prior to the war.

6

SEPTEMBER, 1945, THROUGH SPRING, 1949

6.1 Reorganization of Licensee Related Activities

Rather promptly after WWII was over, our corporate activities were organized into patent-oriented R&D, under A. V. Loughren, and government-related R&D and production, under O. M. Dunning. The patent-oriented activities had three distinct parts at Little Neck, namely: TV research; FM advanced development; and licensee receiver testing and special reports for licensees. The first activity (TV research) was directly under Art Loughren, with W. F. Bailey (Bill) as deputy. The second activity (FM advanced development) started with Les Curtis in charge and BDL as assistant, but soon Les retired and I took over. The third activity (LN licensee lab) started with G. C. Larson (Gil) in charge, but was eventually taken over by R. J. Farber.

Somewheres in the overall picture, for a short period of time, Ralph Langley was involved in the overall management (Mac's boy) of the licensee activities. In my mind, his most lasting imprint was when he painted our beautiful red brick Building 1, all white! Actually, Ralph was not a good fit with our license R&D; but he was well-known to our licensee managements. I believe he left us some time in 1946.

6.2 Some Highlights of Our Work Through About Mid-1948

In this section, "we" is used to refer to the cumulative work of all three patent-oriented R&D groups at Little Neck.

6.2.1 Selection of Intermediate Frequencies

Pre-War (WWII) experimental TV sets used relatively low IFs in the 5 to 10 MHz range. An FM set also used a relatively low IF, like around 5 MHz. But the FCC had changed channel allocations so, first, more VHF channels were available for TV, and FM was moved from around 40 MHz to the new 88 to 108 MHz band permitting more stations. This meant that a new IF selection was needed for both TV and FM. The selection for TV turned out to be just above the 20 MHz region (sound at 21.75 MHz) and FM IF at 10.7 MHz. (Eventually with the opening of UHF, a later story, TV IF was moved up to the 40 MHz region). So, helping licensees with information on new IF selectors and detectors was an important item.

6.2.2 TV Antenna Improvements

Relatively early in this period, we constructed a long "slotted line" to permit measurement of antenna impedances down to the lowest TV channel (and eventually to 40

MHz). Tests on a very popular antenna of the time (Amphenol) showed a deficiency at Channel 2 which was fixed by lengthening the reflector. This gave a significant improvement in the Channel 2 picture.

6.2.3 Hazeltine's 10" B&W Set

RCA's early set, after WWII, which became quite popular was the RCA 630, a 10" direct-view receiver. Before the release of complete data on this set, we had developed a 10" mirror-view receiver for our licensees. Details were made available upon special arrangements to licensees that "paid-up". However, our efforts were somewhat "scooped" by RCA's eventual complete release of data on the 630.

6.2.4 Signal Generating Equipment

We had some equipment from before the War, but various changes had been made in the standards. FM broadcasting was moved to the 88 to 108 MHz band; the higher VHF channels were opened (Channels 7 through 13); and TV scanning was changed from 441 to 525 lines. These various changes required either new test equipment or modifications in the old equipment.

Such data was made available to our licensees.

6.2.5 Ratio Detector Work

RCA released information on a new FM detector which was "AM-rejecting", did not need a limiter, and had a varying audio output vs. signal level - which helped make tuning much like an AM receiver. We spent quite a bit of time determining optimum design procedures (in the general case) for such a detector. Some specific designs were made available to licensees for such various applications as FM reception and TV sound channel. Also both the "Foster-Seeley" format and a "side-tuned" format were released. I wrote a report on the details of how AM rejection was produced in the ratio detector and the report was published in March, 1952, Proc. of IRE. Shortly thereafter, Major Armstrong subpoenaed me for pre-trial deposition in his suit vs. RCA regarding the ratio detector. He claimed I did the work for RCA and was a liar! His attorney made him apologize!

6.2.6 Superregeneration Applied to FM

During WWII, Hazeltine had a lot of experience with superregeneration applied to IFF. Harold Wheeler had developed a theory which permitted prediction of the selectivity of a superregenerative receiver from the quench waveform (through determination of the conductance vs. time function resulting across the resonator).

A determination of realizable bandwidths for quench rates adequate to handle audio frequencies indicated that the use of superregeneration was appropriate for the wideband FM as specified for broadcasting. Accordingly, the FM advanced development group made a rather extensive investigation of superregeneration applied to FM broadcast receivers since such circuits could provide a large gain from one regenerator tube.

A wide range of the superregenerative techniques were investigated, including:

a. Both linear and logarithmic mode separate quench oscillator circuits.
b. Self-quench circuits.
c. Self-stabilizing circuits requiring no controls for a wide range of tube characteristics.
d. Double regenerators forming a side-tuned discriminator.
e. Tracking circuits with fast AFC.
f. One tube circuits operating as a mixer and an IF regenerator.
g. Comments: In those days, the cost of vacuum tubes represented a significant fraction of the parts cost for a receiver, so reducing the "tube count" was important. The old stand-by AM receiver was a 4-tube AC-DC model, and adding FM by a conventional superheterodyne circuit could more than double or triple the tube count.

The goal of our efforts was a high-performance (but low tube count) FM receiver, and we almost made it. We had finally developed a circuit arrangement which worked well against our laboratory signal generators. But, on broadcast signals, it would occasionally jump (this was a fast AFC tracking circuit). This difference was quite puzzling.

Finally, suspecting that the FM stations were over-deviating, we constructed a very wide band (±200 KHz) linear discriminator to monitor on-the-air signals. Tests showed that on bursts of high frequency energy many stations instantaneously deviated as much as ±150 KHz due to the use of pre-emphasis, thus invading the next channel. These out-of-channel bursts could not be handled by our otherwise good superregenerative FM receiver. Thus our goal was almost reached, but was defeated by over-modulation of broadcast stations (resulting from pre-emphasis, with no compensation to eliminate out-of-channel bursts).

6.2.7 Fremodyne

As a side product of our efforts described in the previous section, and as a laboratory reduction to practice of certain ideas, we built an interesting circuit which received more publicity than was appropriate. The circuit was a dual triode, half of which was a local oscillator and the other half was a combined mixer and IF superregenerative detector. The detector was self-quenched, d-c stabilized and waveform shaped to have linear side-slopes to the selectivity as seen through the logarithmic detector function (providing FM to AM conversion). The audio recovery was sufficient so that the single double triode (12AT7) could be added to a 4 tube AC-DC AM receiver to provide FM reception. Of course, the FM reception had no AM rejection, had two tuning spots (one on each side slope), and poorer signal-to-noise ratio that a well-designed FM receiver. We also eventually found that there was back-conversion in the mixer, so some radiation of the super-regenerative energy was produced at the desired signal frequency.

During this period of 1946-1947, TV sales had not developed significantly and there was more consumer interest in FM than in TV. So MacDonald wanted something that might increase licensee income from radio receivers and he became interested in this laboratory curiosity circuit as a possibility. I objected, because of its inferior performance, but was overruled.

So, we wrote a report on the circuit, had a corporate-wide contest for a name for the circuit, and released the data to licensees. Someone coined the term Fremodyne, based on "Frem" - for FM - and "odyne" from the name Neutrodyne. A splurge was given at the release of the data to licensees, several licensees put out receivers including the Fremodyne circuit for FM reception, and shortly such receivers were a "flop", because of marginal performance and re-radiation.

6.2.8 1948

This was a "low" period for our licensee activities. Licensee income prospects were not good. TV sales were still building slowly, and we had nothing of value in FM. MacDonald decided to cut the licensee activities "to the bone", and put staff on some developing Government work. The two groups of FM advanced development and the LN licensee lab were eliminated and only a very small staff was left on TV work. This consisted of Art Loughren, Bill Bailey, John A. Hansen, and BDL (plus possibly a technician, but I am not sure). Of course, this put me back in the technology of my real interest - TV.

During this period, our major effort was on a "low-cost 10-inch direct view TV set". I believe that Bill Bailey, John Hansen, and BDL worked jointly on this effort. Report 7069, issued 12/30/48, reports on this effort. We apparently had released early data on some of the circuits of this set to Westinghouse (Gil Larson had left us and was Chief Engineer for Westinghouse TV development, in Sunbury, Pa.). Report 3135, issued on 12/10/48, reports on the work that Johnnie Hansen and BDL did, during a very cold period in Sunbury, Pa., trying to fix their version of some of our circuits.

6.2.9 Some Report Titles From This Period

The breadth of some of the work during this post-WWII and pre-color period is indicated by the following selected report and engineering memo titles:

ENGINEERING MEMOS:

No.	Title	Date	Author*
E-103	Summary of Present Experience with F-M Ratio Detectors	10/25/45	LFC-BDL
E-112	Selection of Intermediate Frequency Range for Television Receivers	12/19/45	WFB
E-113	Performance of Developmental 7-Tube A-M F-M Receiver with Type 7003 F-M Detector	12/27/45	KW
E-125	Slope Detector for Testing Line Scanning	5/16/46	WFB
E-133	Line Cord Antennas for F-M Receivers	7/15/46	MWS
E-143	Permeability Tuned A-M/F-M R-F Tuner	10/17/46	DS
E-144	A Balanced Ratio Detector Using Side-Tuned Circuits	10/23/46	MA
E-151	21.75 Mc Ratio Detector Transformer	5/8/47	CEP
E-153	Three-tube F-M Receiver	6/18/47	BDL
E-158	Tentative Descriptive Specification For Hazeltine 10" Prototype Television Receiver	8/14/47	FAD

* Names from initials can be found in Section 21.4 - Initials.

No.	Title	Date	Author
E-163	Four-Tube Plus Rectifier AC/DC, FM/AM FreModyne Receiver (Model AF4/148)	10/3/47	MWS
E-175	Modified FreModyne with Pulsed Local Oscillator	1/22/48	DR
E-179	Investigation of Superregenerator Selectivity	2/24/48	MWS
E-181	Laboratory Measurement Procedure for Television Receivers	3/5/48	JAH

INTERNAL REPORTS:

No.	Title	Date	Author
4002	Amplitude Modulation Rejection in F-M Detectors	12/21/45	BDL
4003	Compensation of Input Capacitance Variation in I-F Amplifiers for 10.7 mc	1/21/46	BDL
4008	Dynamic Diode Limiters for F.M.	9/27/46	JC
4015	Measuring A-M Rejection in F-M Detectors	12/18/46	KF
4017	An F-M Detector System Using a Dynamic Limited Followed by a Ratio Detector	4/17/47	WG

REPORTS TO LICENSEES (From Little Neck):

No.	Title	Date	Author
7003	A Frequency Modulation Detector Which Rejects Amplitude Modulation	11/14/45	KW
7005	An Eleven Tube Broadcast and F-M Receiver	12/10/45	DS
7008	Impedance Measuring Lines for 40 to 250 Megacycles	1/5/46	MWS
7011	An Eleven Tube A-M/F-M Receiver Having an Amplitude Rejecting Detector and a Reflex Audio Circuit	3/22/46	KW
7014	A Single Picture Control for Television Receivers	4/17/46	WFB
7016	Built-In Antennas for F-M Receivers	5/7/46	JH

No.	Title	Date	Author
7018	A 7-Tube A-C/D-C A-M/F-M Receiver Using a Ratio-Type Detector and Miniature Tubes	6/26/46	KW
7019	Amplitude Modulation Rejection in F-M Detectors of the Ratio Type	6/10/46	BDL
7024	Television 4000-V R-F Power Supply	11/1/46	JAH
7028	F-M Detector Systems	2/19/47	BDL
7029	Design and Measurement of Ratio Detectors	5/12/47	CEP
7030	Superregeneration in F-M Receivers	6/9/47	AVL
7032	Cascade Dynamic Limiter in F-M Detector Systems	7/10/47	SK
7034	An Improved Single Picture-Control for Television Receivers (Automatic Black Level)	12/15/47	JAH
7035	Two-Signal Performance of Some F-M Receiver Systems	9/19/47	DEF/BDL
7037	An A-C/D-C FreModyne Receiver for F.M. and A.M.	12/23/47	CEP
7042	Gain and Selectivity of Superregenerative Receivers	3/16/48	AH DR/BDL
7044	The Hazeltine FreModyne Circuit	4/5/48	BDL
7047	Television Tuner, Model TRX-3-528	6/11/48	JAH
7050	Television Receiving Antennas	6/18/48	CEP
7057	Guide to Test Equipment Requirements for Television Receiver Production	6/30/48	JOM
7059	Modification of Amphenol Model 114-005 Television Antenna	7/1/48	JAH
7060	A Low-Cost Magnetic Deflection System for Television	7/23/48	JAH
7063	The Intercarrier Sound System in Television Receivers	11/2/48	DR/BDL
7069	A Low Cost Television Receiver Using a 10" Electromagnetic Picture Tube (Model T22/157X)	12/30/48	BDL

7

SOME IMPORTANT PERSONAL HAPPENINGS AND DATES IN THE PERIOD 1939 THROUGH 1946

April 27, 1939: Presented my first technical paper, at the 13th annual student convention of AIEE, in the Great Hall of Cooper Union. The paper was entitled "The Vector Response Indicator", and I was awarded first prize.

June 8, 1939: Received my Bachelor of Electrical Engineering degree from Cooper Union.

June 19, 1939: Started work at Hazeltine Service Corporation Laboratory at 58-25 Little Neck Parkway, Little Neck, New York.

October 28, 1939: First date with Dorothy; we visited the 1939 World's Fair.

November 16, 1940: Dorothy and Barney became engaged.

May 12, 1943: Dorothy graduated as a nurse from Cooper Hosptial, Camden, New Jersey.

May 15, 1943: Dorothy and Barney were married.

June 14, 1945: Received EE degree from Cooper Union.

October 21, 1945: David, our first son, was born.

June 22, 1946: Received MS degree from Stevens Institute of Technology.

August, 1946: Purchased our first house - Lynbrook, New York - Lived there for 9 1/2 years.

8

EXPERIMENTS IN COLOR TV PRIOR TO 1949

8.1 Pre-WWII

One evening in 1940, while a group of us (WFB, JAH, AVL, BDL and others) were working at the lab, we noticed CBS transmitting a non-compatible signal. Bill Bailey looked at the waveforms on the Model B oscilloscope, noting that successive fields were significantly different. It was eventually concluded that CBS was "playing around" with color TV.

This 1940 CBS demonstration of a field-sequential form of color system was transmitted within the then standard 6 megacycle channel. To do this the number of scanning lines per field and frames per second were reduced below the standard values for monochrome transmission - resulted in a non-compatible system of lower resolution and more flicker than provided by monochrome standards.

It was later* established that in 1941 NBC had also performed some experimental transmissions with a field sequential system. The referenced IRE article also mentions that the RCA labs had constructed a simultaneous-type receiver in 1939, but the registration was unsatisfactory.

8.2 Post-WWII

When CBS resumed work on color TV in 1946 they appeared to abandon their previous system and instead suggested a field-sequential system having resolution capabilities comparable to the monochrome standards - therefore requiring a substantially wider bandwidth. This system was proposed for use in the UHF band and channel widths of the order of 12 to 16 megacycles were discussed.

Also in 1946 RCA proposed a simultaneous color system having scanning standards identical with monochrome but requiring much wider total bandwidth in order to transmit the three color signals. Channel widths of the order of 14 megacycles were discussed. It was proposed that the green channel signal be used by monochrome receivers for compatible reception. Red and blue color signals were transmitted either on sub-carriers or separate picture carriers, with the red signal having full resolution and the blue signal reduced resolution (not mixed highs). This system was described in the September 1947 issue of Proc. of IRE.

* See Proc. IRE, Sept., 1947, page 861.

8.3 FCC Dilemma Regarding Cochannel Interference, UHF and Color

By the late '40's monochrome television was well under way and the large number of requests for TV station applications made it apparent that the VHF region would not provide sufficient space. Also in the VHF band, a number of examples of undesirable cochannel interference had developed, due to channel assignments with stations too close to each other. In September, 1948, the FCC put a freeze on further TV station licensing until the cochannel interference problem was clarified.

The FCC was faced with the triple problem of: a) possible reallocations of the VHF band; b) allocating UHF channels for monochrome transmission, but at the same time c) having the possible future problem of allocating some number of UHF channels for color with its then wider bandwidth.* Recognizing that their UHF allocation problem might be considerably simplified if color could be put in the same channel width as monochrome, the FCC solicited suggestions from the industry for a 6 megacycle color TV system. I believe this inquiry went out either in late '48 or early '49. The desire for compatibility, to additionally simplify the allocation problem, was recognized and pointed out in the request for comments.**

* RCA eventually solved the cochannel problem with their "offset-carrier" technique.
** See Appendix B.

9

HAZELTINE COLOR EFFORTS PRIOR TO RCA COLOR SYSTEM ANNOUNCEMENT

Hazeltine began thinking about the 6 megacycle compatible color TV problem sometime in the Spring of 1949. I recall a train trip back from the IRE Spring Conference during which a general discussion of this took place with Art Loughren and possibly either Bill Bailey or Charlie Hirsch. Shortly thereafter Art sold the idea to Hazeltine management of starting work on color TV and building up the research group again - to tackle such a project. This discussion on the train was the first of many meetings on what to do about color TV.

We had learned about the mixed highs principle (probably through Art and his committee activities - I believe it had been demonstrated to the FCC) and its possible application to the simultaneous type of system. During this period I made many suggestions* for possible 6 megacycle color systems involving overlapping sidebands to squeeze the information in the 6 mc channel - accepting the resulting crosstalk.

In the meantime, we all started to learn about basic color theory, the early simultaneous color system that RCA had considered for use in the UHF band, and something related to mixed highs, namely that the acuity of the eye for color detail is markedly less than for luminance or brightness detail. These were all new ideas to engineers steeped in monochrome TV technique. One of our favorite text books on color was: "An Introduction to Color" by Ralph Evans of Kodak, just published in 1948. This book contained a picture demonstrating that "low-definition" color added to a "high-definition" black-and-white picture gives a good color reproduction.

In the early summer of '49 Art arranged for a trip to RCA Princeton, during which we obtained information regarding the construction of simultaneous color TV equipments - such as flying spot scanners, crossed dichroic mirror monitors and circuits for video and scanning. (These equipments were to become our basic color picture source and color monitor for most of our early color research). During this trip it was apparent that a lot of secretive work was going on at RCA on a color TV system which they could not talk about to us.**

One bit of useful information was passed on during lunch when we visited RCA Princeton Lab. George Sziklai mentioned to me that "the offset carrier benefit applied right up the frequency scale". Beyond that "hint" we learned nothing about the RCA dot-sequential system during our visit to Princeton. The offset carrier benefit (for just 2

* NB2759.

** However, George Brown of RCA indicated that they were not trying to be secretive, but merely had not made up their mind, at that time, which way they wanted to go.

signals interfering with each other) is maximum when the offset is 1/2 line scanning frequency. Therefore, this "hint" can be translated into the general statement that odd harmonics of 1/2 line scanning frequency are "lower visibility" signals.

During the Summer of '49, we constructed the necessary timing equipment to develop odd harmonics of 1/2 line frequency up in the region of 2 to 4 MHz and confirmed the reduced visibility in comparison to harmonics of line frequency. We also had been thinking about bandsharing red and blue signals high up in the spectrum of a green signal. Tests were run with such bandshared interleaved signals and we determined some relative amplitudes for good compatibility.

In July of '49 proposals were made of band-shared simultaneous systems using mixed highs with frequency interlace (NB2759, p. 56 on). These system suggestions were ones in which the subcarrier information transmitted red and blue color signals (not color-difference signals) and the main signal transmitted either green, or a monochrome combination, to provide compatibility. These system proposals were substantially like those proposed later by R. B. Dome of GE.

During August of '49 internal demonstrations at Hazeltine established that when using a band-shared TV system (that is, having overlapping pass bands) the interference is considerably reduced when the subcarrier has certain precise low-visibility relations. Tests were run to determine the allowable levels of crosstalk in such band-shared systems with the subcarrier modulated by different bandwidth and delay signals (NB2758, p. 10 and pp. 13-15).

By late August of 1949 our thinking was directed to band-shared simultaneous color television systems having frequency interleaving to minimize the visibility of crosstalk. Work towards reduction to practice of such a system was underway; however, as indicated above, the subcarrier signals were considered to have red and blue color information and not color-difference information.

During the summer of 1949 construction started at Hazeltine on simultaneous color signal generating and monitoring equipment patterned after the data that RCA had given us. Also during this period some Hazeltine engineers (I believe either or both Art Loughren and Bill Bailey) participated in early RETMA committee studies on the general characteristics of various color television systems. The systems receiving consideration by this industry committee at that time were the field-sequential, line-sequential, dot-sequential and simultaneous systems.

Also, sometime during the summer of 1949, Charlie Hirsch and I traveled to the AMA convention in Atlantic City to see a demonstration of CBS color equipment -- intended to illustrate possible usage by the medical community. The hall was dimly lit; the color was good; but on saturated colors it flickered. During a film of an operation, the blood stood out so vibrant and pulsating that I came close to fainting (like I always used to do at the sight of blood!). I had to leave the demonstration. This was my first actual viewing of color TV and it made me sick!

10

SYSTEM ANNOUNCEMENTS AND DEMONSTRATIONS DURING LATE '49 AND EARLY '50

10.1 RCA System Announcement

Late in August of '49 RCA announced, in a document to the FCC, their so-called 6 megacycle compatible high-definition color television system. This announcement was extremely short on details and somewhat cryptic. It was not until September 8th that we realized that the system used mixed highs with a 2 megacycle crossover (NB2758, pp. 16, 17, 23).

10.2 The Three Proposals

During this period three systems were announced and demonstrated to the FCC for standardization to provide a 6 megacycle color system. These included the CBS field-sequential system, which was incompatible and much like the pre-war system except that a different compromise in number of scanning lines and fields per second was employed. Another system proposed (by CTI) was the line-sequential system which used monochrome scanning standards and was claimed to be compatible. However, this system failed in its demonstrations because of line crawl and/or jitter on both the so-called compatible monochrome picture and the color picture.

The third system demonstrated was the RCA dot-sequential system with dot interlace and mixed highs. The color demonstrations put on by RCA were not always of highest quality - probably due to the extreme rush in which they put together and demonstrated their entire system. During the early stages there were troubles with color synchronization which at first used trailing edge wiggle of the horizontal sync pulse, but this problem was cleared up later by using burst synchronization. Also in these early demonstrations by RCA the pictures on the color displays were full of sampling dots over the entire raster due to the dot-sequential sampling procedure in the receiver.

10.3 RCA System Description

The RCA literature put out during the early part of this period did not specifically refer to the RCA system as a dot-sequential system. Instead it was called a 6 megacycle compatible high-definition color television system which was a compression of a simultaneous system accomplished by the combination of two processes, namely: the use of the mixed highs principle, and color picture sampling and time multiplex transmission. Of course, the latter aspect clearly indicates that dot-sequential sampling was considered as an essential part of the system. Further, the system descriptions always involved discussions of sampling, with stress upon narrow-angle sampling as being necessary to obtain good colorimetry (or no color crosstalk). Also, the exact frequency used for sampling was described as providing picture dot interlacing (and was not described as a frequency interleaving system).

The industry description of the RCA system was, however, as a dot-sequential method of transmission. An overall description of the three system proposals, with the system concepts used at that time, is given in December 1949 Electronics, in an article "New Directions in Color Television". Later on (about mid-'50) RCA started to refer to their system as dot-sequential (just as we did) even after they had learned about shunted monochrome.

While we cannot predict what went on back at the laboratory, all of the published information on the RCA system clearly indicates that it was considered as being a sampling system and that our shunted monochrome aspect was not appreciated by RCA. All of the stress upon narrow-angle sampling in order to obtain good color purity at the receiver substantiates this position. In addition, there appeared to be no recognition of the fact that monochrome reception on a color receiver could use color killing in order to obtain a clear unsampled monochrome picture. Of course, in the type of sampling circuits used by RCA, such color killing action would have been complicated to perform in a practical receiver. By mid-September of '49 I had recognized the possibility of designing a receiver for their system so as to provide automatic color killing (by using a driven color sync system), and had devised a type of sampling arrangement (reasonably complex) necessary to obtain similar gain when sampling and not sampling (NB2758, p. 32).

It seems that the RCA thinking is clearly indicated by their system description (given in RCA Review, December 1949, and also as presented to the FCC on September 26, 1949) in which it is stated, with regard to reverse compatibility, that: "When a color receiver is tuned to a television broadcasting station transmitting a black and white signal, the picture will appear in black and white with full resolution on the color receiver picture reproducer. The successive pulses delivered to the three kinescopes will all be of equal amplitude, and hence, will produce varying intensities of white - or a normal black and white picture." Thus there appeared to be no recognition of the fact that the sampling pulses could be eliminated during monochrome reception in a color receiver.

10.4 Other Dot Systems

During this period it appears that Philco must also have been thinking about the dot sequential approach, since they published an article, after the RCA system announcement, which seemed somewhat like a "me too" article. This was a two-part article in

December 1949 and January 1950 Electronics entitled "Dot Systems of Color Television". These again are all directed toward sampling and/or time multiplexing techniques.

During this period announcement was made of certain work in applying dot interlace to improve the resolution of monochrome pictures. CBS applied this to their field-sequential color television system in order to partially make up for the loss in resolution of their system. This, of course, fit in nicely with the time multiplexing type of approach, and reference to the editorial in May 1950 Electronics gives us some indication of the thinking within the industry that was then being verbalized. Incidentally, we had given some consideration of the problem also but had already recognized that such dot interlacing could be thought of as band-shared simultaneous transmission of a folded monochrome high definition spectrum (NB2759, p. 60, and NB2759, pp. 5 and 6).

10.5 Summary Comment Regarding Dot-Sequential With Mixed Highs

The above material gives a good idea of the general industry thinking about color TV at that time. It was sequential, sequential, sequential, either of the field type or line type or dot type. It took Hazeltine to shake up the industry into thinking about simultaneous bandshared systems and their revolutionary difference in concept and equipment compared to "sequential" equipment and concept. To quote from an article in November 1955 Fortune entitled "Color TV: Who'll Buy a Triumph?", page 206: "In the history of invention one could probably find many examples of a device working for the wrong reasons. It might be harder to uncover a parallel of RCA's color-signaling invention which worked initially for the right reasons - but worked better still when one of its central concepts was abandoned."

11

HAZELTINE COLOR EFFORTS DURING PERIOD OF LATE '49 AND EARLY '50

11.1 Shunted Monochrome

Because of our previous thinking about band-shared simultaneous systems, we found it appropriate to consider the RCA dot-sequential system in relation to band-shared systems. With our band-shared approach, our analyses were essentially in terms of the frequency domain. But the RCA color system was described in mixed domains. The color processing was described as sampling, i.e., time domain, but the mixed highs were frequency domain. I put the two parts in common terms by finding the frequency domain relations for the color sampling then adding that to the mixed highs (already in the frequency domain.) The frequency domain analysis led us to the shunted monochrome type of equipment for encoding and decoding the RCA signal.

The notebook entries (NB2758, pp. 45-49, made in mid-September of '49) clearly indicate that many of the shunted monochrome circuit advantages were immediately recognized. However, it was some time before we completely appreciated the revolutionary concept and equipment improvements realizable through shunted monochrome. At first, we called it an improved dot-sequential equipment, but eventually we realized that the correct name for what we were doing was simultaneous band-shared. See a following section entitled "Terminology".

11.2 Special Tools

During this period a number of pieces of equipment providing tools for system studies were constructed. The simultaneous signal generating and monitoring equipment were completed - providing simultaneous red, green and blue color signals from color slides and a high quality color display, in the form of a crossed dichroic mirror monitor.

Equipment to experimentally check out the mixed highs principal (in a simultaneous system) with a variety of crossover frequencies was constructed. Incidentally, the first try at this was with 1 mc, 2 mc and 3 mc crossover positions - the philosophy being that since RCA had picked a 2 mc crossover for their dot-sequential system it was probably the optimum with 1 mc representing too much degradation and 3 mc no degradation. However, our tests rapidly indicated that even a 1 mc crossover provided negligible degradation for most scenes. The equipment was quickly modified to include crossover frequencies down to 100 kc.

11.3 System Studies

Equipment was also constructed to permit critical visual observation of the general system characteristics of the three proposals made to the FCC. Suitable keying pulse generators and gating circuits were constructed to view the characteristics of the field-sequential and line-sequential systems by proper gating of the simultaneous signals to the color display.

Encoding and decoding equipment was constructed to evaluate "dot" systems such as the RCA dot-sequential system. Particularly because of our shunted monochrome concept, the equipment (especially the decoder) was built to be quite universal. Specifically, switches were included so that at least the following could be evaluated: simple dot-sequential decoding with narrow angle sampling, shunted mixed high type of decoding, and shunted monochrome type of decoding.

11.4 Simplified Receiver

The above-mentioned universal decoding unit was a rather complex piece of test equipment intended specifically for critical system evaluation. However, during this period we gave some limited thought to the possibility of a simplified color receiver using the shunted monochrome approach. A simplified circuit which has a number of characteristics common with present day color receivers was devised (NB2758, pp. 79, 80). However, at that time we were too busy with system analysis and could not take the time to reduce to practice the simplified receiver.

11.5 RCA Type System With Improved Resolution

During December of '49 (NB2758, p. 81 on), we put in additional effort on low-visibility patterns and devised a method for improving the resolution of the monochrome component in an RCA type color system. This operated by dual low-visibility patterns and was later proposed in an attempt to offset the possible benefit in resolution of a field-sequential system including dot interlace. It was eventually appreciated to have relatively little value.

11.6 S/N of RCA Type System

By mid-December of '49, we had an RCA type color system operating and became quite conscious of the poorer signal-to-noise ratio of the color picture compared to non-sampled monochrome operation. We analyzed the RCA system (NB2758, p. 92) and recognized that it had more noise than necessary because of its equal weighting of the red, green and blue signals. Also, we recognized that an improvement could be made if green were transmitted with most energy.

11.7 Constant Luminance

Methods for modifying the RCA system for better signal-to-noise ratio were described in mid-January, 1950 (NB2760, p. 25 on). However, we were missing the key to the unique arrangement. One lunch time, at our usual eating place in Floral Park, Art Loughren said perhaps the flicker photometer could be a guide. We went back to the lab and I immediately figured out the equipment significance of the theory behind the flicker photometer. We appreciated the optimum arrangement to be one having no luminance contribution by the subcarrier channel - that is, a constant luminance system.

At the end of January (NB2760, p. 44), we conducted a test to visually evaluate the effect of noise at constant luminance and were so impressed with the results that we set out to modify our encoding and decoding equipment to include constant luminance operation. However, it was not until several months later that a reduction to practice of a complete Constant Luminance System was obtained (NB2760, p. 86).

The reduction to practice of the complete Constant Luminance System was dramatic. Our only pictorial signal source was a flying spot scanner, and due to the phosphor decay equalization circuit the output signals had more noise at high frequencies than at low frequencies. The receiver decoding reduced the high frequency noise to low frequency noise which was much more objectionable. This effect made the comparison of CLS and RCA very dramatic, with much quieter pictures for CLS. Also demonstration with an interfering signal near the color subcarrier frequency was very dramatic.

With the combination of constant luminance and shunted monochrome we knew we had a winner, and we needed to sell RCA and the industry that little ole Hazeltine had made a real contribution to the success of the color TV industry.

11.8 One-Gun Tube In Constant Luminance System

All of the above work was done with a three-tube type of color display using dichroic mirrors for image superposition. Also all disclosures by RCA up to this time were with three-tube types of color displays. However, in early Spring of 1950, RCA described their tri-color picture tube both in its three-gun and one-gun forms. Immediately we considered the receiver circuitry necessary to use the tri-color tube in the constant luminance type system. A disclosure was written up (NB2760, p. 63 on, dated 4/2/50) describing such circuit arrangement, particularly for one-gun tubes and including the Y to M converter and the subcarrier modifier.

With regard to this early disclosure of processing circuits for the one-gun tube, there are several other facts which might be noted at this point. This disclosure preceded any discussion to people outside of Hazeltine of the constant luminance system concept. Also, reduction to practice of these circuits with a one-gun tube was not possible for quite a few years. As far as I can remember, RCA never did make a one-gun tri-color tube available to the industry. As a matter of fact, it was quite a while before we had even a three-gun tri-color tube. It was more than three years later before we obtained our first one-gun tube - namely a Chromatron (some time in mid-1953).

Since we could not make effective use of these circuits (not having a one-gun tri-color tube), and since the circuits were of no benefit unless the constant luminance form of transmission was standardized, we proceeded to put full effort on getting the constant luminance system accepted into the color transmission standards. Further work on such processing circuits was almost completely set aside, except for an almost incidental reduction-to-practice of the Y to M converter circuit. By 1953 it was apparent that constant luminance would be part of the color standards. Also at that time, a one-gun tube was available to us (the Chromatron). Therefore, at that much later date of 1953, we continued work on one-gun display processing circuitry.

11.9 Other Work

One other bit of work done at Hazeltine during this period which should be noted is the reduction to practice and demonstration of the use of dot interlace to improve monochrome resolution. However, as noted above, this was eventually appreciated to have little value.

11.10 Terminology

At this point it might be worth a few comments with regard to terminology. The name shunted monochrome was not immediately devised for the designation of the circuit disclosed in September, 1949, but appears in my notebook some months later. Also the term color-difference describing the new type of signals in the color channel of the shunted monochrome receiver was not immediately used. The "difference" concept is clearly indicated by the entry in NB2758, p. 49, made on the date of first written description. However, it was several months after this (NB2758, p. 79) when the exact term color-difference shows up in my notebooks.

Also, a statement that the RCA type of dot-sequential system with mixed highs was really a form of band-shared simultaneous system was not clearly made in writing at the time of disclosure of the shunted monochrome type circuitry - even though it is implicit in such a disclosure. At first, we appeared to continue to use the name "band-shared" for our previous type of system thinking. However, by January, 1950 (NB2760, pp. 19, 20), we got around to writing down the fact that the RCA type system was really a band-shared system.

All of the above new terminology were devised before any disclosures to the industry. Therefore, it seems quite likely that by the time any discussions were had with other members of the industry, terms such as color-difference would have become part of our normal descriptive vocabulary.

The term constant luminance was not originally applied to the constant luminance type system - instead we first referred to it as having constant brightness. I believe there were at least two reasons why we changed nomenclature on this, one of these being that the initials for a constant brightness system would be CBS - and at that time these initials represented the enemy! For a second reason, I believe Art felt that the terminology luminance, instead of brightness, was scientifically more correct.

Also, during these early days, we frequently referred to sampling even though we clearly knew that a conventional modulator could be used in the shunted monochrome system instead of a narrow-angle sampler. Occasional use of such nomenclature may have been through inertia. But, after the FCC decision against the RCA dot-sequential system we felt that all possible terminology common to the dot-sequential system should be deprecated. So, we developed a conscious effort to convert any loose vocabulary to more accurate terms (NB3285, pp. 99, 100).

12

HAZELTINE'S TEACHING OF THE INDUSTRY

12.1 Demonstration to FCC and RCA

Since the FCC was about to make up its mind with regard to standardizing on a particular color TV system, Hazeltine felt that they (the FCC) should have all possible technical facts drawn to their attention prior to such decision - even though this might represent a premature disclosure of information on Hazeltine's part. We had, at Hazeltine, a fairly universal test set up to demonstrate a series of facts which were, to the best of our knowledge, not demonstratable (at least not in a neat package) by any other group.

We had a demonstration of the validity of the mixed highs principle which would (we believed) completely counteract the nonsense that was then being discussed with regard to the "large color crosstalk" resulting from mixed highs. Also, we could demonstrate that the RCA type transmission could be received in a manner which would eliminate the large dot structure present in the pictures shown by RCA. This was by using either the shunted mixed high decoder (which RCA apparently did not demonstrate), or our new shunted monochrome decoder.

We could demonstrate a quite significant improvement in signal-to-noise ratio by what we called a modified type of RCA system - which we now define as constant luminance transmission. We were able to show that with our improvements of constant luminance and shunted monochrome the resulting picture obtainable through a 4 mc video channel was substantially visually equivalent (on most scenes) to that obtained by a simultaneous system requiring 12 megacycles of spectrum space. As an additional item, we were able to demonstrate the use of dot interlace to improve monochrome resolution, and implied that this could be added to the improved color systems developed from the dot-sequential approach.

The above series of demonstrations were made to the FCC on April 27, 1950. Art arranged to make the same demonstrations to RCA engineers on the following day of April 28, 1950, probably because he felt obligated to RCA for their assistance by information on simultaneous signal generating and monitoring equipment. The summary of these demonstrations is given in engineering memo E202, which was distributed at both demonstrations.

Following the demonstration to RCA engineers, there was a technical discussion which lasted most of an afternoon. During this discussion block diagrams of the constant luminance system demonstrated were described together with the system constants employed. Also the shunted monochrome type of equipment was described. I was left with the distinct impression that most of the RCA engineers present were hearing some new concepts for the first time.

George Brown, leader of the RCA color effort, has some comments in his book "and part of which I was" (published 1979) which are worth quoting here. From pages 210 and 211, referring to our demonstrations of April 28, 1950, he says "I saw immediately that this circuit innovation would give us a precise control over signal adjustment not previously available.", and "Thus the final picture was greatly improved over the arrangement we had been using.", and "When we returned home, we immediately changed our transmitting and receiving apparatus to make use of the bypassed brightness (insert 'shunted monochrome') circuitry with most beneficial results." I am thankful to George for these written comments because there were times, during following years, when RCA written material appeared to purposely ignore (or deprecate) Hazeltine's contribution to color TV.

12.2 Demonstrations to Industry

During the next two months of May and June, 1950, we gave many demonstrations of the above items to various interested parties. According to Art's letter of June 30, 1950 (file number G-39-6660), to Honorable Wayne Coy, Chairman of FCC, we gave a total of 27 demonstrations with a total attendance of 152 people. Attached to Art's letter is a detailing of the organizations represented and the visitors. These demonstrations were summarized by report 7104 which was a modified version of the engineering memo E202. Incidentally, it is quite possible that the demonstration with regard to use of dot interlace for improving monochrome resolution may not have been shown to anyone beyond the FCC.

Among the people seeing these demonstrations were various members of the Condon Committee which was "The Advisory Committee on Color Television" to the Committee on Interstate and Foreign Commerce of the United States Senate. Their report, dated July 14, 1950, mentioned the Hazeltine demonstrations and stated that the committee concluded that the Hazeltine developments were an important contribution to the dot-sequential system. This probably represents the first published recognition of Hazeltine's contributions to color TV. This report was also published in the September, 1950, issue of the Proceedings of the IRE. The same issue of the IRE included the paper by Bedford on mixed highs, which, as far as I know, was the first written disclosure in a technical publication giving the details of the mixed highs story.

12.3 First Indications of RCA's Conversion

On July 28, 1950, we find the first example of RCA making use of the shunted monochrome principle in (of all things) an RCA Laboratories Division Bulletin (submitted to FCC and the industry) entitled "An Analysis of the Sampling Principles of the RCA Color Television System". This bulletin was directed mainly to an analysis of the sampling process and showed that it was necessary to use narrow-angle sampling with the RCA dot-sequential system. However, in Appendix II, relating to transmission of the RCA color television signal on coaxial cables of restricted bandwidth, Figure 35 shows a shunted monochrome form of transmitter used to generate a signal having a lower than normal sub-carrier frequency. The text of this part of the appendix states "It should be noted that this filtering action has removed any requirement of short duty factor in sampling. In fact, the sampler can be an ordinary balanced modulator." Thus, RCA slid in the shunted monochrome idea in the tail end of a report which was, on the whole, inconsistent with the shunted monochrome concept.*

The above apparent inconsistency may be partly clarified by the following facts. The above cited article was also published in the RCA Review, but in two parts. Part one (the text) was published in the June, 1950, RCA Review and gives no indications of a second part or an appendix to follow. Instead the article is complete with conclusions and sings the old song about narrow-angle sampling. I believe it was quite likely that this part of the article was prepared before RCA heard about shunted monochrome. The three appendices make up the second part of the article, and this part was not published in the RCA Review until September, 1950. Thus, I feel that it is very likely that the comment in Appendix II was prepared after RCA heard the Hazeltine story. Incidentally, the RCA Review article used the term "dot-sequential" in the title in place of RCA.

On August 18, 1950, RCA issued a license bulletin LB-799 describing a shunted monochrome form of receiver decoder, and entitled: "Circuit Diagram and Description of a Receiver Sampler for Dot-Sequential Color Television". The general layout of this decoder is much like Figure 3 of the shunted monochrome patent - which is a copy of the simplified receiver described in my notebook in November, 1949. Also, this bulletin includes in its introductory summary an unusual comment with regard to cautioning their licensees about patent protection.

* George Brown, in his book, on p. 193, does indicate that he was under great pressure when he prepared Part I.

12.4 Recognition by Electronics

The August, 1950, issue of Electronics included two recognitions of Hazeltine's work. The first was a brief article entitled "Improvements in Dot-Sequential Color TV" which described the constant luminance type system, showed a shunted monochrome form of receiver for practicing such a system, and made, I believe, the first published use of the term color-difference signals. The second was in the editorial which stated that "the demonstrations by Hazeltine engineers of certain improvements on the RCA dot-sequential color system are so impressive that all concerned are greatly heartened over the application of dot-interlace to the color problem."

12.5 Frequency Interlacing

The September, 1950, Electronics contained an article entitled "Frequency Interlaced Color Television" by R. B. Dome of General Electric. This described band-shared types of systems much like those which we were working on in the summer of 1949. However, the issuance of such an article clearly indicated that the industry, in general, still did not fully appreciate the tie-in between the band-shared type of system and the RCA dot-sequential system using mixed highs. This is particularly indicated by the comments by the editor on the first page of this article. I should point out that by this time the editor of Electronics (Don Fink) was very familiar with the Hazeltine work. However, Hazeltine had been presenting their material as improvements on the RCA type system and had not stressed the band-shared aspect by clearly teaching this concept.

12.6 FCC Not Converted

In October, 1950, the FCC decided against the RCA system and in favor of the CBS field-sequential color system. This decision included the famous 80-page diatribe by Commissioner Jones against the radio engineering profession. This situation is fairly well summarized by the editorials of Electronics, November and December, 1950.

12.7 Hazeltine's Educational Program

About this time (probably as a result of the FCC decision), Art decided that a strong educational program should be put on to more clearly present the technical facts which appeared to us to make the FCC decision obviously in error. Art and Charlie gave many oral presentations of a paper directed to a comparative analysis of color TV systems. It was also published in February, 1951, Electronics. This paper attempted to sell the mixed-highs principle, describe things in terms of band-sharing and to describe the constant luminance system. Unfortunately, in the version of the paper published in Electronics, the block diagram for the receiver (which is a shunted monochrome type of receiver) refers to it as utilizing bypassed mixed highs - which is slightly confusing since it also used bypassed mixed lows, or, in other words, shunted monochrome.

12.8 New RCA Demonstrations

In December, 1950, RCA gave a new set of demonstrations of their dot sequential color television system which were stated to be "status report" demonstrations to the press and industry (this in spite of the decision by the FCC). By this time, RCA had converted to the shunted monochrome type of circuitry and even so stated this - verbally recognized Hazeltine's contribution. This is confirmed by Page 1132 of Proc. IRE, October, 1951, in Don Fink's article entitled "Alternative Approaches to Color Television". It stated: "On December 5, 1950, RCA demonstrated a revised form of its system to the press and acknowledged the contributions of the Hazeltine Corporation. In this demonstration the shunted monochrome technique was used and a notable reduction in the dot structure of the images in color and black and white was evident."

RCA did not use the constant luminance system in this demonstration. A summary report on the demonstration is given in the February, 1951, Electronics, pages 80 and 81. The shunted monochrome type block diagram for a color receiver is shown in this article. It is interesting to note that while the terminology color-difference signal had been used before, it had not completely caught on - however, reference is made to primary-minus-monochrome signals.

12.9 Industry Converted

Some indication of industry change in thinking is indicated by the editorial in December, 1950, Electronics. But, it appears that by the spring of 1951 the simultaneous band-shared nature of the RCA type system using mixed highs, as well as the constant luminance modification, were well recognized by the industry. For example, the editorial of the March, 1951, Electronics states that "Largely as a result of the Hazeltine work on the RCA dot-sequential system, it has been realized that the RCA system is in fact a simultaneous system, not only in the bypassed monochrome portion of the system, but also in the interspersed color signals."

Also, in the March, 1951, issue of Electronics, starting on page 154, there is a letter to the editor by A. C. Schroeder of RCA complaining bitterly over the editorial remarks with regard to Dome's system in the September, 1950, Electronics, and he tries to make it clear that the RCA system is really a simultaneous one. In other words, by this time RCA was also really convinced.

12.10 Hazeltine Color School

This part of the story on early developments can probably be appropriately closed by mentioning that by the spring of 1951 Hazeltine had sufficient knowledge to make it worthwhile to have a color school for licensees. Between March and May of 1951, several series of lectures (each series taking about two weeks) were given describing the fundamentals of color television. The lecture notes for this first color school are given in Report 7119. An index to the subjects covered is as follows:

12.11 Pace During This Period

In retrospect, it is interesting to note the tremendous pace during those early color days. In the spring of '49, we had just heard about the need for a compatible 6 mc color system and just started thinking about it. By the spring of 1950, we had sufficient information and new ideas to want to make a demonstration to the FCC and attempt to sway their decision (which we did not, at first). Then, by the spring of 1951, Hazeltine had become expert enough in the color TV field to give a color school which even RCA engineers attended.

13

COLOR PHASE ALTERNATION AND OTHER ITEMS - LATE '50 - EARLY '51

While we were trying to sell the industry and government through demonstrations and lectures, significant laboratory tests and studies of color television continued. NBC New York got on the air, first with color generated in Washington, D.C., and sent up the co-ax cable, and eventually with live color signals generated in New York City. During one of the broadcasts (which were all in the dot-sequential format), we observed that the pictures were much more pleasing when viewed through a constant-luminance/ shunted monochrome decoder than when viewed through a dot-sequential decoder. The pictures were much less noisy and the "incorrect decoding" seemed to make the colorimetry more pleasing. Memo 4281-151d dated February 7, 1951, and attached to page 63 of NB3285, and the written descriptions on page 62, describe this.

13.1 The Path to CPA

My notebooks indicate that during September, 1950, I was studying color crosstalk in a dot-sequential system vs. color mis-phasing and vs. multipath. Also just before this time, someone (I don't remember who) started pushing "dash-sequential" which used "flat pulses" with a lower sampling rate than dot-sequential. So I made a comparison of color crosstalk of dash-sequential with dot-sequential. Once again, I found it useful to analyze things in the frequency domain. This analysis showed that dash-sequential had:

1. A fundamental subcarrier with normal color sequence vs. phase.
2. A second harmonic subcarrier with reversed color sequence (compared to fundamental).
3. A third harmonic with no color sequence for the symmetrical dot-sequential case.
4. Use of third and higher terms, if within the passband, were of no value (although fourth and fifth had opposite color sequence).
5. A good set of numbers were 1.8 MHz for fundamental and 3.6 MHz for second harmonic, letting the third be out of the band.

The above types of analysis showed that the opposite color sequence of fundamental and second gave opposite color error vs. phase error. I was studying what type of signal processing was necessary to get complete cancellation of color errors vs. phase in this "dash-sequential" system. It became evident that for multipath induced phase errors, a phase reference (like the color burst) was needed at both fundamental and second harmonic frequencies. This seemed unnecessarily complicated.

13.2 CPA

Finally, I realized that the opposite color sequences could be used at a single color subcarrier frequency if they were separated in time (instead of in frequency like fundamental and second harmonic in dash-sequential). This can be expressed as a reversal in direction of color sequence vs. phase after each of such periods as a frame, a field, a line (or even faster). The periods for reversal merely need to be convenient for either visual averaging or electrical averaging. Incidentally, when using reversal at a rate faster than line rate (say approaching a dot rate), it becomes apparent that the quadrature components of the color subcarrier have sidebands which clearly separate the stationary color axis and the oscillating color axis into different frequency ranges. When reversing at a line rate or lower, the stationary axis and the oscillating axis have different dot (subcarrier) patterns.

Here again, as with the path to shunted-monochrome, I took a system described in the time domain and analyzed it to find the frequency domain equivalent. But another step was involved: I recognized a problem with the two subcarrier case, and I realized that essentially a one subcarrier case existed by using time sharing or an oscillating color sequence (OCS).

The color phase alternation idea (CPA or OCS) was written down on 9/27/50 - the culmination of a stream of thought from dash-sequential, to two subcarrier case with opposite color sequence, to a one subcarrier case with alternative color phase sequence. But we must have been busy with other things because it was 12/18/50 before we made a partial reduction to practice and 1/31/51 before we made a complete system operating with OCS.

Some time early in 1951, possibly in February, RCA paid us a visit to discuss our respective progress in color TV. The morning was probably a general discussion, and then at lunch time they told us about their new good idea called Color Phase Alternation. We surprised them by responding that a demonstration of the technique was planned by us for them that afternoon. It's not clear that they had working hardware when we showed them our demo.

When we filed our OCS patent application, no interference was declared, so it wasn't clear whether RCA gave up CPA because we had an earlier date, or what. We filed on January 22, 1951.

On May 2, 1951, NBC New York started transmissions with CPA. However, they were still using their symmetrical sampling system, operating at 3.58 MHz and with field rate alternation.

13.3 Ready for Second NTSC

By early 1951, we had the necessary system technology to present to an industry committee (such as a second NTSC), and propose an industry field test. Starting with RCA's dot-sequential system with dot-interlace and mixed highs, we, at Hazeltine, had the improvements of shunted monochrome, constant luminance, and oscillating color sequence which now could make a quality color system. So - NTSC, here we come!

14

EVENTS CULMINATING IN SECOND NTSC (NATIONAL TELEVISION SYSTEM COMMITTEE)

14.1 RMA TV Committee and the First NTSC (Monochrome)

Early television broadcasts used mechanical scanning at both the transmitter and receiver. Mechanical scanning was generally accomplished using a rotating disk with a series of holes (or individual lens) arranged in a spiral, so successive holes scanned across the scene, each one scanning horizontally and the following hole forming the next line displaced vertically down the picture. (Nipkow disk, 1884) Such broadcasts were performed in the late '20's and early '30's, in England by Baird and in U.S. by Jenkins.

The RMA (Radio Manufacturers Association) formed a Television Committee in 1929. Some considerations were given to standards as can be seen by an article in Proceedings of IRE (Institute of Radio Engineers), September, 1929. The suggested bandwidth for this service was 100 KHz, which was 10 times wider than that used for sound broadcasting, and only 1/60th of the bandwidth now allotted to each TV channel. But such systems were extremely crude. The scanning discussed in this 1929 article consisted of 60 lines vertically and 72 "dots" horizontally with a picture rate of 20 pictures/second.

By the early '30's, the more advanced labs were using electronic scanning at the receiver (using a cathode ray tube, CRT). By the mid-'30's, Zworykin had developed a practical electronically scanned camera tube (iconoscope), and all-electronic television replaced the old mechanically scanned TV broadcast systems. Such all electronic systems could use more scanning lines to obtain more resolution and the number of lines being considered rapidly advanced from 60 to 343 and finally by 1936 to 441 lines.

The 1936 RMA Standards Committee proposed 441 lines, 2:1 interlaced scanning at 30 frames per second, an aspect ratio of 4 by 3, double-sideband negative picture modulation, 2.5 MHz video bandwidth and FM for the sound signal.

The RMA Television Committee on June 3, 1938, voted approval of a complete list of recommended standards for TV transmission in U.S. This was reported in July, 1938, Electronics starting on page 29. Also a good listing of the standards is given in an appendix (starting on page 517) in "Principles of Television Engineering" by Don Fink, 1940, published by McGraw-Hill.* Practically all of the standards are identical to (or include within the tolerances) the finally adopted monochrome standard, except for the number of lines.

---

* A copy of pages 517 through 521 is included at the end of section 14.1.

The 1938 recommended standards had several advances over the 1936 proposal. DC transmission of the brightness was specified, details of the horizontal and serrated vertical sync pulses were proposed, as well as vestigial sideband transmission for the picture information. The latter permitted raising the video bandwidth from 2.5 to 4.0 MHz. However, there was still some dissension in the engineering ranks, at least on two points. First, was 441 lines optimum for the new 4.0 MHz video bandwidth, and second, should FM be used for the sync pulses (producing an AM due to sloping characteristic of the receiver IF to properly receive the vestigial sideband transmission).

This whole situation of standards had not been settled and the FCC had not as yet approved a set of specs when, on April 30, 1939, at the opening of the World's Fair, NBC started broadcasting according to the latest RMA specs. Then, in the New York Times and the Herald Tribune, on Wednesday, March 20, 1940, RCA took a full-page ad announcing that TV was here and RCA was making TV receivers available to the public, specifically the Model TRK-12 for $395. This angered the FCC and it stated that RCA's action was tending to freeze the standards. In May, 1940, the FCC announced it would no longer authorize limited commercial operations and that standards would not be set at that time.

The disagreement regarding standards, as well as the RCA action and FCC response, prompted RMA through its Director of Engineering, Dr. W. R. G. Baker, to form the first NTSC (National Television Systems Committee), which was open to all qualified industry members. The first meeting was held July 31, 1940. Industry members devoted 4000 man-hours to meetings and witnessed 25 demonstrations before completing its work on March 8, 1941.

A suitable compromise was reached with 441 lines increased to 525 lines, and with alternate use of frequency or amplitude modulation for sync pulses. I don't know of any significant commercial use of FM for sync pulses. In April, 1941, the FCC approved the NTSC monochrome standards and permitted commercial operation to start on July 1, 1941. This was clearly a case where NTSC and FCC worked together and not as adversaries.

APPENDIX

TRANSMISSION STANDARDS, RECOMMENDED PRACTICES, DEFINITIONS, AND NAMES OF CONTROLS

ADOPTED BY THE RADIO MANUFACTURERS ASSOCIATION

The following list contains accepted standards and terminology as adopted by the R.M.A. Committee on Television and approved by the membership of that body. These standards have been superseded by the N.T.S.C.-F.C.C. standards. The most important change is in T-107, in which the number of lines per frame has been increased from 441 to 525.

TELEVISION-TRANSMISSION STANDARDS

T-101 Television Channel Width

The standard television channel shall not be less than 6 Mc. in width.

T-102 Television and Sound Carrier Spacing

It shall be standard to separate the sound and picture carriers by approximately 4.5 Mc.

T-103 Sound Carrier and Television Carrier Relation

It shall be standard in a television channel to place the sound carrier at a higher frequency than the television carrier.

T-104 Position of Sound Carrier

It shall be standard to locate the sound carrier for a television channel 0.25 Mc. lower than the upper frequency limit of the channel.

T-105 Polarity of Transmission

It shall be standard for a decrease in initial light intensity to cause an increase in the radiated power.

T-106 Frame Frequency

It shall be standard to use a frame frequency of 30 per second and a field frequency of 60 per second, interlaced.

T-107 Number of Lines per Frame

It shall be standard to use 441 lines per frame.

T-108 Aspect Ratio

The standard picture aspect ratio shall be 4:3.

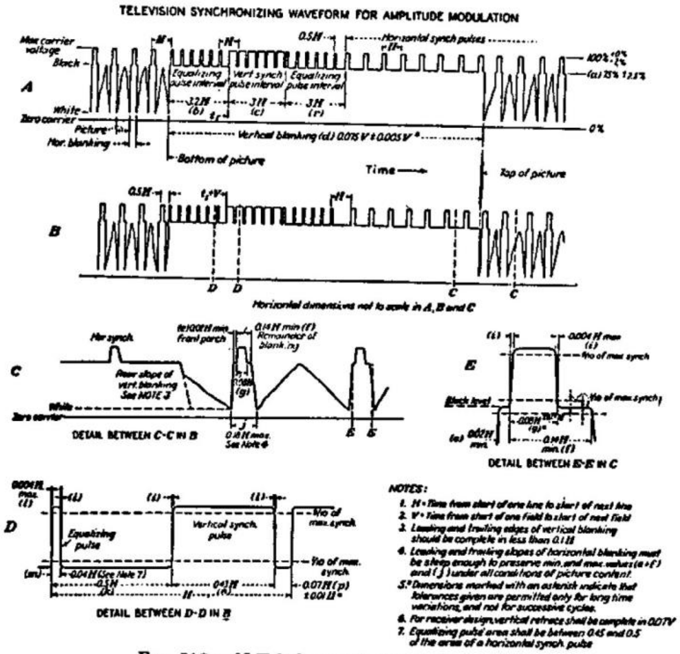


FIG. 312.—N.T.S.C. standard television signal.

T-109 Percentage of Television Signal Devoted to Synchronization

If the peak amplitude of the radio frequency television signal is taken as 100 per cent, it shall be standard to use not less than 20 per cent nor more than 25 per cent of the total amplitude for synchronizing pulses.

T-110 Method of Transmission

It shall be standard in television transmission that black shall be represented by a definite carrier level independent of light and shade in the picture.

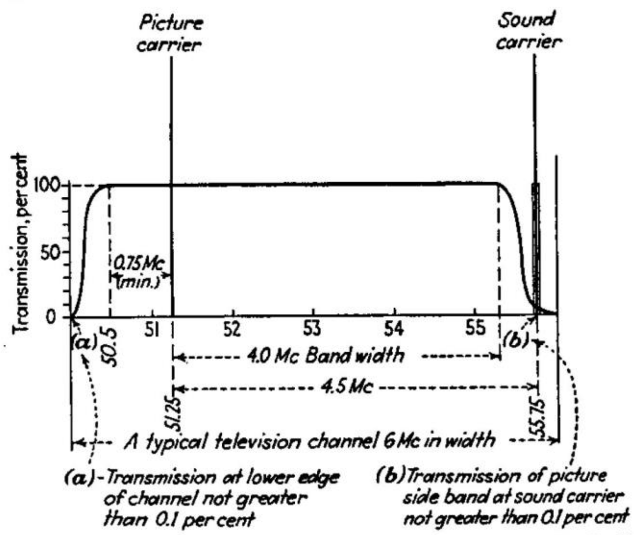


FIG. 313.—Reprint of R.M.A. Standard T-115, Transmitter Amplitude Characteristic, as defined by the R.M.A. Television Committee.

T-111 Synchronizing

The standard synchronizing signals shall be as shown on Drawing T-111.

T-112 Transmitter Modulation Capability

If the peak amplitude of the radio frequency television signal is taken as 100 per cent, it shall be standard for the signal amplitude to drop to 25 per cent or less of peak amplitude for maximum white.

T-113 Transmitter Output Rating

It shall be standard, in order to correspond as nearly as possible to equivalent rating of sound transmitters, that the power of television picture transmitters be nominally rated at the output terminals in peak power divided by four.

T-114 Relative Radiated Power for Picture and for Sound

It shall be standard to have the radiated power for the picture approximately the same as for sound.

T-115 Transmitter Amplitude Characteristic

It shall be standard to use the transmitter amplitude characteristic shown in Drawing T-115.

T-116 Scanning

It shall be standard to scan at uniform velocity in horizontal lines from left to right, progressing from top to bottom when viewing the subject from the camera position.

T-117 Sound Transmitter Amplitude Characteristic

It shall be standard in television sound transmission to pre-emphasize the modulation at the higher frequencies according to the impedance-frequency characteristic of a series inductance-resistance network having a time constant of 10 μseconds.

RECOMMENDED PRACTICES

Polarization of Radiated Wave

It shall be recommended practice in television transmission that the radiated wave shall be horizontally polarized.

Intermediate Frequencies for Television Receivers

It shall be recommended practice in Television Receivers to place the sound modulated intermediate frequency carrier at 8.25 Mc. and the picture modulated intermediate frequency carrier at 12.75 Mc.

DEFINITIONS

Receiver Definitions

It shall be standard to define at least three classes of receivers as follows:

1. Picture receiver. A receiver for picture only, with no facilities for receiving the associated sound.
2. Picture receiver with sound converter. The same as a picture receiver, with the addition of an incomplete sound channel, requiring the use of a suitable auxiliary sound receiver.
3. Television receiver. A receiver having complete channels for receiving the television picture and its associated sound.

Transmitter Definitions

Television transmitter. A transmitter which transmits both picture and sound shall be called a Television Transmitter.

Picture transmitter. A transmitter which transmits the television picture only shall be called a Picture Transmitter.

Sound transmitter. A transmitter which transmits the television sound only shall be called a Sound Transmitter.

Names of Controls of Television Receivers

The following list of controls and their functions shall be standard for Television Receivers:

Name of Control	*Function of the Control*
Focus	Adjustment of spot definition
Contrast	Adjustment of video frequency signal amplitude
Brightness	Adjustment of average light intensity
Tone	Same as in sound receiver practice
Volume	Same as in sound receiver practice
Station selector	Same as in sound receiver practice
Horizontal hold	Adjustment of the free-running period of the horizontal oscillator
Vertical hold	Adjustment of the free-running period of the vertical oscillator
Width	Adjustment of the picture size in the horizontal direction
Height	Adjustment of picture size in the vertical direction
Horizontal centering	Adjustment of the picture position in the horizontal direction
Vertical centering	Adjustment of the picture position in the vertical direction
Fine tuning	Vernier tuning control
Linearity control	Adjustment of scanning wave shapes May be qualified by the adjectives "top," "bottom," "right," "left"

14.2 The Ad Hoc Committee of the Second NTSC (Color)

The general situation in the late '49-early '50 period can be gleaned from section 10. The FCC was disenchanted with compatible color TV. So in 1950, when Dr. Baker was setting up the second NTSC to study compatible color, the FCC, contrary to their action in 1940 re: first NTSC, was dead silent.

The first significant action of the new NTSC was by the Ad Hoc Committee, led by Dave Smith (of Philco) and set up to study the status of compatible color. The committee consisted of leading engineers from DuMont, GE, Hazeltine, Philco, RCA, and Sylvania. The respective engineers were: Thomas T. Goldsmith, Ira J. Kaar, Arthur V. Loughren, David B. Smith, Elmer W. Engstrom, Robert M. Bowie. The Ad Hoc Committee reviewed the work being done at all of these labs, and studied the available technical material.

The schedule of demonstrations witnessed follows:

21 November 1950	- Hazeltine Electronics Corporation at Little Neck, Long Island
11 January 1951	- Radio Corporation of America at Trans-Lux Building, Washington, D.C.
29 January 1951	- Allen B. DuMont Laboratories, Inc. at Passaic, New Jersey
8 February 1951	- Philco Corporation at Philadelphia, Pa.
23 February 1951	- General Electric Company at Electronics Park, Syracuse, New York
27 February 1951	- Hazeltine Electronics Corporation at Little Neck, Long Island

From the dates, the second demonstration at Hazeltine must have been to show our work with OCS (Oscillating Color Sequence).

A complete listing of items demonstrated by Hazeltine is given on the following four pages:

COLOR TELEVISION DEMONSTRATIONS FOR AD HOC COMMITTEE ON COLOR TV HELD AT HAZELTINE ON SEVERAL OCCASIONS

The following items were demonstrated to the NTSC Ad Hoc Committee on color television on several occasions:

The subject matter consisted of a variety of color slices picked up by a three-color flying spot scanner with gamma correction in each color signal output. The pictures were shown simultaneously on three trinoscopes and on a black-and-white receiver. Adders, matrix units, samplers, desamplers, filters, amplifiers, etc. were inserted between the transmitter and receiver as the occasion demanded.

I. Mixed-Highs

Simultaneous "mixed-highs" were demonstrated using "cross-over" frequencies of 0; 0.1; 0.25; 0.50; 1.0; 2.0; and 4.0 Mc. Composite pictures, low frequency components of color, and "mixed-highs" only pictures were shown. The "mixed-highs" were proportioned according to the luminosity of the component primary color.

II. Dot-Sequential System

The following variations of the dot-sequential system were demonstrated and compared with each other:

A. 0° and 90° phase shift of the color subcarrier after every field.

B. Symmetrical sampling.

C. Asymmetrical sampling for

1. Exact constant luminance
2. Simplified constant luminance

D. Bandwidth limitation of

1. Monochrome channel
2. Color Channel

E. Sampling of the brightness signal at the transmitter only only for the purpose of compensating for spurious effects and making them appear on the blue tube only.

F. Transmission of color subcarrier at reduced amplitude.

G. Combinations of items A, B, C, D, E, and F above.

H. Oscillating-color-sampling sequence for increased immunity to unwanted phase shift of color-subcarrier or receiver desampler.

III. Receivers Used

The variations of the dot-sequential system listed above were demonstrated simultaneously using three types of receivers having the following characteristics:

A. Narrow-angle-sampling receiver.

B. Shunted-monochrome receiver with and without 3.5 Mc traps in the brightness channel using

1. Symmetrical desampling
2. Asymmetrical desampling for
    a) Exact constant-luminance
    b) Simplified constant-luminance
3. Amplitude and Bandwidth limiter in blue color-difference channel when signal increases in positive direction
4. Adjustable gain in color channel
5. Phase-inverter in blue channel for Oscillating-Color-Sequence
6. Alternate-frame-blanking to show nature of interference without integration

C. Monochrome receiver for test of compatibility.

IV. Transmitter

The signal was transmitted

A. Over three wires for demonstrations of simultaneous color such as for "mixed-highs" demonstration.

B. Video link for the color receivers.

C. R-F link carrying composite color information to a standard monochrome receiver.

V. Characteristics Demonstrated and Compared with Each Other and with 12 Mc Simultaneous Picture.

A. Reduction of visibility and crawl of the dot pattern on both color and monochrome receivers by 90° phase shift of the color subcarrier.

B. Elimination of dots in gray areas of the original scene by the shunted-monochrome type of color receiver.

C. Elimination of dots from large colored areas of the original scene in the shunted-monochrome type of receiver by means of

1. Traps in the brightness channel
2. Bandwidth limitation in the brightness channel

D. Constant-Luminance System

1. Output of brightness channel only (i.e., brightness picture only)
2. Output of color channel only (constant-luminance color picture only)

E. Improvements Due to Constant-Luminance System

1. Reduction of cw interference
2. Reduction of low frequency noise produced by heterodyning of high-frequency noise by the desampler
3. Reduction of crosstalk of monochrome information into color channel. This crosstalk produces shimmers, crawls, moire.

F. Effect of transmitting all brightness in monochrome channel on a black-and-white receiver.

G. Sampling of the brightness signal at transmitter for the reduction of crosstalk of the brightness information into color by dumping all spurious effects into the blue channel.

H. Reduction of Amplitude of Color Subcarrier.

1. Reduction of dot visibility in black-and-white receiver by reducing amplitude of color subcarrier
2. Effect on color reception of reducing amplitude of color subcarrier

   a) With no compensating increase in gain of color channel
      (1) Effect of reducing saturation
   b) With compensating increase in gain of color channel
      (1) Strong increase in color channel noise
      (2) Strong increase in crosstalk of monochrome into color
   c) Reduction in noise and crosstalk by "20 db package" made up of
      (1) Constant-luminance system
      (2) Reduction of monochrome bandwidth to 3.5 Mc

(3) Reduction of color channel pass-band to 3 to 4 Mc
(4) 90^{o} phase shift of color subcarrier
(5) Sampling of the brightness signal at transmitter

The elements of the above package were demonstrated individually and collectively.

I. Constant-Luminance Color Receiver having only two desamplers (one for red and one for blue). Recovery of green by phase inversion of red signal.

J. Use of Oscillating-color-sequence resulting in

1. Increased tolerance to phase shift of color subcarrier or desampling signal in large color areas.
2. Increased tolerance to single side-band transmission due to cut-off characteristic of receiver. This in turn allows increasing monochrome bandwidth, color bandwidth, and reduces visibility of dots in monochrome receiver by permitting the color subcarrier to be shifted to higher frequency.

REFERENCES:

Hazeltine Report 7113 - "An Analysis of Color Television"

Hazeltine Report 7116 - "Recent Improvements in "Dot-Sequential" Color Television Systems"
Part I: The Constant Luminance System and Related Improvements
Part II: Color Television Systems with Oscillating Color Sequence

From the complete list of items, you can see that we "pulled-out all of the stops" for the Ad Hoc Committee and laid a good ground-work for the NTSC work to follow. In April, 1951, the committee finished its analysis and stated that it concluded that a compatible color system could be evolved on the following premises:

1. Existing B&W standards should also apply for color.
2. To the B&W signal, a "practically invisible" color subcarrier should be added which contains information regarding chroma and hue, as amplitude and phase of subcarrier.
3. Color sync should be transmitted during horizontal sync time interval.

14.3 Reorganization of Second NTSC

The NTSC was reorganized after receiving the report of the Ad Hoc Committee, as follows:

1. Ad Hoc Committee and several of proposed panel chairmen to act as a Coordinating Panel (Panel 18).
2. In addition, three basic groups of panels would be established:
   - 2.1 A group dealing with fundamental technology.
   - 2.2 A group to design the specific system.
   - 2.3 A group to field test the system.

Panels 11, 11-A, 12, and 19 fall in the first group. Panels 13 and 14 fall in the second group. Panels 15, 16, and 17 fall in the third group. Note that panel numbers are in the "teens" to prevent confusion with previous NTSC panels, and the duties of each panel were carefully refined.

Starting in June, 1951, many panels had regular monthly meetings, some with field tests during the wee hours of the morning when broadcast stations were free of commercial obligations.

The overall NTSC organization is nicely summarized on one page from the Record of Proceedings for CCIR in March, 1956. A copy is on the next page.

NATIONAL TELEVISION SYSTEM COMMITTEE
ORGANIZATION

W. R. G. Baker............CHAIRMAN

THE AD HOC COMMITTEE—NOVEMBER 20, 1950 TO APRIL 19, 1951

D. B. Smith..*Chairman*
Members...........R. M. Bowie, E. W. Engstrom, T. T. Goldsmith, I. J. Kaar, A. V. Loughren

THE NTSC—FROM JUNE 18, 1951 TO FEBRUARY 4, 1954

VICE CHAIRMEN

David B. Smith.......................*Vice President—Research, Philco Corp.*
Arthur V. Loughren...................*Vice President—Hazeltine Corp.*
Elmer W. Engstrom...................*Vice President in Charge of the RCA Laboratories Division—RCA*
Mrs. Martha Kinzie..................*Secretary for NTSC—GE*
Robert M. Estes....................*Counsel—GE*

PANEL ORGANIZATION

PANEL 11—SUBJECTIVE ASPECTS OF COLOR

Dr. Alfred N. Goldsmith......*Chairman* D. E. Hyndman......*Vice Chairman*

PANEL 11-A—COLOR TRANSCRIPTION

Dr. Alfred N. Goldsmith......*Chairman* D. E. Hyndman......*Vice Chairman*

PANEL 12—COLOR SYSTEMS ANALYSIS

D. G. Fink......*Chairman* A. G. Jensen......*Vice Chairman*

PANEL 13—COLOR VIDEO SIGNALS

A. V. Loughren......*Chairman* W. T. Wintringham......*Vice Chairman*

PANEL 14—COLOR SYNCHRONIZING STANDARDS

D. E. Harnett......*Chairman* R. N. Harmon......*Vice Chairman*

PANEL 15—RECEIVER COMPATIBILITY

Rinaldo DeCola......*Chairman* W. O. Swinyard......*Vice Chairman*

PANEL 16—FIELD TESTING

Knox McIlwain......*Chairman* D. W. Pugsley......*Vice Chairman*

PANEL 17—BROADCAST SYSTEM

*R. E. Shelby......*Chairman* J. M. Barstow......*Vice Chairman*

PANEL 18—CO-ORDINATION

D. B. Smith......*Chairman* I. J. Kaar......*Vice Chairman*

PANEL 19—DEFINITIONS

Dr. R. M. Bowie......*Chairman* M. W. Baldwin, Jr.......*Vice Chairman*

THE EDITORIAL COMMITTEE

D. G. Fink..*Chairman*
Members...........E. W. Engstrom, I. J. Kaar, A. V. Loughren, D. B. Smith

**Deceased*

Now the second NTSC is established and off running. Hazeltine has a VP of NTSC: Arthur V. Loughren; has two panel chairmen: A. V. Loughren (Panel 13) and Knox McIlwain (Panel 16); one panel vice chairman: W. O. Swinyard (Panel 15); plus many members, alternates and observers covering most panels.

The following is a tabulation of our formal membership re: each panel, but beyond this, many other Hazeltine engineers and technicians attended selected meetings and demonstrations.

Committee	Names and Type of Membership
Main	A. V. Loughren, member; Knox McIlwain, alternate
Panel 11	Knox McIlwain, secretary
Panel 11-A	R. P. Burr, member
Panel 12	C. J. Hirsch, member; W. F. Bailey, alternate
Panel 13	A. V. Loughren, chairman; C. J. Hirsch, member, B. D. Loughlin, alternate; W. O. Swinyard, observer
Panel 14	B. D. Loughlin, member; W. F. Bailey, alternate
Panel 15	W. O. Swinyard, vice-chairman; R. F. Tschannen, alternate
Panel 16	Knox McIlwain, chairman; J. A. Hansen, member; R. J. Farber, alternate
Panel 17	R. P. Burr, member
Panel 18	A. V. Loughren, member; W. O. Swinyard, alternate; Knox McIlwain, member
Panel 19	C. J. Hirsch, member; R. P. Burr, alternate
Editorial	A. V. Loughren, member

An interesting perspective which relates to the items in this section is presented in "Perspectives on Television: The Role Played by the Two NTSC's in Preparing Television Service for the American Public", by Donald G. Fink, Proceedings of IEEE, September, 1976, pages 1322 through 1331. Our technical contribution is recognized at two places in this article.

15

SOME DETAILS OF THE SECOND NTSC ACTIVITIES

This material is grouped according to Panel number and is thus not necessarily in chronological order. For example, much of Panel 12 monographs follows after decisions in other panels.

Many of the Panel meetings were held at the then IRE Headquarters at 1 East 79th Street, New York City.

15.1 Panel 11 - Subjective Aspects of Color TV

Panel 11 addressed itself to the specific task of the relative bandwidth required for chrominance and luminance, as determined from observations by the members, of a color TV system. The variable cross-over mixed-highs unit (see section 11.2), which I designed, was a major tool used in this study. We had cross-over frequencies of 0.1, 0.25, 0.5, 1, 2 MHz, as well as full 4 mc color and monochrome. A selection of slides were available for our flying spot scanner, and tests were run in a completely random fashion, so the panel members did not know what cross-over they were evaluating when they rated each individual picture. The total bandwidth for each case is:

4.2 MHz	for 0.1 MHz cross-over
4.5	for 0.25
5	for 0.5
6	for 1
8	for 2
12	for no cross-over

The subjective data taken shows that with 1 MHz cross-over, 90% of all combinations of viewers and scenes are satisfactory, and about 70% of the viewers notice no degradation at all. It was concluded from this that at least 1 MHz cross-over is a minimum requirement. However, later data shows that the same bandwidth is not needed for all color-difference axes of the chrominance signal.

In some ways, these tests were "overly critical", being taken with still pictures, but not critical enough in view of today's signal processing of both horizontal and vertical aperture equalization. But actually, most sets sold even today (which appear to be satisfactory in view of the number sold) do not make full use of the equivalent of a 1 MHz cross-over.

Knox McIlwain was secretary for Panel 11. He wrote a comprehensive description of these color tests, published in a paper entitled "Requisite Bandwidth for Simultaneous Color-Television Systems", published in Proc. IRE, August 1952.

It is essential that substantially identical subject matter be used by various laboratories and that ready comparisons be made with the original. Accordingly, Panel 11 proposed that there be produced for the NTSC field tests a suitable set of color test slides and an appropriate reel of color motion-picture film. Panel 11 was fortunate in securing the helpful cooperation of the Eastman Kodak Company in both of these items. Kodak distributed, gratis, 68 sets of 27 Kodachrome test slides (1,836 slides). These slides were our main-stay, and we spent many hours looking at them, through all kinds of system tests.

15.2 Panel 12 - Color System Analysis

The eventual charge to Panel 12 was: "The function of Panel 12 shall include the detailed analysis and interpretation of such new technology as may be evolved in connection with the NTSC signal and the preparation of tutorial papers concerning such new technology." The panel prepared a general description of the NTSC signal and 14 technical monographs. These documents covered subject matter directly connected with the work of the NTSC and Panels 13, 14, and 17. The 14 monograph titles, authors, and questions answered by each monograph follow:

Monograph 1, "Colorimetry In Color Television - Part I", F. J. Bingley (Philco):
Question: "If at some future time it proves desirable to construct color receivers using four or more primary colors, in the interest of covering the widest possible gamut of colors in the reproduced image, would any changes in the NTSC signal be necessary to accommodate such receivers?" Answer: "No, the three-color quantities present in the NTSC signal are sufficient in principle to operate a receiver having any number of primary colors."

Monograph 2, "Quadrature Cross Talk In NTSC Color Television", W. F. Bailey and C. J. Hirsch (Hazeltine):
Question: "How is cross talk between the two chrominance signals minimized in the NTSC signal?" Answer: "By appropriate choice of the chrominance axes and the bandwidths assigned to each, and by transmitting at least one of the chrominance signals by double-sideband modulation of the chrominance subcarrier."

Monograph 3, "The Frequency-Interleaving Principle In the NTSC Standards", I. C. Abrahams (General Electric):
Question: "How are the luminance and chrominance sidebands put into interleaved relationship?" Answer: "By choosing the chrominance subcarrier frequency equal to an odd multiple of one-half the line-scanning frequency."

Monograph 4, "Mathematical Formulations Of The NTSC Color Television Signal", G. H. Brown (RCA):
Question: "In how many different ways can the complete color signal be represented symbolically?" Answer: "There are an infinite number of ways of expressing the basic equation. There are four ways of tutorial interest: in terms of red and blue color-difference signals, in terms of the three primary signals, in terms of red, blue, and green color-difference signals, and in terms of symmetrical components."

Monograph 5, "Narrow-Band Transmission Of The NTSC Color Signal", J. G. Reddeck (RCA):
Question: "How can the complete color signal, including the chrominance subcarrier (frequency 3.579+ mc), be transmitted over a coaxial cable limited to a maximum frequency of 2.7 mc?" Answer: "By heterodyning the subcarrier and its adjacent sidebands to a lower frequency, within the cable passband, before transmission, and heterodyning them back to the standard values after transmission, and by cutting off the luminance signal at a frequency low enough to avoid interference with the subcarrier and its sidebands while the signal is on the cable."

Monograph 6, "Colorimetry In Color Television - Part II", F. J. Bingley (Philco):
Question: "If the blue color-difference signal is interrupted by the failure of a video amplifier tube carrying this signal, but the red color-difference signal is present, what colors will appear on the picture tube, assuming the receiver is otherwise operating correctly?" Answer: "The image will be reproduced in cyans and purples of various saturations."

Monograph 7, "Color-Carrier Reference-Phase Synchronization Accuracy In NTSC Color Television", D. Richman (Hazeltine):
Question: "How much random noise may be present in the color-synchronizing signal, in a correctly designed receiver, before the reproduced hues are noticeably affected by loss of synchronism?" Answer: "The rms value of the noise may be as great as the peak value of the synchronizing signal (unity signal to noise ratio), if full advantage is taken of the information present in the color-burst signal."

Monograph 8, "Colorimetry In Color Television - Part III", F. J. Bingley (Philco):
Question: "What is the effect of gamma correction on the shape of the chrominance axes?" Answer: "The axes (straight lines with linear transmission) become curved when gamma correction is employed; the curved lines pass through the white point and, in the vicinity of the white point, have the same slope as the straight-line axes."

Monograph 9, "Choice of Chrominance-Subcarrier Frequency In The NTSC Standards", I. C. Abrahams (General Electric):
Question: "Why is the line-scanning frequency in the NTSC specification 15,734+ cps rather than 15,750 cps as in the present monochrome standard?" Answer: "To maintain the sound-picture intercarrier spacing at the exact value of 4.5 mc for which existing monochrome intercarrier receivers are designed, while keeping the chrominance subcarrier sideband in offset relationship to sound and picture carriers, it was necessary to select the scanning frequencies 0.1 per cent lower than the monochrome values."

Monograph 10, "System Delay Characteristics In NTSC Color Television", R. C. Palmer (DuMont):
Question: "On what basis was the transmitter time-delay specification selected?" Answer: "To compensate for the measured phase response of typical monochrome receivers, which have been found to display a high degree of uniformity in this respect."

Monograph 11, "The Constant-Luminance Principle In NTSC Color Television", W. F. Bailey (Hazeltine):
Question: "What is the most important benefit of the constant-luminance method of color transmission?" Answer: "The effect of spurious components, such as noise and interference, is rendered less visible if the effect of these components is transferred as much as possible from the luminance signal to the chrominance signals."

Monograph 12, "Transfer Characteristics In NTSC Color Television", F. J. Bingley (Philco):
Question: "What is the principal difference between the several proposed methods of gamma correction, so far as the reproduced image is concerned?" Answer: "The proposed methods operate identically in the vicinity of the white point; the difference appears in the relative luminances of highly saturated colors."

Monograph 13, "The Effect of Transmitter Characteristics On The NTSC Color Television Signal", G. L. Fredendall and W. C. Morrison (RCA):
Question: "In what way does the radiated color-sync burst (modulation envelope) differ most noticeably from the corresponding waveform applied to the transmitter modulator?" Answer: "The percentage peak-to-peak amplitude of the burst as radiated is one-half that of the modulating waveform, since the burst frequency is transmitted by vestigial sideband."

Monograph 14, "Choice of Axes and Bandwidths For The Chrominance Signal In NTSC Color Television", G. H. Brown (RCA):
Question: "What is the effect on the reproduced image of the frequency content from 0.6 to 1.3 mc in the I-channel chrominance signal?" Answer: "If these frequencies are utilized in the receiver, picture details corresponding in size to this frequency range are reproduced in two colors, orange and cyan, whereas larger details are reproduced in full colors."

Of the above list of 14 monographs, twelve are concerned with the Color Video Standards (Panel 13 responsibility), one concerns Color Synchronizing Standards (Panel 14 responsibility) and one concerns the Broadcast System (Panel 17 responsibility). In most cases the author(s) of the monograph were either a member or alternate of either Panel 12 or the Panel of responsibility.

15.3 Panel 13

The charge to Panel 13 read: "It will be the responsibility of this panel to provide recommended standards relating to the complete video signal. As such, it will include the determination of both colorimetric and electric specifications. The purview of this panel will include the following:

1. Camera taking characteristics.
2. Gamma Characteristics.
3. Color carrier frequency and its phase relationship with respect to horizontal synchronizing signals.
4. The color sequence to be used and whether or not it should be of the oscillating type.
5. Bandwidths of the monochrome and color signals.
6. Relative amplitudes of the monochrome signal and color carrier.
7. Determination of the maximum system-amplitude demands at critical colors to enable the determination of picture-to-synchronizing ratios.
8. Specification of radiated signal.

Conclusions/Decisions

Prior to the first meeting, AVL circulated a two-page memo treating scope for the panel and a proposed agenda for the first meeting.

Meeting No.

1 June 25, 1951 - Mainly airing of various opinions regarding agenda items and decision to hold demonstrations of OCS and other proposed systems characteristics; schedule: August 6 at GE; August 7 at RCA; August 8 at Philco; August 9 at Hazeltine; findings to be summarized at meeting on August 10 at IRE Headquarters.
Decision: A subcommittee to study gamma correction was formed.

2 July 2, 1951 - Subcommittee appointed to draft complete set of words (less numbers) as framework for final standards. Subcommittee on receiver problems formed. A review of what demonstrations will cover week of August 6th, plus some modifications in schedules. Panel membership established with: Chairman, Vice Chairman, 18 members and 13 alternates.

3 August 10, 1951 - Total present: 33 persons representing 19 organizations. Chairman suggested first explore areas of general agreement. To aid this, Hazeltine Engineering Memo E215 of July 31, 1951, entitled "Proposal to Panel 13 of NTSC for a Complete Video Signal for Compatible Color TV" was used. Considerable discussion followed with following Motions:

1 "The color subcarrier frequency be 3x3x5x11x15,750/2 = 3.898,125 mc." Passed unanimously.

2 "The main video signal is to be proportioned to carry all the luminance to be produced by the receiver." (It was understood by previous agreement that, for these preliminary agreements, the system will be treated as being linear.) Passed unanimously.

3 "The phase sequence of the color subcarrier shall be reversed at field rate." Passed unanimously.

4 "The color synchronizing signal shall be the equivalent of the gating of a continuous wave whose frequency is that of the color subcarrier." Adopted unanimously.

5 "The stationary OCS axis shall be in quadrature with the phasor representing the color synchronizing signal." Adopted unanimously.

6 "The relative amplitude and phase of the color subcarrier components shall be expressed by the following equation:

$$(E'_x - E'_y)\cos(2\Pi f_{sc} t \mp \Phi) + 0.5(E'_z - E'_y)\cos[2\Pi f_{sc} t \mp (\Phi + 108°)]."$$

Adopted unanimously. George Brown (RCA) stated his affirmative vote was conditioned on further investigation as to whether the phase angles specified were in fact a good compromise.

7 "While the value of K_1 cannot be determined at present, its final value will lie between 0.7 and 1.5." Adopted unanimously.

Meeting called to order at 10:00 AM, panel adjourned at 5:30 PM. It is interesting to note that at this critical meeting the RCA member (George Brown) neither moved nor seconded any motion, but did vote for all of them. Basically, at this point, Hazeltine had won the battle of NTSC!

Appendix 3, NTSC P13-162 notes: "Reasons for the adoption by Panel 13 of the motions listed in Appendix 2 --- P2, motion 3 ends with the sentence 'It was decided to propose Color Phase Alternation at field rate instead of line rate because line rate results in annoying line crawl.'"

4 <u>September 7, 1951</u> - After considerable preliminary discussion the following two motions were made and carried without dissent.

1 "The chromaticity for which the subcarrier shall vanish is x = 0.310, y = 0.316 which corresponds to illuminant C."

2 "The composition of the signal on the color subcarrier shall be such that the red and blue color difference signals, for Panel 7 primaries, can be regained directly by demodulation by two carriers in quadrature, and the relative amplitude of the two color difference signals be such that overloads of the order of 1/3 occur for the colors corresponding to Panel 7 primaries or their complements at maximum intensity."

More discussion followed and by the next motions some members were missing. The following motions were approved without dissent.

3 "The stationary OCS axis shall coincide with the (B-Y) component referenced to Panel 7 primaries."

4 "The (B-Y) phasor shall lag the color synchronizing signal by 90°."

5 "The subcarrier phasor representing (R-Y) shall lead the phasor representing (B-Y) for the field following the vertical synchronizing pulse shown in diagram (1) of Appendix 1 of the FCC TV standards, December 19, 1945; and shall lag for the field following the vertical synchronizing pulse shown in diagram (2)."

Discussion followed regarding actual value of gamma for which system should be corrected.

6 "It is recommended that the transmitter characteristic have a light-input/voltage-output characteristic such that when received on a receiver having a signal-input/light-output characteristic expressed by an exponent of 2.75 the pictorial result will be that desired by the producer; however, it shall be possible so to adjust the transmitter that an overall gamma of unity results."

At this meeting RCA played a more active role. George Brown seconded Motions 1 and 2, moved Motions 4 and 5, while Ray Kell (RCA) moved Motion 6. Chairman A. V. Loughren stated that the coefficients and angles for the equation from the third meeting should be recomputed in light of these motions and should be done in terms of E'_x, E'_y, and E'_z. George Brown volunteered the services of Al Schroeder, and Charlie Hirsch volunteered the services of BDL and himself. F. Bingley volunteered. This fourth meeting at IRE Headquarters was called to order at 10:00 AM and adjourned at 5:45 PM.

Beginning about now, the Panel 13 meetings became more involved with "fine details" in the system. Therefore, I will attempt to touch on these with a "broader touch".

5 <u>October 8/22/23, 1951</u> - General subjects: gamma correction; luminance band-
6 width; color bandwidth; 10 dB excess color gain for field test receivers; set-up; relative coincidence of color and monochrome signals at second detector for best compatibility; report on delay equalization; tolerances; numbers put in draft of standards. Panel believes it has accomplished tasks, awaiting field test results.

7 <u>January 21 and May 19, 1952</u> - Review of certain previously selected standards;
8 new report regarding delay equalization; revised color sync signal (from P14); Color-sound beat note; recommends sound power be somewhat reduced; discussion of possible changes in view of small area and large area flicker; suggestion that B-Y be only double sideband; Hazeltine notes that with present phosphors flicker is most visible in blue; (CPA falling apart).

Subcommittee established to explore spec changes to improve small and large area flicker. 7 subcommittee meetings/demonstrations June 10/25, August 13/19/25 at GE, Hazeltine, RCA, GE, RCA of "narrow band B-Y"; Improved Constant Luminance; and Wide-Band Orange-Cyan. The last item was a new system modification suggested by RCA in which the chrominance signal had different bandwidth along quadrature axes (wide along orange-cyan axis and narrow along green-purple axis). Followed by two demonstrations at RCA to Panel 13 of (1) Improved Constant Luminance, on August 26, and (2) Wide Band Orange-Cyan (WBOC) on August 27.

9 <u>June 27, September 4, October 10, November 11, 1952</u> - Report regarding
10 June 18 tests at Princeton regarding color-sound beat-note; Panel 13 consider-
11 ing picture-sound to remain at 4.5 mc and decrease color subcarrier frequency
12 to make color-sound beatnote low visibility; AVL discussion regarding A^2 corrector and circular subcarrier; demonstration scheduled at Hazeltine on July 25; (subcommittee recommended circular subcarrier; rejects A^2 corrector, says WBOC promising; wants more time to study); RCA on-air tests of 3.58, 3.75, 3.89+ mc subcarrier, week of September 15 to check compatibility; Panel requests extension until December 15; after much soul-searching and more tests during wee hours of morning at Princeton on October 23 (27 mono receivers), Panel recommends <u>no use of CPA</u> and subcarrier frequency reduced to <u>3.58 mc</u>; much discussion regarding proper choice of wide band and narrow band axes; recognition that Kodachrome slides deficient along green-purple axis; attempts to compensate by "electronic-masking".

13 <u>November 19, December 2, 1952, January 13, May 12, June 9, 1953</u> - More com-
14 patibility tests (at Astoria) using 3.58 and 3.89 mc, all scenes with color camera
15 and live model; summary as follows:
16 "1. The color subcarrier did not deteriorate the sound performance of black
17 and white receivers.

2a. When retuning on color transmissions, then there is little reason to prefer one color subcarrier frequency over another.

2b. When retuning on color, then at a viewing distance of five times picture height, "perceptible but probably tolerable" effects were introduced in the set most affected. (Rating #2) These effects were objectionable when viewed at one time picture height. (Rating #3)

3. When tuned for best reception on black and white, and viewed at a distance of five times picture height, the reception contained detrimental effects which were definitely objectionable on the set most affected, (rating #2.9); however, the average set was probably tolerable (rating 2.2) with a subcarrier of 3.58 mc. The corresponding ratings, with a subcarrier of 3.89 mc, are 2.3 and 1.9.

4. The tuning range for color is narrower than, but is included by, the tuning range on black and white.

Sets from the following manufacturers were used in the tests: Emerson, General Electric, Philco, RCA, Sylvania, Tele-King, and Westinghouse."

Subcommittee on choice chrominance axes performed tests at RCA, Philco, and GE with both slides and studio cameras; subcommittee recommendation approved for incorporation into specs; luminance signal = weighted sum of gamma corrected primary signals; subcommittee appointed to make further investigations and report on whether spec regarding gamma correction should be changed; spec for field tests put together; tolerances on choice of axes requested of subcommittee regarding axes; AVL stresses early completion of work by various subcommittees; tolerances for subcarrier set; NTSC prefers to leave exact matter of gamma correction open for present; gamma for field test set at 2.2 replacing previous 2.75; letter from JAH indicates that set that buzzed in compatibility field tests had ratio detector out of alignment and did not buzz when aligned; RCA planning petition to FCC by July 1, thus a real push for NTSC to clean up many details.

With regard to this early filing by RCA, George Brown states in his book, on p. 227: "RCA jumped the gun by filing a 697 page document on June 25, much to the annoyance of many people from other companies who had worked so diligently and honestly with us. I did not approve of this affront to my professional friends who had trusted me."

18 July 8, 1953 - Many last minute subcommittee reports to wrap up; minutes include 40 pages of subcommittee reports as appendices; Appendices:

- A Report of Subcommittee 11
- B Letters supporting color sync signal tolerances
- C Letter to Panel 14 from AVL (P13) regarding tolerances on subcarrier frequency
- D Second report of Gamma Subcommittee 14
- E Draft #2 of NTSC signal specs
- F Final report of Subcommittee 7, ceiling performance.

July 23, 1953 - Mail response to request by Panel 17 for modification (clarification) of delay specification.

Summary of the Findings and Conclusions of Panel 13

"Panel 13, having given extensive and careful study to proposed signals for color television broadcasting, finds that the specification for such a signal should be based upon the following considerations:

1. The quantity "luminance" and two suitable components of the dual quantity "chrominance" should be chosen for explicit transmission;

2. Luminance transmission should conform in all essential respects to the current FCC standards for monochrome transmission;

3. The chrominance components should be transmitted as the amplitude modulation sidebands of a pair of chrominance subcarriers;

4. The chrominance subcarriers should be at the same frequency but separated by 90 degrees in phase, and the subcarrier frequency should bear the relation of a high and odd multiple of one-half the line scanning frequency;

5. The chrominance signal content should vanish on all grays of a specified chromaticity;

6. A color synchronizing signal, at the frequency of the subcarriers, should be provided as a phase reference for use by receivers in detecting the chrominance signals;

7. Some measure of compensation for non-linearity of picture display devices should be included;

8. The horizontal scanning frequency should, within suitable tolerances, be an exact integral submultiple of the separation between the radiated picture and sound carriers.

The Panel concludes:

1. That the detailed specification set forth later in this report, and based upon the foregoing principles, is a sound and suitable specification for a signal for color television broadcasting.

2. That having examined all matters known to the Panel to be within its charge, its detailed specification presented herein is sufficient."

Selected sections from Chairman's Report

"3. Meetings and Demonstrations

Panel 13 has held eighteen formal meetings and has witnessed eight demonstrations. Additionally, the Panel's subcommittees have held meetings and attended demonstrations as given in the following tabulation. The dates and places of these meetings and demonstrations are set forth in Appendix B of this report.

Subcommittee No.	No. of Meetings and Demonstrations
1	1
2	3
3	2
4	(No meetings - work conducted by telephone)
5	1
6	2
7	9
8	2
9	8
10	1
11	5
12	2
13	1
14	6 "

"5. Historical Summary of the Panel's Proceedings

The Panel was fortunate in having available to it the preliminary survey presented in the April 19, 1951, report of an NTSC Ad Hoc Committee. During the summer of 1951 the Panel studied this report, viewed a series of demonstrations, and discussed the basic theoretical forms of color television signals at its meetings. In the fall of that year, agreement was reached on the characteristics then believed appropriate for inclusion in a signal specification, and the Panel concluded from the tests made under its supervision, that this specification held forth a sufficient measure of promise to justify its being recommended to the NTSC for careful preliminary field testing.

The principal characteristics upon which that specification was based included the following:

1) Explicit transmission was provided for luminance and for two suitable components of chrominance;

2) The luminance component was transmitted in a fashion conforming in all essential respects with the current FCC monochrome TV standards;

3) The chrominance components were transmitted as the a-m sidebands of two subcarriers which were at the same frequency but separated by 90 degrees in phase;

4) The subcarrier frequency was a high and odd harmonic of one-half the horizontal scanning frequency;

5) A color synchronizing signal was provided as a phase reference for use by color receivers in detecting the chrominance components;

6) The subcarriers themselves were suppressed, leaving only their sidebands to be transmitted, and the gray upon which the chrominance signals completely vanished was specified as having the chromaticity of standard Illuminant C as defined in the specifications of the CIE*;

7) To provide for at least a one megacycle bandwidth for each component of chrominance while still maintaining a reasonably high value for the subcarrier frequency, vestigial sideband transmission of the chrominance components was employed, as a means of distinguishing between the two chrominance components, the practice of color phase alternation -- the reversing of the phase of one chrominance component in alternate fields of the picture -- was used.

A specification based upon the foregoing characteristics was recommended by the Panel in October 1951 and was adopted for preliminary field testing carried out using that signal specification is of course reported elsewhere by the chairmen of Panels 15, 16 and 17.

During the preliminary field testing of the November 26, 1951, signal specification, the Panel continued its own studies and its members maintained informal but close contact with the field tests. The Panel, from its members' observations and from informal discussions with members of the Field Test Panels 15, 16, and 17, gradually developed the view during the spring and summer of 1952 that the signal specification of November 26, 1951, did, in fact, make possible the broadcasting and the reception of compatible color television pictures of a high grade, but that (at least with the receiver apparatus then available) flicker on some image edges was noticeable. Simultaneously with the development of this view, recognition developed that the eye's need for chrominance (coloring) information was quantitatively less than had previously been realized, if, for example, one chrominance component were associated with orange-cyan information while the other transmitted green-magenta information. Careful and elaborate experiments conducted in several laboratories during the fall and winter of 1952-53 were viewed by the Panel; these experiments established to the Panel's satisfaction the eye's need for detail equiva-

* Commission Internationale de'Eclairage.

lent to a megacycle or somewhat more* in the orange-cyan direction and the adequacy of information corresponding to only about one-half megacycle for the green-magenta direction. The conclusion to which these experiments pointed was that both chrominance components could be successfully transmitted on the same subcarrier frequency without using color phase alternation, but instead using the conventional double side band transmission for a distance of about one-half megacycle each side of the subcarrier, with single side band transmission employed below the subcarrier for an additional half megacycle or more. This conclusion, in company with a small reduction in chrominance subcarrier frequency, formed the principal basis for the revised specification recommended by the Panel on January 13 described in the NTSC Field Test Signal Specification dated February 2, 1953.

In the course of the preliminary field tests made under the November 26, 1951, signal specification, it was noted that a beat frequency signal of appreciable amplitude could be produced between the chrominance components and the sound signal. The experiments of the Panel's Subcommittee No. 8 demonstrated that there would be a substantial advantage in receiver performance if the frequency relations were so chosen that the beat or frequency difference between the chrominance signals and the unmodulated sound carrier were made to be an odd multiple of one-half the horizontal scanning frequency. The Panel found that the necessary frequency relationship could be obtained by:

1) Establishing a tolerance of ±1000 cycles on the frequency difference between the actual picture carrier and unmodulated sound carrier frequencies; and

2) Specifying the horizontal scanning frequency as an integral submultiple of this nominal carrier separation (which resulted in reducing the nominal value of the horizontal scanning frequency by .1%, an amount well within the presently existing tolerances (a .1% reduction was also required in the vertical scanning frequency, from 60 to 59.94 cycles nominal value). This relationship was also included in the revised specification.

Since January 13, 1953, the Panel has continued its studies with the several objectives of

a) establishing a basis for the recommendation of tolerances where needed,

b) developing evidence which may lead to a recommendation for the optimum manner of introduction of gamma correction in the transmitted signal,

c) establishing the ultimate ceiling performance characteristics of the signal which the specification describes.

The tolerance recommendations which the Panel has adopted since January 13 appear in the foregoing paragraphs 4(a) through 4(u).

The conclusion with respect to ceiling performance, based in part upon theoretical and in part upon experimental evidence collected by the Panel's subcommittee No. 7, is that a signal conforming to the NTSC signal specification is not limited in any respect to performance exhibiting any perceptible inferiority compared to standard monochrome broadcasting.

---

* For a 525 line 30 frame system

The results of the work to date of Subcommittee No. 14 on gamma correction practices has been incorporated in the specification of paragraphs 4(a) - 4(u) above; the subcommittee's work is continuing."

"8. The Panel's subcommittees have reported to the Panel as follows:

No.	Title	Final Reports
1.	Subcommittee on Gamma	NTSC-P13-134 dated 9/6/51*
2.	Subcommittee on Receivers	NTSC-P13-172 dated 10/17/51 (attachment to minutes of 6th meeting of Panel 13.)
3.	Subcommittee on Drafting of Standards	Dated 8/3/51*
4.	Special Task Group on Computation of Color Signal Parameters	Appendix I of NTSC-P13-162* dated 10/5/51 (Cover letter, NTSC-G-166, 11/16/51)
5.	Subcommittee to List the Reasons for the Motions Adopted by Panel 13	Appendix 3 of NTSC-P13-162* (Cover letter, NTSC-G-175, 12/14/51.)
6.	Ad Hoc Subcommittee I on Review of Matters Pending Before Panel 13	Hazeltine letter and attachment 4281-1343d, 12/18/51*
7.	Subcommittee on Ceiling Performance	Appendix F of Minutes of 18th meeting of Panel 13.
8.	Subcommittee on Visibility of Beatnote Between Sound and Color Subcarrier	Dated 8/21/52*
9.	Subcommittee on Chrominance Signal Specification	NTSC-P13-279 dated 9/2/52 (attachment to minutes of 10th meeting of Panel 13.)
10.	Ad Hoc Committee to Judge the Compatibility of Monochrome Receivers on 12/23/52	NTSC-P13-285 dated 11/11/52 (attachment to minutes of 12th meeting of Panel 13.)
11.	Subcommittee on Choice of Axes	Successive reports appended to minutes of Panel 13 meetings as follows: 1) NTSC P13-332, 15th meeting 2) NTSC-P13-350, 16th meeting Appendix A 3) Minutes of 17th meeting Appendix B 4) Minutes of 18th meeting Appendix A

12.	Subcommittee on Standardization of Set-up in the NTSC Color Signal	Minutes of Subcommittee Meeting, dated 2/10/53*
13.	Ad Hoc Subcommittee on Viewing of Compatibility Tests on 11/19/52	NTSC-P13-311 dated 11/21/52 (attachment to Minutes of 14th meeting of Panel 13.)
14.	Subcommittee on Gamma Specification	Progress Report with recommendations issued as Appendix D of minutes of 18th meeting of Panel 13.

The items marked with an asterisk, which are final reports of several subcommittees, are included herewith as Appendix C. Those which are indicated as attachments to panel minutes will be found with those minutes in Appendix E."

15.4 Panel 14

The charge to Panel 14 was: "It will be the responsibility of this panel to provide recommended standards for color synchronizing signals and the interrelation with normal deflection synchronizing signals. This panel will consider also the interaction between the proposed color standards and the existing black-and-white standards in this regard."

Meeting
No.

1 June 26, 1951 - Figure 1 shows an H sync pulse of .070 to .074 H, a breezeway of .025 to .028 H, and a pedestal (and color burst) of .036 to .040 H. Concern over where waveform is measured. Concern over pedestal minus burst going below blanking and over pedestal plus burst exceeding sync tip. Question of whether special sync information needed for OCS. Burst during vertical blanking, ask RCA.

2 August 13, 1951 - No quorum, therefore meeting considered as a subcommittee meeting. Three sync waveforms were discussed: (1) like Ad Hoc committee but numbers were RCA's numbers with H sync pulse of .06 H, (2) no breezeway, (3) burst on top of H sync. RCA uses 9 line key-out of bursts (and pedestal); Hazeltine uses 3 line key-out. RCA uses no special information for OCS purposes. Subcommittee to investigate accuracy of color sync.

3 September 27,1951 - Zenith proposes no breezeway, and cutting front porch in half to get long back porch for "Phone-vision". Mr. Morris (ABC) says dangerous to reduce front porch due to ringing from sharp cut-off of networks. Regarding CPA sync: Motion "for purpose of field tests extra sync information for CPA will not be included". Networking and stab-amps discussed at great length. Regarding burst wave shape Mr. Doba pointed out that due to vestigial sideband transmission (burst near upper cut-off) quadrature spikes will exist. Finally agreed that present signal waveform is at studio (before networking). Agreed that width of H sync should read .06 H nominal with no tolerance specified (BDL comment: not Ad Hoc proposal!).

4 November 5, 1951 - Tests at Hazeltine to investigate the effect of burst position and key-out duration. Conclusions:

1. No observable effect on interlace

2. No observable effect on phase of horizontal sync

3. The NTSC signal (.06 H for H sync) had slightly less pull-in range on some sets, with either burst position, than did the RMA signal.

4. No observable effect on the colors at the top of the picture over a wide range of time constants.

5. The early burst position gave a picture which was freer of color contamination than the picture received when the burst was in the late position and the burst gate was moved to its latest position.

6. Delay equalization eliminated a following ghost in a high definition monochrome set when viewing black blocks against a red background. It resulted in a transmitted sync wave form with ripples on the sync pulse and some of the cycles of burst in the gap between the sync pulse and the burst pedestal.

5 December 13, 1951 - Two motions from this meeting are quoted here:

A. "The color synchronizing waveform specified is that which exists at the input to the transmitter. In view of the distortions which may be introduced by networks and other transmission media, Panel 14 is agreed that reconstruction and proper phasing of the color burst relative to the color subcarrier in the picture is probably necessary ahead of the transmitter. Panel 14 requests consideration by Panel 17 of the technical problems associated with such a new stabilizing amplifier or other auxiliary apparatus."*

B. "Panel 14 is considering the recommendation of the following synchronizing signal shown in the attached figure (early burst). It is requested that this waveform be studied by the NTSC, particularly Panel 17. It is expected that a final recommendation will be made by February 1, 1952."

6 January 30, 1952 - Subcommittee on CPA sensing; two questions: 1) Can a usable CPA sensing signal be added to the present signal without causing any interference with the other functions of the synchronizing wave form?; 2) Can the present signal be made to operate satisfactorily without regard to receiver complexity? Studies underway. Tests made the night of January 29: 1) readjustments necessary when tuning from one station to another, 2) relative failure with thermal noise, 3) relative failure with impulse noise, 4) effect of echoes. Resolved "It is the opinion of Panel 14 that its current proposed specification relating to the synchronizing wave form is the best that can be agreed upon based upon existing knowledge."

---

* In spite of this obvious warning, this problem was not really solved until early 1970's when the EIA BTS (Broadcast Television System) proposed the VIR (Vertical Interval Reference signal), to be discussed later.

7 March 12, 1952 - Several sources have reported incompatibility of the present NTSC signal in the form of an uncertainty of horizontal scanning phase due to presence of burst pedestal and due to narrowing of the horizontal sync. Proposed design philosophy: The synchronizing signal as viewed through a low pass filter (of about 2 1/4 mc cut-off to remove all subcarrier frequency components) should be identical to that of a present day monochrome synchronizing signal viewed through the same filter -- except for possible tightening of tolerances (remove pedestal and widen the pulse). Many tests followed, but once this philosophy was followed, we were out of the woods, except for one alternate that kept coming up - that of burst on top of the sync pulse. Mr. Doba nicely dismissed this by stating that the Telephone Company clamp circuits now used would strip off the burst on top of sync, and this situation would take considerable development time.

8 March 26, 1952 - At this meeting many more tests regarding compatibility were reported as well as many suggestions on how to spread the burst around during horizontal blanking. No conclusions.

9 May 20, 1952 - At this meeting a color synchronizing signal was adopted that is very close to the final wave form. However, some further tests were still needed to dismiss some of the variants that had been proposed along the way.

10 December 1, 1952 - Panel 13 motion to change color subcarrier frequency to 3.58 mc and to remove CPA were reported. The Panel 14, May 20 waveform was adopted with the following changes: breezeway to be .006 H min.; burst frequency changed to 3.58. Theoretical investigation of color sync stability by D. Richman, as a paper for Panel 12, was reported. Final Panel 14 meeting.

15.5 Electronic "Masking" In Color TV

When we started to seriously look into the question of which axis of the chrominance signal could be narrow-band and which needed to be wide band, we became aware of a certain deficiency in Kodachrome slides. Specifically, using the Vectorscope we found that most energy was along the presently defined I axis and very little energy was along the presently defined Q axis. Page Burr made a study of the cross-coupling effect of the dyes in Kodachrome which confirmed the likelihood of low energy along the Q axis; very specifically, it showed that a saturated green exposing Kodachrome would result in a transparency in which the green is reduced significantly in both luminance and saturation. A similar effect applied to blue, but to a lesser extent, and to red to an even smaller amount.

Both the study and the experimental observations convinced us that we should design circuits to produce, electrically, the inverse of the cross-coupling effects.* To do this job completely would have required a number of non-linear circuits to simulate

* R. P. Burr, "The Use of Electronic Masking in Color Television", Proc. IRE, January 1954, p. 192-200.

logarithmic and exponential functions. We decided to only use linear cross-coupling circuits, as a first order simulation. This produced a significant improvement in saturation of all colors and particularly green. However the luminance of green was not resorted to the original scene luminance, but the value of slides in evaluating narrow-band vs. wide-band axes was improved.

The final choice regarding narrow-band vs. wide-band axes needed conformation using signals derived from live scenes in front of a TV camera.

15.6 The Vectorscope*

A vectorscope, in its simplest form, shows a spot, on a cathode ray tube, whose position relative to the origin is a vectorial representation of the chrominance signal. So, for example, if the chrominance signal is that of a bar chart of primary and complementary colors, a series of dots will be displayed (roughly around a circle) in which the successive dots represent the red, yellow, green, cyan, blue and magenta bars. Such a simple vectorscope can be made from the following structure: 1) a band-pass filter to select the chrominance signal; 2) a pair of synchronous demodulators having reference subcarrier sources in quadrature; 3) a low pass filter in the output of each synchronous detector; 4) applying the filtered signals respectively to the vertical and horizontal deflection circuits of a CRT. Such a simple arrangement can give a general picture of what is happening, but we wanted a piece of measuring gear which could permit us to determine whether the signal was "within specs". This needed a series of self-checking features which could be used in field tests and could rapidly confirm the accuracy of the vectorscope system to give us assurance of the appropriateness of the vectorscope answers. We conceived such a system and Charlie Page designed and built it. The system operated as follows:

1) a transparent polar graph overlay is put in front of the CRT with small squares at positions that correspond to the primary and complementary colors and their tolerances according to the NTSC specs;
2) during a first period of time all input signals are gated off to provide a dot at the origin, to check H and V centering controls on the CRT;
3) a subcarrier reference signal is generated, locked to the burst and applied in quadrature to a set of synchronous demodulators;

---

* C. E. Page, "A Monitoring System for NTSC Color Television Signals", Convention Record of IRE, Vol. I, Part 4, 1953, pp. 61-65.

4) during a second period of time a signal "10 Kc-off" from the subcarrier is gated in to generate a reference circle;

5) during a third period of time, while the "10 Kc-off" signal is gated on, a 180 degree phase shift is inserted before one of the synchronous demodulators. This generates another circle, which if the demodulator's reference is truly 90° will coincide with the first circle. If the 180° is really 180°, then a very small difference between the two 90° references will produce opposite ellipticity for the two circles which is very obvious. These "outer" check circles are on all the time so a check of 90° relation is continuous;

6) an occasional check on the 180° relation (which is quite stable) can be made by a switch which feeds the same reference signal to both demodulators. This gives an X display in which one or both of the lines opens to a small ellipse if the 180° is not perfect;

7) to check for possible quadrature errors in the CRT, a pulse is generated from the fourth harmonic of the 10 Kc signal and used to blank out a small segment of the circle which should agree with quadrate axes on the polar overlay;

8) for complete calibration the remaining item is to adjust horizontal and vertical gains to make a circle of appropriate size from the "10 Kc-off" signal which agrees with the overlay;

9) then during a fourth period when the 10 Kc is gated off and the 180° phase is removed, the chrominance signal is applied to make an accurate vector display upon the CRT of the chrominance signal.

The vectorscope system was very handy, was used frequently in our lab and frequently during field tests. After NTSC was approved, and color broadcasting started, a couple of companies made this vectorscope designed with most of our self-checking features. Today you find vectorscopes in substantially all studios for generating NTSC and PAL signals.

16

POST NTSC R&D

16.1 One-Gun Chromatron

Sometime around the latter days of NTSC, a one-gun picture tube with color switching near the phosphors became available. The tube was developed by Lawrence and was exploited by a subsidiary of Paramount Pictures called Autometric. The picture tube had horizontal color stripes with a grid of closely spaced wires near the phosphor screen. Every other wire was connected to one switching terminal and the "other" set of wires was connected to another switching terminal. With zero potential difference between the switching terminals, the beam, after going through the wire screen, was focused onto the green phosphor stripe. The focusing occurred because a large d.c. potential difference was applied between the wires and the screen with a much smaller potential between the electron gun and the screen. This also gave a post-deflection acceleration. Between every other green stripe was a red phosphor stripe, and between the other pairs was a blue phosphor. With this arrangement, if the potential between switching terminals had one polarity and magnitude, the red phosphors could be excited, and when the opposite polarity was applied the blue could be excited. The sequence of phosphor stripes, in the vertical direction, was: RGBGRGB...etc.

The original disclosures for this tube used a color subcarrier frequency for color switching, with NTSC decoder and a sampler to provide the RGBGRGB sequenced information. I developed several techniques for direct application of the NTSC signal to the picture tube gun, adding necessary processing to provide near correct color. These are described in a paper, "Processing of the NTSC Color Signal for One-Gun Sequential Displays", published in Proc. IRE, January 1954.

One technique used enough switching potential to increase the dwell time on R&B giving the sequence of RRGBBGRRGBB, and then by adding a third harmonic signal to the electron gun at a proper phase and amplitude so that every other color in the sequence RRGBBGRRGBB was knocked out; this gives the sequence RGBRGB. This was called CCS (Continuous Color Sequence), had simplified processing, but less light output. The preferred arrangement used a sixth harmonic gating to provide RCS (Reversing Color Sequence) - like RGB BGR RGB BGR. This arrangement required slightly more complicated processing, but was more efficient in light output.

We succeeded in making reasonably good color pictures on the Chromatron, particularly with RCS. Paramount was sufficiently impressed that they contracted with us to make six complete receivers using our direct processing. The one-gun feature resulted in better and more stable tracking of the grey scale on monochrome images. But a major flaw existed in many picture tubes. The large potential difference between the deflection wires and the phosphor screen (spaced about 1" apart) would result in a continually glowing spot (not under control of the electron gun) if any small dust particles eventually came loose within the tube and settled on the wires. Tubes which were OK originally could develop such spots in time, particularly if they were moved.

Another problem with this picture tube was the large reactive circulating energy necessary to switch colors at a fast rate. This energy was within the 80 meter amateur band.

16.2 Projection Color Displays

It appeared that the lack of sufficient production capacity for the RCA tri-color tube might limit the growth of color TV. A small high-intensity CRT had been developed and used by Philco for monochrome TV in the late '40's. This CRT was designed, in conjunction with a low cost Schmidt optical system, to make a "neat" package. We persuaded the manufacturer of the unit to supply us with red, green, and blue units, and designed a projection unit intended to be competitive in price and performance with the RCA tri-color tube.

As I recall, the receiver design we were using was a vertically standing unit with folded optics within the cabinet. Various layouts for the cluster of three Schmidt optics were tried and the in-line arrangement was preferred. With the size of the cluster and the optical path length obtainable in a reasonably sized cabinet, the color registry over the picture area was generally a problem. I don't remember whether we ended up with modulated deflection or just distorted deflection fields, but I do remember some of the pictures having acceptable registry. Of course, there was always the compromise between brightness and angle of view, even with the size picture we were making (about the equivalent of a 24" to 30" diagonal).

I do not remember what was the demise of our projection color display, but I suspect it related to such things as the Flyer "phosphor dots on the front glass", increased production by more manufacturers getting into the business, reduction in cost of the tri-color shadow-mask CRT, and flatter face plates.

16.3 Color Film Analyzer Tests

This is really a whole new by-product of our color work, but it did start while we had our 18 racks full of color TV R&D equipment in the basement of Building 1. Charlie Hirsch had a "back-door" neighbor who was in the color film processing business. Charlie was talking with him over the back fence one evening, telling him about the color equipment we had and what we could do with it. I suspect he was even talking about Page Burr's electronic masking circuits (see section 15.5), and what they could do. Anyway, his neighbor, Mr. Giarraputo of Pathé, told Charlie about the problems they had with "timing" negative film to make a good positive, and asked whether our equipment could be of help to him. Charlie sprang the question on us the next morning. I believe that Bill Bailey, Page Burr, and I "put our heads together" to get a phase inversion in the red, green, and blue channels in a way that used the masking circuits but did not preclude "a demonstration of our wares" upon a minute's notice. We did, we put in a negative transparency, and had a beautiful demonstration of making a positive color picture from a negative, and being able to adjust the color via masking. In a few days, we showed the demonstration to Giarraputo and he was excited about the prospect of our being able to help with their problem.

More about the Color Film Analyzer later.

17

OTHER ITEMS OF NTSC DAYS UP TO SEPTEMBER 1, 1957

Through this period of mid-1950 to 1957, many things happened beyond NTSC activities, which indicated Hazeltine's stature, during these "colorful days". The general teaching of the industry has been covered in section 12.0. In this section 17.0 I wish to cover a variety of items ranging from industry recognition up to dissolution of the color group. The items I will cover are mainly those that affected or were related to me, either directly or indirectly.

17.1 Pictures, Papers and Early Awards

The first picture of our equipment showed up on the cover of the October 1950 Proc. of IRE. This shows the flying-spot scanner, the crossed-dichroic color display, and several racks of processing equipment. Charlie Hirsch is in front of the FSS, Bill Bailey is in front of the display, and I am in front of the processing equipment. This picture was taken before we got up to any number of racks like 19!

Then over the next year or so, three color front covers of Electronics appeared, illustrating:

1 - Mixed-Highs, December, 1950
2 - Color Bars, August, 1951
3 - OCS (CPA), February, 1952

Beyond the comparative analysis papers given by Art and Charlie (see section 12.7), other color TV papers were given or published during this time. My paper, "Recent Improvements in Color Television", which covered "shunt-monochrome", "constant luminance", and "Oscillating Color Sequence" was published in October, 1951, Proc. IRE, and presented at "Television Symposium, N.Y. Section of IRE", February 3, 1951; Dayton Section of IRE, September 13, 1951; NEC, October, 1951; L.I. Subsection of IRE, May 13, 1952, and many more. Charlie Hirsch, Bill Bailey, and I co-authored a paper, "Principles of NTSC Compatible Color Television", which was published in Electronics, February, 1952, and given at Cincinnati Spring Tech. Conference, April 19, 1952. Charlie and I co-authored a paper, "General Considerations in Design of Color Television Receivers", published in Trans. PGBTR, IRE, March, 1953, and given at Radio Fall Meeting, October 21, 1952. We shared many of these kinds of tasks, and that gave me more time at the lab for further experimental work, for working on patents, and developing new ideas. One more paper worthy of note is "Processing of the NTSC Color Signal for One-Gun Sequential Displays", published in January, 1954, Proc. IRE.

In November, 1951, I received a great surprise and honor, namely that I was going to receive the first Vladimir K. Zworykin Award. This award had recently been established by RCA in honor of Zworykin and was to be given annually for outstanding technical contributions in the field of electronic television. The presentation of the award was at the National IRE Convention in the Spring of 1952, at the Waldorf-Astoria. Hazeltine had several tables near the front and many Hazeltine dignitaries attended, including MacDonald and Professor Hazeltine and wives. Dorothy sat with the dignitaries, while I was on the podium. The award included $500, which was a lot more money then compared to now, and which was used to buy a fur coat for Dorothy to wear to the Waldorf. A friend designed a special evening gown for Dorothy to wear. This affair was very exciting, and one of those times to be long remembered. The citation was "For his outstanding contributions to the theory, the understanding, and the practice of color television". The actual piece of paper was a "sort of" standard award (black letters on white paper), but several months later I was informed that Zworykin himself was displeased with the plainness of the award and was designing one himself. When the Zworykin-designed award arrived, I was very pleased. It has various colored drawings around the periphery of Zworykin's many inventions, and is significantly larger than the original award. It is rather impressive.

I believe the next honor to come to our small group was the David Sarnoff Gold Medal to Art Loughren in 1953. Then in 1954 Bill Bailey received the Fellow award from IRE. In 1955 I received the Fellow award from IRE with the citation of "For contributions to color television, frequency modulation, and superregeneration", thus covering a wider field of technology. Also in 1955 I had another great surprise from an organization that I was less familiar with: the SMPTE, or Society of Motion Picture and Television Engineers. This was the David Sarnoff Gold Medal with a citation of "For his many contributions to the science of color television, notably in the optimum method of transmitting a compatible color picture and in his fundamental of constant luminance". This was presented at the Lake Placid Hotel in up-state New York, during the Fall, which was a beautiful time of year. Dorothy and David (#1 son) went with me for a brief vacation. It was a beautiful hotel, but David was mainly interested in the self-serve elevators and kept traveling up and down pushing the buttons for various floors!

Just before the 1955 SMPTE Convention, the November, 1955, issue of Fortune came out with an article, "Color TV: Who'll Buy a Triumph?". It had parts that were very favorable to Hazeltine. The article was well written, the author having spent some time at Hazeltine being properly briefed. It contained a classical paragraph, after properly describing the "shunt-monochrome" concept. Quote: "In the history of invention one could probably find many examples of a device working for the wrong reasons. It might be harder to uncover a parallel of RCA's color signaling invention, which worked initially for the right reasons - but worked better still when one of its central concepts was abandoned."

17.2 Second Color School

After the NTSC work was completed, Hazeltine gave a second color school to help our licensees get a good footing on the design of various portions of an NTSC color television receiver. The first color school, given in 1951 (see section 12.10), was directed mainly to fundamentals of color television, while this second school in 1953 was directed to receiver design. The following list of lectures indicates the subject material:

Lecture No.	Title
1	An Introduction to Color Television Receivers
2	National Television System Committee Signal Specification
3	Part 1 Display Devices
3	Part 2 Three-Gun Shadow-Mask Kinescope
4	Laboratory Demonstration of Color Display Devices
5	Decoders
6	Color Television Synchronization in NTSC Color Television
7	IF and Video Amplification Considerations
8	Laboratory Apparatus

In order to accommodate most licensees, this second school was given in three locations: Little Neck, New York; Chicago; and Los Angeles. We had a full staff in New York and Chicago; but the LA staff was limited to Dud Foster and myself. (Dud Foster was in charge of Hazeltine Research, Inc., of California, established in 1947.) This was a rather busy task for me since, as I recall, each school took four reasonably full days with a short period between each school.

However, the California trip was a first for me. Dorothy was originally scheduled to join me in Chicago but, due to her mother's recent operation, did not join me until after the LA school. Bill Swinyard convinced me to change my Chicago to LA transportation to the California Zepher, which was quite pleasant and scenic. I stopped for a few days at Salt Lake City, which was very impressive, particularly the great organ at the tabernacle.

Dorothy's trip from New York to LA was her first commercial flight, a long 12 hours (prop plane). We took a vacation after the LA school, first seeing the sights of LA; then upon the recommendation of Dud Foster we visited Yosemite, "roughing it at the Ahwanei". Then, on to San Francisco, staying at the Mark Hopkins. On the way home, we took the train to Salt Lake City so Dorothy could see what I had enjoyed on the way out.

The three school sessions plus our vacation spread over October and November, 1953.

17.3 Books

"Principles of Color Television" by the Hazeltine Laboratories Staff, was for many years referred to as "The Bible" of color TV. Over the period of 1952 through 1955, a series of 18 reports were prepared by the following staff:

Knox McIlwain, Charles E. Dean, Editors

Contributing Authors:

William F. Bailey	Charles J. Hirsch
R. Page Burr	Bernard D. Loughlin
Charles E. Dean	Knox McIlwain
Walter C. Espenlaub	Charles E. Page
Richard J. Farber	Donald Richman
John A. Hansen	W. Robert Stone

and edited to make suitable chapters of "The Book". The reports/chapters are:

PRINCIPLES OF COLOR TELEVISION

Rpt. No.	Chapter	Title	Dated
7124	1	Light and Photometry	3/19/52
7125	2	Color Perception	4/4/52
7127	3	Color Space and Color Triangles	5/14/52
7128	4	Colorimetry	6/10/52
7131	5	Color in a Television System	7/21/52
7135	6	Required Information Content	9/11/52
7142	7	Additional Properties of the Eye	4/27/53
7143	8	The Choice of Color Components and Their Interleaving in the Composite Signal	6/5/53
7144	9	Production of Composite Color Signal	7/29/53
7150	10	Synchronization	2/5/54
7158	11	Nonlinear Amplitude Relations and Gamma Correction	8/19/54
7159	12	The Color Television Standards of the Federal Communications Commission	9/28/54
7161	13	Equipment for Producing the Transmitted Signal	11/18/54
7163	14	Color Television Principles	1/7/55
7169	15	Decoders for Three-Gun Displays	4/18/55
7174	16	Decoders for One-Gun Picture Tubes	7/13/55
7175	17	Test and Measuring Methods	9/12/55
7176	18	Glossary of Color Television Terms	10/5/55

These were published as a book by John Wiley in 1956 (preface dated May 21, 1956); Library of Congress Catalog Card Number 56-8693. The material was edited to be particularly applicable to NTSC, so reference to OCS/CPA, treated in the first color school (see section 12-10), only appears in the Glossary of Terms. Unfortunately this book is now out of print.

An early version of certain selected parts of "The Bible" was edited by Charlie Dean, published by John Rider late in 1955 as a paper-back entitled "Color Television Receiver Practices". Contents of this paper-back are:

1 An Introduction to Color Television - Arthur V. Loughren
2 The Color Television Signal - Bernard D. Loughlin
3 Display Devices - William F. Bailey
4 Three-Gun Shadow-Mask Kinescope - Karl M. St. John
5 Decoders - Bernard D. Loughlin
6 Color Synchronization in the Receiver - Charles E. Page
7 I-F and Video Amplification - Richard J. Farber
8 Laboratory Apparatus - R. Page Burr

In addition, two of us, Bill Bailey and I, were asked to be co-authors of one chapter of Don Fink's new "Television Engineering Handbook". We prepared Chapter 9, "Transmission of Chrominance Values". This chapter, as published, has 66 pages and 102 references. My notes indicate that our first draft was ready in August, 1954, but the book is copyright 1957, Library of Congress Catalog Number 55-11564. This Handbook had 33 contributing authors. (This TV Engineering Handbook was updated and expanded approximately 30 years later, copyright 1986, by Blair Benson. I was asked to update previous Chapters 8 and 9 into Chapter 4, "Monochrome and Color Visual Information Transmission". My chapter as published has 88 pages and 152 references. This time 71 contributing authors are involved with the complete book, with 1478 pages and 1091 illustrations. Of course, during the approximately 30 elapsed years, color television has developed from an infant to a very mature adult.)

17.4 Demonstrations for CCIR

Some time after NTSC, Charlie Hirsch started to spend considerable time overseas on an "off-shore" program for our military electronics group (and the State Department). As I recall, he was mainly based in London and used every opportunity he could to discuss NTSC principles in Europe and England. In Europe, he became known as "Mr. NTSC". Some time before March, 1956, he became Chairman of the United States Preparatory Committee for CCIR (International Radio Consultative Committee) Study Group XI. At the Brussels CCIR meeting in 1955, a number of specific questions were raised for study regarding color TV (Europe was just starting to think and talk about color TV, without any definite decisions as yet).

Charlie became active in organizing a series of demonstrations sponsored by NTSC and our State Department. The program for the visit of CCIR Study Group XI covered the period March 5-March 16, 1956. A nice 187-page report was issued on the demonstrations/discussions. The Contents of this report are as follows:

---

* Vice Chairman

RCA is conspicuous by its absence in the program planned by NTSC. RCA refused to be a part of the NTSC effort and instead invited the entire CCIR Study Group to some demonstrations at the RCA Laboratories in Princeton, New Jersey. As best as I can tell, these RCA demonstrations were aimed at showing how the NTSC signal was essentially what RCA proposed in 1949. I am guessing that Sarnoff and Elmer Engstrom (head of Princeton Labs) had become quite upset over such things as: a) the Fortune article; b) Charlie Hirsch's teaching in Europe which stressed Hazeltine's contributions; c) the fact that the first two Zworykin Prize Awards of IRE did not go to RCA engineers; and d) of the first 5 Sarnoff Gold Medal Awards of SMPTE, only two went to RCA engineers. Whatever the reason, George Brown in his book, "And Part of Which I Was", attempted to explain RCA's actions with some words that seem somewhat inconsistent with other statements in his book about RCA and NTSC cooperation. RCA management and RCA engineers have forever been taking quite different positions with regard to the contribution of others. I am reminded of an early comment (during early NTSC days) to me by Bob Shelby of NBC which in essence indicated that we would hear all kinds of lack of recognition by RCA, but "don't worry, Barney, we (the engineers) recognize your contributions."

But, returning to the show, Hazeltine gave a nice demonstration which was aimed at teaching the principles of NTSC. Experiment 1 illustrated NTSC, within its 4 Mc video bandwidth, vs. simultaneous color (3 independent channels) of 12 Mc total bandwidth. Experiment 2 was an optical experiment with small circles of colored light showing: a) fine detail, only in luminance; b) medium detail, 2 colors along orange-cyan axis; c) large detail, 3 color gamut. Experiment 3 showed relative visibility of noise and interference in luminance vs. chrominance. Experiment 4 illustrated optimum bandwidths for Y, I, and Q. And Experiments 5, 6, 7, 8, 9 were directed to adding color with minimum visibility on a monochrome receiver.

Charlie Hirsch's teaching plus this series of demonstrations to CCIR Study Group did much to raise the stature of Hazeltine in the eyes of overseas TV engineers.

17.5 The British Are Coming

During either late '55 or early '56, a young "Englishman", Ian MacWhirter, came over to work at Hazeltine for about a year and learn about color TV "by doing". I believe the company which sent him was either EMI or Marconi. Ian added a bit of mirth to our lab, being a pleasant bachelor fellow who periodically got into trouble by not knowing our "ways". The classic "story" was that the first day he got a car over here, he got three tickets for a variety of reasons. We invited Ian out to our new house in Centerport several times during 1956, including for Thanksgiving and Christmas, and became reasonably well-acquainted. When Ian went back to England, he became their "constant luminance" expert, writing a number of technical papers on the subject.

In 1965, Dorothy, the twins, and I had a combination business/pleasure trip to England, and we visited several days with the MacWhirters (Ian married since we had seen him). Also, Ian arranged for me to present a brief technical talk at The Television Society, Fellows Luncheon, and to take John with us. In our most recent trip to England, in 1986, we again visited the MacWhirters and their grown-up family.

During roughly the same period, we had another "English" apprentice, from Australia, Graham A. Warner. Graham's father, Sir Warner, owned Neutrodyne, Ltd., of Australia, which handled Hazeltine patents for that area of the world. While I got to know Graham at work, I believe that Dorothy and I only socialized with him at a dinner at the Arthur Loughrens'. However, quite a few years later (I think it was 1975), in London, Graham and his wife invited Dorothy and me out to dinner. By that time, Graham was in charge of Neutrodyne, Ltd. We just heard early in this year of 1988 that Graham had died.

17.6 The Colorful Days Start To Fade

It was only a few months after the CCIR demonstrations that our very efficient group of the previous 6 1/2 years started to fall apart. I have a memo dated May 12, 1956, appointing Charlie Hirsch as Director of Research (essentially replacing Art Loughren). I did not know all the details, but I understood that MacDonald wanted our "efficient" consumer-electronics R&D group (having patents as its emphasis) to also take on R&D for the government/military side of the company (then under Orville Dunning). My recollection is that Art objected because he believed the types of R&D, plus the significant efforts in "putting out fires" on the military side, would eat into the R&D group's activities and result in an ineffective patent-oriented R&D group. I also understood that Orville was not in favor and wanted a separate R&D group. Whatever the precise reasons were, Art left Hazeltine after 20 years and after making such a tremendous contribution through his leadership of the color TV activities.

I was moved up to Chief Engineer of Research Division and Bill Bailey was an associate to Charlie. During the following year, the Research Lab did get started in several non-TV areas. I don't remember all of the details, but I do recall Fred Halden getting started on a computer and Don Richman getting into such fields as synchronization for deep space probes and pulse compression work.

This year, starting the Summer of 1956 through the Summer of 1957, was a very unhappy year for me. Art and I could communicate very effectively and, when I needed technical guidance, I could count on getting something useful from Art. Now, suddenly it was as if I had no higher source to "lean on" technically. Even though Charlie Hirsch and Bill Bailey were still there, it wasn't the same. They were closer to equals, in spite of titles.

Then, something happened that I did not previously expect. Art had been a very good buffer between MacDonald and the engineering staff, allowing us to concentrate on technical matters without being swayed by some of Mac's ideas. Unfortunately, Charlie was not as good a buffer and I saw the effect upon Charlie. Finally, during the Summer of 1957, I decided I did not want to eventually advance to my boss's job, because of the interface with MacDonald. Having decided I didn't want my boss's job, I decided to retire from Hazeltine.

In the early '50's, I received an employee agreement which, after five years, would pay-out upon retirement 1/4 salary for five years. So, I decided to use this as a base, retire from Hazeltine on September 1, 1957, do consulting for Hazeltine and other clients (see next section), and, in the meantime, look around for a more suitable position. Mac tried to persuade me that leaving was not a good idea, but he never tried to use a salary increase to see if I would stay.

Before I had made my decision to "retire at 40", Charlie Page had gone on a vacation to Maine. When he came back and found my decision, he said to me, in no uncertain terms, "Barney, why didn't you let me know while I was in Maine; if I had known, I wouldn't have come back". Charlie's strong feelings about wanting to work with me, and not work with someone else, left a strong impression on me. He, too, was seeing the Colorful Days fade.

18

CONSULTING, EVENTS, AND DECISIONS

When it came to getting consulting work, I was well enough known and very fortunate in that the work seemed to come to me without any marketing effort on my part. As I recall, the first two efforts were for two friends, Page Burr and Johnnie Gray. Page Burr was getting a business started with a friend of his by the name of Brown, who lived in Arizona. Page was to do design and Brown was to do production. The joint effort became Burr-Brown, which I believe still exists in Arizona. As I recall, the business was semi-custom differential-amplifiers.

Johnnie Gray was running the coil company which started as Harnett Electric with Dan Harnett as general manager and Johnnie as production manager. Dan eventually left and went to GE, leaving Johnnie in charge of the coil business. John and I were good friends, he having been my best man. During the early part of my consulting period, I helped John with some general design information regarding coils. John and his wife, Helen, became good friends of Dorothy and myself. Much later, after a session in the Army (as MP), my #1 son, David, went to work for John. This was David's first job, and he is still in a related business.

During the entire consulting period, I did work for Hazeltine. Averaged over the five years, they were my major client. As I recall, the first significant effort I did for Hazeltine was for the Color Film Analyzer. I did the necessary calculation work to optimize the color filters and matrix networks for a best match to various film stock of interest and best match of the display to a projector system.

I believe it was in 1960 when Larry Dodds recognized that the Hazeltine Research Corporation (HRC), then in Plainview, was no longer doing R&D for the home-entertainment industry, in HRI's interest. So Larry asked me to work with HRI (Chicago) and help to convert it from just licensee measurements, by adding an R&D effort. This was the start of a long relationship with HRI in which I acted as a stimulus to develop an R&D capability within HRI.

Another pair of clients that I had were Boonton Radio (of Q meter fame), Boonton, New Jersey, and Autometric Corporation (a subsidiary of Paramount Pictures) in New York City.

Boonton Radio was at a state where they were looking for a new chief engineer. I think Harold Wheeler proposed my name. Downsborough, then head of Boonton, invited Dorothy and me over to see the Boonton area, and "wined and dined" us. I decided against this opportunity, but offered to help him with part time leadership of their engineering efforts until they could find a suitable chief engineer to replace the current one. He took up the offer, and I had a ticklish situation for a while during the final stay of the then chief engineer. First, I was "acting" as a technical consultant to the then chief engineer; then, as a part time chief engineer after they let the former man go. Then, near the end of my efforts for Boonton Radio, I had a brief overlap with the new chief engineer, John VanDuyne.

With regard to Autometric, through our previous work on the Chromatron, I had come to know Bob Dressler, who at that time I believe was chief engineer of Autometric. They still had some work on the Chromatron, but to help him I had to get an OK from Hazeltine that there was no "conflict of interest" in the particular areas of work. This I did clear through Hazeltine (they were still paying my base "1/4 salary"). But the major effort I put in for Autometric was not on the Chromatron, but on automatic devices to register overlapping parts of a map (really aerial photos of land detail). This device helped in providing the precision match needed to assemble the aerial photos into one large map and also to estimate relative heights of objects.

Autometric was in the Paramount Building in New York City and thus, at that time, a relatively simple commute from home. By this time, I needed to expand my office space at home. Besides my desk and files, I had a desk for a part-time secretary and photographic copying equipment to make decent reports. I got a loan from Autometric, permitting me to add an office-type room, and worked for Autometric long enough to pay off the loan.

While this is not in chronological order, somewhere along the way I did an expert witnessing job for GE. One of Hazeltine's former patent attorneys, Jack Harvey, had joined a New York City firm doing patent work for GE. As a result of our past working together at Hazeltine, Jack decided I would make a good witness and approached me. The subject was an RF TV Tuner, and I don't remember anything else. My report list seems to indicate that I made some measurements on a GE tuner - therefore, I suspect GE was being sued - but I have no idea who won.

Another company I did work for was Zenith Radio, in Chicago, and this eventually led me into some "soul searching" problems. During the color TV days, I had become acquainted with several of the Zenith engineers. Also, I knew the then head of Zenith's Patent Department, Frank Crotty. Frank had been a member of Hazeltine Patent Department and wrote a number of patent cases for me. The Crottys and the Dodds earlier had both lived in Westchester and had been good friends; that is, until Larry divorced his former wife (whom the Crottys knew very well) and married his Hazeltine secretary, Carol Scott. (Dorothy and I were friends with Frank and Frances Crotty and, of course, I knew Larry and Carol from Hazeltine.)

Dismissing the personal items for the moment, I believe Frank found that I was consulting and thought I might be of some help with Zenith's problems with their Phone-vision. Phone-vision was a subscription broadcast TV system, one form of which received both audio and some key data regarding picture scramble via telephone line. Broadcast sound was used to "hype" the programs being, or about to be, transmitted.

During the time I did some work for Zenith, I co-invented an idea with Erwin Roschke and a patent (written by Francis (Frank) Crotty) was filed in March, 1959, and issued in March, 1963. However, eventually, it became clear that HRI was going to bring suit against Zenith with regard to Loughren's keyed AGC patent. Also, it became clear that both HRI and Zenith wanted me as their expert witness! So I had some "soul searching" to do, and to pick sides. Eventually, I stopped working with Zenith.

During the consulting period, I prepared a number of reports for my clients. A list of reports is given here:

REPORTS FOR HAZELTINE RESEARCH CORP:

201	11/1/60	Some notes and suggestions on the D-C restoration problem
202	11/10/60	A comparison of tunnel diodes vs. junction diodes as low-level square-law detectors
203	8/24/61	Patent review of RCA color receiver CTC-11
204	11/1/61	Patent review of Zenith color receiver
205	2/6/62	Signal-to-Noise Ratio Limitation Upon Wide-Band Scan-Converter Systems
206	5/3/62	Early Color TV History and Hazeltine's Contributions

REPORTS FOR AUTOMETRIC CORP:

301	12/3/58	Electronic means for developing servo signals in response to registration errors of substantially identical images
302A	3/4/59	Some notes on the comparison of difference matching with product matching
302	12/30/59	A comparison of various signal processing methods for the Chromatron

303	4/22/60	Dependence of V-shaped match curve upon electrical pulse shape
304	Not issued	Study of electrical signal processing errors in uniscale matcher
305	10/19/61	The colorimetric effect of some variations in signal processing for the equal-resolution Chromatron
306	7/17/61	Considerations regarding preliminary design of stereometer
307	10/3/61	Rough terrain study regarding stereometer design

REPORTS FOR ZENITH RADIO CORP:

401	12/5/58	A Suggested System for Broadcast Subscription Television Employing Suppressed-Carrier Plus Quadrature-Component Transmission Note: Report never issued
402	3/9/59	Some Comments Regarding Scramble and Security of the Suppressed Carrier Quadrature Component System

REPORTS FOR BOONTON RADIO CORP.:

501	5/16/60	Preliminary Report on Discontinuity Inductance and Excess Loss Produced by Non-Coaxial Connection to a Coaxial Reactance Standard
502	10/10/60	Relation between Discontinuity Inductance and Resistance Produced by Non-Coaxial Connection to a Coaxial Reactance Standard
503	6/13/61	Study Regarding High Sensitivity Detector Suitable for Co-Axial Hybrid Bridge

MISCELLANEOUS REPORTS:

900 (GE)	2/29/60	Measurements on GE Tuner UHF-59
901 (LBD)	3/29/61	Investigation Regarding Use of Certain EMI Patents in the United States
902 (IRE)	3/29/62	A Review of Some of the Recent Developments in Color TV

Also, I prepared 38 short Engineering Notes, which either "stood on their own" or were used as appendices to certain reports.

Two events of particular significance during this period were: a) Charlie Hirsch left Hazeltine and joined RCA (George Brown's staff) in 1959; b) on August 11, 1961, MacDonald died of a sudden heart attack. Mac had been preparing Web Wilson for corporate leadership, with Dick Beam as second in command, so these were the new corporate leaders.

At the end of 1959, the Research Lab (as Hazeltine Research Corporation) had moved to Plainview, with Commodore Jennings Dow in charge. The lab had three groups: Systems Research with Don Richman in charge; Apparatus Research with Bill Bailey in charge; and Industrial Research with Dick Farber in charge (the Research Lab had stopped doing any R&D in the interest of HRI, as I mentioned before).

Another activity directly involving me that took place during this general period was Larry Dodds preparing me to be an "expert witness". This started by his taking me to watch the trial of HRI vs. Dage Electric (in 1958) regarding the BNC connector (Salati patent). Later, I got directly involved as "expert witness" in HRI vs. Firestone (1963) and HRI vs. Zenith (1964), both regarding Loughren keyed AGC patent.

While still in a consulting position, I also prepared a paper entitled "Review of Some of the Recent Developments in Color TV", published in IRE Transactions PGBTR, April, 1962, and presented orally twice. I believe the paper was "invited", but I am not sure.

As I mentioned near the end of section 17.6, I started consulting with the intent of looking around for a more suitable position. As I mentioned near the start of this section 18.0, I had an opportunity with Boonton Radio that I declined. There were two other opportunities that I declined. George Sziklai, formerly of RCA, invited me to consider joining him at the Westinghouse Research Lab at Pittsburgh, Pa. His interest at that time was "video on a record". Dorothy and I went to Pittsburgh in the winter, visited the lab, but were completely disillusioned with Pittsburgh as a place to live. Next, Don Fink, formerly of Electronics, had become head of R&D at Philco, invited us down to Philly for a discussion and look around. Again, I declined. None of these "opportunities" seemed quite right.

I had found consulting to be somewhat rewarding. There was quite a variety in the work; the pay was good (twice what I made when I left to start consulting); relative freedom in hours and less than 40 hours per week; but no medical insurance or any of the other "fringe benefits", and I was depleting my employee agreement retirement benefits.

In the Summer of 1962, Harold Wheeler and Philip LaFollette of Hazeltine's Board of Directors approached me to find out what it would take to make me come back to Hazeltine. I guess I had had enough of consulting, as I settled for: re-establishment of employee agreement; a Vice Presidency of HRI; employment considered as continuous since 1939; usual fringe benefits; salary at least equal to my consulting income plus the "retirement pay"; and an office in Little Neck, not in Chicago. For about eight months, besides my usual trips to Chicago, I had a nice quiet office in Little Neck to think through and develop further useful ideas for color TV receivers. In the meantime, Bill Bailey and Dick Farber had left the Research Lab to join Art Loughren in a new venture, "Key Color Lab".

Then, one Sunday night in April, 1963, Dick Beam (who had replaced Web Wilson) was hectically trying to reach me. We had been away during the day. Dick wanted to see me at the East Norwich Inn, that night. When I got there, he indicated that the next day he was letting Don Richman go, and he wanted me to "hold together the Research Lab". Of course, what do you say to the boss when he makes such a statement? YES! Running the Research Lab, which was mainly, but not solely, military electronics oriented, was not why I came back to Hazeltine! While Jennings Dow was still "in charge", it was clear that he expected to retire soon, and Dick Beam expected me to "take over".

The next morning, after Dick Beam did his job, I showed up at Plainview, called all of the lab heads together, made it clear I would do what I could, but my background was not in military electronics; I was not a marketeer; so I would have to rely heavily on each one of them. This was the start of another career for me; some of the times during the next 15 years were hectic; but most of the time was very interesting; and I got a chance to know a group of extremely capable and hard-working people.

Also, in April, 1963, Hazeltine Research Corporation, a wholly-owned subsidiary, was merged into Hazeltine Corporation, and became known as Hazeltine Research Division (HRD).

19

AFTERWARDS

After joining the Research Labs, I had many duties, all of which seemed to be of top priority. Running the Research Lab, I had such new duties as: manpower forecasting; review of job prospects and problems; certain "sticky" personnel problems; selling/R&D budgets; optimizing the organization; arbitrator regarding budget and space allocations; and, at one time, selling to management to put up the money for establishing the micro-electronic lab (MEL). Concurrently, I was the company's expert witness in several patent trials; technical expert on our color TV patents, helping in licensee negotiations; technical guide for HRI (Chicago) research work, and inventor with regard to some of HRI's areas of interest (as well as VP for HRI). I also wrote some technical papers and became involved in industry committees concerned with certain color TV matters.

In this section and the following sections, I intend to mainly treat briefly the subjects most closely related to color TV.

19.1 Licensing Activities

Originally, HRI's patent license was a "package" form, in which several (or all) patents were considered, and licensed, as a group. The early color TV licensing was of this nature. But a court decision, some time in the early '60's, made HRI decide that licensing per patent, per usage, was appropriate for the U.S. This meant that HRI needed to carefully put a price (royalty rate) on each patent, and to sell prospective licensees on licensing as many as seemed appropriate for their current and future receivers. Since most of the more important patents on color TV were mine, this got me directly involved in recommending a royalty for each patent; reviewing receivers to decide whether they were used; and, in many cases, getting involved with our lawyers in the first contact with prospective licensees, carefully telling their engineers and lawyers how their sets met each clause of our claims in each patent.

Dave Westermann was President of HRI during these important early color TV licensee negotiations and, in most cases, was our lead lawyer in such negotiations. Dave took notes in shorthand, and it would amaze me how, when he got back home, he would write a 10 to 15 page memo on our meetings, and every technical detail was in the memo and correct. Dave and I developed respect for each other, particularly as a result of these early color TV license negotiations.

In those days, RCA was the major manufacturer of color TV sets, and so licensing them under the per use, per patent approach was very critical. They, in essence, forced us down in our prices by taking a very strong position that they were making a "certain number of sets per year" and could "only pay us so many dollars per year", and they didn't care how we set our royalty rates as long as the total, for the patents they were using, fit into their specified limit. This forced our royalties down, but gave us recognition that the major manufacturer considered our patents* valid enough to take a license under them. This resulted in another pricing exercise, per patent, in which I was involved, and which set the prices we would use in negotiations with the rest of the industry. RCA became licensed under HRI's new license form on November 15, 1966.

HRI did license most, but not all, of the industry under the prices per patent, per usage, settled with RCA. Zenith got a license, as part of the settlement of the anti-trust suit, described in some detail in Appendix C, Chapter IX/C, which related to a black and white TV patent, not a color TV patent. Motorola did not become licensed, for reasons that were really not valid. However, management chose not to sue, because of the drain it would cause on valuable management time during the critical Zenith suit, and the likelihood that some potential licensees might hold off until the suit was settled.

The Japanese industry was quite reasonable and, when they understood HRI's patent position, they signed up without undue legal and management effort (see Appendix C, Chapter X/C).

In spite of the Zenith suit and the many millions of dollars that HRI had to pay them as a result of the settlement, after all the bills were paid, HRI still collected millions of dollars on usage of its patents. On June 4, 1973, HRI paid off the Zenith settlement ($525K, early payment), and that year it made several million additional on patents. For the next couple of years, patent income, mainly on prior usage and foreign patents, continued to be over a million dollars/year. Through an unusual situation, one of HC's color TV patents in Canada will not expire until 2000. HC is continuing to collect around a tenth of a million on this each year.

19.2 CFA/Color Previewer

Section 16.3 mentions the early tests to confirm the feasibility of the Color Film Analyzer. Further discussions with Leonard Giarraputo and Arthur Miller of Pathe Laboratories made it clear that the "timing" process, then employed for obtaining proper color balance and printing density, required many trials and successive approximations before all scenes were satisfactory. The problem was particularly difficult due to the low gamma negative original film from which a proper gamma positive film had to be

---

* Our 2 most valuable patents were: Shunted Monochrome - 2,774,072, issued on December 11, 1956; and Constant Luminance - 2,773,929, also issued on December 11, 1956.

developed. These successive approximations result in expensive delays and also involve the scrapping of valuable film stock.

During 1957, the design for a complete stand-alone system was made. This system used a flying spot scanner to illuminate the original film; a set of optical filters to analyze the colored light coming through the film; a set of controls to simulate variable exposure light color; a set of non-linear circuitry plus cross-coupling matrices, and a color cathode-ray tube. The non-linear circuitry and matrices were designed to simulate the film processing plus projection system for the developed film. Thus, the complete system permitted the CRT picture to simulate the final projected image. The set of controls were adjusted to obtain the desired projected picture before actually exposing and developing the final film. Proper calibration of the controls permitted direct transfer of information to the exposing red, green and blue lights in the printer.

Also during 1957, a breadboard model of this stand-alone Color Film Analyzer was made and tested with Pathe Laboratories. Then a technical paper entitled "An Instantaneous Electronic Color-Film Analyzer" was authored by Charles E. Page, William F. Bailey, Charles J. Hirsch, Arthur J. Miller, Leonard Giarraputo, and BDL. The paper was presented at the SMPTE Convention, October, 1957, and published in Journal of SMPTE, January, 1958. Patent 2,976,348 was issued on March 21, 1961, on this Color Film Analyzer system with co-inventors of William F. Bailey, Charles E. Page, and BDL.

After the good experience that Pathe had with the breadboard CFA, it was decided to make a "production design" machine. A first production unit was finished by mid-1958 and was installed in the Hazeltine Timing Center, near Pathe Labs in New York City, to be available to Pathe and other film developing labs that might want to use it.

Five additional production units were made and completed either near the end of 1958 or early 1959. Charlie Page had direct responsibility for the design and operation of these units. One of these was modified to handle 70 mm film and rented to Air Force Missile Test Center, Patrick Air Force Base. I believe that another unit was also used by another Government agency.

When I arrived at the Research Labs in Plainview in 1963, there were still some units available, and I recall Jerry Stone trying to sell them. It took the "explosion" of color TV in the mid-60's to open the real market. The 1965 Annual Report says: "The Color-Film Analyzer is a device developed by your Company some years ago. It was designed for use by color-film processors as an aid in predicting and controlling the outcome of printing a color positive from a color negative. Its principles and construction were a by-product of your Company's pioneering work in color television. Following its use by a few Government and civilian laboratories for several years, the demand for the CFA has increased with color television programming relying on color film. Several orders for improved models have been received in 1965 and more are expected in the near future."

The 1966 Annual Report has a similar statement with the additional comment: "With the ever-increasing activity in color TV programming, the demand for this machine has grown, resulting in orders, during 1966, for 15 more units." The 1967 Annual Report has a color picture of an operating CFA (under Industrial Products) with the statement: "Sales of the Color Film Analyzer exceeded $1 million in 1967."

Sometime during 1965 or 1966, we moved the CFA out of the Research Lab into "Special Products". This did not receive proper attention, and we needed a real product line director for this product. I was instrumental in persuading Al Arbeeny to take on this job, and Al was responsible for the "exceeding $1 million in 1967".

Every Annual Report from 1967 through 1983 recognized the stream of business which Al developed into the broader product line of Color Analysis and Simulation (CAS). There were times during the early '70's when earnings were low that Dave Westermann would say to Al Arbeeny: "Al, can't you sell a few more CFA's this quarter to keep up our earnings?".

In April, 1970, in Hollywood, Hazeltine Corporation was presented with an Academy Award for technical achievement for the design and development of the Hazeltine Color Film Analyzer. The corporate bulletin board notice says:

> "The Hazeltine Analyzer is used by virtually every major film processing laboratory serving the motion picture and TV industries in the United States and throughout the world. Such films as "Midnight Cowboy", "Butch Cassidy and the Sundance Kid", and "Hello Dolly" -- three of the five nominees for this year's Best Picture Award -- were electronically analyzed for scene-to-scene color balance on the Hazeltine Analyzer. Most leading color TV film series, such as "Bonanza", "Mission Impossible", and "That Girl" are analyzed using this equipment.
>
> The Hazeltine Analyzer makes it possible to achieve optimum scene-to-scene color correction and balance before the film is committed to printing, thereby eliminating costly trial and error prints.

In September of 1969, Hazeltine introduced a new generation, solid-state electronic version of the Analyzer that provides for instantaneous fingertip control, resulting in increased efficiency."

During the years, Al expanded the product line to include an "Electronic Color Proofing System for the Graphic Arts industry"; Photofinishing Analyzer; Separation Previewer and a Scanner Previewer, both for the Graphic Arts industry.

Regarding the CFA, the 1978 Annual Report quotes: "Your Company's Academy Award winning Color Film Analyzers are the standard of the industry." As a matter of fact, after the solid-state version of the CFA was introduced, it was more stable than the chemical-photographic process. There were instances when the CFA indicated that a certain "timing" was proper but the end chemical-photographic image was not, and investigation proved the chemical-photographic process to have an error.

A number of auxiliary items for the CFA were developed which helped to increase the income, which for a number of years was several million dollars per year. Al was a real entrepreneur and world-wide marketeer, including selling CFA's in such places as the Peoples Republic of China (PRC). However, the Graphic-Arts products did not "catch-on" like the film products, and eventually the world was reasonably saturated with stable CFA's and what the Graphic-Arts industry needed - a scanner-previewer - was too expensive to develop, at least for our management.

There were a number of years during which income from the CAS product line and from our color TV patents kept Hazeltine solvent.

19.3 Vertical Interval Reference (VIR) Signal

From 1969 through May, 1974, I was chairman of the Broadcast Television Systems (BTS) Committee of EIA (Electronic Industries Association). Charlie Hirsch was the previous chairman, and he convinced me to take over the chairmanship, using such comments as "the committee meets very infrequently and there isn't too much to do". Fortunately, I took this "with a grain of salt"; the next 5 years were very busy for the committee.

The Joint Committee on Intersociety Coordination (JCIC) established an Ad Hoc Color Television Study Committee in 1968 to consider the various possible causes for the significant variations in the color characteristics of pictures observed on home television receivers, and then to allocate to existing industry organizations appropriate questions for further investigation and resolution. Early tests indicated that one of the many possible causes was the effect of video signal variations which are actually within approved FCC specifications. Investigation of these problems was turned over to the Broadcast Television Systems Committee (BTS) of the EIA Engineering Department, since the BTS charge given by EIA includes "examination of the FCC signal specifications and recommendation for desirable changes."

Starting on April 2, 1969, the BTS committee was very busy, meeting almost every month for the next several years.

The BTS study soon established the desirability of having an ever-present reference signal during the vertical interval which is associated with a particular program signal and is a proper reference for both the chrominance and luminance of that program signal. Some reasons for this are:

First, the tie of the burst amplitude to the chrominance signal through the various tolerances present in the FCC specifications is inadequate. But, operationally this tie needs to be good since most receivers make use of the burst amplitude as a reference in automatic chrominance controls (ACC) circuits to set the gain of the chrominance channel. NTSC did not consider this problem in setting up the signal specifications. The chrominance to luminance ratio is defined with one tolerance, the luminance to deflection sync ratio is defined through another set of tolerances and, finally, the burst amplitude is defined in relationship to the deflection sync amplitude. The possible buildup of tolerances through this chain is large. Of course, signals actually broadcast may not have made full use of this tolerance range on the average, but this sequential set of multiple tolerances to tie the burst to the program chrominance needed to be replaced by a direct tie.

Second, it is standard practice to use "stabilizing amplifiers" throughout a broadcast television system in many places. Once a signal has gone through such a stabilizing amplifier and the sync and color burst have been reconstituted, there is no real check by looking at the signal to confirm that the burst and chrominance do have a proper relationship. Also, the problem of reconstitution of sync and burst can be a severe problem with video tape equipment.

The above and many other considerations led BTS to devise a Vertical Interval Reference (VIR) signal which, after considerable study and field-testing, was made the subject of an EIA Recommended Practice for Use of a Vertical Interval Reference (VIR) Signal. This is EIA Television Systems Bulletin No. 1, issued July, 1972. The VIR signal is shown in Figure 1, next page. The VIR signal is intended to be representative of the program picture information and, accordingly, is on a late line in the vertical interval so it can be treated like picture, and regarding amplitude is in the picture black-to-white region, additionally so it is treated like picture. The VIR signal contains reference levels for black, gray (50 percent), chrominance phase, and amplitude, the latter being superimposed on a luminance level corresponding close to typical skin-tone luminance.

The BTS Committee and its sub-committees contained a good cross section of broadcast network engineers, receiver manufacturers engineers, and color television systems experts, so that this EIA Recommended Practice contained significant industry-wide input and agreement.

BTS recognized that after the EIA Recommended Practice for the VIR signal had been issued, a next important step in encouraging and facilitating its usage would be for the FCC to amend its rules to both accord specific status to the VIR signal and to designate and reserve a specific place for its transmission in the vertical interval. As BTS approached this question, it found that its original proposal to use line 20 for the VIR signal was not supported by some broadcasters. After much discussion and consideration, BTS decided to request EIA to petition the FCC for reservation of line 19, so as to prevent conflict with other proposed uses of line 20 by broadcasters.

The appropriate divisions of EIA filed a petition with the FCC on May 14, 1973, to amend the Commission's Rules so that a single line, in both fields, in the vertical blanking interval of the television broadcast signal is designated for exclusive use in the transmission of a Vertical Interval Reference (VIR) signal. The Commission followed closely the development of the Vertical Interval Reference (VIR) signal, and shared EIA's belief that its general use by those involved in the production and transmission of color programs would result in greater uniformity in color characteristics, as among programs, in the viewer's receiver. They further agreed that an important step in promoting and standardizing VIR signal use would be the establishment of a specific vertical interval assignment for its transmission. Also, the Commission said: "We believe that the public interest requires that we press action toward this end as expeditiously as possible." Accordingly, the Commission issued Notice of Proposed Rule Making, Docket No. 19907, RM-2192, released December 28, 1973, directed mainly, but not solely, to this subject. Report and Order by the FCC adopted November 12, 1974, reserved line 19 on both fields for the VIR signal defined exactly as proposed by BTS.

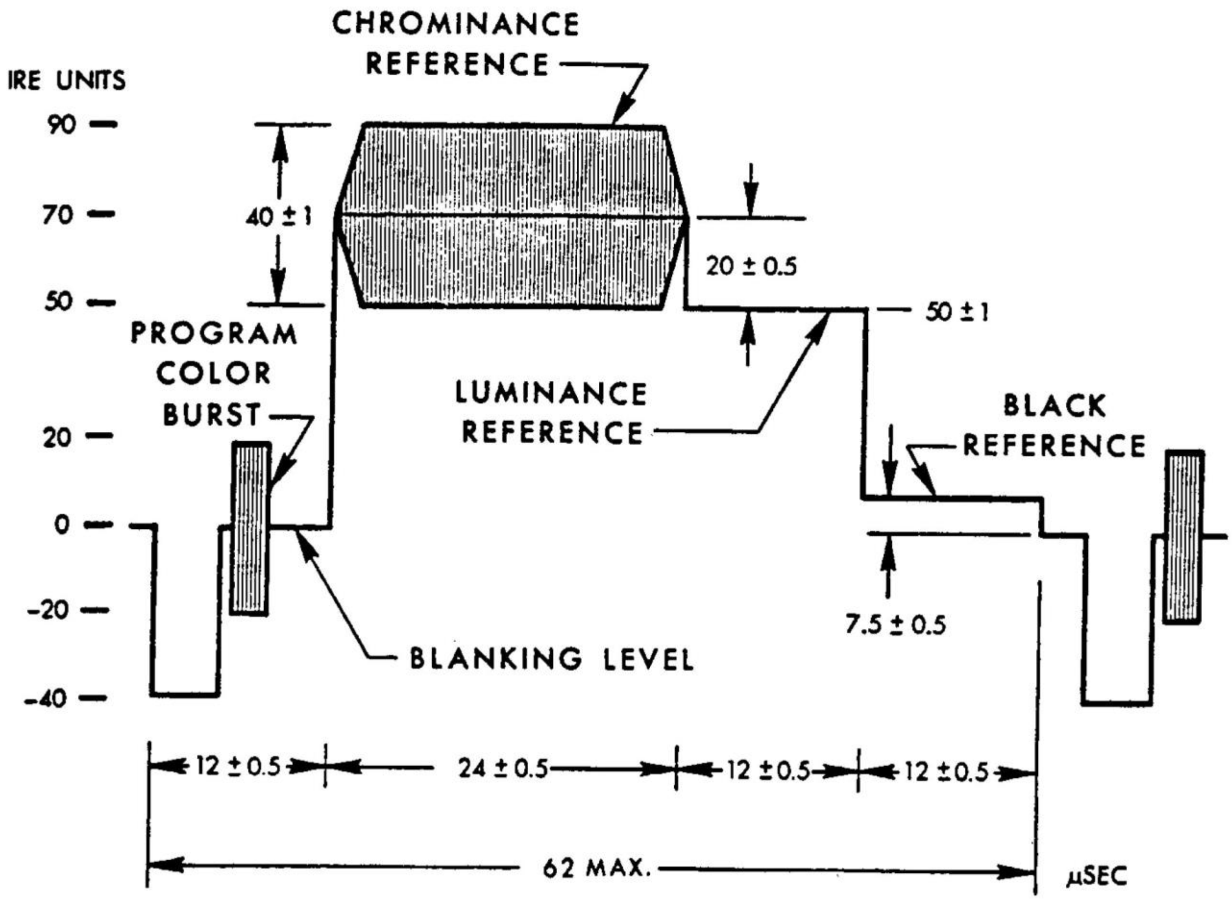


Figure 1. The VIR Signal

Over the years, color uniformity has slowly improved, certainly not just due to use of the VIR signal, but also improved operating practices by the broadcasters, and various receiver improvements and stability.

On May 3, 1978, I accepted an engineering Emmy Award from the National Academy of Television Arts and Sciences, on behalf of the Electronic Industries Association Broadcast Television Systems Committee. The award was for Outstanding Achievement in Engineering Development of the Vertical Interval Reference signal system.

During this session as chairman of BTS, I got acquainted with a number of the top broadcast engineers from ABC, CBS, NBC and PBS, as well as some of the receiver engineers not in NTSC, and re-acquainted with a few of the NTSC engineers. I got to know Joe Flahery of CBS fairly well, and after the Emmy award I received a letter from Joe including the following: "I know very well the effort that you put into the activities of the BTS Committee in making this signal a reality. Without your effective and persuasive guidance, it is doubtful if so much would have been accomplished." The last time I saw Joe, in 1987, was on the Great Wall in China.

On May 23, 1974, I resigned from chairmanship of BTS "for business reasons". (I had to give more attention to the Research Labs, and lso, in December, 1972, I had become a member of the Hazeltine Board of Directors.) I picked Bailey Neal (then Sylvania, now RCA/GE) as my successor and he accepted and was accepted by EIA and BTS. My trustworthy secretary of BTS, Charlie Page, continued as secretary for a few months to help in the transition. Bailey Neal is still chairman of BTS (as of 1988).

19.4 Large Cut-Backs

The very early '70's had a number of BLACK DAYS. In particular, there were cancellations, reductions, delays and stretch-outs in defense contract awards, which affected the majority of our corporate business. On June 15, 1970, we had our first significant layoff of the year, 330 employees. But things kept getting darker, and on November 6, 1970, we had a big layoff. The sum of the two 1970 layoffs amounted to approximately 1500 employees out of a total of approximately 3000 employees at the beginning of the year. So 1970 was the year the company was cut in half. All sections of the company were treated approximately equally. We had a very competent group in the Research Labs, so a number of valuable people had to be terminated. On November 6th, after completing my ugly task, I closed the door to my office and sobbed for about an hour.

The problem of making the decisions as to who stayed and who left was horrendous. In some cases, people on existing contracts had to receive some priority over excellence but, fortunately, only in a very few cases in RL. But even so, some Lab Heads did not agree with my decisions.

Pete Baum, Director of Engineering, had a bigger job, since the engineering department was at least an order of magnitude larger than RL. It is quite likely that the stress led to Pete's first heart attack.

Dave Westermann, in spite of the Zenith case uncertainty, took a very wise risk with our lean engineering groups and lean contract work - he increased the dollars into IR&D, which eventually paid off.

As we slowly recovered, a number of the good employees came back.

20

TECHNICAL PAPERS, AWARDS, AND PATENTS

20.1 Technical Papers

The following is a list of my technical papers prepared either for publication or oral presentation outside of the company. Those with a "C" after the number are concerned with Color TV.

	Title	Published	Oral
1	Vector Response Indicator	Trans. AIEE, June, 1940	Twice
2	Phase Curve Tracer for TV	Proc. IRE, March, 1941	Twice
3	Distortion Analysis by a Taylor Series Expansion of Complex Trans. Freq. Charac.	Master's Thesis, Stevens Inst. of Technology, 1946	
4	FM Detector Systems	Tele-Tech., Jan., 1948	Once
5	Two Signal Performance of Some FM Detectors	Not published	Three
6	Information Theory Applied to FM and Wide Band AM Systems	Not published	Once
7	Hazeltine Fremodyne Circuit	Not published	Once
8	Superregenerator Design (Co-Author with D. Richman and A. Hazeltine)	ELECTRONICS, Sept., 1948	
9C	Recent Improvements in Band-Shared Simultaneous Color TV	Proc. IRE, Oct., 1951	Four
10C	Principles of NTSC Compatible Color TV (Co-Author with C. J. Hirsch and W. F. Bailey)	ELECTRONICS, Feb., 1952	
11	AM Rejection in Ratio Detector	Proc. IRE, March, 1952	Once
12C	General Considerations in Design of Color TV Receivers (Co-Author with C. J. Hirsch)	Trans. PGBTR, IRE, March, 1953	
13C	Processing of the NTSC Color Signal for One-Gun Sequential Displays	Proc. IRE, Jan., 1954	Once

	Title	Published	Oral
14C	Principles of the NTSC Color TV System	Not published	Full day lecture, State College, Pa., June, 1954
15C	General Characteristics of Color TV Displays	Not published	Twice
16C	Color Signal Distortion in Envelope Type of Second Detectors	IRE Trans., PGBTR, Oct., 1957	Once
17C	An Instantaneous Electronic Color Film Analyzer (Co-Author with C. E. Page, W. F. Bailey, C. J. Hirsch, A. J. Miller, and L. Giarraputo)	Journal SMPTE, Jan., 1958	
18C	Review of Some of the Recent Developments in Color TV	IRE Trans., PGBTR, April, 1962	Twice
19C	The PAL Color Television System	IEEE Trans., BTR, July, 1966	Once
20C	JCIC/SMPTE Ad Hoc Television Study Committee Progress Report (Co-Authored with K. B. Benson-BDL part re "BTS Activities")	Not published	Once - NAB Conv. Chicago 4/7/70
21C	Improved Color Uniformity Through Use of Vertical Interval Color Reference (Co-Authored with F. Davidoff)	Synopsis, Journal SMPTE, November, 1971	Once - SMPTE Tech. Conf. 10/6/70
22C	Techniques for Improving Broadcast Color Television	IEEE INTERCON Conference Record, 1973	Twice - IEEE INTER-CON, 3/29/73. IEEE SYMPO-SIUM, 9/73
23C	The VIR Signal and its Status		NAB Conv. Houston 3/18/74

	Title	Published	Oral
24	Results from an Analytic Study of AM Stereo Systems		Prepared and submitted to FCC, 3/78
25C	The Revolution and Evolution from Dot Sequential to NTSC	IEEE Trans., Consumer Elec., May, 1984	Once, in China, 1987

20.2 Awards re: Color TV; and Other Recognitions re: Same

This listing is mainly mine, but where I have the data I will list awards of others that relate to our color TV work.

1952	BDL	(first) Vladimir K. Zworykin Award, IRE - "For his outstanding contribution to the theory, the understanding, and the practice of color television."
1953	AVL	David Sarnoff Gold Medal, SMPTE - "For his contributions to the development of compatible color television, including his active work on the principle of constant luminance; for his participation in color video standards activities; and for his guidance in compatible color television."
1954	WFB	Fellow, IRE - "For his contributions to the theory, practice, and standardization of television."
1955	AVL	Morris N. Liebmann Award, IRE - "For his leadership and technical contributions in the formulation of the signal specifications for compatible color television."
1955	BDL	Fellow, IRE - "For Contributions to Color Television, Frequency Modulation and Superregeneration."
1955	BDL	David Sarnoff Gold Medal, SMPTE - "For his many contributions to the science of color television, notably in the optimum method of transmitting a compatible color picture and in his fundamental of constant luminance."
1955	BDL	Fortune Magazine - "One of the three architects of color television."
1957	AVL	AIEE Fellow - "For technical leadership in the electronic industry with major contributions toward standardization of color television."
1957	DR	Vladimir K. Zworykin Award, IRE - "For contributions to the theory of synchronization, particularly that of color subcarrier reference oscillator synchronization in color television."
1957	BDL	Professional Group of BTR Award, IRE - "For his significant contributions in the field of color television circuitry."

1961	DR	Fellow, IRE - "For contributions to color television."
1965	BDL	Modern Pioneer Award, NAM - "An electrical engineer who has made outstanding contributions to the theory, understanding and practice of color television. He showed that the TV signal used in a compatible color television system contained two useful kinds of information, a brightness signal and a coloring information signal, which concept greatly clarified the design and engineering of transmitters and receivers, making possible great advances in color TV and is used in the electronic circuits of all such sets today."
1967	BDL	National Academy of Engineering - "For Research and Development of Television Systems."
1968	BDL	Tau Beta Pi, Cooper Union - (See 1985 re: Tau Beta Pi).
1969	BDL	Cooper Union Professional Achievement Citation - "This Citation is the counterpart of the honorary degrees that other institutions confer, and is the highest award that Cooper Union gives to its alumni."
1969	CJH	International Television Symposium Citation - (often characterized as the Father of NTSC)
1970	HCFA	Hazeltine Color Film Analyzer - Wins Academy Award for Technical Achievement for the design and development of the HCFA.
1970	BDL	Gano Dunn Medal, Cooper Union - "For distinguished professional achievement in engineering and science."
1972	BDL	Consumer Electronics Award, IEEE - "Throughout his career Mr. Loughlin has creatively solved many different problems confronting the consumer electronics industry and his pioneering work in color television has been recognized as basic to the development of the NTSC Color Television System."
1973	BDL	International Television Symposium Citation - "In recognition of his outstanding leadership in the development of world television and his valuable support of the international television symposium as a medium for extending the international exchange of ideas and new developments among television experts."
1973	CJH	Herbert T. Kalmus Gold Medal Award, SMPTE - "For his leadership in the development of the Hazeltine color analyzer."
1974	AVL	Consumer Electronics Award, IEEE - "For outstanding contributions to consumer electronics."
1977	BDL	Special Commendations Award, SMPTE - "For his many outstanding contributions to television technology."
1977	VIRS	At International Television Symposium, the Engineering Vice President of SMPTE stated that the latest improvements in NTSC signal handling techniques, including VIRS, had finally removed the stigma of "Never Twice the Same Color" from NTSC.

1978	BDL	On behalf of BTS/EIA, engineering Emmy Award - "For outstanding achievement in engineering development of the Vertical Interval Reference signal system."
1981	AVL	Armstrong Medal, Radio Club - "For his pioneering contributions to Color TV."
1983	BDL	IEEE PRESS "Engineers & Electrons, A Century of Electrical Progress" - "Bernard Loughlin, of the Hazeltine Corporation, suggested that the dots could be eliminated by two improvements. One, now used throughout the world, was the constant-luminance principle by which the color-difference signals did not affect the brightness of the received picture. The other was his proposal to apply the combined monochrome sum signal directly to the electron guns of the picture tube."
1985	BDL	The Bent of Tau Beta Pi, Distinguished Member - "Bernard D. Loughlin, NY I '39, holds 107 patents; did basic work regarding theory and development of color television."
1987	BDL	People-to-People International - Invited as a member of a group (22) of broadcast engineers, to visit the Peoples Republic of China.

20.3 BDL Patents (120 patents, some with co-inventors)

Letters after patent number refer to the generic classification of the patent material, as follows:

- AM = Amplitude Modulation
- CFA = Color Film Analyzer
- CPA = Color Photofinishing Analyzer
- CTV = Color TV
- DF = Direction Finding
- FM = Frequency Modulation
- MISC = Miscellaneous
- SR = Superregeneration
- TV = Television

Patent No.		Issue Date	Title
2,285,038	TVTE	6/2/42	System for Indicating Electrical Phase-Shift Characteristics
2,401,007	FM	5/28/46	Phase-Modulation System
2,403,385	FM	7/2/46	Signal-Translating System

Patent No.		Issue Date	Title
2,404,238	DF	7/16/46	Position-Indicating System
2,406,468	DF	8/27/46	Direction-Indicating System
2,413,637	DF	12/31/46	Direction Indicating Device
2,415,359	DF	2/4/47	Wave-Signal Translating System
2,429,513	SR	10/21/47	Gain-Control Arrangement
2,429,519	DF	10/21/47	Radiant-Energy Signal Direction Finder
2,432,026	DF	12/2/47	Position-Indicating Arrangement
2,444,741	DF	7/6/48	Wave-Signal Translating System
2,461,120	TV	2/8/49	Signal Generator
2,469,168	AM	5/3/49	Loop-Antenna Tuning System
2,472,598	SR	6/7/49	Ultra High Frequency Oscillation Generator
2,478,409	DF	8/9/49	Time Sharing Transponder System
2,481,852	SR	9/13/49	Superregenerative Receiver
2,490,530	TV	12/6/49	Wave-Signal Analyzing System
2,495,938	TV	1/31/50	Signal Generator
2,498,253	FM	2/21/50	Frequency-Modulation Detector System
2,513,731	FM	7/4/50	Frequency-Responsive System
2,550,486	FM-TV	4/24/51	Wave-Signal Transformer
2,577,781	FM-SR	12/11/51	Wave Signal Receiver
2,577,782	FM-SR	12/11/51	Superregenerative Frequency-Modulation Receiver
2,588,021	FM-SR	3/4/52	Superregenerative Receiver
2,588,022	SR	3/4/52	Superregenerative Superheterodyne Wave-Signal Receiver
2,609,492	SR	9/2/52	Tunable Superheterodyne Superregenerative Receiver
2,613,316	FM-SR	10/7/52	Angular-Velocity-Modulation Wave-Signal Translating System
2,614,212	FM	10/14/52	Frequency Converter System For Radio Receivers

Patent No.		Issue Date	Title
2,617,928	SR	11/11/52	Superregenerative Receiver
2,623,166	SR	12/23/52	Superregenerative Superheterodyne Wave-Signal Receiver
2,624,837	FM	1/6/53	Tuning Indicator System
2,633,527	FM-SR	3/31/53	Angular Velocity Modulated Wave-Signal Receiver
2,678,388	TV	5/11/54	Signal-Translating System for Television Receivers
2,678,389	TV	5/11/54	Signal-Translating System for Television Receivers
2,678,964	TV	5/18/54	Modifying the Transient Response of Image-Reproducers
2,707,206	TV	4/26/55	Electromagnetic Beam-Deflection System for Television Receiver
2,722,563	CTV	11/1/55	Image-Reproducing System for Color-Television Receiver
2,728,813	CTV	12/27/55	Color-Signal Detection System
2,730,564	FM	1/10/56	Frequency-Modulation Detection System
2,734,940 (Reissued as Re.24,882)	CTV	2/14/56	Image-Reproducing System for a Color-Television Receiver
2,759,993	CTV	8/21/56	Compatible Image-Reproducing System
2,765,363	FM-TV	10/2/56	Signal-Detection Systems for Intercarrier Television Receivers
2,773,929	CTV	12/11/56	Constant Luminance Color TV System
2,774,072	CTV	12/11/56	Color-Television System
2,774,867	FM-TV-SR	12/18/56	Frequency Modulation Detector Having Fixed Output Frequency Converter
2,807,661	CTV	9/24/57	Matrixing Apparatus for a Color-Signal Translation System
2,810,780	CTV	10/22/57	Color Television Interlacing System
2,814,778	CTV	11/26/57	Signal-Modifying Apparatus
2,833,851	CTV	5/6/58	Color-Television Signal-Modifying Apparatus
2,841,643	CTV	7/1/58	Color-Saturation Control Apparatus

Patent No.		Issue Date	Title
2,851,517	CTV	9/9/58	Color-Television Signal-Translating Apparatus
2,856,454	CTV	10/14/58	Video-Frequency Signal-Translating Apparatus
2,864,951	CTV	12/16/58	Chrominance-Signal Component-Selection System
2,868,872	CTV	1/13/59	Matrixing Apparatus for Color-Signal Translating System
2,877,295	CTV	3/10/59	Color-Image-Reproducing Apparatus
2,885,464	CTV	5/5/59	Color or Monochrome Image-Reproducing Apparatus
2,885,465	CTV	5/5/59	Image-Reproducing System for a Color-Television Receiver
2,890,273	CTV	6/9/59	Wave-Signal Modifying Apparatus
2,892,021	CTV	6/23/59	Luminance-Signal Component-Conversion System
2,896,014	CTV	7/21/59	Gamma-Correction Apparatus
2,898,454	AM	8/4/59	Five Zone Composite Transistor With Common Zone Grounded to Prevent Interaction
2,905,749	CTV	9/22/59	Screen Structure for Constant Luminance Color Receiver
2,905,752	CTV	9/22/59	Automatic Index Level Control Circuit
2,905,753	CTV	9/22/59	Color-Television Transmitting System
2,913,522	TV	11/17/59	Automatic-Control Systems for Television Receivers
2,914,606	CTV	11/24/59	Detector System Correcting for Single Sideband Distortion
2,924,651	CTV	2/9/60	Signal-Translating Apparatus for a Color-Television Receiver
2,941,072	CTV	6/14/60	Chrominance-Signal Component-Selection System
2,943,142	CTV	6/28/60	Color-Television System
2,944,105	CTV	7/5/60	Signal-Translating Apparatus for Modulated Wave Signals
2,950,349	CTV	8/23/60	Synchronizing System for Beam-Indexing Color-Television Display

Patent No.		Issue Date	Title
2,951,897	CTV	9/6/60	Synchronous Detector System for a Color-Television Receiver
Re.24,882	CTV	9/27/60	Image-Reproducing System for a Color-Television Receiver
2,965,703	CTV	12/20/60	Colorimetric Computer
2,976,348	CTV	3/21/61	Electronic Previewer for Simulating Image Produced by Photochemical Processing
2,976,351	CTV	3/21/61	Color-Signal Modifying Apparatus
2,976,409	CTV	3/21/61	Detector Circuit
2,987,572	CTV	6/6/61	Color-Image-Reproducing Apparatus Utilizing Velocity Modulation
2,987,617	CTV	6/6/61	Apparatus for Converting a Vestigial-Side-Band Carrier to a Double-Side-Band Carrier
3,002,048	CTV-CFA	9/26/61	Stabilized Image Scanner
3,002,049	CTV	9/26/61	Chrominance Subcarrier Component-Selection System
3,043,909	TV	7/10/62	Direct-Current Restorer System For Television Receivers
3,081,376	TV	3/12/63	Subscription Television System
3,098,895	CTV-CFA	7/23/63	Electronic Previewer For Televised Color Pictures
3,128,333	CTV-CPA	4/7/64	Electronic Previewer For Color Printing Processes
3,128,437	FM	4/7/64	Balanced Frequency Detector Circuit
3,146,402	FM	8/25/64	Frequency-Modulated Subcarrier Detector
Re.25,636	CTV	9/1/64	Luminance-Signal Component-Conversion System
Re.25,775	CTV	5/11/65	Screen Structure For Constant Luminance Color Receiver
3,181,067	FM	4/27/65	Muting Circuit For Signal-Translating Apparatus
3,187,103	FM	6/1/65	Mono-Stereo Control Apparatus For An F.M. Stereo Signal Receiver System
3,163,717	FM	12/29/64	Signal-Processing Apparatus Utilizing Variable Threshold Limiting Means For An FM/FM Multiplex Signal

Patent No.		Issue Date	Title
3,215,947	MISC	11/2/65	Internally Synchronized Gated Clock Oscillator
3,219,760	FM	11/23/65	Mono-Stereo Control Apparatus For FM Multiplex Stereo Signal Receiver System
3,235,656	CTV	2/15/66	Color-Television Receiver
3,249,694	TV	5/3/66	Black Level Stabilization System For A Television Receiver
3,249,695	TV	5/3/66	Control Apparatus For A Television Receiver
3,250,853	CTV-TE	5/10/66	Color-Television Test Signal Generator
3,255,310	TV	6/7/66	Image-Reproducing System For A Television Receiver
3,258,532	TV	6/28/66	Automatic-Picture-Control Circuit For A Television Receiver
3,277,384	FM	10/4/66	Balanced Frequency Detector Apparatus
3,297,821	TV	1/10/67	Contrast Control Apparatus For Controlling The Video Signal Of A Television Receiver
3,305,637	TV	2/21/67	Control Apparatus For A Television Receiver Comprising A Back Porch Keyed AGC System
3,309,462	TV	3/14/67	Television Receiver Circuit Means For Stabilizing Black Level On Scenes Of Low Average Brightness And For Suppressing Black Level On High Brightness Scenes
3,312,778	CTV	4/4/67	Control Apparatus For A Television Receiver
3,313,882	TV	4/11/67	Black Level Control Circuit For A Television Receiver Utilizing A Keyed A.G.C.
3,316,349	TV	4/25/67	Image Orthicon Beam Control System For Automatically Optimizing Signal-To-Noise Ratio of the Video Output
3,316,351	TV	4/25/67	Black Level Control Circuit For A Television Receiver
Re.26,202	CTV	5/9/67	Color-Signal Detection System
3,322,895	TV	5/30/67	Television Receiver Circuit For Stabilizing Black Level and Limiting CRT Beam Current

Patent No.		Issue Date	Title
3,334,180	TV	8/1/67	Television Receiver Control Circuitry Coupled To The Picture Tube Screen Grid For Regulating Beam Current
3,397,281	CTV	8/13/68	Chrominance Signal Processing Apparatus
3,441,670	TV	4/29/69	Black Level Control Circuit For A Television Receiver
3,641,259	CTV	2/8/72	Flarelight Compensator
3,842,196	CTV	10/15/74	System For Transmission Of Auxiliary Information In A Video Spectrum
3,838,444	CTV	9/24/74	System For Transmitting Auxiliary Information In Low Energy Density Portion of Color TV Spectrum
4,420,658	AM	12/13/83	Multiple Tone Signal System
4,479,233	AM	10/23/84	Distortion Correcting AM Stereo Receiver With Non-Flat AGC
4,536,885	AM	8/20/85	Distortion Correcting AM Stereo Receiver With Non-Flat AGC
4,589,127	AM	5/13/86	Independent Sideband AM Multiphonic System

21

MISTAKES, OBITS, A. M. STEREO, INITIALS

21.1 Mistakes

Hindsight is 20/20 vision. A little better foresight could have resulted in more income from our color TV efforts. Here are a few examples of possible mistakes:

A. When filing for patent protection on our basic color TV inventions, "shunted monochrome" and "constant luminance", Japan was only 6 or 7 years out of defeat, so HC didn't file our basic cases in Japan, rationalizing "Japan will never get anywhere with color TV!!" Of course, all sets imported into US were covered by HRI's US patents.

B. After the first NTSC field tests, we (HC and the industry) didn't give line rate Color Phase Alternation, with electrical averaging, serious thought. We assumed that the necessary one line delay line would be too expensive to put into a receiver. Of course, we were in a great hurry to get compatible color TV going and couldn't wait for the development of such a component. But it was less than a decade later that Henri deFrance developed a one line delay device for a receiver, at a reasonable price, because it was required for SECAM.

C. Patents filed overseas require an annual maintenance fee. So, four or five years after the NTSC decision, and while Europe was playing with investigating color TV, HC decided to drop the European Color Phase Alternation patents. It was about a half decade after we dropped CPA that Bruch became active, pushing PAL (Phase Alternation Line rate). HC's European patents would have clearly covered PAL. Of course, the overlap of the life of the patent and significant European production would have been far from full, but I am sure HC could have received a good income from the overlap. Incidentally, we were able to increase the overlap of our basic patents in England by a rule permitting extension of the life of a patent if effects of the war had delayed usage.

D. A mistake on my part for, at least, not trying the following: When I was approached to come back to HC in 1962, I was asked what it would take to make me come back. I never thought of adding: 5 to 10% of the income from my color patents. With that I could have retired a lot earlier. Oh well, no point crying over spilt milk!

E. Another situation, not directly related to color TV, was during the HRI vs. Zenith trial when Zenith turned around and filed anti-trust claims. It was a mistake to have not treated this as a serious matter. It was a very serious mistake which chewed up a lot of income from HRI color TV patents, under the settlement.

F. There is a question in my own mind as to whether I made a mistake in accepting Dick Beam's desire for me to run the Research Lab. During the years, there have been a number of ideas I thought about but didn't have time to develop that someone else did and got patent income from. It is staggering to hear how much money comes in from RCA patents, and I suspect I might have been able to grab some of that for HRI if I didn't take over the Research Labs, but too late now!

21.2 Obits

There were two deaths of close technical friends that came close together and took a little while for me to get over. In the fall of 1975, Charlie Page's skin began to get quite yellow. At first, he didn't do anything about it, but was eventually convinced to see a doctor. He had cancer and he didn't live too long after the diagnosis and operation. During the "dying" period, Dorothy and I visited Charlie and Betty Lou several times and helped in setting up some of the Hazeltine legal matters. We had known Charlie and Betty Lou since the mid-40's. Charlie was my "right hand man" during at least the last decade of his life. Betty Lou had come to work at Hazeltine during the latter part of WWII. Charlie died on December 10, 1975.

Soon after Charlie's death, Charlie Hirsch died on January 20, 1976. Besides working closely during the color TV days, Dorothy and I had become friendly with Charlie and his wife while he was still at Hazeltine. His wife died several years before he did. Charlie was responsible for proposing me for the International Television Symposium citation in 1973. In both 1973 and 1975, we spent some time with Charlie in Montreux. Even though Charlie lived in Princeton, besides a Princeton service, there was another one in Westchester, and Don Richman, Dorothy and I went together to the service.

Helen O'Connor was a long-time secretary with the company. She was a professional secretary, active in professional activities, and the author of our secretarial handbook. I believe she worked for Charlie Hirsch during the color TV days. She was my secretary for a short time before I went on the consulting period and became one of my secretaries shortly before we moved the Research Labs from Plainview to Greenlawn (May 8, 1971). She had emphysema, even though she didn't smoke, and shortly after we moved to Greenlawn she became disabled. During her last days she lived most of the time in an iron lung. Dorothy and I visited her several times during her illness. She died in November, 1976.

Rose Hanna early on was Erik Isbister's secretary and then John Strong's after Erik left us. When John came to the Research Lab as one of my Associate Directors of Research, Rose came with him. Shortly after coming to Greenlawn, Rose became my secretary, sometime during Helen's illness. Rose was a chain smoker and not in very good health. In May, 1984, Dorothy and I took a 3-week vacation to see our grandson (#3) in San Diego. Right after we left, Rose became ill and went to the hospital. We knew nothing about her hospitalization until one day shortly before we were due to come back, when I got a call from Harold Wheeler informing us about her untimely death on June 8, 1984. Rose was very loyal and had a "mothering nature", sometimes to a fault, but I always got my work done promptly and correctly. She kept the record on prospective use for the conference room at the Southeast corner of Building 1, first floor, which became known as the "Rose Room".

21.3 A. M. Stereo

During the last decade (Mid '77 through '87), I have been concerned with technical matters other than color TV. Specifically, the major portion of my technical effort has been in the field of AM stereo, that is, a system for transmission and reception of stereophonic sound via the AM (Amplitude Modulation) broadcast band (550-1650 KHz).

We had no previous technical experience with AM stereo but, in 1977, Mr. Kahn (of Kahn Communications, Inc.) realized that his small company did not have the resources to compete with some of the larger contenders in the AM stereo race. Therefore, he approached Harold A. Wheeler with a proposal that Hazeltine Corporation and Mr. Kahn join forces in the AM stereo race. This was a potential business opportunity that merited investigation, and one of the first steps taken was a thorough study of all five systems' capabilities. After I did an in-depth analytic study of the competing systems, it was concluded that the Kahn single-sideband system had distinct advantages over the four competing systems.

Consequently, in September, 1977, HC entered into an agreement with Mr. Kahn. Under the terms of the agreement, Mr. Kahn turned over both his US patents and his foreign patents on AM stereo to HC, and HC assumed responsibility for licensing those patents. Further, HC agreed to support Mr. Kahn in his petition before the FCC. Kahn Communications received a lump sum payment at that time, and was to share in royalties collected as a result of licensing those patents. Subsequently, it was further agreed that Mr. Kahn would share in royalties from Hazeltine-generated patents on AM stereo as a result of work we were doing in support of the AM stereo program.

Prior to the time that HC had entered into the agreement with Mr. Kahn, an industry committee, The National AM Stereo Radio Committee (NAMSRC) had been formed to evaluate the various AM stereo systems that had been proposed. Three companies, Magnavox, Motorola, and Belar, had submitted their systems to the NAMSRC for field testing. Kahn Communications, Inc., and Harris Corporation had independently decided to run their own evaluations and not submit their systems to NAMSRC. In the case of Kahn Communications, Inc., the resources in time, money and equipment were not available to participate in the NAMSRC test.

HC requested that HRI run laboratory tests to evaluate the system performance of what had now become known as the Kahn/Hazeltine AM Stereo System, also referred to as the ISB (Independent Sideband) AM Stereo System. Both exciters and receivers, provided by Kahn Communications, Inc., were evaluated. Report 6333 entitled "Laboratory Performance Measurements of the Independent Sideband AM Stereo System" was ready in February, 1978, and, along with BDL report "Results from An Analytic Study of AM Stereo Systems", issued March, 1978, were submitted to the FCC in support of Mr. Kahn's petition.

Following the above tests and reports, HC and HRI cooperatively took on the job of designing an ISB receiver suitable for field tests. We also needed a laboratory ISB signal source for testing the receivers, so both an encoder and a decoder were designed. I worked with HRI on both items, the encoder being a complete "home-brewed" job, and the decoder being an add-on to a Realistic (Radio Shack) table model radio, and an add-on to an Audiovox auto-set. After successful preliminary field tests of these two models of receivers, Kahn Communications took the designs and assembled a quantity of both types of receivers, which were distributed to interested broadcasters.

These early decoders were made using a group of available ICs and thus were rather complicated compared to a decoder using a custom-designed IC. For some time, it had been recognized that it would be highly advantageous to have a cost-effective integrated circuit (IC) primarily for decoding the ISB signal (but also capable of multi-system decoding). Early in 1983, Hazeltine engaged Analog Systems Division of J. R. Conwell Corporation in Tucson, Arizona, for the development and delivery of 100 samples of such an IC. The program had far-reaching potential benefits with respect to future income. HRI cooperated in the program with the development of measurement procedures and in the actual testing. Samples of the first run did not meet specifications, and a second iteration was started. However, Analog Systems underwent changes of management and eventually went into Chapter 11 bankruptcy, and the project could not be completed.

For some time, SANYO has been working on the development of a multi-system AM stereo chip (IC), and is currently making additional small production runs to evaluate tolerances. We are awaiting the results of Sanyo's evaluation.

21.4 Initials

The following initials are used are various places in this treatise:

People:

MA - M. Aron
WFB - W. F. Bailey
JC - J. Charlton
LFC - L. F. Curtis
FAD - F. A. Darwin
DEF - D. E. Foster
KF - K. E. Farr
WG - W. Gruen
AH - Alan Hazeltine
JAH - J. A. Hansen
SK - S. Kramer
AVL - A. V. Loughren
BDL - B. D. Loughlin
JOM - J. O Mesa
Mac - W. A. MacDonald
CEP - C. E. Page
DR - D. Richman
DS - D. Sillman
MWS - M. W. Slate
HAW - H. A. Wheeler
KW - K. Wysocki

Organizations:

AIEE - American Institute of Electrical Engineers
AMA - American Medical Association
BTS - Broadcast Television System
CAS - Color Analysis Systems
CCIR - Consultative Committee International Radio
CTI - Color Television, Inc.
CU - Cooper Union
CU-EE - Cooper Union Electrical Engineering
EIA - Electronic Industries Association
FCC - Federal Communications Commission
HEC - Hazeltine Electronics Corp.
HRD - Hazeltine Research Division (of Hazeltine Corp.)
HRI - Hazeltine Research, Inc. (Chicago)
HRIC - Hazeltine Research, Inc., of California
HSC - Hazeltine Service Corp.
IEEE - Institute of Electrical and Electronic Engineers
IRE - Institute of Radio Engineers
JCIC - Joint Committee on Intersociety Coordination
NAMSRC - National AM Stereophonic Radio Committee
NTSC - National Television Systems Committee
RETMA - Radio Electronics Television Manufacturing Association
RL - Research Laboratories
RMA - Radio Manufacturers Association

Systems:

CFA - Color Film Analyzer
CLS - Constant Luminance System
CPA - Color Phase Alternation (OCS)
ISB - Independent Side-Band (system)
NTSC - National Television Systems Committee
OCS - Oscillating Color Sequences (CPA)
PAL - Phase Alternation Line-rate (CPA-line)
SECAM - Sequential and Memory (French color TV system)

VIR - Vertical Internal Reference signal

WBOC - Wide-Band Orange-Cyan

Word Groups:

ACC - Automatic Chrominance Control

AC/DC - refers to radio which operates either from AC or DC power

AFC - Automatic Frequency Control

AGC - Automatic Gain Control

AM - Amplitude Modulation

B&W - Black & White; i.e., monochrome TV

C - Capacitance

low C - low capacitance end of a variable condenser

CRT - Cathode Ray Tube

CW - Continuous Wave; refers to code transmission

DX - Distance (reception or communication)

EE - Electrical Engineering

FM - Frequency Modulation

Hz - Hertz (cycles per second)

IC - Integrated Circuit (chips)

IF - Intermediate Frequency (of a superhet receiver)

IFF - Identification Friend or Foe (adjunct to radar)

KHz - KiloHertz (i.e., 1,000 cycles per second)

L - Inductance

LN - Little Neck (laboratories)

MHz - MegaHertz (i.e., 1,000,000 cycles per second)

QSL - Cards which Amateur Radio Operators exchange to confirm contact

RF - Radio Frequency

SW3 - Model of National Radio Short Wave Receiver (RF, regenerative detector, and audio amplifier)

UHF - Ultra High Frequency (300 MHz to 3,000 MHz)

VHF - Very High Frequency (30 MHz to 300 MHz)

WWI - World War I

WWII - World War II

x - variable in horizontal direction

y - variable in vertical direction

22

CONCLUSION OF TREATISE

The Chief Engineer of Emerson Radio led me to Hazeltine. Thus, my career of 49 years (starting on June 19, 1939) with Hazeltine came about because of Emerson Radio. As I retire from Hazeltine on June 24, 1988, Hazeltine is a subsidiary of Emerson Electric (and I do not mean to imply my career with Hazeltine is ending because of the Emerson take-over). But, Hazeltine's business is now substantially all government-related, and consumer electronics, specifically broadcast TV, has always been my "cup of tea". Also, since 1985 both my wife and my doctor have wanted me to retire. We are now in the process of selling our home in Centerport and establishing ourselves in Raleigh, NC.

Harold Wheeler joined Hazeltine in 1924 and after 63 years retired to Malibu, CA. Recently he moved to his daughter's home in Santa Barbara, CA. Brief discussions with Harold lead one to believe that he may have completely retired from engineering, but that is hard to believe.

While I am retiring from Hazeltine, I do have a consulting contract with New York Institute of Technology. The subject is HDTV (High Definition TV)!

APPENDIX A

A SUPPLEMENT TO

THE EARLY HISTORY OF COMPATIBLE COLOR TELEVISION

A. V. Loughren

February 8, 1974

A SUPPLEMENT TO THE EARLY HISTORY OF COMPATIBLE COLOR TELEVISION

I. INTRODUCTION.

An excellent general treatment of the history of color television and of the development of the signal specification which made possible the broadcasting of color and monochrome television compatibly is presented in (1)*. The present paper is intended to supplement that work and thus present some of the history of the development in greater detail.

Pages 1-14 of (1) recite the early history of the color television art and some of the events leading to the adoption by the U.S. Federal Communications Commission in October 1950 of standards for color TV broadcasting which were incompatible with the monochrome TV standards.

A substantial importance attaches to the property of compatibility of monochrome and color TV. Accordingly, the reader should have the nature of compatibility - in the television environment - clearly in mind. The property may be defined as that which permits a color broadcast to be received in monochrome on an unmodified monochrome receiver and in color on a color receiver, while the color receiver may also receive a monochrome broadcast in monochrome.

During the period 1949-1953 which these notes cover, it was a practical necessity that the signal for compatible color television be a signal in which all color information for a given picture element be transmitted simultaneously with the brightness information for that same element. While sequential transmission and simultaneous display of all components for a given element was theoretically possible, the amount of information to be stored in the receiver would have resulted in a prohibitive apparatus cost. (Incidentally, the system which was originally called "dot-sequential" was shown by B. D. Loughlin to be a simultaneous system. We shall return to this point later.) Other color TV systems in which one color component of a picture element was transmitted at one time with the other components for that same element following after substantial time intervals, called sequential systems, were also under consideration from time to time during the period.

The importance of compatibility arises out of the "chicken-and-egg" nature of the initiation of a public TV service. In the beginning, there are few transmitters and few

---

* See list of references.

receivers. The small number of receivers makes the value of a program small because it reaches few viewers, it is therefore difficult to justify program expense, and so the amount of program time per day and of program choice are too small to encourage a rapid growth in receiver ownership. This in turn keeps the program funding small, keeps the incentive for the public to buy receivers small, and so on almost ad infinitum.

However, once a public TV service has achieved a substantial size, incentive for program presentation and incentive for acquiring receivers exist, and the service "snowballs".

If now a new form of service is proposed using signals which cannot be received usefully on the already existing receivers, the new service must start from scratch. It is further faced with the difficulty that instead of being alone in the TV field, it has a viable competitor whose demonstrated success makes it difficult to obtain programs, TV channels and viewers for the new service.

Further, the presence of such a new and incompatible service is likely to lead to substantial confusion among potential new TV viewers. Which type of receiver should they buy? For the existing successful service? for the untried and ill-supported new service? or perhaps a much more expensive receiver capable of operating on both services?

From the point of view of growth of TV as a public service, proposals for incompatible systems risk being proposals for chaos in the industry and among the potential new viewers. The prospect that this risk might be great enough to jeopardize the expansion of TV as a public service was a source of major concern among the informed and interested broadcasters and apparatus manufacturers. As a consequence, the proceedings initiated by the Federal Communications Commission in 1949 led to strong feelings within the industry against any attempt by the FCC and others to railroad a non-compatible system of color TV into existence.

A counter-consideration to that of the prospective chaos caused by operation of two non-compatible systems of TV side by side was the state of apparatus development in 1949-1950. A sequential color receiver, particularly if sequential at a field rate, could be constructed at that time having a display device which is in principle very much like the device for a monochrome television receiver, namely, a single cathode ray tube. For color, the cathode ray tube phosphor must contain significant amounts of energy at the several regions of the visual spectrum which have been selected for the three primary colors, and a set of color filters must be sequentially placed in front of the tube so that a given field is viewed through one filter, the next field through a second filter and the third field through a third. If the three primary colors are chosen in such fashion as to produce a large range of color gamut it will be found that the green component contains essentially the same information as a normal black and white picture. The other two components contain very much less of the brightness information. In consequence, the apparent flicker rate of a field sequential color picture is at the frequency at which a set of all three primaries is reproduced rather than the frequency of a single vertical scan as in the normal monochrome transmission. In consequence of this, either the data transmission rate and the channel bandwidth must be increased, the pictorial information content in a picture substantially reduced or the picture reproduction rate reduced (with enough reduction in image brightness to make flicker acceptable). However, while an equivalent of a normal monochrome receiver supplemented by a rotating disc carrying color filters could be made to display a sequential color picture, no comparably simple device existed in 1940 or even 1949 to show a simultaneous picture. Two display arrangements for simultaneous color TV were shown in 1949 (2). One of them used three separate directly viewed cathode ray tubes, with an array of dichroic mirrors to cause their images to appear superposed in space; the arrangement produced good pictures, but could be viewed only within a quite limited angle in front of the display. The other was a projection system in which red, green and blue images were superposed on a projection screen. Both of these had practical problems of registration; in addition, the display using three directly viewed tubes was bulky, while projection television was expensive and has not been economically successful even yet for household use. The view could therefore be taken "We can have color TV now, by a sequential system, but we shall have to wait for an unknown length of time for a compatible system employing apparatus suitable for household use".

It will become clear that the apparatus limitation was not fundamental, but required that engineering and manufacturing development take place. It will also become apparent that the sequential system's limitations were much more difficult to escape because of their more basic nature.

The portion of (1) cited above tells of the Federal Communications Commission's instituting proceedings in 1949 to determine whether or not color TV standards for broadcasting should be established and if so what the standards were to be. It was part of the "ground rules" for the hearing that the color transmissions were to be contained within the already standard 6-MHz channel. Proposals for color systems were submitted to the

Commission for consideration in the proceedings by three parties: namely, the Columbia Broadcasting System, Color Television, Inc., and Radio Corporation of America.

The CBS and CTI proposals are treated adequately in (1).

The RCA proposal (2) was an ingenious combination of the simultaneous system described in (1) p. 11, the observation by A. V. Bedford (3) that the eye acuity was reduced in fine color detail (use of this came to be known as "mixed highs") and the use of a color signal multiplex switching system employing a switching frequency chosen in accordance with the much earlier work of Frank Gray (4). This color switching frequency was an odd multiple of one-half the line-scanning frequency, as Gray taught, and had relatively low visibility on a monochrome receiver. Its modulation components were primarily in regions separated from the sampling frequency by the line frequency or its harmonics, and were therefore also odd-multiples of one-half the line frequency, so they also had relatively low visibility. Further, the samples were so taken that on neutral gray of any brightness, the color sample amplitudes were alike, so no fundamental component was generated at the sampling frequency; and the sampling rate was rapid enough to produce only a fine-detail structure, not too easily visible at normal picture viewing distances. The RCA signal was contained within a standard 6 MHz channel and operated a normal monochrome receiver to give a monochrome picture normal except for the added fine-detail structure. A receiver equipped with a demodulator or de-multiplexer could extract the full color information from the multiplexed transmission and by feeding the three color signals to a suitable three-color display device reproduce the picture in full color. In the system proposed by RCA the mixed highs were present in each of the three channels after demodulation, so that each of the three carried its full complement of pictorial detail. In the first presentation of the RCA system, a three unit projection system was used, as well as receivers which employed directly viewed picture tubes whose images were superposed by dichroic mirror systems. Somewhat later, the tri-color shadow-mask tube of Dr. A. N. Goldsmith was employed to demonstrate the RCA system.

The comparisons of these systems and other possible systems were studied by the Federal Communications Commission and its staff. In addition, Dr. W. R. G. Baker, Vice-President of the General Electric Company, a past President of the Institute of Radio Engineers, and Director of the Engineering Department of the Radio-TV Manufacturers Association, organized a National Television System Committee with RTMA sponsorship. (Dr. Baker had organized a similar committee in 1940 when the problem of choosing between competing proposals for monochrome TV signal specifications became acute. The first NTSC was actively sought by the Federal Communications Commission to assist it in making the selection during the controversial period of 1939-40. The second NTSC thus had a background of previous procedures and of assured industry support to go on.) This second NTSC, like its predecessor, undertook the appraisal of the various system proposals.

II. HAZELTINE'S INITIAL WORK.

Another party to the events, although not a party to the formal proceedings before the FCC, was Hazeltine.* Hazeltine was not a manufacturer of TV equipment but at that time operated in the TV area exclusively as a licensor of manufacturers under its several patents dealing with transmitters and receivers. It had had a policy for many years of providing laboratory service to assist its licensees in the effective use of the rights which they obtained under their Hazeltine licenses and it directed its laboratories in such fashion as to seek to be well informed about new developments of potential interest to its licensees.

The invitation of the FCC to propose standards for color television broadcasting came at a time when Hazeltine was not prepared to offer any such proposal. Hazeltine proceeded, however, to analyze by both theoretical and experimental methods the merits of the several proposals that were before the FCC.

Hazeltine's initial step was to design and construct a "performance yardstick" color TV demonstration system. The system employed three separate 4 MHz channels, each complete from light pick-up to display and each completely independent. All three channels viewed a common picture (a color photographic slide) and each channel supplied its own tube in a display device which was arranged to superpose the red, the green and the blue images. When this system was operated with all channels in proper adjustment, the resulting picture from a monochrome subject was a monochrome image. When a color subject was employed, with the three channels preserving their independence, an image in full color resulted. The third case, a color slide but all three channels tied together also resulted in the production of a monochrome image. The images were all of as good detail as can be obtained in a 6 MHz standard television channel (since that 6 MHz channel provides effectively approximately a 4 MHz picture bandwidth).

---

* At the time Hazeltine Corporation, the parent Company, had two subsidiaries, Hazeltine Electronics Corporation and Hazeltine Research, Inc., which were the corporate entities actually involved in the work to be described. For convenience, the 3 companies are collectively referred to as "Hazeltine".

While the yardstick system used more bandwidth than was available for a broadcast system, it was nevertheless an appropriate performance reference, since it combined the already publicly accepted characteristics of monochrome TV and of color motion pictures - three colors, simultaneously presented - without compromising either. It thus offered a basis for comparison against which proposals for 6 MHz color TV could be compared for performance, with the assurance that the yardstick was sufficiently demanding. Any system whose performance was acceptably close to the yardstick was, therefore, certain to perform to the public's satisfaction.

The next step in the Hazeltine research was to study the phenomenon of "mixed-highs". For this study, a set of electrical filters was constructed for use with the three channel system just described. These filters were so designed that it was possible to transmit individual signals through each of the three individual channels for the entire 4 MHz bandwidth, or to substitute for the upper portion of each individual channel's frequency band an identical mixed or monochrome signal, while retaining individual transmission of each color within its own channel for all frequencies below the chosen transition frequency. Transition frequencies at 2 MHz, 1 MHz, 0.5 MHz, 0.25 MHz, 0.1 MHz and 50 kHz were available. Delay equalization was provided, so that artificial effects were essentially avoided. Further, the transmission amplitudes were carefully equalized so that switching from completely independent transmissions to transmissions with mixed highs or transmission with all three channels combined into one did not alter the significant amplitude relationships of the overall system.

With this equipment, it was possible to demonstrate the effect of the use of the "mixed-highs" principle for a variety of transition frequencies between mixed-highs and independent channels.

The initial experiments using the apparatus described above were performed by Hazeltine engineering personnel. The earliest finding was that the system employing three independent channels did in fact give excellent color reproduction performance; the only significant limitation was that because of the nature of the display the observer viewing angle was relatively small. The color reproduction performance, the range of brightnesses, the amount of detail present all represented a high standard of television achievement. Next, it was observed that when "mixed-highs" were introduced and were shown to observers on a blind basis (that is, condition A versus condition B where one of these conditions was "mixed-highs" at some transition frequency and the other condition was completely independent channels) the observers were in many cases unable to distinguish between the "mixed-highs" presentation and the presentation using completely independent high quality channels. The statistics of these early observations were approximately as follows (but see (5) for exact results from later experiments):

(1) On no subject matter was any observer able to distinguish between three completely independent systems and "mixed-highs" with a transition frequency of 2 MHz; with one particular slide of an outdoor scene including a restaurant in the central portion of the scene, the transition frequency between independent channels and "mixed-highs" could be reduced to as little as 50 kHz before most observers were conscious of any difference between the "mixed-highs" transmission and a transmission using three separate 4 megacycle channels. On intermediate content slides and with some differences between observers, the results are more complicated to describe. However, these initial experiments left no doubt whatever in our minds of the basic validity of the "mixed-highs" principle.

While Hazeltine was engaged in assembling and analyzing the performance of the apparatus just described it became apparent that two aspects of the color encoding or multiplexing (and the corresponding decoding) apparatus shown by RCA were worth examination for possibilities for system performance improvement.

The first of these was the practice of generating the color-multiplexed signal by narrow-angle sampling of the three color signals from the camera, and of decoding by a corresponding narrow-angle sampling process at the receiver. The modulation content of the signal radiated was found by Loughlin, on analysis, to consist of a signal at normal video frequencies approximately representing the brightness of the picture, a set of subcarrier sidebands representing the hue and saturation, and spurious components introduced by the narrow-angle sampling process. The analysis made it clear that the spurious components introduced by the narrow-angle sampling process, and the fixed amplitude relationship between brightness signals and color-difference signals were unnecessary limitations to the available performance (6).

It thus became important to augment the "yardstick" and mixed-highs demonstration facilities by providing color decoding in such fashion that both the method shown in 1949 by RCA and the Loughlin modification could be compared with each other and with the "yardstick". This was done by arranging to switch the mixed-highs component or the entire brightness component either through or around the narrow-angle sampler circuit of the decoder of the receiver. Accompanying this switching around the decoder, the band-pass and low-pass characteristics of the two branches were modified in complementary fashion, so that (a) the entire signal was applied only to the sampler, (b) the signal from

2-4 MHz was also applied to the mixed-highs channel and a 0-2 MHz filter limited the sampler output, or (c) the 2-4 MHz signal only was applied to the sampler, its output was limited to 0-2 MHz and the entire 0-4 MHz signal was used as the brightness signal.

The Loughlin signal paths and the associated filter pass-bands had the effect on the system performance of eliminating much of the spurious picture content exhibited in the original RCA demonstrations. They also brought along three other consequences:

(1) the color-signal gain and brightness-signal gain were now independently adjustable;

(2) the color channel of the receiver could conveniently be automatically disabled when the incoming signal was a monochrome program, thus avoiding the annoyance of coarse colored interference on monochrome program reception;

(3) wide-angle demodulators were usable and highly advantageous.

The next experiments at Hazeltine included the comparison of an encoded and decoded transmission using mixed-highs with the transmission using three independent 4 MHz channels. This comparison was made under different conditions, including both (1) different transition frequencies between three channels with mixed-highs and the encoding-decoding process and (2) the use of narrow-angle sampling versus the Loughlin demodulation circuits (equivalent to wide-angle demodulation). The expected benefits of the simulated wide-angle demodulation were clearly observed.

The second area where improvement was found possible arose from the practice employed in the RCA apparatus in which the system took equal amplitudes of red, green and blue signals for the sampler inputs and the mixed-highs component. The monochrome component resulting from the average of the R, G and B samples was an incorrect - that is, non-panchromatic - representation of the scene brightness, and correct brightness reproduction required a low-frequency brightness component to be derived from the high frequency sampled color components and added to the base-band component. When this was done, the correct brightness resulted.

However, the high-frequency brightness signals corresponding to fine picture detail were also converted down to coarse, low-frequency components by the same decoding means that converted the color and the brightness-correcting information from high-frequency sampled components to relatively low-frequency color difference and brightness signals respectively. These converted high-frequency brightness signals were at odd multiples of one-half the line frequency, and so had lower visibility than the intended components, as Gray taught, but this lower visibility was not low enough to make them negligible as sources of picture disturbance.

The low visibility of frequencies which are odd multiples of one-half the line frequency is a consequence of the fact that such a component in one frame repeats in the next frame with opposite polarity. Thus, if the following conditions are satisfied, the cancellation of one by the next is exact, and the odd-multiple component is invisible;

a. the system is linear;
b. the eye-brain system integrates over a two-frame period;
c. the picture is stationary.

In practice, these conditions are only partially met, but a useful measure of effectiveness is obtained.

The incompleteness of the cancellation process is particularly important for components in the vicinity of the sampling frequency. These components are heterodyned to low-frequency, coarse-structured patterns which are of course far more visible than the fine structure which they represent before heterodyning.

The problem of increased visibility of unwanted signals of high video frequency because of the structure-coarsening caused by heterodyning is even worse with c-w or random interference since it may heterodyne to a high-visibility pattern rather than to one that more or less completely cancels.

Flicker resulting from the heterodyning both of the high-frequency monochrome components and of random or c-w interference was recognized experimentally and theoretically at Hazeltine as an area where improvement in the system as demonstrated by RCA would be welcome.

On one occasion, I commented to Loughlin that flicker was primarily a brightness or luminance phenomenon, and I cited the flicker photometer as an example. Loughlin then examined the nature of the sampled high-frequency component of the RCA system. He concluded that it should be unnecessary to use it as the channel for a part of the luminance information, and that a receiver designed to derive no luminance signals from this component would not produce any spurious coarse flicker by conversion of either this component or interference signals into luminance, at least to a first order approximation. He also recognized that a complementary modification in the signal assembly circuits at the transmitter would result in a signal which would produce correct color and luminance on such a receiver.

A quantitative demonstration that Loughlin's principle of signal construction was valid is described in (7), page 60 and Figure 1.

The Hazeltine laboratory equipment was then modified further to permit two quite different modes of operation when using a combined signal for the low frequency portion of the band. In the first of these modes, the red, green and blue signals were combined for transmission in relative electrical intensities equivalent to those which were represented when these signals were used to produce a reference white color on the display, as employed in the RCA proposal. In the second mode, the red, green and blue signals were additively combined prior to encoding in such fashion that their contributions to the brightness component of the encoded or sampled signal corresponded to their relative brightnesses as seen by the eye. (As a consequence, the angles for deriving red, green and blue in a receiver using narrow-angle sampling were no longer 120° apart, but other angles or matrixing in the receiver easily corrected for this). This led to our having a demonstration system which included provision for all of the following features, and for direct intercomparison between them:

(1) A three-independent-channel system having 4 MHz bandwidths individually for the red, the green, and the blue channels.

(2) A system in which the three channels were completely independent from zero frequency up to a chosen transition frequency, with the signal content above the transition frequency being identical for all three channels, with equal weighting of each of the three colors in the mixed-highs portion of the signal.

(3) A system similar to the preceding except that the composition of the mixed-highs signal was luminance-weighted;

(4) A system in which the three channels were encoded by narrow-angle sampling into a single signal (employing an encoding frequency chosen in accordance with the Frank Gray principle) using equal amplitudes of red, green and blue to feed the encoder for all frequencies up to a chosen transition frequency and a mixed-highs signal of the equal amplitude

composition above the transition frequency, with a corresponding set of decoding operations to convert this multiplexed signal into individual signals for the several display terminals of the display system in which the decoding circuits were switchable to conform to the narrow-angle sampling as shown by RCA in 1949, to narrow-angle sampling with a low-pass output filter and bypassed mixed-highs, or to narrow-angle sampling limited by 2-4 MHz input and 0-2 MHz output filters, shunted by a 0-4 MHz brightness signal;

(5) A system similar to that just described, except that the red, green and blue signals were combined prior to encoding to produce luminance-weighted signals, and the decoding system in the receiver was rearranged to deliver true luminance-representative monochrome signals directly while obtaining only coloring information from the decoded subcarrier.*

This set of possible variations in available signal handling behavior made possible experiments and demonstrations which turned out to be quite illuminating. A discussion of these experiments and of the demonstrations of some of their consequences is presented next.

III. THE HAZELTINE EXPERIMENTS.

Experiments using the equipment which Hazeltine built in accordance with the preceding description had led in early April 1950 to this general set of conclusions:

(1) The 3-channel 12 MHz apparatus was an adequate "yardstick";

(2) The mixed-highs principle was valid and essential for compatible color television and for any color television which was to be economical in use of the radio spectrum;

(3) The mixed-highs principle in combination with an advantageous encoding scheme based on low-visibility multiplexing had the potential of placing

* (In consequence of picture tube transfer-characteristic curvature, this statement is exact for first-order coloring components only.)

within a 6 megacycle channel all of the monochrome picture content then normally being radiated in such a channel plus color, with only a moderate amount of additional disturbing material in the monochrome picture;

(4) The sampled picture could be decoded to produce a color picture not significantly different from that which could have been obtained by the use of a total of three complete television channels;

(5) The disturbing content of the picture on both monochrome and color presentations could be markedly reduced by routing all brightness information around the sampler, thus eliminating the undesirable consequences of narrow-angle sampling, and further reduced by employing luminance-weighted proportioning in the decoding process; there was also advantage in using luminance-weighting in construction of the mixed-highs signal;

(6) Compatibility on a basis which would be certain to be acceptable to viewers had been demonstrated as being achievable;

(7) The observations at Hazeltine of broadcasts of field-sequential transmissions employing the standards proposed in 1949 had established clearly (although not recited in the foregoing) that not only was the lack of compatibility a disadvantage, but that in addition to this, there were other disadvantages as follows:

(a) On rapid motion, severe color break-up was evident and quite troublesome from the point of view of observer satisfaction;

(b) The information content of the picture was substantially reduced as compared to the picture which could be obtained compatibly with a simultaneous system;

(c) The brightness level at which the apparatus could be operated was inherently limited by flicker to perhaps one-third to one-fifth the brightness of a U.S. monochrome picture or a compatible color picture;

(d) There were prospects of substantial mechanical difficulties with the field-sequential system, although it is proper to note that these might well have become unimportant if the field-sequential system had in due course adopted the display devices which were subsequently developed for use with the simultaneous system.

(8) The line-sequential system was reduced to practice at Hazeltine in only one of its proposed forms; however, enough simulation work was done to establish to the satisfaction of the Hazeltine engineers that the phenomenon known as "crawl" would produce a sufficiently adverse viewer reaction to make the system extremely unlikely to have any prospect of commercial success.

To summarize these conclusions:

A high-quality color television system could be operated within a 6-MHz channel compatibly with monochrome operation, using simultaneous color signals; no comparable performance either for picture quality or compatibility was available from sequential signal systems.

IV. THE HAZELTINE DEMONSTRATIONS.

At this point, the Hazeltine engineering staff invited its management to observe this same set of experiments. The Hazeltine management satisfied itself that the experimental results were as stated above, and that the significance attached to them by the engineering staff was justified.

The Hazeltine management proceeded to invite the Federal Communications Commission to a private demonstration; this invitation was accepted, and on April 27, 1950, a party consisting of Commissioners Coy, Walker, Sterling, Hyde and Jones, the Commission's Chief Engineer C. B. Plummer, and Messrs. Plotkin, E. W. Allen, Chapin, and Cowperthwaite witnessed the entire demonstration. They appeared to be highly impressed.

Up to this point, I have not acknowledged the substantial assistance from RCA which Hazeltine obtained in constructing its experimental apparatus. Large dichroic mirrors, special cathode ray tubes with colored phosphors, a short persistence white phosphor cathode ray tube for a slide scanner and other items had all been made to our order by RCA. Hazeltine felt that RCA had gone out of its way to be helpful in this matter and so a private demonstration was next given to some ten RCA managers and engineers who visited the Hazeltine Laboratories at Little Neck shortly after the demonstration to the Federal Communications Commission. They appeared to be very much interested in the Hazeltine confirmation of the value of their work and also in the additional improvements which certain of the Hazeltine contributions (with respect to elimination of the undesired effects of narrow-angle sampling and to luminance weighting, for example) had made to the viability of the simultaneous color TV system.

Hazeltine, as a licensor, had the practice of demonstrating matters of this sort to interested licensees. Arrangements were being made during the interval between the firming up of the FCC demonstration date and the actual taking place of that demonstration to invite all Hazeltine licensees who were interested to attend demonstrations of the same sort. Some twenty or twenty-five such demonstrations were given over the ensuing months.

This series of demonstrations also included certain semi-official groups; the Senate Advisory Committee on Color TV to the Senate Committee on Interstate and Foreign Commerce (5/22/50); the Joint Technical Advisory Committee (6/15/50); representatives of the National TV System Committee (6/15/50) but separately from the JTAC.

Demonstrations were also made to companies who were active in the hearing before the FCC or active in the National Television System Committee, and to representatives of the technical press. These demonstrations were made during June 1950.

V. THE SUBSEQUENT EVENTS.

I believe it is fair to say that the Hazeltine experiments and demonstrations established incontrovertibly, by July 1950, in the minds of most of the competent and responsible people in the television industry that: (1) a simultaneous color TV system was the proper way to broadcast color; (2) that the essential features of such a system should include mixed-highs, a multiplexing frequency chosen as an odd multiple of half line, avoidance of the undesired consequences of narrow-angle sampling, the use of luminance-weighting, or "constant-luminance" as it became more generally known, and the use of a suppressed color subcarrier; (3) that no other known system had any prospect of becoming commercially viable or of offering a comparably effective measure of spectrum utilization.

Most technically informed individuals recognized the fallacy in being swayed by short-term considerations of the state of the apparatus art in making long-term decisions on TV standards, but some members of Congress and some FCC Commissioners were unable to appreciate the difference between fundamental limitations and apparatus limitations. In addition these non-technical people would not rely on the expert technical talent they themselves had selected. For example, the Senate Committee on Interstate and Foreign Commerce had appointed an advisory committee of true expertise to report on the proposals. Its report was made available, of course, to the FCC, and was disregarded. One Commissioner instead even publicly questioned the technical and personal integrity of the engineers who urged consideration of the simultaneous system. And so, the Federal Communications Commission proceeded on October 11, 1950, to authorize the set of incompatible color television broadcast standards proposed in 1949 by CBS for commercial broadcasting of color TV (8).

The subsequent chapters in the history are concerned with first, the commercial fate of incompatible color TV broadcasting; second, the NTSC's careful program of accumulation of test data relating to details of system construction, choice of system parameters and verification that these choices were soundly made; third, the obtaining of a consensus of industry technical opinion on a truly wide basis; fourth, the submission of this complete package of evidence and information to the FCC together with a formal request for the reopening of the question of the color TV standards, the withdrawal of the sequential standards adopted by the Commission's 1950 decision and the adoption of standards as proposed by the NTSC; fifth, the favorable response of the FCC to that submission and request. These matters are well treated in (1); other references cited therein may also be consulted. (Color Phase Alternation, as now used in the PAL system in Europe, was considered during this work, and was finally discarded).

The engineering group at Hazeltine active in the initial period included:

Charles J. Hirsch	W. R. Stone
B. D. Loughlin	W. C. Espenlaub
W. F. Bailey	R. J. Keogh
R. P. Burr	J. R. White
Knox McIlwain	D. Richman
Paul Rogell	

Subsequently, others joined in the work, including:

Alan Hazeltine	C. E. Dean
L. F. Curtis	W. O. Swinyard
R. F. Tschannen	R. J. Farber
J. A. Hansen	D. Sillman
R. O. Noyer	S. P. Ronzheimer
C. E. Page	

In one capacity or another, I directed the Hazeltine organization's work on television during this period. My recollections, assisted by references and discussions with colleagues, are probably a reasonably trustworthy report of the events.

Acknowledgement of the contributions of other individuals and organizations to the final result may be found in (1), and has therefore been omitted here.

REFERENCES:

(1) Fink, D. G. "Color Television Standards" - McGraw Hill Book Co.

(2) RCA Review Dec. 1949 "A Six Megacycle Compatible High Definition Color Television System".

(3) A. V. Bedford, Proc. IRE Sept. 1950 "Mixed Highs in Color Television".

(4) Frank Gray U.S. Pat. #1,769,920 and Pierre Mertz and Frank Gray, Bell System Technical Journal July 1934 "A Theory of Scanning".

(5) K. McIlwain, Proc. IRE Aug. 1952 "Requisite Color Bandwidth for Simultaneous Color TV Systems".

(6) B. D. Loughlin, Proc. IRE Oct. 1951 - "Recent Improvements in Band-Shared Simultaneous Color-TV Systems".

(7) W. F. Bailey, Proc. IRE Jan. 1954 "The Constant Luminance Principle in Color Television".

(8) Federal Communication Commission Order #55,655, Oct. 11, 1950:

Orders 55,702, 55,703 of same date are also relevant.

/s/ A. V. Loughren

Arthur V. Loughren

February 8, 1974

APPENDIX B

F.C.C. CRITERIA FOR COLOR TELEVISION

by

E. W. Allen
Chief Engineer, Federal Communications Commission

Presented to Members of C.C.I.R. Study Group XI during visit to USA
March 5 - March 16, 1956

The F.C.C. and its predecessor, the Federal Radio Commission, had made provision on several prior occasions for the authorization of experimental television stations, but it was not until 1937, when 19 channels were allocated, that sufficient space was provided to allow television to move from an experimental to a broadcast status. Although a limited form of commercial operation was authorized in 1939, this was unsuccessful because of a tendency to freeze the development of television systems for which no standards had been adopted. The first National Television Systems Committee (NTSC), organized by the Radio Manufacturers Association, was successful in recommending monochrome standards which were subsequently adopted by the F.C.C. for commercial broadcasting in April, 1941. The NTSC considered color television but it could not agree on standards and recommended further experimentation. A second report of the NTSC, in April, 1942, confirmed the monochrome standards and the recommendation for further experimentation in color systems.

The advent of the war precluded the further consideration of color television standards. On the other hand, the war was responsible for tremendous developments in electronics which found application in post war systems of color television. These developments not only greatly improved television per se but were also responsible for opening significant portions of the VHF and UHF spectrum for use by broadcasting and other services.

In 1944, the F.C.C. conducted a service allocation hearing wherein conflicting views were presented by those who favored color television in the UHF spectrum and those who favored monochrome in the VHF spectrum. The Commission heard extensive testimony regarding such factors as the provision of space for color and superior monochrome systems, channel widths and the requirements for spectrum space by television and other established radio services in addition to the needs for new radio services. At the conclusion of this hearing, thirteen VHF channels were allocated for commercial television broadcasting. The UHF television band (480-920 Mc) was made available for experimental television, pending determination of channel width and resolution of technical problems. The channel width for the VHF channels was set at 6 Mc. Subsequently, in 1945, the F.C.C. reaffirmed the monochrome standards which had been in use since 1941 and have remained in effect since that time (525 lines, 60 fields, 30 frames).

In 1946 and 1947, the Commission considered, in hearings, a specific proposal by CBS for adoption of field sequential color standards for UHF only, using 16 Mc channel width. At the same hearing, RCA described a simultaneous color system using 12.5 Mc channel width. During these hearings, the Commission witnessed demonstrations of both systems. At the close of these hearings, the F.C.C. found neither system to be ready for public use. In its report of March 18, 1947, the Commission concluded with the following statement of its objectives in seeking a system of color television:

> "....The evidence before the Commission shows that 27 channels may not ultimately be enough to provide for a truly nationwide competitive television system. Every effort must, therefore, be made to narrow the bandwidth required for color television. It should be emphasized that narrowing the bandwidth should not be at the expense of picture brightness, picture detail, color fidelity, or other features of television performance. The objective should be a narrower bandwidth while retaining and even improving the quality of television performance.
>
> "....The Commission is of the opinion that compatibility is an element to be considered, but that of greater importance, if a choice must be made is the development of the best possible system, employing the narrowest possible bandwidth, and which makes possible receivers capable of good performance at a reasonable price."

These objectives as to bandwidth, quality and compatibility were amplified and restated at a later date, to become the criteria by which the Commission was to judge the adequacy of proposed standards of color television.

In September, 1948, the Commission conducted a hearing to determine whether the UHF television band could be used for monochrome or color broadcasting. At that time, the UHF band had been set aside for television experimentation and it was important to avoid any action which would restrict the band to monochrome television only. Testimony presented at the hearing, however, indicated that progress had been made in the development of a color system using a channel width of but 6 Mc. From September, 1948, to July, 1949, additional information reached the Commission indicating the practicability of 6 Mc channel width for color. Accordingly, the F.C.C., in July, 1949, issued a notice which included the following provisions:

> "It is proposed to consider changes in Transmission Standards for channels 2 through 55 only upon a showing in these proceedings that:
>
> 1. Such system can operate in a 6 megacycle channel; and

2. Existing television receivers designed to receive television programs transmitted in accordance with present transmission standards will be able to receive television programs transmitted in accordance with the proposed new standards simply by making relatively minor modifications in such existing receivers."

Thus, more specific criteria regarding bandwidth and compatibility were developed. No specific criteria for quality were stated but the F.C.C. requested data on the following factors affecting quality: color breakup, flicker, color fringing, image registration, color fidelity, picture brightness, camera light efficiency, and definition. At this time, July, 1949, the number of receivers in use had increased to approximately 2 million, with consequent increasing emphasis on compatibility, but with primary emphasis on quality and bandwidth.

These criteria guided the F.C.C.'s considerations in the subsequent color television hearing where the field sequential, line sequential and dot sequential systems were described and demonstrated. In October, 1950, at the conclusion of these proceedings, the F.C.C. adopted the first color television standards, based on the field sequential system employing 405 lines per picture and 144 fields per second. The field sequential system had satisfied the first two criteria, namely, quality and bandwidth; however, it did not meet the third criterion, compatibility, which was considered to be of lesser importance than the first two. The line sequential and dot sequential systems were rejected by reason of unsatisfactory quality.

In an effort to alleviate the problems relative to incompatibility, the Commission proposed that the manufacturers incorporate adjustable scanning circuits in receivers. This proposal was not adopted by the majority of manufacturers. The system was beset by other troubles as well. By reason of the Korean War, materials for color receivers became unavailable and color broadcasts ceased. Moreover, the legality of the Commission's decision was tested in court and finally sustained by the Supreme Court of the United States in May, 1951.

In June, 1951, the F.C.C. published a notice relative to the steps necessary for proponents of new color television standards which included the following detailed criteria:

"1. It must be capable of operating within a 6-megacycle channel allocation structure.

"2. It must be capable of producing a color picture which has a high quality of color fidelity, has adequate apparent definition, has good picture texture, and is not marred by such defects as misregistration, line crawl, jitter or unduly prominent dot or other structure.

"3. The color picture must be sufficiently bright so as to permit an adequate contrast range and so as to be capable of being viewed under normal home conditions without objectionable flicker.

"4. It must be capable of operating through receiver apparatus that is simple to operate in the home, does not have critical registration or color controls, and is cheap enough in price to be available to the great mass of the American purchasing public.

"5. It must be capable of operating through apparatus at the station that is technically within the competence of the type of trained personnel hired by a station owner who does not have an extensive research or engineering staff at his disposal and the costs of purchase, operation, and maintenance of such equipment must not be so high as unduly to restrict the class of persons who can afford to operate a television station.

"6. It must not be unduly susceptible to interference as compared with the present monochrome system.

"7. It must be capable of transmitting color programs over inter-city relay facilities presently in existence or which may be developed in the foreseeable future."

The concurrent organization of the NTSC and the subsequent development of its specifications for a system of color television will be related by other speakers. However, in 1953, the NTSC petitioned the F.C.C. for adoption of its color system. The extent to which the NTSC specifications met the criteria are discussed at length in the

Commission's decision of December 17, 1953. Time does not permit a full discussion here, but the system was found to meet the essentials of all criteria. As a result, the F.C.C. deleted its field sequential color standards and adopted the NTSC color standards, which remain in effect at the present time. The establishment of these standards has given a firm basis for the large amount of development work which has been and is being accomplished by the industry to produce color receiving and transmitting equipment in increasing quantities and to provide incentive for broadcasters to produce increasing amounts of color programming.

At its meeting in Brussels in the spring of 1955, Study Group XI revised the questions and study programs intended to supply the information required for the standardization of color television. Document 79 lists ten criteria whereby the performance of color television systems can be appraised. Seven of these criteria are in substance the same as the F.C.C. criteria, and it would appear that the system to be described here meets both sets of criteria. The three remaining C.C.I.R. criteria relate to (h) international exchange of programs, (i) scope for development and (j) the differences between Bands I and III as compared with Bands IV and V. The system likewise is capable of satisfying these criteria. The international exchange of programs without resort to such procedures as recording or standards conversion depends upon the international standardization of a common system of color television, for which purpose these and the succeeding demonstrations are being given. Again, the system offers a wide scope for development of future improvements, among which may be mentioned the generation of the luminance signal and the introduction of gamma correction. Finally, there are no restrictions in the television bands on which it can be used. It is designed to be used on VHF bands I and III or on UHF bands IV and V indiscriminately.

APPENDIX C

HISTORY OF HAZELTINE RESEARCH, INC.

PEOPLE, PLACES AND PERSPECTIVES

By

Stephen P. Ronzheimer

March 10, 1988

-TABLE OF CONTENTS-

CHAPTER I/C

SUMMARY OF CORPORATE HISTORY, LOCATION

While HRI's Corporate existence began in 1946, this history will begin with the opening of the predecessor Chicago Laboratory which ultimately evolved into Hazeltine Research, Inc. (HRI). The history will center mainly on highlight events and the more outstanding people who contributed to the successes of HRI. A substantial amount of the history was drawn from Corporate records; however, many of the gaps were filled in from the memory of the writer who has been with Hazeltine since 1942. Although the history of HRI is closely entwined with that of its parent company, Hazeltine Corporation, this account will be confined as much as possible to the history of HRI only.

Back in 1929, Hazeltine Corporation had formed a subsidiary, Hazeltine Service Corporation, to handle laboratory work, both development work and service for licensees. In those early days most of the radio production was concentrated in the Eastern part of the United States. However, with the passage of time, by the mid '30's the center of the industry was shifting toward the Midwest. In order to have its services conveniently available to its licensees, Hazeltine Service Corporation opened a laboratory in Chicago in 1937. J. Kelly Johnson, a former Hazeltine employee, was rehired to manage the new laboratory, and William O. Swinyard was transferred from New York to be his assistant.

The new laboratory followed the pattern of the Bayside and New York laboratories of Hazeltine Service Corporation in rendering engineering service to the patent licensees of the company. Laboratory activities were quite varied. The most frequent work involved performance measurements on the radios manufactured by our licensees. In addition the laboratories were often involved in modifying receivers for improved performance. It was also necessary to frequently make measurements to determine patent usage on radio receivers. Another activity involved the design and fabrication of specialized test equipment to assist in the measurement procedures.

Because railroads were the common mode of transportation in the '30's, it was felt necessary to locate the Chicago Laboratory convenient to rail transportation. Therefore, the first laboratory was located at 325 West Huron Street in Chicago, in an industrial area just north of the Chicago "loop". The lab was located in a suite of rooms on the 7th floor of an 8-story building. Because of increases in staff size and equipment inventory it was necessary to expand the rental space during the occupancy at that location, which continued until October 1, 1956.

In 1943, Hazeltine Service Corporation was renamed Hazeltine Electronics Corporation[1], and Chicago Laboratory personnel were employees of that Corporation during the years of World War II.

On March 28, 1946, Hazeltine Research, Inc., was formed as an Illinois corporation, with headquarters at the 325 W. Huron Street address. Jack Binns served as HRI's first president for six years. Thus, the Chicago operation emerged as an independent, wholly-owned subsidiary of the parent, Hazeltine Corporation. Establishment of the subsidiary in Illinois was prompted by several considerations. First of all the radio industry, and newly-emerging television industry, was clearly becoming more and more centered in the Midwestern area. Further, statistics indicated that the Federal courts in the Midwest were more reasonably disposed toward patent holders than the Eastern courts.

With passage of time the 325 W. Huron Street location became less and less desirable, for a variety of reasons. The area was deteriorating and the crime rate was rapidly rising. Also, the common mode of travel was shifting from rail to air; consequently, the former convenience for out-of-town licensee visitors no longer existed. Also, congestion in the area, accompanied by parking difficulties for local licensees who came to the lab, impeded HRI's effort to carry on licensee service work in the most effective manner.

Thus, in 1955, Admiral D. F. J. Shea, then manager of HRI, and W. O. Swinyard, his assistant, began searching for new quarters. Eventually arrangements were made with a real-estate developer to build a 4,000 square foot building to HRI's specifications at 5445 W. Diversey Ave., in a pleasant, primarily residential area on Chicago's Northwest side.

The original plan was to move into the new quarters by October 1, 1956, but, due to construction delays, occupancy did not take place until March of 1957. The move was accomplished overnight with the energetic cooperation of HRI's engineers. The original lease ran for fifteen years, followed by several extensions up until 1981.

During the period of occupancy at 5445 W. Diversey, staff size had grown to the point where additional space was needed. In 1963, approximately 1,300 square feet of space at 5435 W. Diversey (two doors away from the main office) was rented and occupied until April 1975. The space was known as the Annex.

Again, several factors, including cost, the changing nature of HRI's business and reduction of staff size dictated the desirability of a change in location. After an extensive search, a suite of rooms covering approximately 1,100 square feet and readily adaptable to a small laboratory operation was located in a large office building in an industrial park in Elmhurst, Illinois, about twenty miles west of Chicago. In April, 1981, the move was made to the quarters at 188 Industrial Drive, Suite 315, Elmhurst, Illinois. The move was made on a Saturday under the leadership of Ron Groll, and due to his excellent planning two large vans full of furniture and test equipment were neatly fitted into the newer, much smaller quarters.

On March 31, 1985, HRI's laboratory activity was discontinued, and its office moved to correspondingly smaller space in Suite 116 at the same address, where it remains today.

Over the years many illustrious people have served Hazeltine in the Chicago area. A list of HRI's Officers and Directors is included in Appendix I/C. A list of the HRI employees and also the earlier Chicago Laboratory employees is covered in Appendix II/C.

CHAPTER II/C

THE PRE-WAR YEARS

J. Kelly Johnson, best known as "Kelly", was manager of the Chicago Laboratory from the time of its opening in 1937 until he left the Company in late 1942. When I started with the Company in May of 1942 I quickly found Kelly to be a friendly, outgoing, gregarious man. His big grin, cheerful manner, and hearty greeting every morning as he entered the office left a lasting impression on me. He was skilled in both laboratory and analytic work.

Kelly had some memorable habits and characteristics. First of all, he insisted that his engineers develop the ability to do rapid calculations, including decibel conversions, without the benefit of slide rule or pencil and paper. A less-endearing quality was his habitual pipe smoking. I well remember the many times that he came out to the laboratory to work with me, just after I had cleaned the work space, only to see him take his pipe out and knock out the ashes on the edge of the bench, making quite a mess on both floor and bench top.

William O. Swinyard was Kelly's assistant during the pre-war period. Bill began his career at Hazeltine in 1930, continuing on with the Company until the end of 1970. He was president at the time of his retirement. A man of high moral and ethical standards, he always commanded the respect of those who worked for him. In attacking problems, whether engineering or managerial, he was thorough and precise.

The Chicago Laboratory quickly became very active in serving the licensees during the pre-war period, and Bill Swinyard was on the forefront of the licensee measurement work. Kelly Johnson at one time wrote a memorandum commending Bill as having the best and most rapid ability at measurements of any engineer he had ever known.

After the laboratory was established in 1937, as just mentioned, it quickly became busy. In 1939, 100 licensee reports were issued, most of which were written by Bill Swinyard. Additionally, eleven reports on test equipment were issued. Sixteen different licensees were served that year; among them were many famous names such as Scott, Hallicrafters, Motorola, Wells Gardner, Majestic, Stewart Warner, and Noblitt-Sparks (later Arvin).

Another engineer who came to the Chicago Laboratory in 1939 and is still remembered by many today was Robert J. Brunn. Besides being an accomplished engineer, Bob was well known for the speed with which he could wire a chassis or disassemble it. For many years people delighted in retelling the story about the time that Bob attended a staff meeting in which it was decided that a rather complicated developmental receiver was no longer needed and could be disassembled. Immediately after the meeting, Bob's supervisor decided that before the receiver was disassembled he would like one more set of measurements. However, by the time he reached Bob's bench, all that remained was a cabinet and pile of resistors and capacitors. In a matter of a few minutes Bob had disassembled the entire receiver. This skill was developed in the depression days when he worked for a company which disassembled receivers and sold the used parts. Bob had developed a great skill at that art.

Paul O. Jensen, another employee who came to work in the Chicago Laboratory in 1939, also deserves mention. Paul was in charge of the mechanical shop and was responsible for fabricating chassis and any other mechanical parts that might be required. A pleasant, diligent man, he served well until his retirement in 1970.

In the late '30's, events in Europe had developed to the point where it was obvious that war was imminent, and by the end of the decade Hazeltine was deeply involved in work related to military preparedness. Toward the end of 1941, licensee work had begun to taper off. However, royalty income that year was almost 1.9 million dollars.

The titles of a few of the reports written by Kelly Johnson in 1941 are a clue to the concerns of the time:

Airplane Telemetering
Aircraft Direction Finder-Progress Report
Airplane Telemetering Pickup Systems
Ultra-High Frequency Friendly Airplane Locator.

The following year saw the United States engaged in World War II and brought about a drastic change in the activities of the Chicago Laboratory.

In this period just before the war, an interesting event with far-reaching effects occurred. An independent inventor, Pierre M. G. Toulon, had offered to sell a patent on one of his inventions to Hazeltine. The patent, which covered automatic frequency control (AFC), particularly as it might be applied to television-receiver scanning synchronization, was considered by the Company's patent-review committee in New York. In the accepted wisdom of that period, reliable scan synchronization could best be achieved by directly locking the oscillator with the incoming sync pulses. Thus the committee recommended that the patent not be purchased. However, the following quotation from a letter dated October 30, 1984, written by Arthur V. Loughren to the writer of this account relates an unusual series of events that led the committee to later reverse its decision.

"My recollection of the development of AFC for horizontal scanning is something like this:

"In the summer of 1937, Harold Lewis and I (Arthur V. Loughren) visited the UK to make a first-hand study of British TV. The British had a regular broadcast service going on one channel using 50 fields per second interlaced 2:1, and I think 625 lines. I built an oscilloscope that would allow examination of related portions of field 1 and field 2 simultaneously, and we made many observations of UK practice using a GEC receiver and a Ferranti receiver. We also saw demonstrations at GEC, Ferranti, Scophony and perhaps others, as well as visiting the transmitter at Alexandra Palace.

"One of the observations that stuck with me was the advantage of transmitting the d-c component of the picture. At that time, US experimental transmissions suppressed the d-c component, so it had to be reinserted at the receiver. This led us to take a strong position with respect to the d-c component when the NTSC got started. I think that a number of others had reached this same conclusion.

"Another observation was that line tearing was present on the UK receivers whenever there was ignition interference, except on the Scophony receiver, where no tearing occurred. The Scophony receiver used a crystal light-valve (quartz, I think), a laterally moving image of each picture element, lasting for perhaps 10 or 20 element durations. To immobilize this moving element on the screen, the light was passed from the light-valve to a mirror-drum which rotated at the right speed to make the moving light-valve image of a picture-element stationary on the screen.

"The mirror-drum had, of course, substantial inertia, and thus was immune to ignition disturbance. The Scophony picture was rock-steady. I thought about this after our return to the US, and my thoughts led me to invent a TV line-scan system which contained an electrical flywheel - an oscillator whose phase was compared with the incoming synchronizing pulse to form an a-f-c circuit. I sent a disclosure of this to the HC patent department, and in due course it was discussed.

"The HC patent committee had as its principal technical members at that time Harold Lewis and J. C. Wilson. When the committee reviewed my docket, I believe Jack Wilson made the comment, "Haven't we seen something like this before?" This led to a reexamination of the file on the Toulon invention, which had been previously considered for purchase by HC, and turned down. It turned out that the Toulon invention was still available for purchase, and my advocacy of A-F-C for line-sync was enough to get action to that effect. My invention was entirely independent of Toulon's, but I was not the first inventor. Nevertheless, my invention did HC some good."

After the war, the use of horizontal AFC in television receivers became universal, and the Toulon patent was one of the stronger patents in Hazeltine's portfolio.

CHAPTER III/C

THE WAR YEARS

By the time I came to work for Hazeltine in May of 1942, production of civilian radios had been stopped under the War Powers Act. Of course, this meant that all royalty income from that source stopped with the cessation of production. However, by mid '42, the Chicago Laboratory was busily engaged in the fabrication and, in some cases, the design of specialized laboratory equipment needed by the parent company. In addition to the electronics laboratory, HRI also had a shop which had the equipment and capability to fabricate chassis and all the mechanical parts that we required. During the war years, oscilloscopes, signal generators, power supplies, RC bridges, square-wave volt meters, a frequency calibrator, and a frequency standard were built and, in some cases, the design work was carried on in Chicago as well.

One project, for the U.S. Army Signal Corps, involved the design and construction of a 600 MHz signal lamp transceiver. This equipment was intended to replace the optical signal lamps that had been used up to that time for communication between artillery crews and artillery observers. The specs called for the ability to communicate over a range of 10 miles with portable equipment. During 1942, Kelly Johnson supervised the project and got it under way.

At the end of 1942, Kelly Johnson, an intensely patriotic man, resigned his position at Hazeltine and took a job with the U.S. Navy as a dollar-a-year man. It is my recollection that he served as consultant and as an expediter on Navy contracts.

At the end of 1942, Charles T. Carroll, who had been working in New York, returned to the Chicago Laboratory and took over the supervision of the 600 MHz signal lamp transceiver project which was completed a few months later in 1943.

In 1943, the name of the subsidiary company of which the Chicago Laboratory was a part was changed from Hazeltine Service Corporation to Hazeltine Electronics Corporation. However, as far as the Chicago Laboratory was concerned, this was a change in name only, and there was no impact on the operations.

1943 also was the year that Emmett J. Duffy, better known as just plain "Duffy", came to work at Hazeltine. This was the beginning of a relatively long career with the company which lasted 27 years, until his retirement at the end of 1970. Duffy had a keen analytic mind and an unusual ability to solve difficult mathematical problems by means of unusual and simple approaches. That ability, along with his gift at story telling, gained him the respect and friendship of licensee engineers. He is probably one of the best-remembered of all HRI engineers among his peers. Many a bright young licensee engineer was humbled by the challenge of some of his "trick" problems. After his retirement he was a frequent contributor to the problem section of MIT's magazine, Technology Review.

During the war years, Duffy worked on the design and construction of several pieces of laboratory equipment which were quite sophisticated at that time.

For a period of several months during the war years, a laboratory room, under 24-hour security guard, was set up in the Chicago Laboratory for the use of Hazeltine engineers from New York. They were coordinating the efforts of Chicago area manufacturers who were subcontractors under Hazeltine prime military contracts, but the nature of their work was never disclosed to the Chicago Laboratory personnel because of the highly confidential nature of the work they were doing. Gilbert C. Larson was leader of the group, accompanied by Robert J. Brunn (who had returned earlier to work in New York), Rodney Lohman and Frank Delaney.

From the time that Kelly Johnson left Hazeltine, Bill Swinyard had been managing the operations in Chicago.

CHAPTER IV/C

TRANSITION FROM WARTIME TO PEACE-TIME ECONOMY

In 1945, World War II came to an end, and very quickly industry began to convert back to civilian production. Of course, there was a pent-up demand for radio receivers which had not been produced for three years. In preparation for a renewal of licensee activity, Bill Swinyard began the training of engineers who had not had previous experience at receiver measurement. He also wrote a report on radio performance measurement procedures to be used as a reference by the engineers. Licensee activity got underway rather slowly in 1945 and there were only six licensee measurement reports issued that year, along with thirteen equipment design reports. However, laboratory activity accelerated significantly in 1946.

As mentioned earlier in Chapter I/C, the Chicago organization became an Illinois corporation on March 28, 1946, a wholly-owned subsidiary of Hazeltine Corporation, known as Hazeltine Research, Inc. (HRI). HRI became the owner of all U.S. Patents owned by Hazeltine and, in addition to its previous responsibility for rendering licensee service, it was now responsible for the maintenance and licensing of those patents. Many new (as well as old) names began to appear on the roster of licensees including such well-known names (at the time) as Radio Corporation of America, Sparks-Withington (Spartan), Crosley, Emerson, Farnsworth, John Meck Industries and many others. Royalties on radio receiver patents remained the main source of income at that time.

In 1946, HRI engineers began to have contact with B. D. Loughlin who was head of the FM receiver laboratory at Little Neck in New York. Our first work with him was on ratio detector problems, and this was the beginning of a long and lasting relationship which has been most profitable for HRI. Barney Loughlin's accomplishments have been partially chronicled in Wheeler's book, "The Early Days of Wheeler and Hazeltine Corporation - Profiles in Radio and Electronics", and will be covered in more detail in a subsequent history of Hazeltine Corporation. However, it must be said here that the inventions of Loughlin have resulted in more royalty income for HRI than the inventions of any other individual. Further, his creativity has been an inspiration to HRI engineers from 1946 to the present time.

In 1946, another noteworthy event took place. A developmental television receiver was constructed at HRI.

1947 saw increasing licensee activity under the leadership of Bill Swinyard. Although there was growing interest in television, laboratory activity that year was confined to radio measurements and instrumentation work.

In addition to licensee activity in Chicago, a laboratory was maintained at Little Neck in New York by the parent Corporation. At that time their main emphasis was on FM radio and television plus some licensee activity. That was the year that Barney Loughlin issued reports entitled "FM Detector Systems", and "The Hazeltine FreModyne Circuit".

1947 also saw the start of a new subsidiary of Hazeltine Corporation, Hazeltine Research, Inc., of California, better known as HRIC. The new company, located in Burbank, California, was a corporation of Delaware and was managed by Dudley E. Foster. The purpose of this laboratory was to serve several West Coast licensees. At one time there were at least 12 licensees on the West Coast including such well-known names as Packard Bell, Hoffman, Gilfillian, Conrac, and Calbest. This laboratory continued to operate in close cooperation with HRI until 1963. By that time, there had been such great attrition of licensees on the West Coast that HRIC was dissolved.

Dud Foster who managed HRIC was a well-known engineer. He had resigned a position as Vice President at Majestic in order to come to Hazeltine, and probably is best known for his invention (jointly with Stuart Seeley) of the Foster-Seeley discriminator which was used so widely for many years for FM detection.

CHAPTER V/C

CHANGES IN DIRECTIONS

1948 was a landmark year at HRI in many respects. There were changes in technology occurring in the industry that were causing changes in the activities at HRI, and new personnel came into the Company which were to have a significant impact on operations in the years ahead.

Up to this point in time, Hazeltine's licensing efforts had been concentrated on radio. Now, however, a whole new era was about to open up. Whereas sound had been the only medium transmitted by radio waves up to this time, there was intense interest in the exciting possibility of transmitting pictures as well as sound, and in 1948 the first licensee television receiver was submitted to HRI for performance measurements.

On April 1 of that year, Robert F. Tschannen came to work for the Company and stayed with HRI until his retirement in 1980. Bob brought with him some experience in TV receiver design, having worked for a company that later became a licensee of HRI. He was (and is) a skillful and dedicated "ham" operator. The knowledge and skills gained in building most of his own equipment were reflected in his extremely competent laboratory work. He was especially effective in working on television receiver problems with licensees, interfacing very well with licensee engineers. In later years he worked very effectively on contracts with Hazeltine Corporation, both with the computer terminal group and the color analysis system group.

On April 21, 1948, Rear Admiral Daniel Francis Joseph Shea, U.S.N. Retired, came to work for HRI as its manager. Admiral Shea (no one ever called him Mr. Shea more than once), was a very dynamic person with a strong personality. He once stated to me that he had no friends, only acquaintances. I have good reason to doubt that statement, but it is undeniable that he had an ability to make enemies. He came to HRI at a relatively young age, in his 40's, directly after retiring from the Navy. There was a difficult period of adjustment in which he had to learn that the command tactics of a Navy line officer did not work too well in civilian life. Conversely, there was a difficult period for HRI personnel who had to adapt to the ways of this new manager. It was undoubtedly especially difficult for Bill Swinyard who had been managing the lab since J. Kelly Johnson's retirement in 1942. However, the adjustment was made in due time by all concerned and the laboratory became a well-functioning unit again.

There were some interesting incidents that occurred during the transition period. During his first week as manager, he announced that there was to be a thorough cleanup of the laboratory on Friday, and that he would conduct an "inspection" on Friday afternoon. We engineers thought we had done a good job of tidying up the place, and were quite proud of ourselves when he began his tour through the premises. Floors were swept and bench tops were clean. However, he spotted an overhead conduit which carried cables from one laboratory to another, and, in true Navy fashion, he reached up and ran his hand across the top of the conduit to see if we had dusted it. Much to the glee of a poker-faced group of engineers standing at respectful attention, a shower of soot, grime and dust came down upon his head and face. Friday cleanups remained an institution, but I do not recall the Admiral ever again making a round of inspections as he did that day.

There were many, many other interesting occurrences during that transition period. Every day at about 10 A.M., it was Admiral Shea's custom to leave the office and go across the street to an old saloon to have his morning cup of coffee. Usually Bill Swinyard accompanied him, but on occasion when Bill was not on the premises, Admiral Shea would go through the lab and select someone and command (not request) that person to accompany him to his morning coffee. I was frequently selected for this honor, and would go along dutifully holding doors for him as a good subordinate should do. (He always stood at a door waiting for the person who accompanied him to open it and hold it for him.) Finally a day came when I was again selected, and I do not recall what prompted an unusual spirit of rebellion in me but as we approached the outer door the building, we were in conversation and I decided that I would not open the door that day. In his usual manner, Admiral Shea approached the door, stood aside, and I stood there talking with him as if nothing was happening. After a standoff which seemed like an eternity, he angrily flung the door open, I followed, and we went and had our coffee in silence. While it may not have seemed to be the most courteous behavior on my part as a young man, I do believe that it improved our relationship.

If the foregoing incidents seem to be demeaning to Admiral Shea, they are not intended in that light. I quickly learned that, in spite of his somewhat pompous ways initially, he was a highly intelligent man with a tremendous memory. One day, after having worked several days on a Wells Gardner receiver, I was called into Admiral Shea's office to give him a report on our progress. I was somewhat puzzled at his interest in the technical details since, although he had an engineering background, he had not been active in engineering for many years. However, I gave him a detailed report of various measurements and the modifications we had made on the receiver.

That afternoon George Gardner, one of the founders of Wells Gardner Company, came in to visit Admiral Shea. Admiral Shea brought him out into the laboratory where I was working and took my notebook record, laid it out on the bench and, as he went through the pages, he explained to Mr. Gardner all that had been done on his receiver. I was shocked to hear my earlier report to Admiral Shea being played back almost word for word, as if it had been recorded. He frequently demonstrated that capability to remember details and facts, even when they were related to things with which he was not highly familiar.

Admiral Shea quickly established some substantial changes in our laboratory procedures. Up to this time all work on licensee receivers was concluded with the writing of a formal report which was bound in a binder and sent on to the licensee. He quickly concluded that too much time was spent in the production of these reports, and that it would be more valuable to the licensees to get an answer to their problems perhaps as much as a day earlier. Consequently, he instituted what became known as letter reports. The data was put together in a somewhat informal form, and was accompanied by a covering letter. There is no question that this procedure greatly improved the efficiency of our operations. However, the change was not accomplished without a considerable amount of grumbling on the part of engineers who felt that these letter reports did not reflect the dignity of their efforts.

Admiral Shea was well known among managerial personnel at licensee and prospective licensee companies. He made frequent visits to the various companies on what were intended to be good will visits which would make HRI's licensing efforts more effective. However, later assessments indicated that this type of activity was probably not as significant a help as had been hoped.

When Admiral Shea left HRI in 1957, after almost ten years with the company, Bill Swinyard again resumed the position of manager, and continued in that responsibility until his retirement in 1970.

There were several other people at HRI during 1948 who had a significant role in the Company's development. On April 1, Rinaldo DeCola came to the Company with previous TV experience and stayed at HRI for two years. At the end of the two years he left to take an executive position at Admiral Corporation.

There was also Martin Fox. Martin had been a Chicago Lab employee from 1939 to 1941, at which time he left to join the Navy. He returned in 1945 and was more or less in charge of laboratory activities under Bill Swinyard until 1948.

Chad Pierce was another achiever. He came to the Company in 1942 as a cooperative student from Northwestern University. He was an excellent engineer and served exceptionally well on licensee activity. In 1949, he left HRI to go with Wells Gardner where he stayed until his retirement around 1980, at which time he was Vice President of Engineering.

During 1948, in addition to licensee measurement work, there was a significant amount of activity constructing test equipment for both radio and television. At that time, radio royalty income was beginning to dwindle, but royalty income from television was just beginning.

CHAPTER VI/C

TELEVISION, THE NEW WONDER

For younger people who have been born and raised in the television era, it is difficult to understand the tremendous impact that television has had on society, and the excitement experienced by those involved in the development and growth of the industry. Both HRI and its parent company, Hazeltine Corporation, were heavily involved in the exciting challenge of television receiver development taking place at the end of the '40's. As an indication of the intensity of industry activity, in 1949 three million sets were sold, up from 975,000 receivers in 1948. The year 1950 saw continuing rapid expansion in the monochrome television receiver business, with almost 7.5 million television receivers and 13.5 million radio receivers produced.[2]

In 1949, Hazeltine Corporation came out with a line of television test equipment. Included were a picture-modulated generator and a modulation monitor receiver. While the equipment was of excellent design, the company was never able to develop an ongoing test equipment business. However, these early items of equipment served very effectively, both in the Hazeltine Corporation laboratories and at HRI, for many years.

During 1949, HRI was busily engaged in the development of specialized radio and television test equipment, but was also very busy at licensee work, as evidenced by the record of 193 letter reports having been issued that year in addition to twelve formal measurement reports and two reports on equipment design.

Although the monochrome TV business had barely begun to develop, at the Hazeltine Corporation laboratory at Little Neck, New York, engineers were already beginning to think about compatible color television in the Spring of '49.[3] Early in 1950, they were deeply involved in research and development in that area, and by the second quarter of that year were presenting color television demonstrations to a wide range of interested parties. A. V. Loughren directed the parent company's research and development activities in color television.

At the same time that this intense research effort was taking place at Hazeltine, many other companies, including RCA, Philco and General Electric, were similarly engaged in intensive research programs directed toward the development of a compatible color television system. There was great urgency since the Columbia Broadcasting System (CBS) had already petitioned the FCC to approve a non-compatible field-sequential color television system. The term "non-compatible" refers to the fact that the proposed CBS system would use a different set of scanning standards than the then current monochrome television standards. Therefore, monochrome receivers would be unable to receive color transmissions, and conversely receivers designed to receive the CBS color signal would be unable to receive monochrome transmissions.

The vast majority of people in the television business were convinced that an incompatible color system was totally impractical and would hurt the television industry. Therefore, there was feverish activity to develop equipment and demonstrations which would convince the Federal Communications Commission (FCC) that the CBS system should not be adopted, and that a decision concerning a color system should be deferred until a compatible system was ready. However, in October of 1950, the CBS color system was adopted by the FCC.[4] The concern in the television receiver and broadcast industries was so great that in the month following the FCC decision an Ad Hoc Committee of the National Television Systems Committee (NTSC) was formed to make an appraisal of the state of the color art.[5]

In June of 1951, the original National Television Systems Committee, which had formulated the current monochrome television transmission standards, was replaced by a second NTSC[6] which was charged with the responsibility of developing a set of compatible color television system standards through a cooperative effort on the part of all interested parties. There was strong support and involvement in the NTSC by Hazeltine companies and personnel. At HRI, William O. Swinyard was vice chairman of Panel 15, the Receiver Compatibility Panel, and he served as an observer on Panel 13, Color Video Standards. Bob Tschannen served as an alternate on Panel 15 also. At the parent company, Arthur V. Loughren was vice chairman of the NTSC and chairman of Panel 13 on Color Video Standards. B. D. (Barney) Loughlin was also intensely involved with the NTSC activities, along with at least seven other Hazeltine Corporation personnel, including such well known names as Knox McIlwain, Charles Hirsch, William Bailey, and Charles Page.[7]

The activities of the NTSC continued on through 1952 in what was probably the greatest cooperative effort ever undertaken by industry in the United States. The NTSC as a whole, and its various panels, operated in a highly effective manner without government intervention.

During the period that the NTSC was pursuing its studies, the Hazeltine Corporation laboratory at Little Neck was carrying out one of the most intensive team development efforts ever undertaken by the Company. As a result, Hazeltine was a major contributor to the compatible color television systems standards proposed by the NTSC in its final report, and adopted by the FCC on December 17, 1953. Hazeltine's contribution is covered in a paper, "The Revolution and Evolution from Dot Sequential to NTSC", by B. D. Loughlin on pages 18 through 23 of the May, 1984, issue of the IEEE Transactions on Consumer Electronics, the IEEE Consumer Electronics Society's Historic Issue commemorating the 100^{th} anniversary of the IEEE.

While Hazeltine's color development program was of great benefit to the NTSC, its impact on HRI's future cannot be underestimated. Many U.S. patents were issued as a result of that work, but the most important from the standpoint of income potential were based on inventions of B. D. Loughlin and Donald Richman. Two of Loughlin's inventions, Shunted Monochrome (U.S. Patent 2,774,072) and Constant Luminance (U.S. Patent 2,773,929) proved to be by far the greatest income producers in the future. These two patents have generated royalty income of the order of 10's of millions of dollars.

While Loughlin's efforts have been greatly appreciated by the Company, his achievements also have been widely recognized in the technical community. Among awards and citations he has received for his contributions to the color television art are:

Zworykin Television Prize Award - Institute of Radio Engineers (IRE) - (1952)
IRE Fellow (1955)
David Sarnoff Gold Medal Award - Society of Motion Picture and Television Engineers (1955)
Outstanding Achievement Award - IRE Professional Group on Broadcast and Television Receivers (1957)
Modern Pioneers in Creative Industry Scroll Award - National Association of Manufacturers (1965)
Cooper Union Professional Achievement Citation (1969)
Cooper Union Gano Dunn Medal (1970)
Consumer Electronics Award - IEEE Broadcast and Television Receivers Group (1977)
Special Commendation Award
International Television Symposium Citation

While the NTSC activities were in progress, routine licensee work continued at HRI, and some significant events occurred. In 1950, the U.S. Supreme Court handed down a decision in favor of HRI in a case in which patent misuse was an issue. Sometime earlier, HRI had become involved in litigation with Automatic Radio Manufacturing Co., Inc., and the Supreme Court's ruling upholding HRI's licensing procedures was highly important and had a significant impact on future licensing policies. The precedent established by this decision was an important factor in the strategy adopted by HRI in its litigation with Zenith Radio Corporation several years later. However, that is another story which will be covered later in this account.

In 1951, the activity at the HRI laboratory was concentrated mainly on television; radio work had significantly diminished by this time. During that year, measurements were made on a receiver designed for the CBS Color Television System. It incorporated a 10-inch black and white tube, in front of which was a large rapidly rotating color wheel in synchronism with the vertical scanning rate of the television receiver to produce the field-sequential color pictures. While the technical details and attributes of this receiver have long since been forgotten by the author of this account, he does well remember that one of our engineers, Colbert Nakata, accidentally got too close to the color wheel, which quickly sliced his leg to the bone at the kneecap. Several stitches were required to repair the damage to his person and his trousers.

In addition to a great deal of routine licensee measurement work in 1951, there was also considerable activity taking place in attempts to develop a reasonably economical dual-standard television receiver, i.e., a receiver which would be capable of receiving both the normal monochrome television signal and CBS color television signals. A great deal of switching in the scanning circuits was required, and it is felt that no reasonable compromise was ever achieved by ourselves, or anyone else for that matter.

By 1952, HRI had gained a great deal of experience in the measurement of performance of television receivers, and by this time was ready to issue the first of many reports listing the averages of television receiver performance. The first report covered the years 1950 and 1951. These reports proved to be of great value to our licensees in years to come, assisting them in evaluating the performance of their own receivers as compared against the averages of receivers measured at HRI. During this time, many additional famous names were included among the roster of HRI licensees, such as Spartan, Garod, Capehart Farnsworth, and Arvin Industries. Due to later attrition caused by intense foreign competition, most of the famous names of that era have long since disappeared from the American scene and have been forgotten.

HRI continued to be busy at licensee measurement work as well as in the construction of color test equipment, not only for its own use, but for the use of its parent company laboratories as well. Since television technology was still very young, there were many problems that plagued the receiver industry. HRI was called upon frequently by its licensees to assist in solving these problems, some of which included intercarrier buzz, scanning synchronization irregularities, and aberrations in linearity in the scanning of the television raster. Licensee engineers frequently came to our laboratory to work with us on these problems, not only because of our superior test equipment, but also for the benefit of interfacing with our engineers. Also, it was not unusual for HRI engineers to travel to the plants of licensees to work and consult on receiver problems. Thus, while it was a longstanding policy of HRI not to do design work directly for a specific licensee, we frequently did assist in improving the designs of our licensees. On the other hand, the straightforward performance measurement process normally was used by the management of licensee companies to obtain an independent evaluation of their receivers.

Some television receiver manufacturers had anticipated the FCC approval of a compatible color television system, and had completed the design of prototype color television receivers by the end of 1953. Five such receivers were submitted to HRI during November and December of 1953 for measurement and modification. In addition to this work, HRI had a reasonably heavy workload of routine measurements on monochrome receivers, and was also involved in the design of television IF amplifiers for the 40 MHz region. At this time, the industry was changing over from the use of IF amplifiers in the 20 MHz region to an industry-agreed-upon standard of IF amplifiers in the 40 MHz region, placing the picture IF at 45.75 MHz, and the sound IF at 41.25 MHz.

In 1954 and '55, the preponderance of laboratory work was on monochrome television receivers. Approximately 15 color sets were worked on during that period, and only a few radio receivers.

The market for color television receivers was much slower in developing than had been anticipated by most industry experts. The old chicken and egg problem persisted. Receiver manufacturers were unwilling to embark on costly marketing programs for color receivers when there were only a few stations equipped to broadcast in color. Conversely, many broadcasters were reluctant to make the large investment required to equip themselves to produce and broadcast color programs.

In addition to in-house work, Hazeltine people were deeply involved in professional activity. Bill Swinyard was chairman of the IRE Standards Subcommittee on Television Receivers, and the writer was chairman of the Editing Subcommittee of that group. The outcome of this activity was IRE Standard No. 60 IRE 17.S1, "IRE Standards on Television: Methods of Testing Monochrome Television Broadcast Receivers, 1960".

A paper on methods of measurement of color-television receiver performance, written at HRI, also had been published in 1956.[8]

CHAPTER VII/C

STABILIZATION

The years from 1956 through the early '60's might be characterized as a period of stabilization. The frantic efforts put into the NTSC were concluded and industry now settled down to the competitive process of making a better and cheaper television receiver. The monochrome receiver market was maturing; however, the color receiver market continued to be very slow in developing. The slow development of the color market had serious implications for HRI. The two most significant color patents, Shunted Monochrome and Constant Luminance, issued in 1956; thus the life of these patents began to run with virtually no receivers to license. Radio patents were expiring and royalty income from that source was dropping off. Monochrome TV royalties had become the main source of HRI income, but by 1958, total royalty income was less than half the 1956 royalty income. Royalty income stayed low until 1964 when color royalties began to come in.

In 1956, the Television Allocations Study Organization (TASO) was organized. TASO, an industry-sponsored organization, was formed at the request of the FCC to study the matter of allocation of frequencies, by the FCC, for television broadcasting. Specifically, the FCC desired a broad study of the effectiveness of television broadcasting in the UHF range versus the VHF range. HRI personnel were involved in TASO's activities with Bill Swinyard as chairman of Panel 2, Receiving Equipment, and the writer of this account serving as Secretary of that Panel.[9]

TASO did not operate with the freedom enjoyed by the NTSC. Few people had realized at the time of the NTSC that this was perhaps the last industry-wide effort that would operate with relatively complete freedom, unhindered by government intervention. However, by the time TASO was organized, the U.S. Justice Department had become so preoccupied with anti-trust issues that, in order to avoid the risk of anti-trust action against TASO participants, it was necessary to have a government representative present and chairing all Panel and Committee meetings. These restrictions greatly impeded the efforts of TASO, and with such restrictions it is doubtful whether accomplishments comparable to those of the second NTSC can ever be achieved again. However, TASO did complete its work, and its final report was issued March 16, 1959.

During the mid '50's, a series of tutorial reports on color television was issued by Hazeltine Corporation. These reports were edited by Charles E. Dean and Knox

McIlwain, and were then published in book form by John Wiley & Sons, Inc., in 1956.[10] This volume was virtually the standard text on color television for many years, and served as a great aid to HRI's licensees.

In the latter part of the '50's, Hazeltine Corporation formed a new wholly-owned subsidiary, Hazeltine Research Corporation, also known as HRC, which became the research arm of the Company. By that time, research on color television at Little Neck had been pretty well concluded. HRC continued in existence until 1960, and during that period HRI funded licensee-related research work at HRC.

In addition to its radio and television receiver patents, HRI owned several patents, non-related to receivers, which were licensed to commercial manufacturers. One such patent, known as the Salati Patent (U.S. Patent No. 2,540,012), covered the invention of a BNC coaxial connector which had the properties of matching the characteristic impedance of the transmission line to which it was connected. HRI had brought an infringement suit against Dage Electric Co., Inc., for infringement of that patent. The lower court ruled that the patent was invalid, but infringed if valid. However, the United States Court of Appeals for the 7th Circuit reversed the lower court's decision as to invalidity, and in its decision of July 8, 1959, ruled that the patent was both valid and infringed. The case did not go to the Supreme Court. Over the life of the patent, HRI licensed at least 83 manufacturers to use the invention in their products.

As chronicled earlier, at the end of 1957 a significant organizational change took place at HRI. Admiral Shea left the company, and Mr. Swinyard again became manager of HRI's laboratory. Laurence B. Dodds was President of HRI at the time, but the day-to-day management was in Bill Swinyard's hands. This was not as great a change as it may seem at this time. Bill Swinyard had worked closely with Admiral Shea on managerial problems, and had also been almost solely responsible for laboratory activities. Therefore, the transition occurred without disruption.

In addition to his HRI responsibilities, Bill Swinyard was active professionally during this period. He was vice chairman of the IRE Professional Group on Broadcast and Television Receivers in 1958, and served on the Administrative Committee of the group from 1957 to 1964.

Toward the end of the '50's, licensee laboratory work had become highly refined and somewhat routine. However, the winds of change were beginning to blow, out in the television receiver industry. Between the mid '40's and mid '50's, HRI had signed at least 237 receiver licensees. Many of these were small companies that sprang up after World

War II, flourished for a brief period, and then disappeared. By the end of the '50's, a long and steady period of attrition of ever-larger receiver manufacturers was beginning to set in. Few people, if any, realized at that time the extent to which the attrition would go in the U.S. radio and television industry. The changes which were to take place were to have a significant impact on HRI's operations.

CHAPTER VIII/C

INTROSPECTION

During the course of the history of Hazeltine Corporation and HRI, research efforts directed toward continuing the flow of inventions that would produce future royalty income had followed a logical progression. It all began with licensing the newly-born radio industry in 1924 to use Professor Alan Hazeltine's Neutrodyne patent. The transmission and reception of sound had barely begun, yet some of the more creative people at Hazeltine had begun to think of the additional transmission of pictures. Thus, there was a rather natural progression from the transmission of sound to the transmission of both sound and pictures simultaneously. Then, as we noted earlier, almost before monochrome television had made its debut, creative minds were searching for ways to paint those pictures with life-like color. By the time the '60's arrived, color television was a reality. But this time, the next step in the evolution was not at all obvious. A continuing search for the best course of action for HRI to follow in the future was begun.

In this general time frame, several events occurred at the parent company which had an impact on HRI's operations. In 1957, B. D. Loughlin resigned his position at Hazeltine Corporation and became a private consultant. Later, in 1960, all licensee-related activity at Hazeltine Corporation ceased. Hazeltine Research Corporation, subsidiary of Hazeltine Corporation, was dissolved in 1960, and at that time Mr. Loughlin began to serve at HRI as consultant for one or two days per month. His highly creative abilities were immediately put to work in helping solve problems encountered in laboratory projects currently in process. He also assisted greatly in helping formulate plans for future projects.

During the period 1960 through 1962, Loughlin assisted in several projects including development of an FM stereo system, investigation of black level stabilization in television receivers, and the development of equipment to provide rapid measurement of color television receivers. His creativity was an inspiration to people who worked with him.

An outcome of some of these projects was the development of the so-called "Slip Signal Generator and Video Sweep Generator". A paper by R. F. Tschannen and E. J. Duffy describing this apparatus was presented at the Radio Fall Meeting in Toronto in 1962.[11] Another paper describing a novel approach to the DC restoration problem was presented at the same meeting.[12] That paper received an award as the best paper published in the IRE Transactions on Broadcast and Television Receivers in 1962.[13]

After his consulting career, during which Hazeltine Corporation and HRI had become major clients, Barney Loughlin returned to Hazeltine Corporation in 1962, and was also elected a Vice President of HRI. In 1963, he was appointed head of the HC Research Laboratory. His consulting continued to be available to HRI under the terms of an intercompany agreement with Hazeltine Corporation. Normally, he came to HRI for two or three days every other month to consult on projects. In the intervening months, I would go to his laboratory at Plainview, New York, to spend an equal amount of time in discussion of HRI programs. For four or five years thereafter, HRI contracted with Hazeltine Corporation's Research Laboratory to perform various projects on behalf of HRI's interests. Included among these were the development of a UHF/VHF television tuner, a study of light valves, a study of the status of three-dimensional color television, a study of computer-aided design feasibility, and thin-film color demodulator development, among many other projects.

1963 saw the occurrence of several noteworthy events. First, a significant increase in staff size was begun which extended until 1970. In 1963, there were 10 full-time workers and three part-time workers. By 1970, the staff had expanded to 18 full-time workers and two part-timers. The goals of the expanded staff included development of new sources of income, and the creation of new inventions for future royalty income.

A long-term employee who was part of the expansion program of the '60's was Ronald A. Groll, who joined the Company as an Engineering Aide in 1960. Ron, an unusually versatile, reliable man, carried a wide range of responsibilities over the years and advanced to the position of Engineer. For several years, he was responsible for compiling the data and writing the series of HRI reports on average performance characteristics of television receivers.

During 1970, an extensive long-range program to determine usage of HRI patents in television receivers on the market was also begun. That program included the preparation for demonstrations intended to show the benefits of certain HRI inventions, particularly constant luminance.

A commercial patent, U.S. Patent 3,102,213, issued in August of 1963. This patent, which became commonly known as the Bedson Patent, covered the invention of a method of plating through holes on multi-layer circuit boards. The product of three co-inventors, D. E. Bedson, S. DiNuzzo, and A. C. Suleski, it became the source of a significant amount of commercial royalty income in future years.

In 1963, Hazeltine Research, Inc., of California was dissolved, due to a fall-off in demands for licensee work on the West Coast. In the following year, Dudley E. Foster, who had managed that laboratory, became a consultant to HRI. For several years, his main activity was circuit diagram analysis of TV receivers on the market, to determine HRI-patent usage, and also the categorizing of new patents issued by the U.S. Patent Office that were within the sphere of HRI's field of interest.

While all of these technically related events were taking place, negotiations to license HRI's color patents were taking place. David Westerman had become President of HRI in 1963 and he, with the assistance of Bill Swinyard and Kenneth P. Robinson (from the legal department at Hazeltine Corporation), was energetically pursuing license negotiations. At the same time, preparations were well under way to go to trial against Zenith Radio Corporation in a patent infringement case. But that is another story which will be dealt with in the next chapter.

CHAPTER IX/C

THE GATHERING STORM

Early in the '60's, there had been a breakdown in the license negotiations with Zenith Radio Corporation. Originally, HRI brought suit for infringement of a Loughren patent, U.S. Patent 2,547,648, which covered the invention of a method of keyed AGC. Initially, the suit was thought to be a "friendly" suit, to determine the validity or invalidity of the patent. However, in time, Zenith filed a counter-suit, alleging patent misuse and anti-trust violations. The case then took on a much more serious complexion, but the precedent established in the Supreme Court decision in the Automatic Electric case gave some reason for confidence on the part of HRI. Additionally, outside legal anti-trust consultants issued an opinion which indicated that the probability of favorable outcome for HRI was very good. The case went to trial in October of 1963 in the United States District Court, Northern District of Illinois, Eastern Division, before Judge Richard Austin. On April 5, 1965, Judge Austin ruled in Zenith's favor, both with respect to the patent infringement issues and the anti-trust issues. The trebled damages would have amounted to almost $39 million. However, HRI engaged outside anti-trust counsel who, along with HRI counsel, engaged in intense activity prior to entry of judgment which resulted in a substantial reduction of the trebled damages to approximately $19 million. However, even the reduced damages were a crippling blow to HRI. The case was appealed and, on December 13, 1967, the U.S. Court of Appeals, 7th District, reversed a major part of the lower court's judgment. The court upheld the lower court's decision of invalidity of the patent, but reversed its decision with respect to anti-trust issues.

Zenith filed for an en banc hearing before the U.S. Court of Appeals. This petition was denied. The case ultimately went to the Supreme Court, a complex decision was rendered, and the case was remanded to the Court of Appeals for execution of judgment. However, in strong disagreement with the Appeals Court interpretation of the Supreme Court ruling, Zenith managed to get the case back before the Supreme Court. In its final decision on February 24, 1971, the Supreme Court upheld the decision of invalidity of the patent and upheld the judgment of trebled damages in the amount of approximately $19 million.

A substantially correct account of the Supreme Court action was covered in a Wall Street Journal article in the February 25, 1971, issue and is included in this history as Appendix III/C.

HRI, of course, did not have the resources to pay the $19 million in damages. Additionally, Zenith was demanding payment of all court and legal costs, in addition to interest on the $19 million. They further stated their intention to go to court, if necessary, to attempt to make the parent company, Hazeltine Corporation, liable for the damages assessed against HRI. In view of these and other considerations, under the strong and capable leadership of David Westermann on behalf of the Hazeltine companies, a settlement agreement was reached on April 29, 1971. A reasonably accurate newspaper account from the New York Times of April 30, 1971, of the terms of that agreement is given in Appendix IV/C.

Looking back over that troubled period, David Westermann had resigned as President of HRI at the end of 1966 in order to accept the Presidency of the parent Company. W. O. Swinyard was then elected President of HRI in January of 1967, and served in that capacity until his retirement, December 31, 1970. The writer of this account was elected President of HRI effective January 1, 1971, and, at that time, was reasonably optimistic of the outcome of the Zenith litigation. However, the final judgment by the Supreme Court suddenly faced us with the stark reality that, in the opinion of many people, HRI would not survive. The predictions of doom were so rampant that many of HRI's personnel avoided technical seminars and meetings in order not to be confronted with the "gloom and doom" comments of their peers. A good deal of time was spent in encouraging the staff and attempting to boost morale. A few engineers became frightened and left the Company; however, great credit is due the majority of employees, who stayed and were intensely loyal.

It was immediately recognized that, in view of the Supreme Court decision, license negotiations would undoubtedly be more difficult than they had been previously. However, following execution of the Settlement Agreement, Ken Robinson, Ed Onders (both Patent Counsel for the Company), Barney Loughlin, and I rolled up our sleeves and proceeded to make the best of a difficult situation. Successful we were, and, before the deadline date for the final payment to Zenith arrived, we were able to meet all obligations of HRI under the Settlement Agreement.

As grim as the outcome of the Zenith litigation was for HRI, there were some interesting, sometimes humorous, sidelights that occurred during the course of the proceedings. In the process of preparing for the hearings before the Appellate Court and the

Supreme Court, the Chicago law firm of Chadwell, Keck, Kayser, and Ruggles had been engaged to handle the litigation. David Westermann, in his typically thorough fashion, was monitoring and supervising all aspects of the litigation. It was not unusual for him to telephone sometime after 4 o'clock in the afternoon and request that someone immediately go to the Chadwell office and pick up papers for delivery that night to Hazeltine counsel in New York. With proper caution, he did not trust delivery to courier services. For several months, I always had an overnight case packed and ready to go on a moment's notice; however, these junkets usually involved only a flight to New York and immediate return to Chicago. We would be met at the LaGuardia Airport by someone from the legal staff at Hazeltine Corporation and, after quickly turning over the packet of papers to that person, we would quickly dash off to the cab stand and take a cab to Kennedy Airport, getting there just in time to catch the last flight out to Chicago. I often felt like the participant in a spy movie or some undercover activity.

At a later date, an income-tax refund check in the amount of almost $6 million was received from the U.S. Government at the Hazeltine Corporation offices in New York. (Hazeltine Corporation and HRI had been filing consolidated Federal Income Tax Returns in prior years.) As a result of the huge judgment against HRI, carry-back losses were applied against the income of the three prior years, and application had been made for refund of the Federal Income Taxes paid in those years. Under the terms of the Settlement Agreement, HRI was to turn over the refund to Zenith within 20 days of receipt. Plans had been made in advance that HRI would invest the money in U.S. Treasury Bills for the full extent of the grace period in order to obtain the full benefit of the interest earned. Arrangements had been made with George Weddle of the accounting department at HC to bring the checks to HRI as soon as they were received, and I was to meet him at the airport. At the appointed time, I was at the airport but could not find him. His plane had arrived, but he was nowhere in sight. After a thorough search of the various areas in the terminal, I finally went outside and noticed a man nervously pacing up and down the sidewalk. Since I had not met George Weddle previously, I cautiously approached the man and asked if he were George. After proper identifications were made, with a great sigh of relief he reached into his coat pocket and drew out an envelope and commented that he had never been so glad to see anyone in his life. The check was deposited in HRI's account the first thing the following morning and, by pre-arrangement with Continental Bank, the funds were immediately made available for investment. We felt as if we had accomplished a major coup.

One of the conditions of the Settlement Agreement required that Hazeltine Corporation turn over its main building at Greenlawn, along with slightly over twenty acres of land on which the building was located, to HRI. Thus, for a period of a few years, the subsidiary enjoyed its position as landlord of the parent. However, as soon as the conditions of the Settlement Agreement had been fully met, the property was turned back to the parent.

CHAPTER X/C

BUSINESS DURING THE "ZENITH" YEARS

While all the detailed and involved proceedings of the Zenith litigation were taking place, engineering activity at HRI was still going on more or less as usual. In 1965, we began to transistorize some of our laboratory equipment. In 1966, Charles E. Page, from the research laboratory at the parent Company, began to consult with HRI on various projects under the terms of an inter-company agreement. In 1968, David Sillman, an outstanding engineer, came to work for HRI, remaining with the Company until 1975. He came from Westinghouse, where his last position was Engineering Manager of the TV-Radio Division. He had previously been a Hazeltine Corporation employee from 1944 to 1953. Since leaving HRI, he has continued to have a successful career in leadership positions at Public Broadcasting Service.

In 1965, the writer was made a Director of HRI and in 1967, as stated previously, Bill Swinyard was elected President of the Company and, at that same time, Kenneth P. Robinson and the writer were elected Vice Presidents.

During this same period, HRI did some laboratory work under contract for the parent Corporation. The work involved measurement of certain performance characteristics of foreign-made receivers to verify usage of foreign patents owned by Hazeltine Corporation.

By the mid '60's, Japanese TV receivers were being imported into the United States in large and ever-growing numbers. David Westermann, then President of HRI, and Ken Robinson, Hazeltine Patent Counsel and HRI Vice President, made a trip to Japan and, with the assistance of John B. Christensen, an American attorney living in Japan, began negotiations which eventually culminated in TV license agreements, most of which were executed in 1968. At the beginning of negotiations, representatives of the Japanese companies attempted to meet as a group with Hazeltine representatives. Mr. Westermann explained that, under constraints of U.S. anti-trust law, it was imperative that each company be dealt with individually, giving them the assurance that if concessions were made to one company, those same concessions would be made to all.

At first, there was evidence of caution and perhaps mistrust on the part of the Japanese, and in this first meeting they went into a huddle in a "side" conference, conferring in their native tongue, not realizing that John Christensen understood every word that was being said. A few moments later, he addressed them in fluent Japanese, somewhat to their embarrassment. However, they quickly learned that HRI was to be trusted and, once that point was reached, negotiation proceeded relatively smoothly.

In 1968, an Ad Hoc Committee on color television of the JCIC (Joint Committee for Intersociety Coordination) approached HRI to inquire whether or not we would be willing and able to set up an extensive series of color television tests to be run for representatives of the JCIC. The purpose of the proposed tests was to determine the effects on color television receivers of variation to the tolerance limits established by the FCC of the many critical parameters in the color television signal. For example, the effects of variation of the width, amplitude, phase, and delay of the color burst were to be observed on several different color television receivers. Although many man-hours of effort would be required to set up for these tests, it was concluded that the time would be well spent since the outcome would be highly beneficial to our licensee companies, and further, would give us an insight into problems that had not been studied to date.

Therefore, we agreed to proceed and, on December 18, 1968, a series of closed-circuit tests was run, beginning at 2 P.M. in the afternoon and running continuously until 7:15 P.M. The twenty-one JCIC representatives who were present made observations on four color television receivers of different manufacturers which had been provided by JCIC representatives. The tests ran exceptionally well under the supervision of Dave Sillman, and several observers commented that it was the first time in their experience that they had seen such complicated and extensive tests run without any malfunctions. The effective manner in which these tests were run did much to enhance HRI's image in the technical community.

After the group had returned from dinner, over-the-air tests began at 10 P.M. and continued until approximately 4 A.M. the following morning, December 19. A tired group adjourned at that time, taking with them reams of data to be evaluated and studied.

In other areas of professional activity, David Sillman and the writer served on the Administrative Committee of the IEEE Group on Consumer Electronics in the period 1968 through 1971. I had also served as the group's Awards Committee Chairman in 1967.

In 1969, the HRI staff size had grown to 19, and was busily engaged in a variety of projects. Several engineers at the time had expressed interest in topics in the rapidly-expanding electronics field which were not directly related to work in progress in the laboratory at the time. As an incentive to these enterprising engineers, and also with the thought that new business opportunities might result, a "discretionary-time" program was established. Under this program, an engineer could work on a project of his selection (with approval of management) up to four hours a week on company time with the use of laboratory facilities. Of course, he was free to use his own time beyond working hours as much as he wished. Although no new business opportunities resulted from this program, many of the engineers gained valuable knowledge in new areas which later proved to be of value to the company.

There were some interesting sidelights to this program. Two of our engineers had an interest in medical electronics and were jointly researching for areas to explore in this field. One thing they learned was that there was a need for a method of measuring blood pressure which would not alter the pressure of the individual being measured. They had contacted a doctor in one of the local medical research centers and had arranged a visit to his laboratory. During the visit, the doctor took them into a surgical room where a dog was undergoing experimental surgery. The anesthetized animal had numerous tubes connected between itself and a pump through which blood was flowing. While our engineers were standing watching the whole procedure somewhat squeamishly, one of the tubes broke loose and the animal's life blood began to squirt about in the room as the tube whipped wildly about. This experience had a dampening effect on their enthusiasm for medical electronics and, not long thereafter, they transferred their interest to other areas.

In 1970, HRI was busily engaged in preparing demonstrations to show the benefits of constant luminance. The program was complicated and time-consuming. Obtaining the type of pictorial information which would suitably show the benefits of constant luminance was difficult, and ultimately HRI purchased a broadcast-type video tape recorder. At this time, Arthur V. Loughren was engaged as a consultant to assist HRI in making choices as to the proper material to be displayed and the types of demonstrations to be run.

In this same period of time, Hazeltine Corporation had developed a Color Proof Previewer, which was designed to aid in the color printing process by greatly reducing costly time and materials involved in preparing color plates for the printing process. One unit was installed in a printing plant in the Chicago area, and HRI engineers assisted in the "de-bugging" of that equipment. Under agreement with the parent Company, similar assistance was given at other locations at later dates.

CHAPTER XI/C

DIFFICULT TIMES AND DECISIONS

The year 1970 was characterized by a series of mixed emotions at HRI. On the one hand, there was a reasonable degree of optimism, the Appellate Court had ruled essentially in HRI's favor in the Zenith litigation, yet there was growing concern as to how HRI would be able to develop new sources of income to justify its existence after the income-producing color patents had expired. Many advanced development projects were in process in the laboratory, but most were primarily related to color television. For the most part, they were directed toward finding unique methods of reducing cost and improving performance of color television receivers. However, one project which had been started in 1967 appeared to have unusual potential.

Some years earlier, the National Bureau of Standards (NBS) had developed a method of transmitting digital signals during the vertical interval of a television signal to transmit precise time information. Public Broadcasting Service (PBS) was also investigating the possibility of using this method of transmission to transmit so-called closed captions for the deaf. By this method, specially equipped receivers with decoders could pick up the digitally transmitted signals, decode them, and provide alpha-numeric captions on the television screen to go along with the pictures, thereby enabling totally deaf persons to follow the intelligence of the transmitted signal.

When the NBS work and PBS investigations were discussed by Swinyard, Loughlin, Page, and myself at HRI, it was concluded that Hazeltine had special techniques and know-how that might be applied in a different manner to transmit higher rates of information than were feasible with the method being employed by NBS. Specifically, Loughlin proposed the transmission of a low visibility subcarrier, sandwiched between the spectral information of the picture, in much the same manner as is employed with the color subcarrier. It was further thought that the low visibility subcarrier could be pseudo-randomly modulated to further improve its imperceptibility. As a result of these discussions, it was decided to proceed with a development program.

Early laboratory studies verified the feasibility of this approach. It was found that in typical picture material the video spectrum on the average had a minimum amount of information in the 2-1/2 MHz region. Thus, a subcarrier placed in this region would experience the least amount of video signal interference and could be kept at a very low level to minimize its visibility.

Once feasibility was established, an equipment-development program was undertaken.

As work progressed, it was realized that PBS' interest in captioning for the deaf might be a perfect way to promote our system. Therefore, after several discussions with PBS, HRI entered into a contract with them to build several items of equipment for tests by PBS. Under this contract, HRI delivered two encoders, 20 receivers modified to include decoders, and additional miscellaneous equipment to fully equip PBS to run a series of tests. The money received by HRI for its work helped to defray part of the development cost. A description of HRI's system is covered in a paper by Patrick T. King, entitled "A Novel Television Add-On Data Communications System", which was published in the Journal of the Society of Motion Picture and Television Engineers.[14] At HRI, the system had become commonly known as the AO system.

After a series of comparative tests, PBS decided to adopt the NBS system for transmission of programs captioned for the deaf. Our system had demonstrated superiority with respect to deterioration of error rate in the presence of multi-path signal transmissions and was described by PBS as being "rugged" in that respect. However, even though the AO subcarrier was judged as being virtually invisible, there was concern that it might become objectionable in the future when technological advances resulted in significantly improved signal-to-noise ratios in the transmitted pictures. There was keen disappointment at HRI, and PBS' decision, coupled with other events happening at that time, resulted in a decision by HRI management to discontinue further work on the project.

During this period of the early '70's, there were fewer and fewer requests by licensees for work by HRI. This was caused in large part by the fact that licensee laboratory equipment and personnel had become increasingly sophisticated and HRI no longer had the strong advantage it once had. As a result, our efforts to explore for new business opportunities intensified and we began to engage in contracts with outside companies for a wide variety of work. Under a contract with PBS, HRI did a survey and study of television tuner performance. Measurements were made with a wide variety of American, British, and European made television tuners. This was followed by a study to determine what cost and other factors would be involved in adapting some of the features of foreign tuners to American tuners.

Under another contract, we were engaged by a large Japanese television manufacturer to make measurements of X-radiation on a large number of its receivers. Its receivers had been found to have radiation in excess of established limits under certain circuit failure conditions. The program involved developing and testing methods of curing the problem. In still another project, HRI prepared and conducted a series of extensive closed circuit demonstrations for a local TV receiver manufacturer.

While all these measures were helpful and did produce income, they did not provide a solid basis for a business. During this period of the early '70's, David Sillman, Barney Loughlin, and I were busily engaged in traveling around the country making many contacts in the effort to develop business opportunities. Among our many contacts were television stations, television networks, television component and equipment manufacturers, subscription television proponents, cable television equipment manufacturers, cable television system operators, health equipment manufacturers, NASA, television rating services, university research groups, and, last but not least, Hazeltine Corporation. Discussions were held with many project leaders and division managers at Hazeltine Corporation for the purpose of exploring ways in which HRI could be of use. However, at that time, the Company was faced with a severe cash shortage, and generally these people were unwilling to part with scarce budget dollars. However, contacts made at this time did ultimately lead to a significant amount of work by HRI for the Color Analysis System Group at Hazeltine Corporation.

Mention was just made of a shortage of money at this time in the Corporation. It must be remembered that the Supreme Court decision in the Zenith litigation and the subsequent settlement agreement had imposed a severe financial problem on both the parent and HRI. To compound the problem, Franklin National Bank, with which Hazeltine Corporation had its line of credit, failed during this period leaving the parent without a source of funds. It was a time of acute shortage of money and tight credit in the country, and the Company was suddenly faced with a severe cash flow problem. To cope with the problem, austerity measures were adopted quickly, among them the unpleasant task of reducing the work force. In order to cooperate with the parent Company and make more cash available to it in this time of crisis, HRI reduced its force in 1971 to twelve people. Because of these considerations, and the further considerations that color royalty income was beginning to fall off rapidly due to expiration of patents, and the still further consideration that HRI had not been able to develop a substitute source of income, there was another reduction in force to six people in 1975. Essentially, what was left was a skeleton force to maintain the remaining licensee business.

Following the reduction in force in 1975, HRI continued to do work for the parent Company. A video disc recorder for the Proof Previewer manufactured by Hazeltine Corporation was developed and built by HRI under contract with the Color Analysis Systems Group at HC.

As noted previously, it had been found very difficult to get the various divisions and groups at Hazeltine Corporation to assign contract dollars for work at HRI. However, it was recognized at Hazeltine Corporation that HRI possessed unique knowledge and skills that could be of value to the parent Corporation. One area was in the field of raster displays. In particular, the Computer Terminal Equipment (CTE) division at Hazeltine Corporation was desirous of manufacturing displays which they had been purchasing on the outside.

In order to gain the confidence of the CTE group, HRI officers decided to offer to design a display for a particular terminal at cost. This move was successful. HRI then decided to risk its own money in the development of a display for the next terminal to be produced by the CTE division. Under terms of an agreement, if the design was acceptable to CTE, a royalty was to be paid to HRI on each unit manufactured and sold. Accordingly, a display was designed for the Model 1400 terminal; its success resulted in the return of significant royalties to HRI. However, the risk money spent in developing a display for the word processor did not yield any return on its investment, since the word processor project was cancelled by the parent before there had been appreciable sales. Likewise, the sales of the Executive 80 computer terminals were insufficient to yield an adequate royalty return on the money invested in the development of its display.

Bob Tschannen had very capably supervised the development of the various computer-terminal displays, and had worked closely with HC CTE personnel in getting the units into production. Thus, there was genuine concern when he unexpectedly announced his intention to retire early, toward the end of 1980. However, the impact of his retirement on HRI's work for HC's CTE Division was not as great as first anticipated. By that time, the computer-terminal business had become highly competitive, with foreign products beginning to dominate the market. In response to the price pressures, HC at first went "off-shore" for the design and manufacture of its terminals and ultimately sold the business early in 1983. Thus, by 1981, the design of computer terminal displays had ceased at HRI.

In 1977, another business opportunity, AM stereo, had appeared, a story which will be related in the next chapter. That same year, HRI explored the possibility of moving to a new location in which space would be shared with HC's Midwest CTE sales office.

There appeared to be a possibility of some cost savings for each party. However, after a rather thorough examination of several premises, the project was abandoned. HRI's space needs were judged to be too austere for a sales office.

Finally, in 1980, the decision was reached to relocate HRI's office and laboratory to smaller quarters in Elmhurst, Illinois, a Western suburb of Chicago. Because of space constraints, it was necessary to plan the move very carefully. Ron Groll supervised the project and, prior to the move, had developed a master layout, showing the location in the new quarters of every piece of furniture and equipment. With his careful planning, the move was accomplished with relative ease on a Saturday in April of 1981.

During this difficult period in the life of the Company, HRI people had been active in their professional groups. The writer was a member of the Board of Governors of the IEEE Broadcast, Cable, and Consumer Electronics Society in 1976 and '77, and was Chairman of that Society's Awards and Fellow Committee in 1977. Bob Tschannen and I also were members of the IEEE Consumer Electronics Group Administrative Committee from 1976 to the end of the decade. I was also a member of the IEEE Zworykin Award Committee in 1978, '79, and '80. During the early part of the decade, David Sillman, Vice President at HRI, had been Chairman of Panel III of Cable Television Advisory Committee (CTAC). Barney Loughlin was also active on CTAC and was a member of an Electronic Industries Association Committee which developed the standards for the Vertical Interval Reference signal.

Hazeltine personnel had also received honors for their work in the field of consumer electronics. The IEEE Consumer Electronics Group had presented its Consumer Electronics Award to Barney Loughlin, HRI Vice President, in 1972 for pioneering innovation in color television circuits and systems. In 1973, the award went to Bill Swinyard, then retired but Chairman of HRI's Board, for development of measurement techniques and standards. In 1974, the award went to Art Loughren, consultant to HRI, for contributions to the establishment of monochrome and color-television system standards.

CHAPTER XII/C

AM STEREO, A BRIGHT SPOT ON THE HORIZON

Just as there had been an evolution from radio to monochrome television to color television, there had also been an evolution within the field of radio itself. In 1924, when Hazeltine Corporation had been formed, the method of broadcasting sound was by amplitude modulation, better known as AM. As time went on, new knowledge was gained, and it became apparent that a different form of modulation, frequency modulation, or FM as it is commonly known, had distinct advantages. Therefore, in 1940, the FCC approved standards for broadcasting frequency modulation in the frequency range of 42 to 50 MHz. Later, after World War II, the FCC approved the present 88 to 108 MHz band for FM broadcasting.

Although FM had some definite advantages over AM radio, FM broadcasting had a difficult time competing with AM in the early days. AM radio had become so firmly entrenched that FM radio had a difficult time capturing the audience. However, as a further step in the evolution of radio, various laboratories began investigating methods of transmitting stereophonic sound through the FM channel. In 1961, the FCC, hoping to improve the competitive position of FM broadcasters, adopted standards which provided for stereophonic transmission on FM. The system is compatible, meaning that monophonic FM receivers can receive the stereophonic broadcast monaurally.

In this same time frame, a Mr. Leonard Kahn, an inventor residing on Long Island, had developed a system for broadcasting stereophonic sound compatibly over the existing AM channels. In the mid '60's, Mr. Kahn petitioned the FCC to approve his AM stereophonic system. Because FM broadcasting was having difficulty in getting started and, further, because the FCC had assumed a protective stance for FM, Mr. Kahn's petition was denied. The essential reason given by the FCC for denial of the petition was that the addition of stereo to AM would be detrimental to the development of FM broadcasting.

The matter of AM stereophonic broadcasting laid dormant for several years until a renewal of interest in the '70's. By 1977, Mr. Kahn's company, Kahn Communications, Inc., had again petitioned the FCC for approval of his single-sideband AM stereo system. However, by this time, four other companies had developed AM stereo systems of their own and were competing for FCC approval. Those companies were Magnavox Consumer Electronics Company, Motorola, Inc., Harris Corporation, and Belar Electronics.

Although all of the five systems were compatible with monophonic AM receivers, none of the systems were compatible with each other.

After an in-depth analytic study of all five AM stereo systems by B. D. Loughlin, Hazeltine Corporation (HC) entered into an agreement with Kahn Communications, Inc., in September, 1977. Under that agreement, HC had ownership and licensing responsibility for the Kahn AM stereo patents.

HC then requested that HRI run laboratory tests to evaluate the system performance of what had now become known as the Kahn/Hazeltine AM Stereo System, also referred to as the ISB (Independent Sideband) AM Stereo System. Both exciters and receivers, to be provided by Kahn Communications, Inc., were to be evaluated. We agreed to be responsible for these measurements, but a complicating element arose in that Mr. Kahn did not wish to ship his equipment to the Chicago area. He felt that the equipment was so scarce that he had to have it available to him if he should require it.

Therefore, arrangements were made with Hazeltine Corporation to make laboratory space available to HRI at Greenlawn, New York. An engineer and two engineering aides were also made available to assist in the tests. Because of difficulties too numerous to mention, what had originally been planned as a one or two week measurement program ultimately stretched out into a thirteen week program, covering the months of November and December of 1977 and January of 1978. New Yorkers tend to have a view of Chicago as having very bitter winter weather. However, that winter in New York was one of the worst the writer has experienced. There were warm spells with fog, moderate spells with sleet and ice storms which closed down the plant for a day or two at a time on two or three separate occasions, and then very severe rain storms followed by a severe drop in temperature which resulted in streets full of rutted ice. I hope to never experience that type of winter again.

In spite of all the difficulties, the tests were completed and Hazeltine Report No. 6333, entitled "Laboratory Performance Measurements of the Independent Sideband AM Stereo System", was finally issued in February of 1978.

During this period of activity, Edward A. Onders, HC Associate General Counsel, accepted responsibility as business manager for the AM stereo work and, in that capacity, has very capably coordinated the efforts of HC and HRI. He has been the liaison contact with Mr. Kahn and with the "outside world" in general, including the FCC, the press, and potential licensees.

Recognizing the potential for developing a source of future income, HRI embarked on an AM stereo development program as soon as the measurement program was completed. This work was undertaken with the close cooperation and consultation of B. D. Loughlin. Since HRI did not possess AM stereo equipment, the first project undertaken was the development of an encoder for the ISB AM Stereo System. Before the encoder development had been completed, work was also started on the development of an AM stereo decoder for an ISB receiver. This development program continued on into 1979 and, during the course of development, several side studies were conducted. Several forms of inverse modulator were investigated, as well as many different types of phase-lock-loops. Mr. Loughlin also developed software for programmable calculators to enable us to make rapid calculations of many of the parameters required for the phase-lock-loops.

The encoder design had been completed in 1978 and, in 1979, the receiver design was completed. In order to demonstrate the ruggedness and adaptability of the ISB AM Stereo System, a decision had been made early-on to incorporate the ISB decoder in receivers of the moderate price class. Accordingly, decoders were installed in a Realistic (Radio Shack) table model receiver and an Audiovox auto receiver. Kahn Communications then took the design and assembled a goodly quantity of both the table model and auto receivers, which were distributed to broadcasters throughout the United States for field test purposes. The units functioned very well and resulted in very favorable responses with regard to the ISB system.

One of the early criticisms of the ISB system was that the receivers required so-called 90° circuits. These circuits are required to provide a relatively constant 90° difference in phase between two signal paths in the receiver over a relatively wide frequency range. There was little prior art literature, and our competitors had concluded that these 90° circuits would be difficult to implement and very costly. However, Dr. Harold A. Wheeler studied the problem and developed a series of simple design procedures which enabled us to produce reliable circuits at low cost. Initially, it had been thought that two time constants would be required in each signal path. However, Mr. Loughlin conceived a method of employing the low frequency phase-shift in the phase-lock-loops in the IF as a substitute for one time constant in one of the signal paths.

This early decoder design did not incorporate a pilot tone detector. (Each of the various AM stereo systems has its own pilot tone frequency, the pilot of the ISB system being at 15 Hz.) At the time the first decoder design was concluded, HRI was not satisfied that it had a reliable pilot tone detector, and it was not until some time later that a successful design was achieved.

During 1979, in addition to the receiver design work, there were several separate investigations of various parts of the receiver-decoder circuitry. Several inventions resulted, and a significant amount of time was spent in reducing to practice some of Mr. Loughlin's inventions. Included were a two-tone pilot detector system and a zero-tweet receiver. The latter invention involved the concept of controlling the frequency of the clock oscillator in a receiver with a synthesized tuner in such a way that the frequency difference between a harmonic of the intermediate frequency and the signal frequency was always reduced to zero, thereby making the tweet inaudible.

In February, 1980, HRI purchased Mr. Kahn's U.S. patents from Hazeltine Corporation and assumed the responsibility for licensing them. In April of that year, the FCC issued a report and order authorizing transmission of AM stereo by the Magnavox System. This decision was immediately followed by a loud outcry from broadcasters, who asserted that the Magnavox System's limitations would result in a loss of listening audience for them. The objections were so great that the FCC ultimately issued a new report and order.

Because of the FCC action in 1980, there was great uncertainty as to the ultimate outcome of the AM stereo "race". Therefore, during that year, HRI's AM stereo laboratory work was on a much lower priority than previously. Meanwhile, HRI's work for the Computer Terminal Equipment (CTE) division of Hazeltine Corporation continued, and a study program directed toward the development of a high-resolution color monitor for the CTE division was initiated. A search for new quarters was also begun late that year.

Early in 1981, there was a significant amount of work directed toward troubleshooting of early production models of displays for Hazeltine Corporation's Opus 80 Word Processor and the Executive 80 Computer Terminal. That year, National Semiconductor also introduced an integrated circuit, the LM-1981, designed to decode the Magnavox AM stereo system. HRI undertook an investigation of the performance of that chip as a Magnavox System decoder, but additionally adapted it to the Kahn/Hazeltine System. While the IC functioned about as well for the Kahn/Hazeltine System as it did for the Magnavox System, its performance was significantly inferior to the performance of circuits that had been developed at HRI.

Later in 1981, when it became apparent that the FCC was going to be forced to reconsider its AM stereo decision, HRI's laboratory work on AM stereo was again given a high priority. Among topics investigated that year was the matter of stereo separation. Many significant and interesting facts came out of that study. There was also a study of simplified all-pass 90° circuits. However, as the year came to an end, the future of AM stereo was still highly uncertain. Rumors abounded that the FCC was about to withdraw approval of standards for the Magnavox system and would approve one of the remaining systems.

There was, however, a strengthening movement toward deregulation in the federal government and, by the end of 1981, there was reasonable expectation that the FCC would make a so-called "marketplace" decision, i.e., approve stereo transmission by all systems, rather than a single system.

CHAPTER XIII/C

HRI AND THE AM STEREO MARKETPLACE

Following a lengthy period of uncertainty, the FCC, on April 26, 1982, issued its "marketplace" ruling, authorizing broadcasting of AM stereo by any of the competing systems. While radio receiver manufacturers and the other system proponents were not happy with the decision, many broadcasters and, in particular, those who were backing the ISB system, were enthusiastic. The decision, of course, was a great boost to the hopes of Kahn Communications, Inc., and Hazeltine, since there was always confidence that technically the ISB system would perform favorably in the face of competition.

Eventually, Belar withdrew from the competition and, though Magnavox remained in the race for a while, its system was no longer able to attract support following the strong adverse reaction of broadcasters after the FCC made its first decision in Magnavox's favor. Also, in August, 1983, the FCC ordered Harris to discontinue sales of its stereo exciters and, additionally, ordered broadcasters using the Harris system to discontinue AM stereo broadcasting until certain equipment problems were resolved. It was asserted that technical changes, not type approved by the FCC, had been introduced by Harris into its exciters. The problem was resolved fairly quickly, but Harris suffered a setback which undoubtedly contributed to its eventual decision to withdraw from the AM stereo race. Thus, in 1984, only the Kahn/Hazeltine and Motorola systems remained in the marketplace in strength, and the competition between the two continues to the date of this writing.

Early in the AM stereo race, it had been concluded that the probability of success for the Kahn/Hazeltine ISB system would be greatest if there were multi-system receivers in the marketplace rather than single-system receivers. Judgments based on full system performance comparisons could then be made easily, and there has always been confidence that the ISB system's superiority would prevail under such conditions.

Much of HRI's activity following the FCC marketplace decision centered on development of various forms of multi-system decoder circuits, including the development of reliable pilot-tone detection for automatic switching of the decoding circuits from one system to the other. Also, an improved ISB encoder was developed using HRI-designed audio encoding circuits in conjunction with a commercially available signal generator capable of simultaneous phase and amplitude modulation. The performance was excellent, and it was decided that the encoding circuits should be packaged attractively and made available to receiver manufacturers. This was done and several units were sold. Encoders for the Magnavox, Harris, and Motorola systems were also developed to assist in evaluation of receivers.

The performance of many AM stereo receivers, including both single and multi-system types, was measured in the laboratory for purposes of performance comparisons and patent usage determination. Sony and Sansui receivers were among commercially available multi-system receivers evaluated.

HRI also cooperated in a program undertaken by HC to develop an integrated circuit for AM stereo decoding. HRI's role involved development of test procedures and the measurement of performance of a breadboard model. However, the contractor responsible for the IC design, Analog Systems Division of J. R. Conwell Corporation, eventually went into bankruptcy, and the project was not completed.

Late in 1982, Motorola introduced a low-cost integrated circuit dedicated solely to decoding the Motorola AM stereo signal. This release caused quite a stir in the radio industry, and there were claims that the AM stereo race was over, that Motorola had won. However, with full confidence in the ISB system, Kahn Communications and Hazeltine continued to aggressively push to maintain a solid competitive position for the system. Although the Motorola IC has found application in significant numbers of receivers, particularly for certain General Motors automobiles, the predicted stampede of broadcasters and receiver manufacturers to get on the Motorola "bandwagon" has not taken place, and the ISB system remains a viable contender. However, the competition has been difficult. Neither Kahn Communications nor the Hazeltine Companies begin to have the resources available for system promotion and marketing that have been expended by Motorola. Survival of the Kahn/Hazeltine system against such great odds is testimony to the excellence of the system.

In spite of all the developments and activity in the marketplace, AM stereo has not experienced great growth. HRI continues to believe that widespread availability of multi-system receivers may well provide the impetus for more rapid market growth.

Late in 1984, Sony introduced a multi-system set of two IC's which provided automatically-switched decoding for the Kahn/Hazeltine, Motorola, Harris and Magnavox systems. Performance was good, costs were reasonable, but, apparently because of the space required to accommodate two IC's, there has not been wide application.

More recently, Sanyo has developed a single IC for decoding the Kahn/Hazeltine, Motorola and Magnavox systems, with automatic switching. However, production quantities will not be available until late 1988, and the impact on the market is not known as of this writing.

In view of the delay in development of the AM stereo market, HRI discontinued its laboratory activity in Elmhurst, Illinois, on March 31, 1985. The HRI corporate office was moved to smaller quarters in the same building, where it remains today, with the writer serving as consultant to HRI on technical and patent-related matters. Several technical notes dealing with various aspects of AM stereo, especially system comparisons, have been written and released to receiver manufacturers (and others) during this period.

While the light of AM stereo still shines on the horizon, at this time one cannot safely predict the ultimate outcome of the marketplace race. However, reasonable probability remains that HRI will be in the patent licensing business for some time to come.

As a final word, this historic account has concentrated somewhat on HRI's engineering activities. However, many people on Hazeltine Corporation's legal staff have (through intercompany agreements) played a highly significant role in HRI's history. Of particular importance are Kenneth P. Robinson (HRI Vice President and Secretary, and Hazeltine Corporation Vice President and General Counsel) and Edward A. Onders (HRI Vice President and Assistant Secretary, and Hazeltine Corporation Associate General Counsel). These men played key roles in the patent licensing activities of HRI for many years, and much credit for successes the Company has enjoyed is due them.

- THE END -

REFERENCES

1. Harold Alden Wheeler, The Early Days of Wheeler and Hazeltine Corporation, Profiles in Radio and Electronics, Greenlawn, New York, Hazeltine Corporation, 1982, p. 85.

2. Electronic Industries Year Book - 1967, pp. 9 and 13, published by the Electronic Industries Association.

3. B. D. Loughlin, The Revolution and Evolution from Dot Sequential to NTSC, IEEE Transactions on Consumer Electronics, Vol. CE-30, No. 2, May, 1984, p. 19.

4. George H. Brown, and part of which I was, Recollections of a Research Engineer, Princeton, New Jersey, Angus Cupar Publishers, 1982, p. 213.

5. ibid, p. 217.

6. ibid, p. 218.

7. Final Report of the National Television Systems Committee, Vol. I.

8. S. P. Ronzheimer and R. J. Farber, Tentative Methods of Measurement of Color Television Receiver Performance, IRE Transactions on Broadcast and Television Receivers, Vol. BTR-2, No. 1, April, 1956, pp. 10-30.

9. Report of the Television Allocations Study Organization to the Federal Communications Commission, Engineering Aspects of Television Allocations, March 6, 1969, pp. 678 and 680.

10. The Hazeltine Staff, Knox McIlwain and Charles E. Dean, Editors, Principles of Color Television, John Wiley and Sons, Inc., N.Y., N.Y., 1956.

11. Robert F. Tschannen and Emmet J. Duffy, Equipment and Techniques for Simplified Testing of Color TV Receivers, IRE Transactions on Broadcast and Television Receivers, Vol. BTR-8, No. 3, Nov., 1962, pp. 68-77.

12. Stephen P. Ronzheimer, A New Approach to the DC-Restoration Problem, IRE Transactions on Broadcast and Television Receivers, Vol. BTR-8, No. 3, Nov., 1962, pp. 39-55.

13. Chicago Spring Conference Hi Lites, IRE Transactions on Broadcast and Television Receivers, Vol. BTR-9, No. 2, July, 1963, p. 4.

14. Patrick T. King, A Novel Television Add-On Data Communication System, Journal of the Society of Motion Picture and Television Engineers, Vol. 83, No. 1, January, 1974, pp. 10-13.

APPENDIX I/C

OFFICERS AND DIRECTORS OF HAZELTINE RESEARCH, INC.

Incorporated - State of Illinois - March 28, 1946.

Incorporators

Howard A. Will	3/27/46 to 3/28/46
A. Willard Adcock	3/27/46 to 3/28/46
M. G. Lettola	3/27/46 to 3/28/46

Directors

Jack Binns	3/28/46 to 12/8/59
W. A. MacDonald	3/28/46 to 10/14/49
W. H. Grimditch	3/28/46 to 12/15/48
Paul Armitage	3/28/46 to 6/28/49
L. B. Dodds	3/28/46 to 6/4/63
John D. Grayson	5/21/47 to 11/17/48
E. H. McDermott	5/21/47 to 10/22/47
D. F. J. Shea	1/1/49 to 12/31/57
Philip F. LaFollette	10/13/49 to 1/6/55
E. H. McDermott	10/13/49 to 6/23/82
Jack Binns, Chairman	4/16/52 to 12/8/59
John F. Cusack	6/7/55 to 6/23/82
W. O. Swinyard	1/6/58 to 6/23/82
Dudley E. Foster	2/9/60 to 2/9/63
E. A. Ruestow	2/9/60 to 6/1/65
M. Hudson Rathburn	6/7/61 to 5/13/66
Webster H. Wilson	6/7/61 to 6/18/63
W. M. McFarland	6/4/63 to 12/8/63
John Slezak	6/4/63 to 6/23/82
David Westermann	12/18/63 to 12/5/78
Stephen P. Ronzheimer	6/1/65 to
Bernard D. Loughlin	12/5/78 to
E. A. Onders	6/23/82 to 6/24/82
Samuel Weisbard	6/23/82 to

Chairman of the Board

Jack Binns	4/7/52 to 12/8/59
W. O. Swinyard	1/1/71 to 6/2/81
Bernard D. Loughlin	6/2/81 to 3/19/85
Stephen P. Ronzheimer	3/19/85 to

Chairman Emeritus

W. O. Swinyard	6/2/81 to 6/23/82

OFFICERS

President

Jack Binns	3/28/46 to 4/16/52
L. B. Dodds	4/16/52 to 6/7/61
Webster H. Wilson	6/7/61 to 6/18/63
W. M. McFarland	6/18/63 to 12/8/63
David Westermann	12/18/63 to 12/31/66
W. O. Swinyard	1/3/67 to 12/31/70
S. P. Ronzheimer	1/1/71 to 3/29/85
B. D. Loughlin	3/29/85 to

Executive Vice President

L. B. Dodds	3/28/46 to 4/16/52
A. V. Loughren	4/16/52 to 5/11/56
E. A. Ruestow	6/7/61 to 6/16/64

Vice President

W. A. MacDonald	3/28/46 to 10/13/49
W. H. Grimditch	3/28/46 to 12/15/48
D. F. J. Shea	1/1/49 to 12/31/57
C. J. Hirsch	6/13/56 to 10/2/59
W. O. Swinyard	1/6/58 to 1/3/67
Dudley E. Foster	2/9/60 to 2/9/63
E. A. Ruestow	2/9/60 to 6/7/61
B. D. Loughlin	7/10/62 to 3/29/85
Samuel M. Thomas	12/4/62 to 6/1/65
E. A. Ruestow	6/16/64 to 6/1/65
Stephen P. Ronzheimer	1/3/67 to 12/31/70
Kenneth P. Robinson	1/3/67 to
D. Sillman	1/1/71 to 2/28/75
E. A. Onders	3/29/85 to

Treasurer

John D. Grayson	3/28/46 to 11/17/48
Jack Binns	11/17/48 to 6/13/56
W. O. Swinyard	6/13/56 to 12/31/70
S. P. Ronzheimer	1/1/71 to 3/29/85
V. J. Franzino	3/29/85 to

Assistant Treasurer

Bennett Eskesen	4/21/48 to 6/15/55

Secretary

Paul Armitage	3/28/46 to 6/28/49
E. H. McDermott	10/13/49 to 6/24/82
K. P. Robinson	6/24/82 to

Assistant Secretary

W. M. McFarland	3/28/46 to 6/6/50
H. C. Page	3/28/46 to 4/17/47
Frank D. Crotty	4/17/47 to 4/20/49
W. O. Swinyard	10/22/47 to 12/31/57
John A. Harvey	4/21/48 to 4/20/49
John K. Gowan, Jr.	4/20/49 to 6/17/53
Carol B. Scott	6/16/54 to 6/7/61
Stephen P. Ronzheimer	1/6/58 to 12/31/70
Frank H. Boos, Jr.	5/4/62 to 6/16/64
Marie McCarthy Klang	2/7/67 to 11/4/70
D. Sillman	1/1/71 to 2/28/75
A. A. Karnstedt	1/1/71 to 3/29/85
E. A. Onders	7/25/78 to

Manager

D. F. J. Shea	4/21/48 to 12/31/57

Registered Agent

W. O. Swinyard	3/20/47 to 12/31/70
S. P. Ronzheimer	1/1/71 to

APPENDIX II/C

HRI PERSONNEL*

Employee	From	To	Position, Remarks
Melvin Narcus Beaduette	12/21/43	8/31/45	Expediter
Alan Doyle Bedford	7/17/67	7/2/71	Engineer
Albert Martin Bellamy	4/3/44	12/30/45	Shop Assistant
Anna M. Berner	7/17/70	10/27/70	Accountant
Robert E. Boe	10/7/57	7/17/59	Technician
Bemrose Boyde	6/22/39	8/22/41	Engineer
Robert Brunn	10/3/39	7/7/41	Engineer
C. T. Carroll	7/7/41	1/14/44	Engineer
Beatrice Cibull	6/9/42	2/13/43	Secretary
Virginia M. Coupe	1948	9/17/48	Secretary
James A. Cudney	7/49	1950	Engineer
Celia Rudner Dank	12/20/43	5/13/44	Assembler
Rinaldo E. DeCola	4/1/48	6/23/50	Engineer
Anne C. Dohnal	1/9/67	1/17/69	Secretary
Edward J. Dohnal	5/5/69	2/28/75	Technician
Emmet J. Duffy	10/43	12/31/70	Engineer
LaVerne Eckebrecht	2/14/66	1968	Secretary
Paul J. Evan	8/14/72	1/12/73	Technician
William Clifford Fifer	8/17/64	2/25/66	Engineer
Martin Fox	3/20/39	4/25/41	Left for U.S. Navy
re-employed	10/29/45	10/23/48	Engineer
Carl F. Giacobone	10/19/70	7/14/72	Technician
Ronald A. Groll	4/11/60	3/29/85	Engineer
Allan R. Hambley	6/15/64	1/28/66	Engineer
Ruth Hansen	8/30/37	12/9/37	Secretary
Anna E. Hebel	1/44	1/31/67	Secretary
Irvin T. Hill	1/24/44	8/31/45	Expediter
Anne Janus	4/4/39	7/12/40	Secretary
Paul O. Jensen	1939	12/31/70	Shop Superintendent

*Prior to March 28, 1946, personnel were employees of Hazeltine Service Corporation and/or Hazeltine Electronics Corporation. (See Chapter I/C.)

Edward W. Johanson	6/23/54	4/13/56	Engineer
J. Kelley Johnson	1937	1942	Manager
Arthur A. Karnstedt	10/26/70	3/29/85	Accountant
Russell A. Kasmar	7/2/45	6/46	Engineer
Leo Killian	1/11/44	10/28/45	Engineer
Patrick T. King	2/2/70	3/14/75	Engineer
Marie M. Klang	1/4/60	11/13/70	Bookkeeper
Everette Krewson	6/3/57	4/3/81	Custodian
Mary E. Labno	1937	11/25/59	Secretary
Wanda Lelewski	7/15/40	9/3/40	Secretary
Jerone W. LeMaster	10/46	9/29/50	Technician
Donald W. Majer	4/15/63	5/3/63	Engineer
Meyer Marks	4/8/63	9/11/64	Engineer
Beatrice Marron	9/11/40	5/15/42	Secretary
Arthur L. Martinson	2/28/44	1944	Shop Assistant
James G. Matt	2/16/48	10/20/50	Engineer
Richard B. McFarland	7/47	9/47	Engineer
Robert J. Meersman	7/10/50	3/19/54	Engineer
Madeleine M. Morris	7/24/44	2/22/46	Secretary
Colbert N. Nakata	10/9/50	8/30/57	Engineer
Patrick Nugent	3/31/70	3/7/75	Engineer
C. A. Nye, Jr.	3/13/39	7/25/39	Engineer
Robert H. Peirce	7/1/41	3/26/43	Engineer (Coop student)
Chad Bowen Pierce	1942	9/2/49	Engineer
Joseph P. Polercky	4/20/64	5/14/71	Technician
James H. Pomerene	6/1/42	11/9/42	Engineer Transferred to HC
Panayiotis G. Portoulas	6/8/63	8/25/67	Engineer
Abraham Rade	4/30/42	7/17/42	Shop Assistant
Glenn W. Randolph	3/3/41	10/25/43	Engineer Transferred to field service
Erwin Rapp	1948	12/31/48	Shop Assistant
Richard A. Rikoski	5/12/69	8/29/69	Engineer
Stephen P. Ronzheimer	5/25/42	3/29/85	Engineer, Pres., Treas.
Melvin Ross	3/21/47	1948	Engineer
Theodore S. Rzeszewski	6/12/67	7/2/71	Engineer
Chesterine E. Satkiewicz	1/6/69	8/5/77	Secretary

Donald A. Schmutz	3/5/73	12/31/74	Technician
R. Adm. D. F. J. Shea	1/2/48	12/31/57	Manager
Mayme P. Sheldon	8/24/70	9/28/70	Bookkeeper
Sotirios I. Sideris	8/20/62	4/27/73	Engineer
David Sillman	4/15/68	2/28/75	Vice President, Engineering
I. H. Speice	9/20/37	1944	Shop man
Walter R. Strauss	6/20/38	June, 1939	Engineer
Betty M. Stuenkel	5/11/81	3/29/85	Exec. Secretary
W. O. Swinyard	1930	12/31/70	Engineer, Pres., Treas.
Robert F. Tschannen	4/1/48	12/5/80	Engineer
Rimantas L. Viatkus	9/21/64	9/15/68	Engineer
C. Robert Wallingford	8/66	5/2/75	Engineer
William J. Weishar	6/27/46	6/27/47	Engineer
Duraine E. Welch, Jr.	6/30/69	6/18/71	Engineer
Howard C. Wenger	4/26/44	4/23/45	Shop Assistant
Zbigniew Wiencek	3/9/64	6/17/66	Engineer

APPENDIX III/C

THE WALL STREET JOURNAL
February 25, 1971

Zenith Is Entitled to $19 Million in Damages From Hazeltine Unit, Supreme Court Rules

By a WALL STREET JOURNAL *Staff Reporter*

WASHINGTON — The Supreme Court said Zenith Radio Corp. is entitled to collect triple damages of about $19 million from Hazeltine Research Inc. to conclude "this marathon litigation" that involved foreign patent pools and Zenith's sales losses in Canada.

The litigation began more than a decade ago, and Zenith initially sought damages of about $35 million for alleged loss of sales in England and Australia as well as Canada. But the high court's conclusion that Zenith is entitled to damages of $19 million for Canadian losses represents a substantial victory for the Chicago-based company. However, it still appears unclear how much Zenith will be able to collect.

In 1969, when the case was before the Supreme Court, the court said that Hazeltine Corp., Hazeltine Research's parent, wasn't a party to the case inasmuch as Zenith in its original action named the research unit but not the parent. The court thus seemed to be saying that Zenith could collect only from Hazeltine Research.

But a Zenith lawyer yesterday said Zenith still insists that the parent and the research unit are "one and the same" and that Zenith intends to collect the full amount. He added that the $19 million award plus interest and litigation expenses will bring Zenith's total claim to more than $25 million.

The apparent difficulty is that Hazeltine Research, a wholly owned subsidiary of Hazeltine Corp., has total assets "considerably less" than $19 million, according to its lawyers. In 1969, at the time of the last high court ruling, Hazeltine said the subsidiary's total value was about $5.5 million.

A lawyer for Hazeltine Research yesterday also insisted, contrary to the position taken by the Zenith attorney, that under the Supreme Court's 1969 decision Zenith can collect only from the subsidiary and that Hazeltine Corp. isn't liable.

In Yesterday's opinion, the high court said nothing about who is to pay. Zenith, if it insists that Hazeltine Corp. shares liability, apparently would have to make that argument in a lower court.

The long and complex litigation originally was begun in 1959 by Hazeltine Research, which sued Zenith for patent infringement. Hazeltine Research owns and licenses the use of a number of patents in the radio and television fields and it belonged to patent pools that licensed the use of patents in certain foreign countries. The original suit accused Zenith of infringing by selling its U.S.-made radios and TV sets in such countries without licenses from the pool members.

Zenith countered with its own suit charging that American companies' membership in the foreign pools violated U.S. antitrust laws and asking triple damages for sales losses that Zenith allegedly suffered because of the pool operations. In the first round, a federal district court held that Zenith hadn't infringed and that it was entitled to triple damages totaling about $35 million as a result of sales losses in England, Australia and Canada.

The federal appeals court in Chicago agreed on the infringement issue but said Zenith wasn't entitled to damages because it hadn't proved sales losses. Then the Supreme Court, in 1969, ruled that Zenith was entitled to damages for losses it suffered in Canada but not in England or Australia. The high court didn't mention any figure, but sent the case back to the appeals court "for further proceeding consistent with this opinion."

Back in the appeals court, Zenith argued that the high court's decision meant that the district court's original award of Canadian damages, totaling $19 million when tripled, was to be reinstated. But the appeals court disagreed. It narrowed the time period for which Zenith could collect damages relative to Canadian sales losses and sent the case back to the district court to decide what, if any, damages Zenith was entitled to.

At that point, Zenith again appealed to the Supreme Court. The high court in a unanimous decision held that the appeals court erred and ordered that court to "reinstate the judgment of the district court."

In New York, Hazeltine issued a statement that the ruling "is being considered with counsel." The company didn't have any other comment.

Zenith is "delighted with the Supreme Court decision ordering the court of appeals to reinstate" the district court decision, Joseph S. Wright, chairman, said in Chicago.

APPENDIX III/C

The Wall Street Journal
February 25, 1971
p. 5

APPENDIX IV/C

NEW YORK TIMES

April 30, 1971

NEW YORK TIMES - April 30, 1971

Hazeltine to Pay Zenith $22-Million In Suit Settlement

By WILLIAM D. SMITH

The Hazeltine Corporation and Hazeltine Research, Inc., agreed yesterday to pay the Zenith Radio Corporation $22.5-million in cash and credits in settlement of a 13-year-old antitrust suit that was carried as high as the Supreme Court.

The settlement calls for a $16.5-million cash payment, including an initial payment of $6.3-million to be made today and deferred cash payments to be made over a period not exceeding five years.

In addition to the cash payments Zenith will receive licenses from Hazeltine Research, Inc. and Hazeltine for all inventions in being in the field of consumers home entertainment electronic products with royalty obligations chargeable against a $6-million credit established by the settlement.

The litigation began in 1958 with the filing of a patent infringement suit by Hazeltine Research against Zenith. Ze-

Continued on Page 57, Column 8

HAZELTINE TO PAY ZENITH 22-MILLION

Continued From Page 53

nith responded with a counter-suit alleging that Hazeltine patents were being used in foreign patent pools to prevent the export of American-made radio and television sets to foreign markets.

Zenith had originally been awarded $38.7-milion in damages by Federal District Court in Chicago. The figure was reduced to $19-million in subsequent legal actions.

A spokesman for Hazeltine said that the settlement has removed the prospect of further protracted, costly and burdensome litigation between Zenith and Hazeltine Corporation so that Hazeltine can pursue its planned operations for its defense business and new industrial products."

He said that "While the settlement payments are the primary obligations of Hazeltine Research, Hazeltine Corporation will make additional investments in Hazeltine Research, including the transfer of one of its facilities at Greenlawn, L. I., having a value of approximately $4.6-million, to assure Hazeltine Research's ability to earn income and pay its obligations to Zenith."

APPENDIX D

HAZELTINE SERVICE CORPORATION

REPORT NO. 1157W

A PHASE CURVE TRACER FOR TELEVISION

October 29, 1940

A PHASE CURVE TRACER FOR TELEVISION*

by
B. D. Loughlin

* Prepared for presentation at the Rochester Convention of the I.R.E. on November 11, 1940

Introduction

The desirability of investigating the phase characteristics of television systems has been generally recognized. However, the time involved in making the necessary measurements with usually available equipment has limited such investigations. A solution for the situation lies in the construction of a phase curve tracer which produces a curve showing the variation with frequency of the phase angle between the input and output voltages of a system.

The device to be described shows on the screen of a cathode-ray tube the phase characteristics of any circuit between 0.1 and 5 megacycles. Frequency and phase coordinates are also produced, giving a visual effect of a phase curve plotted on graph paper.

To trace out a phase curve on a cathode-ray tube with linear coordinates, a horizontal sweep is needed which produces a deflection that is a linear function of frequency, together with a phase angle indicating device which produces a vertical displacement that is a linear function of phase angle. A device which indicates phase angles by measuring the time interval between corresponding reference points, such as intercepts or peaks of the two sine waves, can be made to fulfill the latter requirement; but it is preferable that this type of indicator operate at a constant frequency. Thus the apparatus to be described can broadly be divided as:

The Indicator Device - which operates at a constant frequency (50 kc), like the i.f. in a superheterodyne receiver, and produces a phase angle indication on cathode-ray tube.

The Signal Generator - which generates the variable-frequency investigating signal (0.1 to 5 Mc), and also produces two constant-frequency i-f signals -- one a reference derived from signal input to circuit under test, and the other a "test" signal derived from output signal of the circuit under test.

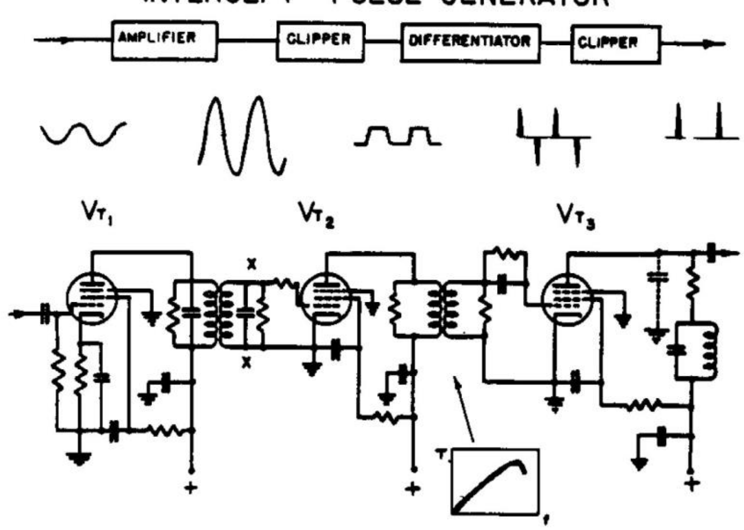
The Horizontal Scanning Unit - which produces a deflection on the cathode-ray tube that is a linear function of frequency.

Indicator

The indicator unit of this apparatus measures phase angles by measuring the time elapsed between corresponding intercepts of the two sine waves being tested. A linear time axis is produced vertically on the cathode-ray tube by a linear saw-tooth deflecting voltage, which is accurately synchronized with one sine wave so that its retrace occurs at the upward intercept. Then a short pulse is produced at the upward intercept of the other sine wave, and this is applied to the grid of the cathode-ray tube, thus modulating the beam. The result is a vertical trace with a spot on it; and since the deflection of the beam along the trace is a linear function of time, the distance of the spot from the starting end of the trace will be directly proportional to the phase angle between the two signals. The vertical sweep can be accurately synchronized with one sine wave by first producing a short pulse from the upward intercept of that sine wave and using this pulse to synchronize a linear saw-tooth oscillator.

These short pulses from the intercept of a sine wave which are needed for both synchronizing of the sweep and modulation of the beam can be produced by a simple wave-shaping process. For convenience, the unit producing this wave-shaping will be called an "Intercept Pulse Generator", or "I.P.G.". Referring to Figure 1: first the signal is amplified so that between 100 and 200 volts peak-to-peak appears across secondary of transformer at x-x. Then this is drastically limited by grid saturation in the positive direction, and plate-current cut-off in the negative direction, so that the plate current of V_{T2} is a square wave. Next, the square wave is differentiated by the mutual inductor between V_{T2} and V_{T3}, producing double pulses as shown; and finally V_{T3} is a limiter or a peak detector so that its output current contains only one polarity of pulse. The plate circuit of V_{T3} contains a low-pass filter used to maintain sufficient bandwidth to transmit the pulse without distortion.

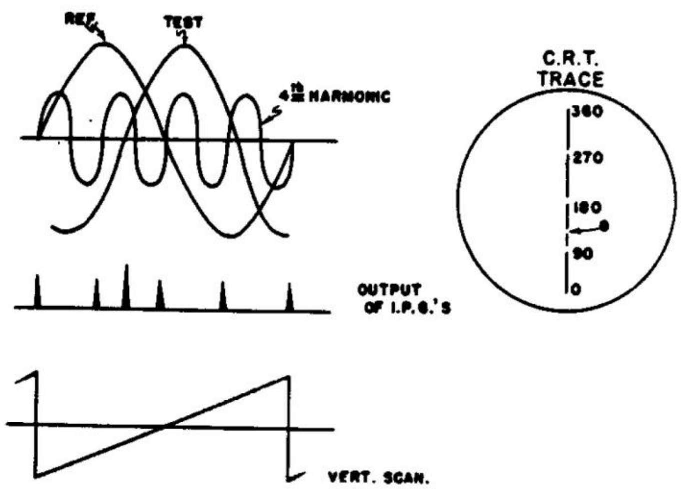
FIGURE 1
INTERCEPT PULSE GENERATOR



One factor determining the accuracy with which the phase-angle indicator can be read is the width of the pulse as a percent of the vertical scanning cycle, since this affects the size of the spot produced by the pulse. It is desirable to have the pulse at least as narrow, or narrower, in degrees than the desired accuracy in degrees. Thus for a 2-degree accuracy, the pulse should not be more than 1/180th of a cycle. Since the duration of the pulse corresponds approximately with half the period of the highest frequency that must be transmitted for accurate reproduction of the pulse, the bandwidth of circuits following the I.P.G. is determined. Accordingly in this apparatus where phase angles are measured at 50 kc, and a 2-degree accuracy of reading is desired, the circuits between the I.P.G. and the grid of the cathode-ray tube have a 5-Mc bandwidth.

By evenly dividing the length of the vertical trace, a scale can be made from which the phase angle can be read directly from the location of the spot with reference to the indexes of the scale. These phase-angle markers can be made a part of the vertical trace by further modulation of the cathode-ray beam. Thus by applying four equally spaced pulses per cycle of the vertical scan to the grid of C.R.T., four markers are produced on the trace which indicate points that are 90° apart. These four equally spaced pulses per cycle can be produced by applying the reference sine wave (i.e. the one used to synchronize the linear sawtooth sweep) to a frequency multiplying stage, selecting the fourth harmonic, and putting this through an I.P.G. (see Figure 2). Thus with 50 kc as the i.f., these 90° markers are really short 200-kc pulses.

FIGURE 2
PHASE-ANGLE MARKERS



Further phase-angle markers can be produced by further frequency multiplications. In the apparatus being described, 10° phase markers were also added. This means that the 200-kc signal was multiplied by nine and applied to an I.P.G., giving 1.8-Mc pulses (i.e. 36 pulses per vertical scanning cycle, or one every 10°). By making the 90° markers of greater amplitude than the 10° markers, the appearance of major and minor subdivisions on a scale is produced.

Figure 3 shows a simplified block diagram of the indicator unit as described up to now. In order to have this indicator produce an accurate measure of the phase angle between V_a and V_b, the timing of all the various pulses must be correct. Thus when V_a and V_b are in phase (or the same signal) the phase-angle indicator spot should be at the bottom of the trace, one of the 90° markers should coincide with the phase-angle indicator spot, and every 9th of the 10-degree markers coincide with a 90° marker. The practical problems involved here, along with those concerning harmonic generators and linear sawtooth oscillators, should make it evident why this indicator unit is operated at a constant frequency, and not directly from the 0.1-to-5-Mc signal going through the test circuit. Operation at a constant frequency also makes the problem of phasing the various pulses quite simple, since simple trimmers on various tuned circuits can be used.

A practical working model of this indicator unit requires the addition of amplifiers and buffers (for freedom from interaction of controls), as well as zero sets for proper phasing of pulses. The expanded block diagram of such a unit is shown in Figure 4.

FIGURE 3
SIMPLIFIED BLOCK DIAGRAM
OF INDICATOR

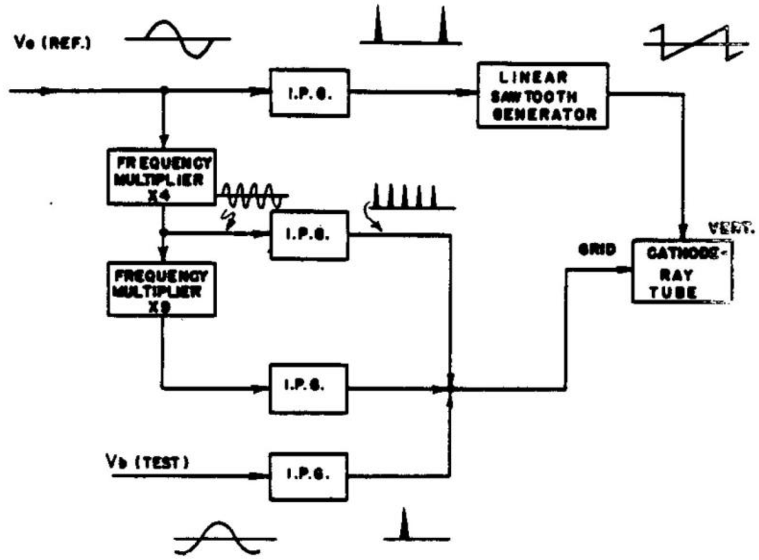
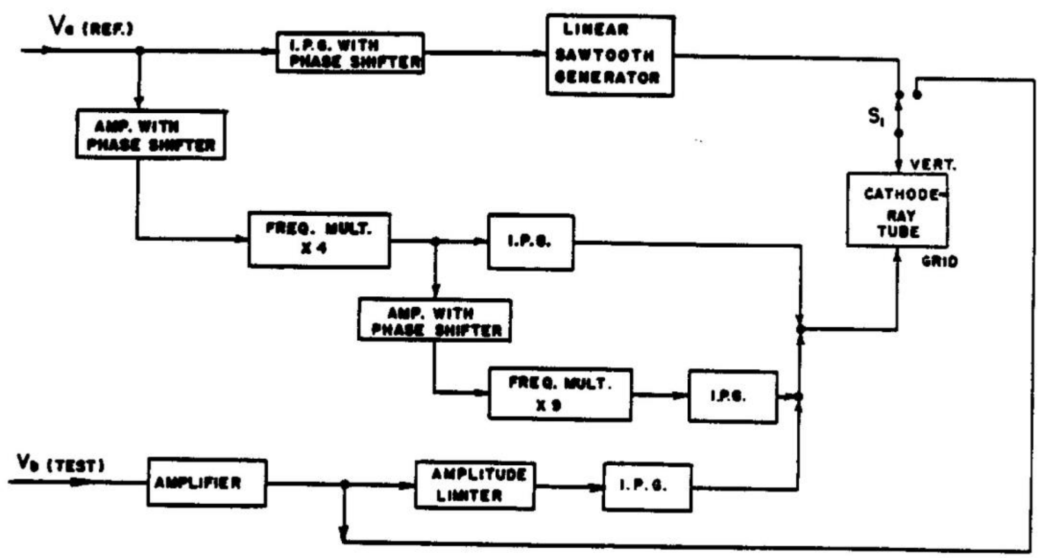


FIGURE 4
EXPANDED BLOCK DIAGRAM
OF INDICATOR



The referenace signal V_a, as produced by the signal generator, is of approximately constant amplitude for various frequencies of investigation of the test circuit, and has only a slowly changing phase angle when the investigating frequency is swept through the 0.1 to 5 Mc range. Thus the design of circuits handling V_a and harmonics thereof present no difficulty. But signal V_b contains the information in regard to the magnitude and phase angle of the amplification of the circuit under test, and therefore can have considerable change in amplitude and a rapidly changing phase angle depending on the circuit being tested. The varying amplitude is taken care of by first amplifying and then amplitude-limiting the sine wave before applying it to the I.P.G. By this means a suitable phase curve can be obtained with as much as a 40-db variation in amplitude. However, the present amplitude-limiting system introduces some errors which are the limiting factors in accuracy of indication. A variation in amplitude of V_b over the 40-db range produces a ± 3 degree error in indication. There is a further error introduced due to the rate of change of amplitude of V_b, and this amounts to ± 5 degrees when sweeping through a trap circuit of reasonable Q.

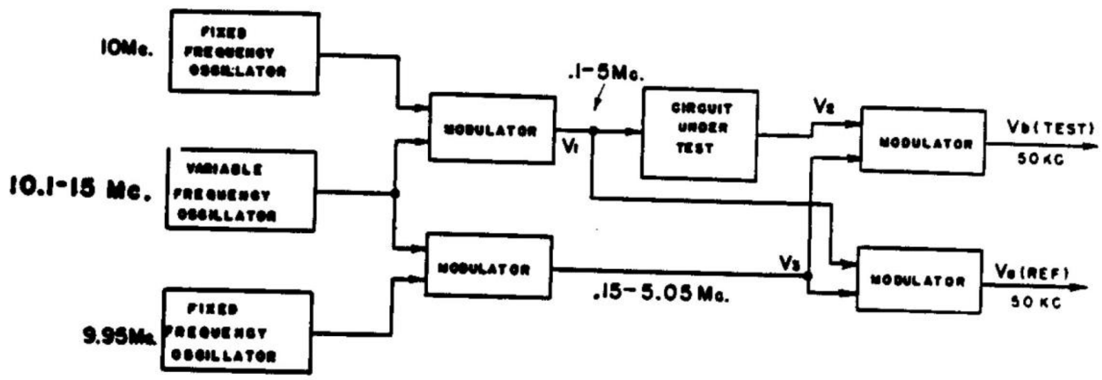
The rapidly changing phase angle of V_b requires that the channel handling this must have sufficient band width and linear phase characteristics in order not to distort this phase- and amplitude- modulated signal. The considerations involved include not only the maximum slope of the phase curve, but also the rate of frequency sweep in the test circuit. In the present apparatus, a band width of 20 kc is used and this channel is consequently substantially flat from 40 to 60 kc, this band width being adequate to handle signals with phase slopes of the order of those in an over-all television system and those produced by trap circuits with a reasonable Q. This figure is somewhat conservative in order to insure a linear phase shift (i.e. a constant time delay) of all essential components of the phase-amplitude modulated signal V_b.

The phase-angle indicating device just described can also be used to indicate the amplitude response of the circuit under test. For this, the vertical deflecting circuit of the cathode-ray tube is connected to some point in the channel transmitting V_b before any amplitude-limiting is produced. Then if the input to the circuit under test is constant at all frequencies, the length of the vertical trace will indicate the magnitude of the amplification of the circuit under test. Switch S_1 in Figure 4 indicates this change.

Signal Generator Unit

The signal generator unit should produce a variable frequency investigating signal (0.1 to 5 Mc) and also two constant frequency signals (50 kc), one a reference derived from the input and the other a "test" signal derived from the output of the circuit under test. These constant frequency signals are produced by heterodyning the investigating signal with a "beating" signal which is always 50 kc higher in frequency than the investigating signal. The problem of "tracking" these two signals is eliminated by producing them from two beat-frequency signal generators which have a common variable-frequency oscillator. Figure 5 shows a simplified block diagram

FIGURE 5
SIMPLIFIED BLOCK DIAGRAM
OF SIGNAL GENERATOR



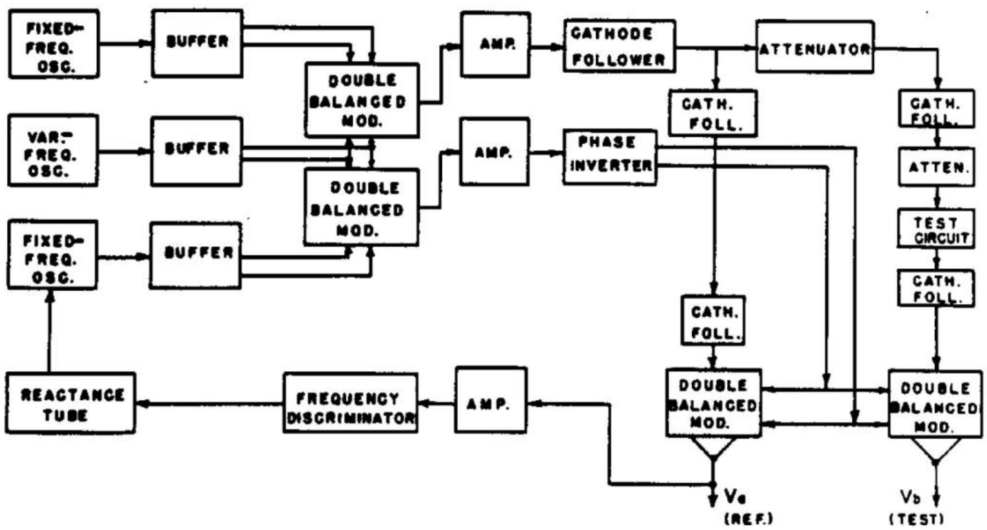
of such an arrangement with the frequencies used in this apparatus being indicated.* From this it can be seen that V_a and V_b are always at 50 kc, and that the relation between them is the same as that between V_1 and V_2, or the amplification of the test circuit. Actually with the beat signal higher in frequency than the investigating signal, the phase angle between V_b and V_a is the negative of that between V_2 and V_1. This merely means that the vertical sweep on the C.R.T. must be scanned from the top down, in order to make a lagging phase angle between V_2 and V_1 produce an upward motion of the spot. If signals V_1 and V_3 are constant in amplitude at all frequencies, then V_a is constant and the amplitude of V_b varies directly as the magnitude of amplification of the circuit under test.

A practical working model of a generator like this requires the use of amplifier buffers, double balanced modulators, impedance transformers (i.e. cathode followers), and attenuators in various places. Figure 6 shows an expanded block diagram of the unit constructed for this apparatus. The cathode followers before the test circuit prevent interaction between the low-impedance attenuator and the high-impedance low-pass filter of the previous amplifier, and also produce a low-impedance output so that test circuits with the usual order of input impedance do not affect the signal output of the generator. The cathode follower after the test circuit is in a "test probe" reflecting a high input impedance to the test circuit and a low impedance to the transmission line feeding the signal back to the modulators.

---

* For a similar signal-generator unit, see: M. Levy, "Methods and Apparatus for Measuring Phase Distortion", Electrical Communication, No. 3, pp. 206-228, Vol. 18, January, 1940.

FIGURE 6
EXPANDED BLOCK DIAGRAM
OF SIGNAL GENERATOR



These impedance-transforming circuits are also simulated in the channel feeding the reference signal modulator, so that the only essential difference between the paths traveled to produce V_a and V_b is that the latter include the circuit under test and attenuators.

Proper operation of the indicating unit requires that the constant-frequency signals be kept quite accurately at 50 kc. This frequency is determined by the difference frequency of the two fixed high-frequency oscillators. When using self-excited oscillators it is desirable to have some form of stabilization, and accordingly an automatic-frequency-control circuit is used as shown so that the difference frequency is stabilized by the 50-kc discriminator.

Stray coupling produces an extraneous 50-kc signal in the output of the first pair of double balanced modulators, which must be prevented from getting into V_a and V_b. This is accomplished by resistance-compensated 50-kc traps in the investigating-signal and beat-signal channels, and also by an accurate balance of the second pair of double balanced modulators.

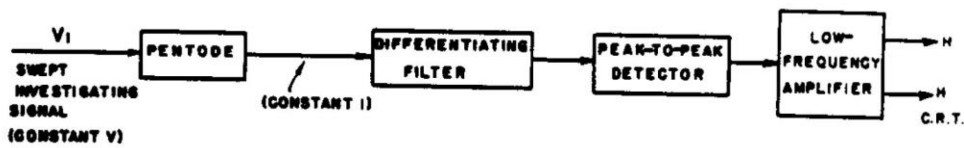
Sweep Operation

To complete the phase curve tracer, it now remains to produce all those operations connected with the horizontal scanning of the curve. This includes periodic variation or sweeping of the investigating frequency, production of horizontal scanning for C.R.T., and the addition of frequency markers which, in conjunction with the phase-angle markers, complete the illusion of graph paper. Sweeping the investigating frequency is a simple problem since only one oscillator frequency is varied. In this apparatus a motor-driven condenser is used which is operated synchronously at 20 cycles, going through the 0.1-to-5-Mc range in 1/40th of a second.

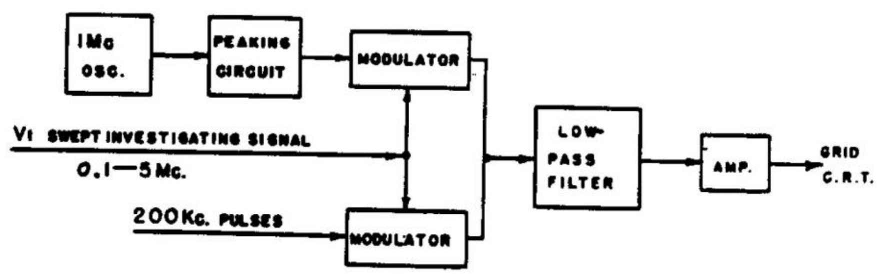
The horizontal sweep is produced by a frequency-discriminator arrangement operated directly from the investigating signal. As indicated in Figure 7a, a dif-

FIGURE 7

(a) HORIZONTAL SWEEP CIRCUIT



(b) FREQUENCY-MARKER CIRCUIT



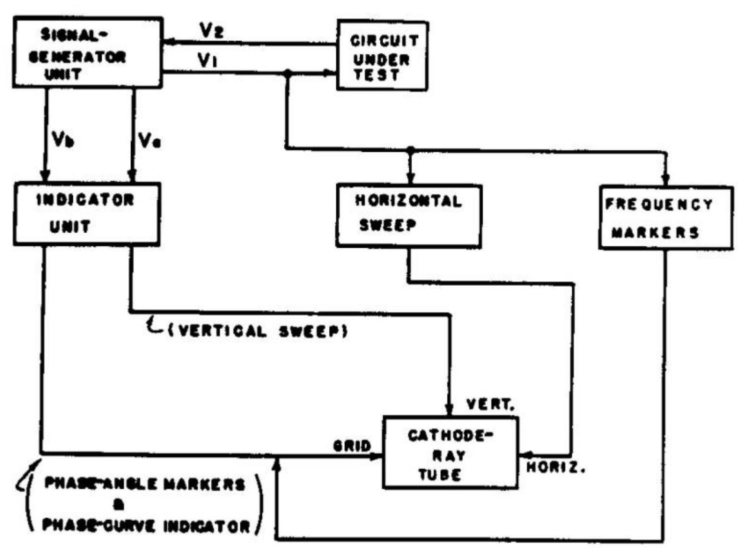
ferentiating filter is used which, when supplied with a constant current, produces an output voltage whose amplitude is a linear function of frequency. Then the envelope of this amplitude-frequency modulated signal is detected and the output is used for the horizontal sweep. This sort of arrangement has the advantage that it will produce a horizontal sweep which is a linear function of frequency regardless of the shape of the frequency-deviation-versus-time curve. Thus the motor-driven condenser used to sweep the frequency need not have specially shaped plates. The differentiating circuit accentuates any harmonic distortion that may exist, and unless a peak-to-peak detector is used, a non-linearity of trace may be produced when the secondharmonic distortion component goes out of the pass band of the system.

Frequency markers are produced by beating the swept frequency investigating signal with standard frequency signals and brightening up several vertical scanning lines as the signals go through zero beat. The block diagram of this circuit is shown in Figure 7b. A 1-Mc oscillator and its harmonics produce markers at every megacycle. Since it is desirable that all harmonics of interest be of approximately equal amplitude, a 1-Mc pulse of short duration should be supplied to the modulator. Accordingly the plate-current pulses of the 1-Mc oscillator are fed to a peaking filter which partially differentiates them. Markers are also added every 200 kc, using the 200-kc pulses which produce the 90° phase-angle markers as the standard. The result is again the appearance of major and minor subdivisions along the frequency axis. It will be noted that if the 1-Mc oscillator is an accurate frequency standard, then the coincidence of the 200-kc markers and the 1-Mc markers offers a convenient means of checking the frequency in the 50-kc channel.

System

The phase curve tracer as a complete system is indicated by Figure 8 which shows the interconnection between the units previously described. It is interesting to note the similarity between this phase curve tracer and a television system. A raster is produced as in a television system and the picture is obtained by proper modulation of the beam of the C.R.T., but here the scanning lines are vertical instead of horizontal. Figure 9 shows a raster of coarse line structure with varying brilliancy indicating the formation of a phase curve along with 90° markers and several frequency markers.

FIGURE 8
BLOCK DIAGRAM OF COMPLETE SYSTEM



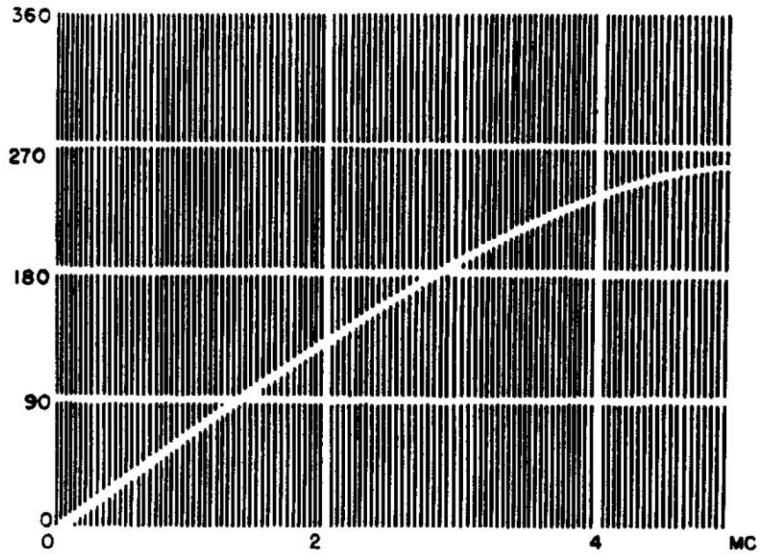
A photograph of the phase curve tracer is shown in Figure 10. The apparatus is built in three units which are mounted on a 19-inch relay rack, and for portability this relay rack is mounted on a dolly. The top unit contains the indicator, horizontal-sweep, and frequency-marker circuits, as well as the cathode-ray tube and its power supplies. The middle unit contains the signal-generator circuits. At the lower right of this unit can be seen the cable which feeds the 0.1-to-5-Mc signal to the test circuit, and also the gooseneck with the probe at the end which receives the output signal of the test circuit. The bottom unit contains the power supplies to furnish filament and plate power to the 67 tubes used in the complete apparatus. In between the middle and bottom units, another small panel will be noted. This contains a number of simple circuits that can be used as test circuits for demonstration of the apparatus.

Results:

The phase and amplitude characteristics of a number of circuits, as produced on the screen of the cathode-ray tube of this apparatus, are shown in Figures 11 to 19. In each case the photograph to the left is the phase characteristic, and to the right the amplitude characteristic. The circuit under test shown in each figure is fed by a constant-current generator, and thus the amplitude and phase characteristics represent the impedance or transfer impedance of the networks.

FIGURE 9

TRACED PHASE CURVE



The characteristics of a single-tuned circuit resonant at about 2.5 Mc are shown in Figure 11. The major coordinates on the phase curve are at every megacycle along the horizontal axis and at every 90° along the vertical axis, with minor coordinates at every 200 kc and at every 10°. The tuned circuit was in a one-stage pentode amplifier, and accordingly, at the resonant frequency the phase shift was 180°. The interrelation of a peaked amplitude characteristic and a steep phase slope is indicated; and, as would be expected, a phase shift of ± 45° from resonant value occurs at points about 3 db down on the amplitude characteristic. The vertical lines on the amplitude characteristic are frequency markers, just as on the phase characteristic.

In Figure 12 the characteristics of an overcoupled double-tuned circuit are shown. The amplitude characteristic has peaks at about 1.8 and 3.2 Mc, and the phase curve has "steps" of about 180° (a pi step) at the corresponding frequencies. Again, as in Figure 11, the circuit is fed by a pentode amplifier, so 180° phase shift is added. Thus the phase angle starts at 90° at a low frequency and goes through two pi steps as the frequency increases, finally ending up with 450° shift at a high frequency. This would require a vertical phase-angle scale of greater than 360° in order to show one continuous phase curve. Accordingly for the phase curve shown in Figure 12, a 720° scale is used. This merely means that the vertical sweep frequency is 25 kc instead of 50 kc. Since, in general, a phase angle of 360° is not distinguishable from one of 0°, the phase curve is repeated 360° away on the graph. One continuous phase curve is produced, and the other repeated traces may be neglected.

FIGURE 10
THE PHASE CURVE TRACER

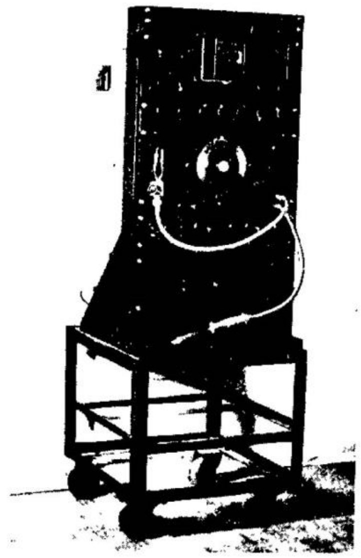
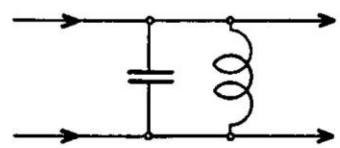
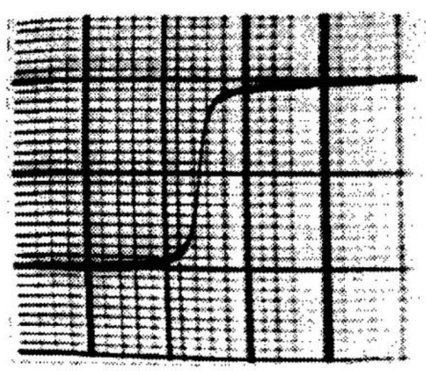


FIGURE 11
SINGLE-TUNED CIRCUIT





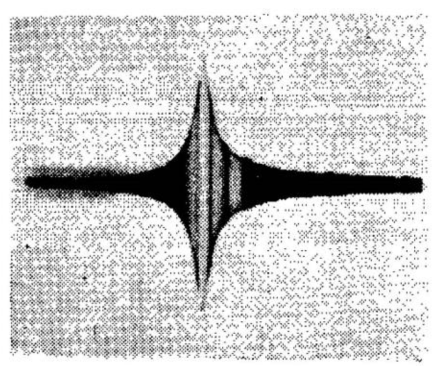
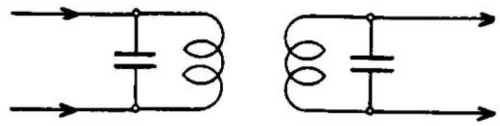
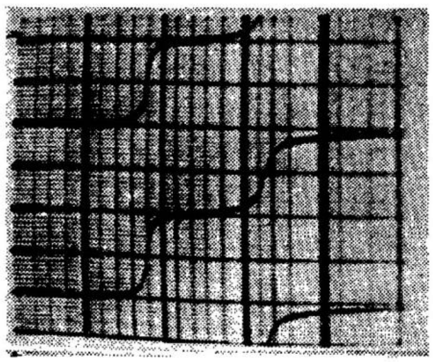


FIGURE 12
DOUBLE-TUNED CIRCUIT OVER-COUPLED





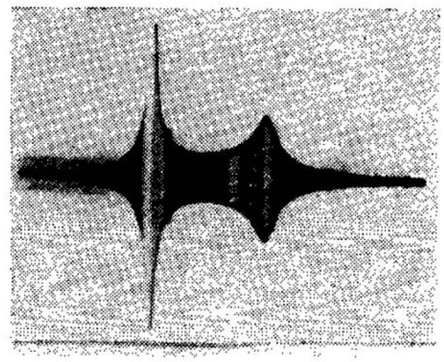
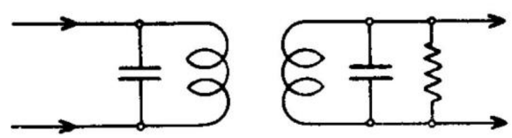
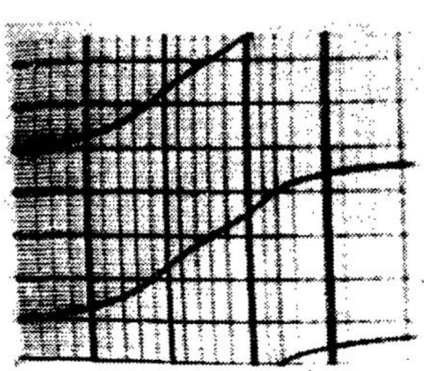
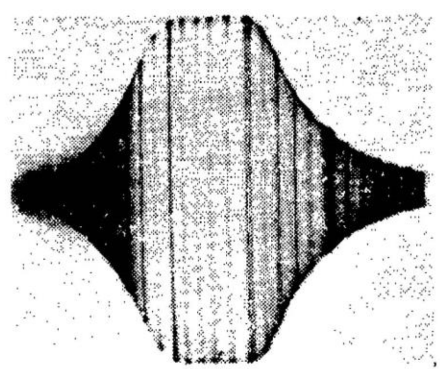


FIGURE 13
DOUBLE-TUNED CIRCUIT OPTIMUM-COUPLED





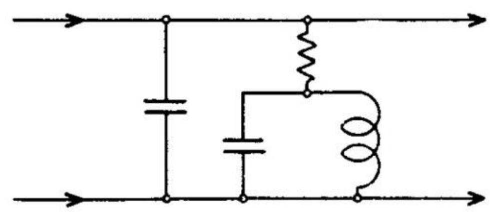


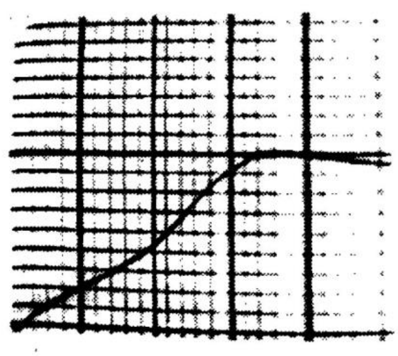
The characteristics of a double-tuned circuit with optimum coupling are shown in Figure 13. This is the same as Figure 12, but with the loading increased to that for which the coupling is optimum, and the signal input to the circuit increased by 20 db. The total change in phase angle between 0.1 and 5 Mc is the same as before, but now the steps in the phase curve are eliminated and the phase slope is almost constant from 1.6 to 3.4 Mc.

A simple half-section low-pass filter designed for a 3-Mc cutoff is illustrated in Figure 14. The vertical scale of the phase curve is expanded by overscanning the cathode-ray tube, so that the major horizontal coordinate about half-way up the photograph is 90°. This filter is a two-terminal network that is resistive at a low frequency and predominantly capacitive above cutoff frequency, and thus the total phase shift is 90°. It will be noted that, while the amplitude characteristic is substantially flat out to 2.4 Mc, the phase curve is not linear over this range, but bends upward indicating that high-frequency components would be delayed more than low-frequency ones.

Figure 15 shows the characteristics of a one-and-one-half-section filter, and again the cutoff frequency is 3 Mc. As would be expected, the extra full-section filter adds an extra 180° phase shift up to cutoff frequency, so that 270° phase shift exists above cutoff. Again it will be noted that while the amplitude characteristic is substantially flat to 2.6 Mc, the phase curve is not linear over this range.

FIGURE 14
HALF-SECTION FILTER





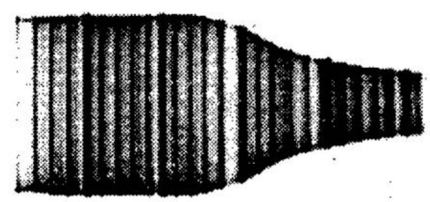
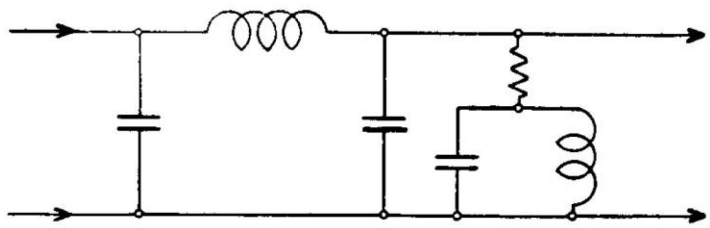
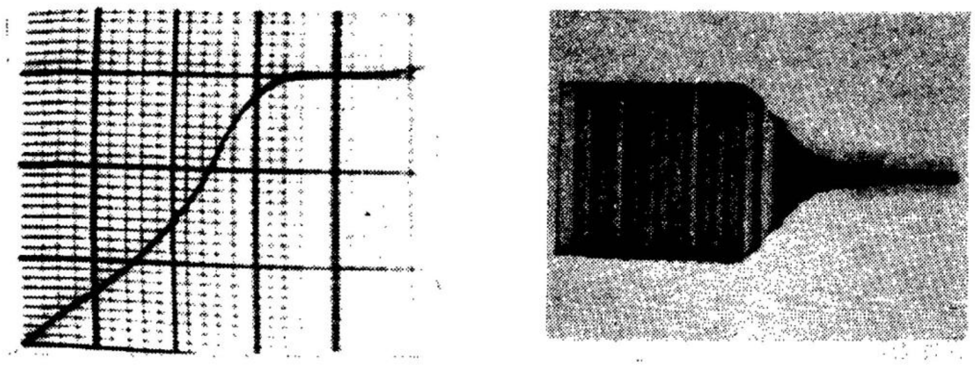


FIGURE 15
ONE-&-ONE-HALF-SECTION FILTER





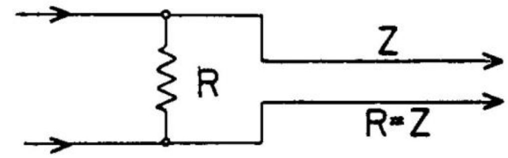
The phase and amplitude characteristics of a transmission line are illustrated in Figure 16. The line consisted of about 250 feet of parallel-wire lamp cord correctly terminated at the generator end, and open-circuited at the receiver end. Here the vertical scale on the phase curve is 3 x 360 = 1080°, which means that the vertical sweep on the cathode-ray tube is a 16.7-kc linear sawtooth. The phase shift is substantially a linear function of frequency going through 360° in 2.1 Mc, indicating a uniform delay of 0.48 microsecond of all frequency components. The amplitude characteristic slopes off slowly as a result of the line attenuation increasing with frequency.

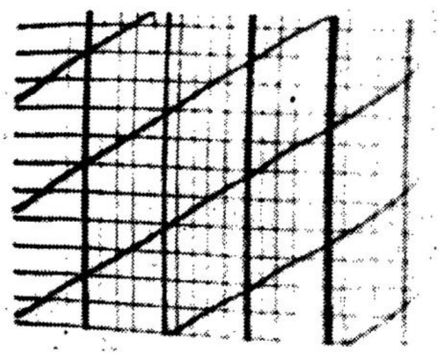
In Figure 17 we have the same line as in Figure 16, but the generator resistance is made larger than the surge impedance of the line. The reflections that result from mismatch produce the waves in the amplitude and phase curves. The period of undulation of both the amplitude and phase characteristics is 1.05 Mc, indicating that these distortions would produce echoes displaced by .95 microsecond from the desired output signal. This is the time required for a signal to travel from the receiver end to the generator and back to the receiver again. The maximum slope of the phase curve will be seen to occur at the peaks in the amplitude response, and the minimum slope at the valleys. It is interesting to note that this circuit has equal amounts of amplitude and phase distortion, since from the nature of the layout, leading echoes are absent and only trailing echoes result.* The in-

* See: H. A. Wheeler, "The Interpretation of Amplitude and Phase Distortion in Terms of Paired Echoes", Proceedings of I.R.E., Vol. 27, No. 6, pp. 359-385, June 1939.

FIGURE 16

TRANSMISSION LINE PROPERLY TERMINATED AT GENERATOR END





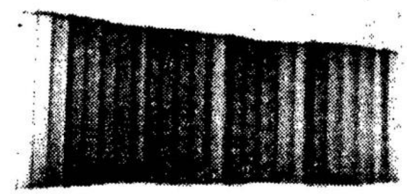
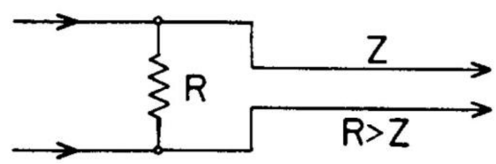
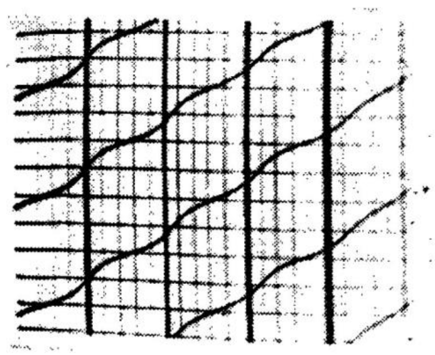
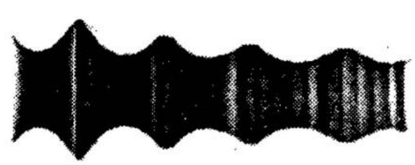


FIGURE 17

TRANSMISSION LINE IMPROPERLY TERMINATED







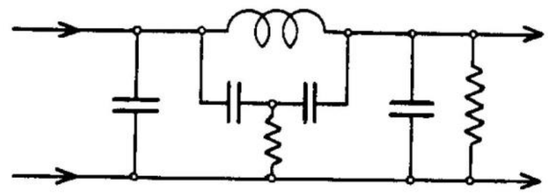
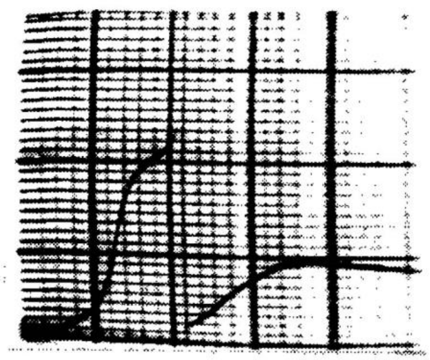


FIGURE 18
TRAP CIRCUIT



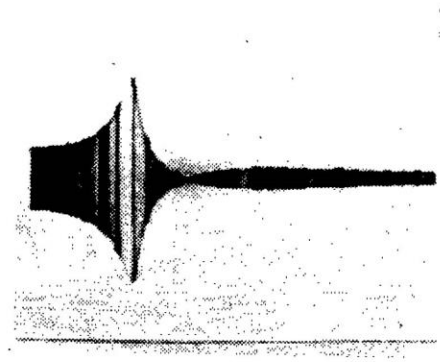
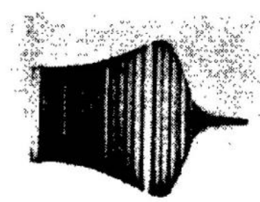
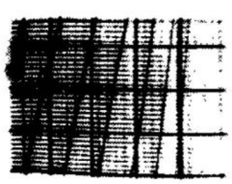
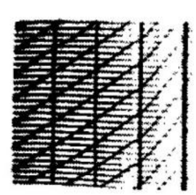


FIGURE 19
AN OVER-ALL
TELEVISION SYSTEM







creasing line attenuation with frequency also attenuates the reflected signals, so the variations in the amplitude and phase characteristics decrease with frequency.

Figure 18 illustrates the phase and amplitude responses of a high-attenuation trap circuit. At the trap frequency of 2.1 Mc the phase curve has a downward pi step, (i.e. a sudden reduction of phase shift by 180°). This is the converse of the upward pi step produced when a peak exists in the amplitude curve, as shown by Figures 11 and 12.

The characteristics of an overall television system are shown in Figure 19. The amplitude response is in the upper right of the figure, and the phase curve is illustrated by the lower photographs, the left photograph having a 360° vertical scale and the right a 7 x 360° vertical scale. The system included both a transmitter and receiver. Input was to the monoscope amplifier and output from the last video stage in a receiver, with the transmitter-receiver connection a radio link on the 50-56-Mc channel. It will be noted that the slope of the phase curve is practically constant up to 2 Mc, and corresponds to a delay of about 1.2 microseconds. Between 3 and 4 Mc the phase slope is almost twice the low-frequency value. The phase curve starts at 180° at a low-frequency indicating a reversal of picture polarity between the monoscope and picture tube of the receiver. The phase characteristic shown with the 360° vertical scale permits accurate measurement of the phase angle at various frequencies, while that shown with the 7 x 360° scale illustrates one continuous phase curve. The amplitude characteristic shows a 4.5-db rise at 3.2 Mc and is down to its low-frequency value at 3.7 Mc.

HAZELTINE SERVICE CORPORATION LABORATORY

B D Loughlin
Engineer

Report 7116

Parts I and II

RECENT IMPROVEMENTS IN BAND-SHARED SIMULTANEOUS COLOR TELEVISION SYSTEMS

as published in

Proc. of I.R.E., Oct. 1951

APPENDIX E

REPORT 7116 - PARTS I AND II

RECENT IMPROVEMENTS IN BAND-SHARED SIMULTANEOUS COLOR TELEVISION SYSTEMS

As published in

Proc. of I.R.E., October 1951

Recent Improvements in Band-Shared Simultaneous Color-Television Systems*

B. D. LOUGHLIN†, MEMBER, IRE

Part I—The Constant-Luminance System and Related Improvements

Summary of Part I—**A number of improvements in band-shared simultaneous color systems (the previously proposed "dot-sequential" system being one of this class) are described. These improvements reduce susceptibility to interference and permit color pictures to be obtained through a total bandwidth of only 4 mc. These color pictures are comparable to those obtained with a nonband-shared simultaneous color system using 4-mc bandwidth for each color. In order to explain these system improvements the simultaneous nature of the so-called "dot-sequential" system must first be developed. Then the constant-luminance system, in which the color subcarrier information does not affect the brightness of the picture, may be described. Additional improvements consist of an improved subcarrier pattern to reduce crawling effects in the picture and sampling of the brightness signal at the transmitter to reduce "shimmer" resulting from cross talk of high video-frequency components into the chromaticity channel. The manner in which this group of system modifications can be used to improve substantially both compatibility and the color picture is explained.**

I. Introduction

DURING THE PAST few years there have been at least two major engineering advances in color-television systems, namely, the mixed-highs theory and the so-called "dot-sequential" form of band-shared simultaneous color system using mixed-highs. The mixed-highs principle is based on the well-established fact that the eye is insensitive to color in fine detail; consequently, it is wasteful of the spectrum to transmit three separate color signals for fine-detail information. This theory was proposed by Bedford[1] and has been clearly illustrated by color slides in recent talks given by Loughren and Hirsch.[2]

The second major advance, the "dot-sequential" color system using mixed highs, as proposed by RCA,[3] is one form of band-shared simultaneous color system and, as such, it has formed the foundation for a compatible high-resolution color system. The purpose of this paper is to describe system improvements which reduce the visibility of certain interference and spurious patterns produced in this early form of band-shared system. These system modifications permit reproduction of high-resolution color pictures without "shimmer" and permit the compatibility of the system to be improved.

II. Simultaneous Nature of the "Dot-Sequential" System

A. The "Dot-Sequential" Signal

While the system proposed by RCA has been called a "dot-sequential" color system using mixed highs, an alternate point of view can be developed, which indicates that the system is substantially simultaneous. However, it should be noted that while "dot-sequential"

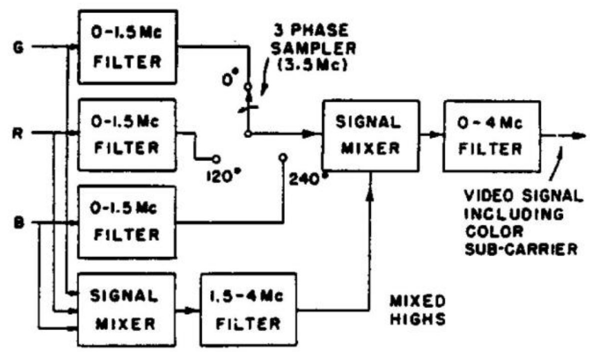


Fig. 1—"Dot-sequential" color transmitter.

receiving apparatus was originally demonstrated by RCA, this *apparatus* should not be confused with the *system* fundamentals now to be reviewed.

The encoding or sampling portion of a "dot-sequential" transmitter is shown in Fig. 1. This is substantially similar to the arrangement originally proposed by RCA.[4] The three-color signals *G*, *R*, and *B*, representing the green, red, and blue signals, are obtained from a color camera and applied to 1.5-mc low-pass filters. The resulting reduced-bandwidth color signals are applied to a symmetrical three-phase sampling system. This three-phase sampling system rapidly and symmetrically measures the amplitude of the reduced-bandwidth *G*, *R*, and *B* signals, and repeats its cycle of measurement at a rate of approximately 3.5 mc. Then a "mixed-highs" signal, containing an equal weighting of the green, red, and blue signal components in the 1.5 to 4-mc range, is added to the output of the sampler to give the desired composite video signal.

B. The Sampling Process

The nature of the "dot-sequential" output signal and spectrum can be deduced from a brief inspection of the

* Decimal classification: R583. Original manuscript received by the Institute, May 11, 1951.
† Hazeltine Electronics Corporation, Little Neck, L. I., N. Y.
[1] A. V. Bedford, "Mixed highs in color television," Proc. I.R.E., vol. 38, pp. 1003–1009; September, 1950.
[2] A. V. Loughren and C. J. Hirsch, "Comparative analysis of color-television systems," *Electronics*, pp. 92–96; February, 1951.
[3] "A six-megacycle compatible high-definition color-television system," *RCA Rev.*, pp. 504–524; December, 1949.

[4] See Fig. 1 on page 505 of footnote reference 3. The present arrangement differs mainly in using 0 to 1.5-mc filters before sampling instead of 0 to 2-mc filters. This simplifies the analysis since the sampling rate is higher than twice the bandwidth of the signal that is sampled. Also, the sampling rate, as stated here, is about 3.5 mc.

sampling process, as shown in Fig. 2. This figure illustrates one channel, i.e., the green channel, of the

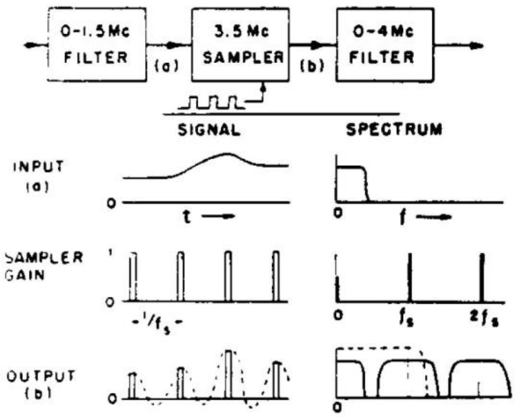


Fig. 2—The sampling process.

three-phase sampler. The reduced-bandwidth signal at point (*a*) is applied to the sampler. The sampling action is merely equivalent to the periodic closing of a switch at a 3.5-mc rate for short intervals of time. Thus, the output of the sampler at point (*b*) is a pulse train with a 3.5-mc repetition rate which has an amplitude proportional to the signal at (*a*); that is, the pulse train is *modulated* in amplitude by the reduced-bandwidth input signal at (*a*).

Considering the Fourier series expansion of the modulated pulse train, it is seen that each harmonic component of the pulse train is modulated by the input signal. Thus, because of the dc component of the pulse train the output signal contains a component equivalent to the input signal; and because of the fundamental and harmonics of the pulse train the output signal contains a series of modulated carriers at the fundamental and harmonics of the sampling rate, which are modulated by the input signal. In other words, the average transmission of the sampling switch results in an output signal equivalent to the input signal, and the heterodyning action of the sampling switch results in the fundamental and harmonics of the sampling rate, which are modulated by the input signal.

In a practical system a bandwidth limitation is required because of the finite bandwidth of the television rf channel (represented here by a 4-mc low-pass filter), so that only the output terms, due to the average transmission of the switch and the fundamental frequency of sampling, are used. Thus, in the proposed "dot-sequential" system the net output of a sampler is merely the low-frequency video signal plus a 3.5-mc modulated subcarrier.[5]

C. The "Dot-Sequential" Spectrum

The "dot-sequential" transmitter includes three samplers, similar to Fig. 2, which operate at 120-degree phase relation and individually sample the green, red, and blue signals. The output signals resulting from the average transmission of these three samplers produce a 0- to 1.5-mc signal which has equal weighting of the original green, red, and blue signals (i.e., $\frac{1}{3}G+\frac{1}{3}R+\frac{1}{3}B$). This is illustrated by the low-frequency portion of the output spectrum, shown in Fig. 3. The modulated carrier output of these three samplers have 3.5-mc subcarriers which are displaced 120 degrees from each other because of the relative timing of the three samplers. Thus, the net carrier signal may be represented by a three-phase vector diagram, as shown above the 3.5-mc component in Fig. 3. When narrow-angle

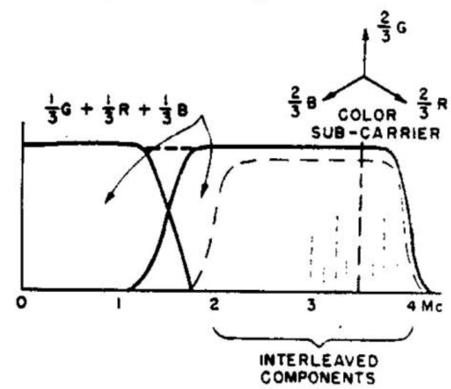


Fig. 3—Spectrum of "dot-sequential" color signal.

sampling is used, the low-frequency components and modulated carrier components have the 1-to-2 relation represented by the $\frac{1}{3}$ and $\frac{2}{3}$ values shown.[6] Also note that the 3.5-mc signal disappears on white (that is, when $G=R=B$) because the vector diagram has symmetrical values.

The total output from the three-phase sampler system is seen to be a composite low-frequency signal plus a composite-color carrier signal. Now, in addition, mixed-highs containing equal weighting of the three color components in the 1.5 to 4-mc range are supplied through the shunt path of Fig. 1. The 1.5 to 4-mc mixed-highs signal combines with the 0 to 1.5-mc signal (resulting from the average transmission of the three-phase sampler) to produce a wide-band 0- to 4-mc (brightness) signal, which is similar to the normal video signal of present-day black-and-white transmission. As will be seen, it is convenient to call this "normal" video signal a "brightness" signal.

It should be noted that as a result of the conventional scanning process the normal brightness video signal consists mainly of bunches of energy clustered about harmonics of the horizontal scanning frequency.[7] The horizontal scanning-frequency harmonics in the

[5] It should be noted here that the above Fourier series-type analysis of sampling may not be particularly useful when the input signal varies *rapidly* compared with the rate of sampling. However, in the "dot-sequential" system the sampled signal is a reduced-bandwidth signal which is sampled at a fast rate; in this case the Fourier series expansion helps to clarify the actual operation.

[6] For example, the output signal due to G is: $G[\frac{1}{3}+\frac{2}{3}\cos(2\pi f_s t)]$ Also, see pages 507–508 of footnote reference 3.

[7] P. Mertz and F. Gray, "A theory of scanning and its relation to the characteristics of the transmitted signal in telegraphy and television," *Bell Sys. Tech. Jour.*, pp. 464–515; July, 1934. Also, P. Mertz, "Television—the scanning process," Proc. I.R.E., pp. 529–537; October, 1941.

3- to 4-mc region are represented by the fine solid lines in the spectrum of Fig. 3. In the "dot-sequential" arrangement the sampling frequency is an odd multiple of one-half the horizontal scanning-frequency, and thus falls half way between the clusters of energy in the normal video signal.[8] In other words, the color subcarrier and its sidebands (represented by the dotted spectrum lines) are interleaved between the high-frequency components of the brightness signal in the 2- to 4-mc range. Since this subcarrier energy is interleaved with the brightness or normal video signal, it tends to integrate out or have low visibility in a receiver reproducing the normal video signal.[9]

From the above analysis, it is evident that the "dot-sequential" system is really one form of ***band-shared simultaneous*** system, having a wide-bandwidth brightness signal and a narrower-bandwidth color or chromaticity signal. The chromaticity information is thus transmitted as a modulated subcarrier of approximately 3.5 mc, the components of which share the 2- to 4-mc band with, and interleave between, the high-frequency components of the brightness signal.

D. Color-Difference Signals

A further look at the nature of the color subcarrier will be useful. Fig. 4 illustrates a greatly enlarged oscillogram of the output signal of a "dot-sequential" transmitter when a flat area, yellow in color, is scanned. The composite signal is represented by a 3.5-mc sine wave (solid-line curve) superimposed on some average or brightness signal (Y'). On alternate frames the sine-wave phase is reversed (as shown by the light dotted line) since the sampling frequency is an odd multiple of one-half horizontal scanning frequency and there is an odd number of lines per frame.

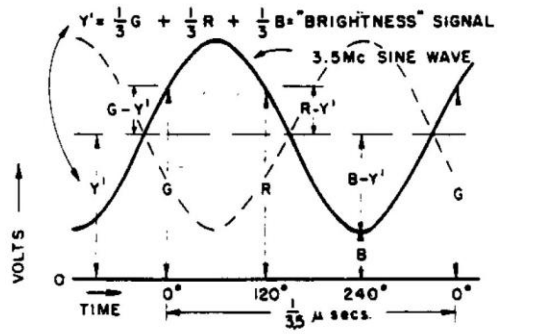


Fig. 4—"Dot-sequential" signal.

In accordance with the "dot-sequential" concept, narrow-angle sampling of the composite signal at 0, 120, and 240 degrees, that is, measuring the instantaneous amplitude at these times, gives output signals proportional to G, R, and B. Now, suppose the low-frequency component of the brightness signal Y' is thrown away in a filter and only the 3.5-mc component is applied to a sampler. In this case, the output signals, resulting from sampling at 0, 120, and 240 degrees, will be proportional to the instantaneous amplitude of the sine wave at these times and will be $G-Y'$, $R-Y'$, $B-Y'$. (Note that one or two of these signals will have a negative value.) In other words, sampling of the subcarrier alone gives ***color-difference*** signals which indicate how the G, R, and B signals differ from the average or low-frequency signal Y'. Thus, the 3.5-mc subcarrier signal carries color-difference signals or chromaticity information, and the low-frequency signal Y' might be considered to be a black-and-white brightness signal. It will be noted that when using symmetrical sampling of the subcarrier alone, the sum of the three resulting color-difference voltages is always equal to zero since the subcarrier is a sine wave. Thus, such a symmetrical system might be called a "constant-amplitude system" since the sum of the resulting G, R, and B *voltages* is independent of the 3.5-mc color subcarrier signal.

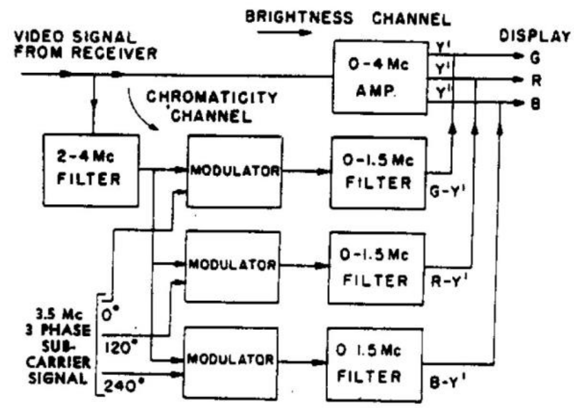


Fig. 5—Color receiver with shunt brightness channel.

E. Receiver with Shunt Brightness Channel

The concept that the "dot-sequential" system using mixed highs is really a "constant-amplitude" form of band-shared simultaneous system leads rather directly to an improved form of receiver, which is shown in Fig. 5. This type of receiver was developed at Hazeltine and a version of it was used by RCA in the demonstrations given in Washington, D.C., during December, 1950. The wide-band brightness signal is applied equally to the green, red, and blue channels of a three-color display (such as a three-gun tricolor picture tube) to produce a ***high-resolution*** black-and-white picture. The high-frequency portion of the signal, which includes the color subcarrier signal, is selected by the 2- to 4-mc filter in the chromaticity channel, and output signals proportional to the 0-, 120-, and 240-degree values of the modulated subcarrier wave may be obtained from either desamplers or modulators. These correspond to the color-difference signals $G-Y'$, $R-Y'$, and $B-Y'$. Since the color information is limited to a 1.5-mc bandwidth

[8] Typical sampling frequencies might be: 441×15.75 kc/2 = 3.47 mc or 455×15.75 kc/2 = 3.58 mc. Also, see footnote references 2 and 3 for more details.

[9] For a more complete discussion on this, see footnote reference 2.

at the transmitter, 1.5-mc low-pass filters can be included in the color-difference channels at the receiver. The resulting narrow-bandwidth color-difference signals are then applied to the appropriate channels of the display, thus *adding color* to the high-resolution black-and-white picture produced through the shunt brightness channel. The receiver is seen first to produce a high-resolution black-and-white picture similar to that obtainable with present-day black-and-white receivers, and then to "color" the picture from information obtained from the 3.5-mc subcarrier signal.

The simultaneous nature of the system is evident from this form of receiver. Even if narrow-angle desamplers were used, the three narrow-band color-difference signals, $G-Y'$, $R-Y'$, and $B-Y'$, are simultaneous signals which are *not* chopped up by sampling. The reason for this is that the 0- to 1.5-mc filter, which has a bandwidth of less than half the sampling rate, can be thought of as acting as a smoothing filter to fill in the gaps between samples. Furthermore, the brightness channel makes a normal video signal. Thus, the resulting G, R, and B signals are really simultaneous and not sequential in nature. However, the brightness signal and the chromaticity signal share the same frequency band, and *interference* "dots" can be produced between the signals. This interference will be treated in more detail.

Even if narrow-angle desamplers were used instead of modulators, it should be noted that because filters are located before and after the desamplers they would merely produce a *synchronous detection* action. Therefore, the narrow-angle desamplers needed in accordance with the "dot-sequential" concept can be replaced by *sine-wave* modulators since it is merely necessary to keep the correct relative gains in the brightness and chromaticity channels. The possible use of sine-wave modulators is a substantial practical advantage, and their use will be indicated in all of the improved systems to be described.[10]

Also, it should be noted that the presence of the color subcarrier signal in the brightness channel may tend to desaturate the reproduced colors because of nonlinear characteristics of the picture tube. This is particularly true if the subcarrier amplitude in the brightness channel is large. Thus, when using the system proposed by RCA, it may be desirable to reduce the bandwidth of the brightness channel in the color receiver from the 0- to 4-mc value shown down to 0 to 3 mc in order to eliminate the direct 3.5-mc signal and its desaturation effects. This would not be necessary if the color carrier is transmitted at a lower amplitude, as will be proposed later.

F. Spurious Signals Produced in Receiver

Now let us look at some of the difficulties encountered in the constant-amplitude form of band-shared simultaneous color system. Annoying spurious signals can be produced in the chromaticity channel of the receiver because this channel takes high-frequency video components and reduces them to more visible low-frequency components due to heterodyne action in modulators. For example, consider a particular 3-mc component in the video signal which might be a desired high-frequency component of the brightness signal, or possibly an undesired 3-mc beat note resulting from oscillator radiation from a neighbor's receiver. The 3-mc signal will go through the brightness channel and appear as a fine-structured black-and-white signal. In addition, the 3-mc component will appear in the chromaticity channel and will heterodyne with the 3.5-mc subcarrier, in the modulators, to produce more visible 0.5-mc beat notes. With the constant-amplitude system, using symmetrical sampling angles and equal gains in the three modulator channels, the 0.5-mc beat notes appearing in the three color-difference channels will be equal in amplitude and will differ in phase by 120 degrees. This is illustrated by the left-hand symmetrical voltage vector diagram in Fig. 6(a), and by the corresponding voltage waveforms in Fig. 6(b).

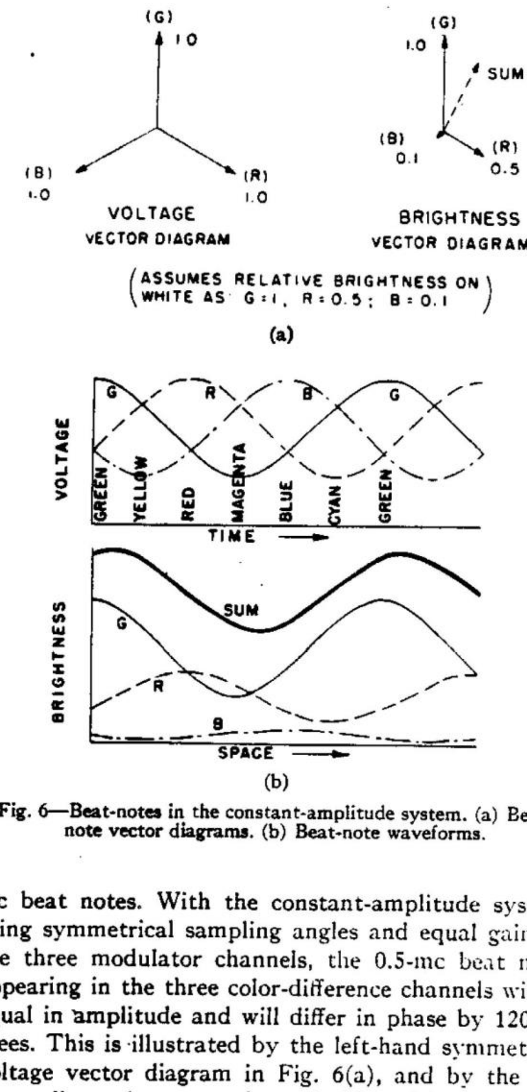


Fig. 6—Beat-notes in the constant-amplitude system. (a) Beat-note vector diagrams. (b) Beat-note waveforms.

While the electrical sum of the three beat notes would add to zero, the visual effect does not, and a colored beat note results. Moreover, since the eye is more sensi-

[10] When using sine-wave modulators instead of narrow-angle samplers, the three-phase signal, referred to in Fig. 5, is properly termed a three-phase *reinserted subcarrier signal*. For brevity, the word "reinserted" will not be used in the block diagrams.

tive to brightness changes than to chromaticity changes, the brightness component of this colored beat note should be particularly considered.

Equal voltage fluctuations in the G, R, and B channels of the display do not represent equal brightness fluctuations. For example, when rather representative primaries are used to reproduce a white picture, turning off the blue primary will change the picture from white to yellow, but hardly change the visual brightness of the picture. In other words, the blue channel mainly affects color or chromaticity and has only a small effect on brightness.

The difference in brightness between the primaries may be illustrated by considering three monochromatic lights of wavelengths 540 mμ (G), 610 mμ (R), and 470 mμ (B). With these three colored lights, a white light of about 4,800 degrees K is produced by equal *energy* from the three light sources. However, the relative brightness of these three lights will be found to be 0.95, 0.50, and 0.09 for the green, red, and blue, respectively.

Actual practical primaries are not likely to differ widely from the monochromatic lights just used for illustration. For example, the relative brightness of three rather representative G, R, and B primaries, when reproducing white, may be about 1, 0.5, and 0.1, respectively. For these assumed relative brightnesses, the brightness variation versus space resulting from the 0.5-mc beat note under consideration is shown in Fig. 6(a) by the right-hand vector diagram and in Fig. 6(b) by the corresponding brightness waveform. Thus, we see that while the sum of the three voltage fluctuations would add to zero the brightness fluctuations do not. This indicates that with the symmetrical system a signal in the chromaticity channel not only causes color fluctuations but may also cause brightness fluctuations.

Because of the band-shared nature of the system under discussion, spurious patterns or beat notes result which can be thought of as interference between the two signals which share the same portion of the spectrum. In particular, the 2- to 4-mc high-frequency components of the brightness signal cross talk into the chromaticity channel and produce a "shimmering" or crawling pattern on edges or in areas of fine detail. In other words, in any area of the picture where high-frequency video components normally appear, there will also appear spurious patterns because of these components getting into the color channel of the receiver.

Now, since the band-shared components are interleaved, the interference has opposite polarity on successive picture frames. This tends to make the interference cancel out visually; however, because of nonlinearities and of inadequate integration of the eye over the 1/15th second involved in two successive picture frames, these spurious patterns are still somewhat visible. In particular the *brightness* component of these spurious patterns is the most visible. Experience indicates these spurious patterns, resulting in the symmetrical arrangement, need to have their visibility reduced.

III. The Constant-Luminance System

A. Color Versus Brightness Fluctuations

The eye is less sensitive to changes in chromaticity, that is, changes in hue and saturation, than it is to changes in brightness. When these are changes versus space, this statement is merely a rephrasing of the mixed-highs principle.[11] But the statement also applies to changes versus time, as is indicated by the flicker photometer. In the flicker photometer two beams of light are alternated at about 40 times per second, and they appear to flicker as long as there is any brightness difference between them. However, if the flicker rate has been set properly, no flicker will result from a difference in hue or saturation.[12] Thus, the flicker photometer illustrates that a flicker produced by brightness modulation is far more readily perceptible than is a flicker of equal energy content representing a change in hue and saturation only.

B. Proportioning of Chromaticity Channel for Constant-Luminance Operation

Since the spurious signals mentioned before result mainly in the band-shared chromaticity channel, it seems reasonable to expect that they would be less visible if this chromaticity channel did not affect the brightness of the reproduced image. This has been found to be true, and such an arrangement, in which the brightness is determined by the direct shunt path of the receiver and the chromaticity channel has been so proportioned that it does not affect the brightness or luminance of the image, has been called the "constant-luminance system."[13]

While an exact constant-luminance system can be constructed, an "approximate" or simplified system, in which the luminosity of the blue-reproducing primary is assumed to be substantially zero, results in some simplifications and will, therefore, be described here. For example, Fig. 7 illustrates a color receiver for a simplified system in which the green and red primaries are assumed to have a relative brightness of 2 to 1 and the brightness of blue is considered to be zero (that is, blue merely affects color). It will be noted that this receiver is similar to the one previously shown for the symmetrical system, except that some of the angles and gains are changed.

For the moment, let us ignore the problem of how to obtain correct color signals and consider merely the spurious signals produced in the chromaticity channel. Since the green and red color-difference channels de-

[11] As a good example of brightness versus chromaticity, see R. M. Evans, "An Introduction to Color," John Wiley and Sons, Inc., New York, N. Y., Plate VI, opposite p. 144.

[12] See page 200 of footnote reference 11

[13] In a similar sense, the symmetrical three-phase system is called a "constant-amplitude system" because the sum of the three color-difference *voltages* from the chromaticity channel equals zero.

modulate 180 degrees from each other, any signal coming through the chromaticity channel will produce opposite signals in the green and red channels. Also note that the relative gain of the green color-difference channel is one-half that of the red color-difference channel. Thus, for any signal appearing in the red color-difference channel, an opposite polarity signal of one-half amplitude appears in the green color-difference channel. For the assumed case of relative brightness of the primaries, one unit voltage fluctuation in the green channel produces one unit brightness fluctuation, but one unit volt-

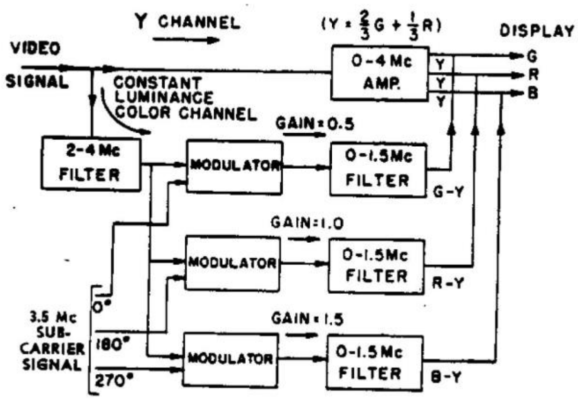


Fig. 7—Color receiver for simplified constant-luminance system.

age fluctuation in the red channel produces only one-half unit of brightness fluctuation. Thus, for the arrangement shown, any signal in the chromaticity channel results in equal and opposite *brightness fluctuations* from the green and red images produced by the display. Thus, the brightness or luminance is independent of signals in the chromaticity channel since the resulting green and red brightness changes cancel, and the brightness of blue has been assumed to be zero.

Since blue has been assumed to have negligible luminosity, the phase angle and gain of the blue color-difference channel are not determined by constant-luminance considerations. For simplicity in the arrangement shown, the system has been designed so that the blue color-difference signal can be obtained in quadrature to the red and green color-difference signal and requires a relative gain of 1.5 times. (The value of 1.5 was chosen since it appears to give optimum performance when using the group of improvements to be described later.)

Fig. 8 illustrates the beat-note vector diagrams for the simplified constant-luminance system. Again these may be considered to represent the vector relations of the 0.5-mc beat notes occurring in the three channels when a 3-mc signal is applied to the chromaticity channel. The left-hand vector diagram represents the voltage fluctuations and the right-hand vector diagram the brightness fluctuations. As shown, the brightness fluctuations from the green and red color-difference channels cancel each other. If the blue primary actually has some small relative brightness, such as 0.1, it is seen that only a very small net brightness fluctuation is produced.

Experience with the simplified constant-luminance system just described indicates that the susceptibility of the receiver to interference and spurious signals produced in the chromaticity channel is reduced by 6 to 8 db, compared with the previously proposed symmetrical system.

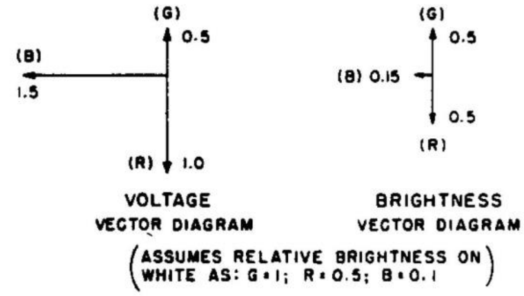


Fig. 8—Beat-note vector diagram in simplified constant-luminance system.

C. Obtaining Correct Color Signals

How the correct color signals are obtained will now be considered briefly. In a constant-luminance system the brightness signal (Y) should be proportional to the visual brightness and thus should contain G, R, and B, weighted according to relative brightness. This is true since the chromaticity channel does not affect brightness. Thus, the shunt or brightness channel must determine brightness and the signal it receives must therefore be proportional to brightness. For the simplified system under consideration this means that

$$Y = \tfrac{2}{3}G + \tfrac{1}{3}R.$$

Using this value we find that

$$R - Y = \tfrac{2}{3}R - \tfrac{2}{3}G$$

and

$$G - Y = \tfrac{1}{3}G - \tfrac{1}{3}R.$$

Thus,

$$G - Y = -\tfrac{1}{2}(R - Y).$$

In other words, in such an approximate system, $G-Y$ and $R-Y$ can be detected 180 degrees from each other, or one can be obtained from the other by a phase inverter. The direct relationship between $G-Y$ and $R-Y$ results since Y contains only the two colors, G and R. Thus, one additional independent quantity containing only G and R (such as $R-Y$) will permit solution for each color signal.

It will be noted that in a color-television system there are three independent quantities to be transmitted. In the simplified constant-luminance system these three quantities may be considered to be Y, $R-Y$, and $B-Y$. One quantity, Y, is transmitted as the normal video signal, and the other two quantities can be considered to be the in-phase component of the 3.5-mc subcarrier $(R-Y)$ and the quadrature component of the 3.5-mc subcarrier $(B-Y)$. Since these three means of transmission are independent of each other, the transmitted signal can be decoded and the three original signals, G, R, and B, can be separated from each other at the receiver to obtain correct color signals.

D. *Receiver with Quadrature Desampling*

As just pointed out, $G-Y$ is $-\frac{1}{2}(R-Y)$. Thus, the receiver of Fig. 7 can be replaced by using only two modulators plus a video phase inverter. Such a tricolor tube arrangement is illustrated in Fig. 9. The Y-signal is applied to the grids of the three guns of the tricolor tube, and negative color-difference signals are applied to the individual cathodes. This produces individual grid-cathode voltages of G, R, and B. For further simplicity, this receiver is illustrated as using only 1-mc bandwidth in the color-difference channels since this may be adequate and permit more gain per stage.

E. *Transmitter (Encoder)*

A rather straightforward transmitter arrangement for the simplified constant-luminance system is shown in Fig. 10. The G, R, and B signals are combined to give a wide-band Y signal and narrow-band $R-Y$ and $B-Y$ signals. The Y signal is transmitted as the normal video signal and the $R-Y$ and $B-Y$ signals modulate 3.5-mc subcarriers in quadrature.

F. *An "Exact" Constant-Luminance System*

The system just described is a simplified or an "approximate" constant-luminance system, in which the blue reproducing primary has been assumed to have

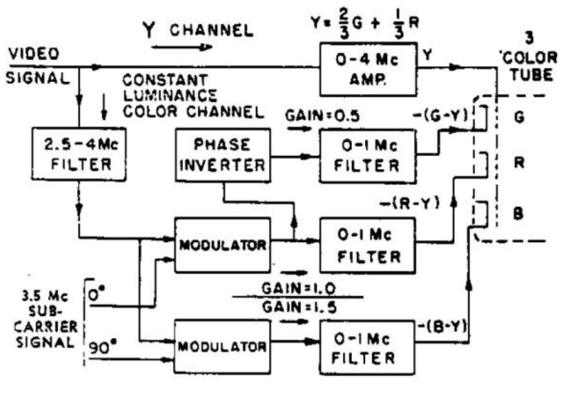


Fig. 9—Simplified receiver for constant-luminance system.

zero luminosity. The construction of a more exact constant-luminance system can be accomplished, if desired, by arranging the chromaticity channel of the system so that the green and red fluctuations do not exactly cancel, but have instead a small net brightness fluctuation which is equal and opposite to the small brightness fluctuation produced by the blue channel. For example, the system could be arranged so that the green and blue color-difference channels have gains and

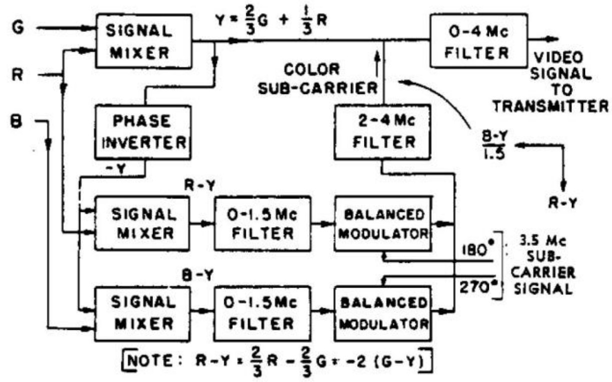


Fig. 10—Color transmitter for simplified constant-luminance system.

angles, as in Figs. 7 and 8, and so that the red color-difference channel has a gain of 1.04 and angle of 163.3 degrees. In this case, the red fluctuation will cancel the sum of the green and blue fluctuations. However, in view of other system limitations, such as nonlinear picture-tube characteristics of brightness versus voltage, the "exact" constant-luminance arrangement is really not exact. Thus, the practical benefits may be small in using the "exact" arrangement in the receiver as compared to the simplified arrangement previously described.

G. *Advantages of the Constant-Luminance System*

Since imperfections (noise or interference) in the chromaticity channel signals are less visible in the constant-luminance system than in the constant-amplitude system, a number of advantages result:

1. High-frequency beat-note interference, such as may be produced by oscillator radiation, is less visible.
2. Noise through the chromaticity channel as well as the color-sync channel is less visible.
3. Cross talk of high-frequency video components into the color channel is less visible (less "shimmer").
4. Color "cross-talk" effects produced by single side-band transmission of color subcarrier information and by mixed highs are less visible since the brightness of reproduced images is correct in spite of the color errors.
5. Nonuniform amplitude and phase characteristics near the color subcarrier frequency do not affect brightness of image. Thus, distortions produced by these nonuniform characteristics are less visible.

It is interesting to note that the above advantages appear great enough to be preferable to exact color rendition. While observing recent constant-amplitude transmissions, it was noted that if these transmissions were viewed on a constant-luminance receiver the result was a more pleasing picture than when observed on a constant-amplitude receiver. This gave incorrect chromaticity and brightness for certain colors, but a phase of reinserted subcarrier could be found which gave very acceptable color rendition. (Note that since the original scene was not available for comparison small deviations from true reproduction were not apparent.) The noise and spurious patterns were substantially less with the constant-luminance system receiver and printing was more legible because of reduction in visibility of spurious patterns on edges. Phase distortion near the color subcarrier frequency produced a noticeable misregistration of lips with the constant-amplitude receiver, but this misregistration substantially disappeared with the constant-luminance receiver since no brightness misregistration was then reproduced. This limited observation indicated that the advantages of the constant-luminance system are more important than *exact* color balance. But, of course, substantially correct color balance can be obtained in addition to the benefits described above by transmitting a constant-luminance signal.

An additional advantage results because the transmitted brightness signal is proportional to visual brightness. This produces a preferred form of picture on black-and-white receivers tuned to the color transmissions because colored areas are reproduced with an intensity proportional to their original brightness as seen by the normal human eye.

IV. Related Improvements

A. Compatibility

A few words about compatibility now seem to be appropriate. Within the original "dot-sequential" system, a rather large 3.5-mc sine wave is transmitted in areas of saturated colors. While this sine wave tends to integrate out since it is an odd multiple of one-half horizontal scanning frequency, it is nevertheless desirable to reduce the transmitted amplitude of the 3.5-mc signal to improve compatibility, that is, to permit reproduction of unimpaired images in black-and-white receivers. Any such reduction at the transmitter must be accompanied by a corresponding increase in gain in the chromaticity channel of the color receiver in order to maintain correct saturation of the colors. Then, the increased gain in the chromaticity channel makes this channel *more* susceptible to interference and spurious patterns.

Any improvement, such as the constant-luminance system, can be used *either* to reduce the visibility of the spurious patterns in the color pictures *or* to improve the compatibility of the system as seen on black-and-white receivers. Laboratory experience with high-resolution color pictures and wide bandwidth black-and-white receivers indicates that both the compatibility and the color pictures should be improved. Besides the constant-luminance system, there are additional means that should be considered to reduce the visibility of the spurious patterns in the color receiver.

B. Subcarrier Pattern

The phase of the beat notes in the chromaticity channels depends upon both the phase of the input signal and the phase of the reinserted subcarrier signal. Thus, the form of the spurious *patterns* depends upon the subcarrier signal *pattern*. If the subcarrier is an odd multiple of one-half horizontal scanning frequency and then has its phase shifted by 90 degrees on every other field, a pattern with reduced visibility is obtained. The predominant upward crawl of the originally proposed signal, shown in Fig. 11(a), is eliminated in the pattern of Fig. 11(b). The difference in apparent motion is illustrated by the arrows in Fig. 11. This difference in motion appears to give a small reduction in visibility of spurious patterns in the color picture plus a small reduction in visibility of the 3.5-mc signal on black-and-white receivers.

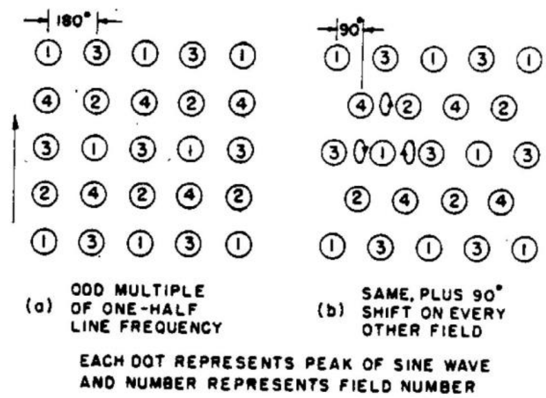


Fig. 11—Dot patterns.

C. Compensation for Spurious Patterns

The visual effect of the cross talk of high-frequency brightness components into the chromaticity channel can be further reduced. Consider for the moment a brightness signal component at 3.3 mc. With a 3.5-mc subcarrier, this would produce 200-kc beat notes in the chromaticity channel. Now assume that every time a 3.3-mc signal is transmitted an additional component is transmitted at 3.7 mc. This would produce a second 200-kc beat note that might be made to add or subtract from the first beat note in specific color channels. For example, consider Fig. 12 and specifically consider the vector relations in the green channel. The 3-5-mc reinserted subcarrier vector in the green channel is illustrated together with the 3.3-mc vector which is rotating with respect to the 3.5-mc subcarrier vector. The vector of the added 3.7-mc component rotates in an opposite direction to the 3.3-mc component. If it is correctly phased, the two components can add to produce a fluctuation in *quadrature* to the green reinserted subcarrier signal. Then the net cross talk into the green color-difference channel will be zero, that is, the two beat notes will cancel.

Note that with the simplified constant-luminance system the condition for cancelling the cross talk in the green color-difference channel also results in cancellation in the red color-difference channel. However, the cross talk in the blue color-difference channel is doubled. This transferring of all the spurious patterns to the blue channel can be made to give a net reduction in visibility of the cross talk of highs into the chromaticity channel because of the very low brightness of typical blue reproducing primaries.

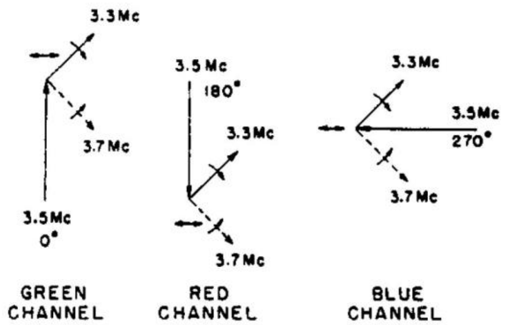


Fig. 12—Cross-talk vector diagrams.

Fig. 13 illustrates how these extra components are produced at the transmitter by including a 7-mc sampler in the brightness channel. The 7-mc sampling signal is obtained by doubling the frequency of the 3.5-mc color subcarrier frequency so that the original video components, such as the 3.3-mc component, and extra components, such as the 3.7-mc component, are symmetrically disposed about the color subcarrier frequency. The 7-mc sampling phase is selected to produce cross-talk cancellation in the green and red channel of the color receiver. In addition, the brightness signal may be limited slightly in bandwidth by passing it through a 3.5-mc filter before sampling to prevent the combination

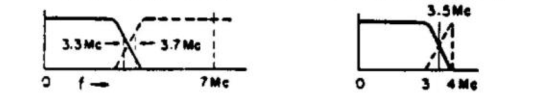


Fig. 13—Sampling of brightness signal for cross-talk compensation.

of the original and added high-frequency components from being excessive in amplitude.

To make the above system practical, the additional components transmitted for cross-talk compensation should be of low visibility so that the black-and-white receivers are free from spurious patterns. This condition is satisfied if the 3.5-mc subcarrier pattern uses the additional 90-degree shift on every other field, as shown in Fig. 11(b). The resulting 7-mc sampling pattern is a checkberboard pattern which repeats in 1/30 of a second. The pattern is like that of Fig. 11(b), with the 3's and 4's replaced by 1's and 2's, because 180-degrees shift at 3.5 mc is equivalent to 360-degrees shift at 7.0 mc. It will be noted that the phase of the pattern on adjacent lines in space differs by 180 degrees, thus giving low visibility.

To prevent excessive rectification effects in the blue channel due to the extra cross talk in this channel, it is desirable to limit the bandwidth of the blue color-difference channel in the receiver to about 0.5 mc. In addition, it may be desirable to include a limiter in the blue color-difference channel to prevent high-amplitude short-duration pulses of cross talk from causing excessive rectification and "blooming" in the blue picture tube.

D. *Proportioning of Bandwidths*

Besides the improvements previously mentioned it is probably obvious that the susceptibility of the chromaticity channel to interference and spurious signals can be reduced by narrowing the bandwidth of the channel *at the receiver*. The optimum bandwidth of the color-difference channels is not known at this time, but it appears that some reduction can be made without appreciable degradation of the color picture. A reduction to 1-mc bandwidth, or possibly even to 0.5-mc bandwidth, appears necessary to reduce the susceptibility to interference. Note that reducing the band-pass filter in the chromaticity channel to a 3- to 4-mc pass band will give a 0.5-mc bandwidth for the color-difference signals. This also produces a frequency-response characteristic for the chromaticity channel that is symmetrical about the 3.5-mc color carrier frequency, thus permitting optimum benefits from the brightness signal sampling arrangement previously described.

Spurious patterns produced in the chromaticity channel by cross talk from high-frequency components of the brightness signal can be eliminated by reducing the bandwidth of the brightness signal at the *transmitter*. While this eliminates spurious patterns, it also reduces the resolution of the system. Such a reduction in resolution may be unnecessary in view of the compensation arrangement, just described, which is included *at the transmitter*.

V. Summary of Improvements ("20-db Package")

Fig. 14 gives a tabulation of the approximate improvements in interference reduction obtained by the various items mentioned in this paper. It will be noted that the first two items in the tabulation, namely, the constant-luminance system and the narrower bandwidth in the chromaticity channel, reduce the probable visibility of external high-frequency interference, such as noise or oscillator radiation, as well as reduce the cross talk of highs into the color channel. The last two items, namely, the 90-degree subcarrier pattern and the brightness channel sampling, are effective only in reducing the visibility of cross talk of highs into the color channel.

It will be noted that the group of modifications de-

MODIFICATION	APPROXIMATE IMPROVEMENT	
	FOR EXTERNAL HIGH FREQ. INTERFERENCE	FOR CROSSTALK OF HIGHS INTO COLOR
CONSTANT LUMINANCE	6-8 db	6-8 db
NARROWER BANDWIDTH CHROMATICITY CHANNEL	1-2 db	1-2 db
90° PATTERN	——	1-2 db
SAMPLING OF BRIGHTNESS	——	6-8 db
TOTAL APPROXIMATE IMPROVEMENT	7-10 db	14-20 db

RECOMMENDED USE OF CROSSTALK IMPROVEMENTS } 6-10db FOR COMPATIBILITY; REST FOR COLOR PICTURE

Fig. 14—Tabulation of interference reduction.

scribed result in a reduction of spurious shimmering patterns due to cross talk of highs into color by an amount which is of the order of 14 to 20 db (i.e., of the order of 5 to 10 times). This package of improvements can be used to improve the color picture or the compatibility of the system, or may be divided between these two items. It is recommended that 6 to 10 db be used for improving compatibility, that is, the color subcarrier signal level should be transmitted at a level that is 6 to 10 db below that corresponding to the "dot-sequential" arrangement. Then the rest of the "20-db package" can be used for reducing the shimmer in the high-resolution color pictures.

VI. Conclusions (Part I)

Because of the band-shared nature of the systems under consideration, spurious signals result in the chromaticity channel of the receiver. In order that these spurious effects have minimum visibility, the system should be designed so that the wide-band signal is proportional to visual brightness and the subcarrier does not affect the visual brightness of the picture but merely adds color. In other words, a constant-luminance system should be used. When using such a system, the visibility of cross talk within the system due to band sharing can be further reduced by using an extra sampling in the transmitter in the brightness signal channel. Additional shimmer reduction can be accomplished by selection of the subcarrier pattern and by limiting the bandwidth of the chromaticity channel at the receiver. By combining the above modifications, a highly compatibility color-television system may be obtained which will reproduce good high-resolution color pictures without shimmer. Laboratory experience with a color-television system using the described improvements shows that color pictures, comparable to those obtained with a *12-mc* simultaneous color system in which a 4-mc bandwidth for *each* color is used, can be obtained through a 4-mc bandwidth.

Part II—Color-Television Systems with Oscillating Color Sequence

***Summary of Part II*—An additional improvement in band-shared simultaneous color systems is described which reduces the visibility of phase errors in the subcarrier channel of the system. This improvement is obtained by periodically reversing the phase sequence (timing order) of the color subcarrier information, for example, after each scanning field so that phase errors may produce opposite types of color errors on adjacent lines in space. At normal viewing distances the human eye averages the color of adjacent elemental areas, thus giving a first-order correction for chromaticity errors due to phase errors in the color subcarrier channel. While this permits a greater tolerance on the phase of the reinserted subcarrier at the receiver, the major advantage results because vestigial sideband transmission of the color subcarrier information is made practical. The manner in which this latter feature can be used to improve both compatibility and the reproduced color pictures is described. The extent to which the improvements of Part I can be used with a system having an oscillating color sequence is also discussed.**

I. Introduction

The first part of this paper was directed toward band-shared simultaneous systems having superior compatibility and reduced visibility of interference and spurious patterns compared with the "dot-sequential" system. Because of the relatively sharp cut-off characteristic of the IF amplifiers of most television receivers, compatibility may be substantially improved by increasing the color subcarrier frequency. The second part of this paper will describe a system improvement which will permit the use of a higher color subcarrier frequency. Thus, it appears desirable to discuss this additional improvement and the manner in which it affects the other improvements mentioned in Part I.

In the type of band-shared simultaneous color-television system which has been considered in detail in Part I, the color subcarrier is used to transmit two quantities which represent chromaticity information. These two quantities can be considered as the in-phase and quadrature components of the subcarrier signal. To prevent cross talk between these two quantities in the previous system, the phase of the transmitted subcarrier signal and the reinserted subcarrier reference at the receiver must be accurately maintained. Also, to prevent cross talk, double sideband transmission of the transmitted subcarrier signal is required. This part of the report describes a band-shared simultaneous color system in which the phase sequence of the color subcarrier information is periodically reversed, for example, after each scanning field. By using such an oscillating color sequence (OCS), a first-order correction is obtained for chromaticity errors that would normally result, because of phase errors, in the color subcarrier channel; vestigial sideband transmission of the color subcarrier information is then made practical. While the sequence reversal rate is not limited to a reversal after each scanning field, the present discussion will be limited to this reversal rate, for simplicity.

In order to understand fully the improvements made by using an oscillating color sequence, it is desirable to study the exact nature of color cross talk resulting from phase errors. While the oscillating color-sequence principle can be applied to the constant-amplitude system, it appears most attractive when applied to the simplified constant-luminance system using quadrature demodulation, as described in Part I. Thus, the color cross talk produced by phase errors in the simplified constant-luminance system will be considered in detail.

In order simply to illustrate the principle of operation of systems using an oscillating color sequence, the result of an incorrect phase of the reinserted subcarrier at the receiver will be considered in detail. However, it should be noted that such phase errors can be controlled and that the major practical improvement results because color cross talk due to vestigial sideband transmission of the color subcarrier is substantially eliminated.

II. Color Cross Talk Due to Phase Errors

If the phase of the reinserted subcarrier reference at the receiver relative to the transmitted subcarrier signal is not correct, color cross talk is produced. If the average value of the relative phase is in error because of the misphasing of the reinserted subcarrier, a *large-area* color contamination results. However, even if the average value of the relative phase is correct, the instantaneous relative value may be incorrect because of the unintentional phase modulation of the received subcarrier signal. Such phase modulation can result when the color subcarrier signal passes through a channel having nonuniform amplitude and phase characteristics. These nonuniform characteristics may result from purposeful vestigial sideband transmission, from phase distortion in the color receiver, or from multipath transmission (i.e., echoes). The spurious phase modulation produced by these nonuniform characteristics results in color cross talk *near edges* of colored areas.

A. Large-Area Color Errors

Consider the output produced by one of the color demodulators of a color receiver with a shunt brightness channel (Fig. 7), under the conditions of incorrect phase of the reinserted subcarrier. The output of a demodulator is proportional to the product of the input signals. Thus, if the color subcarrier information has a desired in-phase component of A and a quadrature component of B, and the reinserted subcarrier has a phase error of δ, the output of the demodulator is proportional to[14]

$$[A \cos \omega_s t + B \sin \omega_s t][2 \cos (\omega_s t + \delta)].$$

Expanding the above relation and using the following trigonometric relations,

$$\cos x \cos y = \tfrac{1}{2} \cos (x - y) + \tfrac{1}{2} \cos (x + y)$$
$$\sin x \cos y = \tfrac{1}{2} \sin (x - y) + \tfrac{1}{2} \sin (x + y),$$

we obtain an output signal from the demodulator of

$$A \cos \delta + A \cos (2\omega_s t + \delta) - B \sin \delta + B \sin (2\omega_s t + \delta).$$

The terms involving $2\omega_s t$ represent second harmonics of the subcarrier which are eliminated in the low-pass filters in the output of the demodulator; therefore, the useful output is

$$A \cos \delta - B \sin \delta.$$

When $\delta = 0$, the desired color signal A is given by the term $A \cos \delta$. Note, that when a small phase error exists, the output *due to* the desired component A is hardly in error, but the error in the output signal is caused mainly by contamination or *cross talk* (represented by $B \sin \delta$) *from the quadrature component* B.

Now consider the operation of the complete chromaticity channel of the color receiver under conditions of the wrong phase of the reinserted subcarrier. The vector relations in this channel are shown in Fig. 15.[15] From the equations shown above, it is apparent that the output of the $R-Y$ and $B-Y$ demodulators is proportional to the projection of the transmitted signal vectors upon the respective reinserted subcarrier vectors, as indicated in Fig. 15. Now, the net output for any color

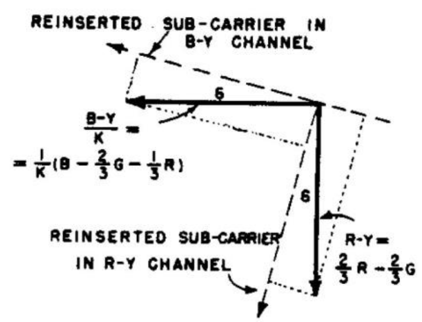


Fig. 15—Vector relations in color demodulators when reinserted subcarrier is at wrong phase.

channel of the receiver is equal to the signal through the brightness channel plus the signal through the respective color-difference channels (see Fig. 7). Using primes to

[14] The coefficient "2" in front of the reinserted subcarrier term is selected to be equivalent to peak detection.

[15] In this section, the transmitted amplitude of the $B-Y$ component is considered to have the general value of $B-Y/K$, where K is some constant having a value probably between 1 and 5. In Part I of this paper, K was chosen as 1.5 since this appeared to give optimum performance with the "20-db package" of improvements tabulated in Fig. 14.

represent the signals produced under conditions of misphasing, we have

$$R' = Y + (R - Y)'$$

$$B' = Y + K\left(\frac{B - Y}{K}\right)'.$$

Since $G - Y = \frac{1}{2}(R - Y)$ (see Section III, C, of Part I),

$$G' = Y - \tfrac{1}{2}(R - Y)'.$$

The values of the various color-difference signals can be found from the projections of the respective vectors in Fig. 15. This gives the following:

$$R' = Y + (R - Y)\cos\delta + \left(\frac{B - Y}{K}\right)\sin\delta$$

$$\approx R + \frac{\delta}{K}\left(B - \frac{2}{3}G - \frac{1}{3}R\right)$$

$$G' = Y - \frac{1}{2}(R - Y)\cos\delta - \frac{1}{2}\left(\frac{B - Y}{K}\right)\sin\delta$$

$$\approx G - \frac{\delta}{2K}\left(B - \frac{2}{3}G - \frac{1}{3}R\right)$$

$$B' = Y + K\left(\frac{B - Y}{K}\right)\cos\delta - K(R - Y)\sin\delta$$

$$\approx B - \delta K\left(\frac{2}{3}R - \frac{2}{3}G\right).$$

Here it has been assumed that δ is small so $\cos\delta \approx 1$ and $\sin\delta \approx \delta$.

Note from the equations that the error signal produced in any color channel is proportional to δ. Also note that the error signal in the red and green channels is reduced as K is increased (i.e., as the $B - Y$ component is transmitted as a lower relative amplitude). However, at the same time, the error signal in the blue channel is increased since more gain (K) is required in the blue color-difference channel. This gives one possible basis for choosing a value for K. By weighing the subjective effects of voltage errors in the three channels (equal voltage errors do *not* produce equally tolerable subjective effects), a value for K can be chosen which gives the minimum subjective color error for a given misphasing of the reinserted subcarrier.

The color errors produced by misphasing can be evaluated from the above equations. If a saturated red is transmitted ($G = B = 0$) and δ has a positive value, a positive error appears in the green channel and a negative error appears in the blue channel so that the red is reproduced with a slight orange tinge (red+small green). If a saturated green is transmited ($R = B = 0$) and δ has a positive value, a positive error appears in the blue channel and a negative error appears in the red channel so that the green is reproduced with a slight bluish tinge. Thus, the colors have been slightly rotated about the color triangle. In other words, the *phase of the reinserted subcarrier* directly *determines the hue* of the reproduced color. Actually, a phase shift of the order of 5 to 10 degrees produces a noticeable hue shift, particularly in colors near yellow.

B. Color Errors Near Edges

Nonuniform transmission characteristics in the vicinity of the color subcarrier can produce spurious phase modulation which results in color errors near edges of colored areas, or in areas of fine color detail. This effect can be illustrated by a special example shown in Fig. 16. In this figure the pattern being transmitted has a white background with alternate bluish and yellowish areas. This pattern represents constant green and red signals, with a sinusoidal variation superimposed on a

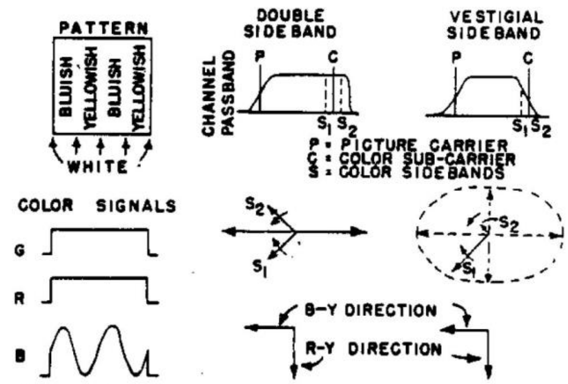


Fig. 16—Vector diagrams showing cross talk due to vestigial sideband transmission of color subcarrier.

constant level for the blue signal. With such a signal, the sinusoidal variation does not appear in the brightness signal ($Y = \frac{2}{3}G + \frac{1}{3}R$) in the simplified constant-luminance system, and the color subcarrier information should merely produce a variation in the blue color-difference channel of the receiver. The sinusoidal variation of the blue signal at the transmitter will produce a pair of sidebands about the color subcarrier. As illustrated by the center portion of Fig. 16, these sidebands (S_1 and S_2) should add to produce a fluctuation *along* the *$B - Y$ axis* (90- to 270-degree axis). This sum of the two sidebands should be along a line *perpendicular* to the *$R - Y$ axis* so that none of this sinusoidal variation is seen in either the red or green channel.

If the channel pass band is narrow so that the color subcarrier falls on a sloping characteristic, the conditions at the right of Fig. 16 apply. Assuming that the color subcarrier is about 6 db down on the side, the color-difference channel will need about 6 db more gain to obtain correct large-area saturation of colors. Then the sideband S_1 will appear larger and the sideband S_2 smaller than before. The resultant of these two unequal sidebands will now move along an ellipse instead of a line. In other words, besides the desired output variation in the $B - Y$ direction, there will be a quadrature component (spurious phase modulation) which is in the $R - Y$ direction, and cross talk into the green and red channels will result.

Over a uniformly sloping amplitude characteristic, the color cross talk resulting from vestigial sideband transmission of the color subcarrier is proportional to the modulating frequency. This is true because the greater the modulating frequency, the greater the difference in amplitude between the two sidebands. Actually, if no phase distortion is present, the quadrature component (cross talk) can be shown to be proportional to the first derivative of the modulating signal. Correspondingly, if the amplitude characteristic is flat but a small curvature (equivalent to a square law term) exists in the phase characteristic, the quadrature component can be shown to be proportional to the second derivative of the modulating signal. This quadrature component that we have just discussed is similar to the quadrature component produced with vestigial sideband transmission of the normal video signal, which has been adequately covered in the literature.[16]

The effect of vestigial sideband transmission of the color subcarrier is further illustrated in Fig. 17. Here the transmitted subcarrier should just turn off blue during the short subcarrier burst to produce a yellow bar. However, a quadrature component is produced which appears as a differentiated signal in the green and red channels. Thus, in the reproduced image, the yellow bar has a greenish-yellow bar to the left and an orange bar to the right.

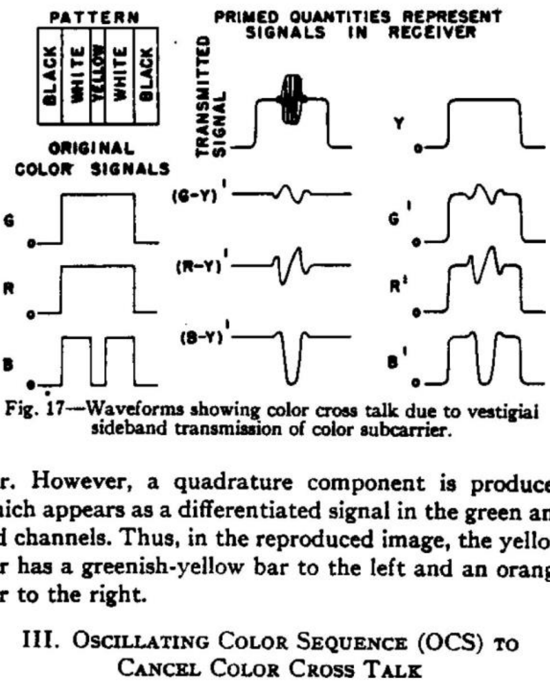


Fig. 17—Waveforms showing color cross talk due to vestigial sideband transmission of color subcarrier.

III. Oscillating Color Sequence (OCS) to Cancel Color Cross Talk

From the previous material, we have seen that errors in a particular output signal produced by phase errors in the color subcarrier channel are due mainly to cross talk from the subcarrier component which is in quadrature to the desired component required for the particular signal under consideration. If this quadrature component is reversed in polarity, the cross-talk error produced is also reversed. Reversing one component of the color subcarrier is equivalent to reversing the color sequence (i.e., instead of the color sequence being green, red, and blue with increasing phase angle, the color sequence is changed to green, blue, and red). Thus, by periodically reversing the color sequence, the color cross-talk errors due to misphasing can be made to be of opposite sign during successive periods of time.

The resolution of the human eye for chromaticity changes at constant brightness is less than 40 per cent of the resolution for brightness changes.[17] Thus, at normal viewing distance, the chromaticity of adjacent lines in space will *automatically be averaged* by the eye. If the color errors due to misphasing are *opposite* on *adjacent lines* in space, such as would be produced by reversing the color sequence after each field, the eye will automatically average the errors so that they *visually cancel* out. This is equivalent to using the mixed-highs principle in the vertical direction. Of course, for the eye to do a good job of averaging the color of adjacent lines and to prevent flicker, it should be only the *chromaticity* that is in error and *not* the brightness. Phase errors in the constant-amplitude system can produce brightness as well as chromaticity errors, but as a first-order approximation only chromaticity errors are produced in the constant-luminance system. Thus, the oscillating color-sequence principle appears most attractive when applied to the constant-luminance system, and particularly attractive when applied to the simplified constant-luminance system using quadrature demodulation.

A. Apparatus for System for OCS

Before describing the cancellation effects in detail, it will be useful to illustrate the equipment needed to practice OCS. Consider a simplified constant-luminance system in which the color sequence is reversed after each field by reversing the direction of the transmitted $B-Y$ component. The transmitted subcarrier signal for such a system is illustrated in Fig. 18, where the vector diagram on the left may apply to odd-numbered fields and the vector diagram on the right to even-numbered fields.

Fig. 18—Vector diagram of color subcarrier for constant-luminance system with oscillating color sequence.

A possible transmitter for this system using OCS is shown in Fig. 19. This is similar to the transmitter shown in Fig. 10 for the simplified constant-luminance system, except that a phase inverter is added to the $B-Y$ subcarrier circuit on every other field to reverse the color sequence. Also, it will be noted that a higher subcarrier frequency (near 4 mc instead of 3.5 mc) is indicated. This will be discussed in more detail later.

The receiver for a signal having OCS requires some arrangement to accommodate the periodic reversal of

[16] Nyquist and Pfleger, "Effect of the quadrature component in single sideband Transmission," *Bell Sys. Tech. Jour.*, pp. 63–73; January, 1940.

[17] See footnote reference 1.

the $B-Y$ signal. This can be accomplished in a number of ways: First, the phase sequence of demodulation can be periodically reversed (i.e., the $B-Y$ component can be demodulated alternately with a reinserted subcarrier

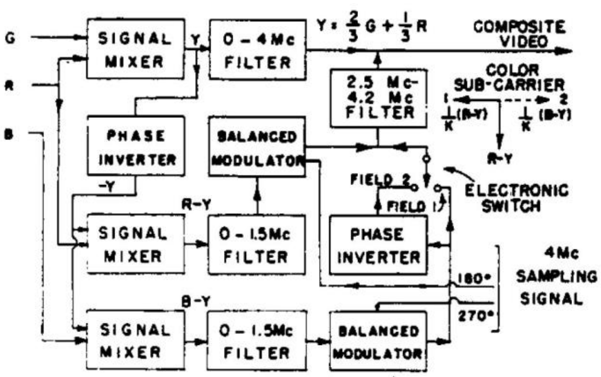


Fig. 19—Transmitter for constant-luminance system with oscillating color sequence.

at 90 and 270 degrees). If the reinserted subcarrier phase shifts are obtained from a delay line, this reversal of phase sequence of demodulation can be accomplished by connecting the reinserted subcarrier signal to opposite ends of the delay line during alternate periods. Second, the phase of the $B-Y$ signal can be periodically reversed in the video channel after demodulation. Third, the phase of the received subcarrier signal can be reversed before application to the $B-Y$ demodulator. This latter arrangement, which has a number of practical advantages, is illustrated in Fig. 20. The form of receiver shown in this figure is similar to the simplified receiver shown in Fig. 9, except that a balanced output is obtained from the band-pass filter, and the $B-Y$ demodulator is alternately connected to the two sides of the balanced output.

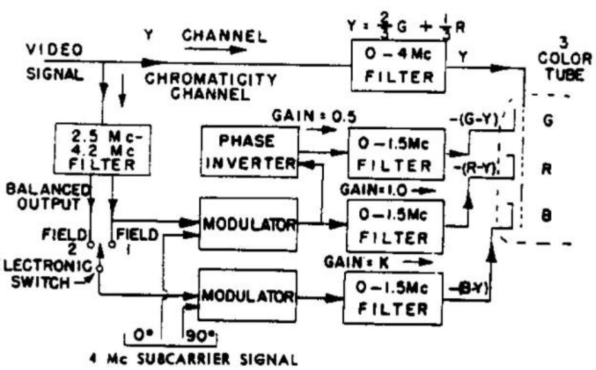


Fig. 20—Receiver for constant-luminance system with oscillating color sequence—using subcarrier channel switching.

Another circuit arrangement for a system with oscillating color sequence is shown in Fig. 21. This arrangement can be inserted directly in the color subcarrier channel of the receiver before the signal goes to either the $R-Y$ or $B-Y$ demodulators. This circuit directly reversed the color sequence of the *complete* subcarrier by using the beat note between the original color subcarrier and a signal at twice the subcarrier frequency.[18] The direct and reversed phase-sequence subcarriers are chosen on alternate fields, thus cancelling the phase reversal applied at the transmitter so that the subcarrier can be applied to a set of normal $R-Y$ and $B-Y$ demodulators.

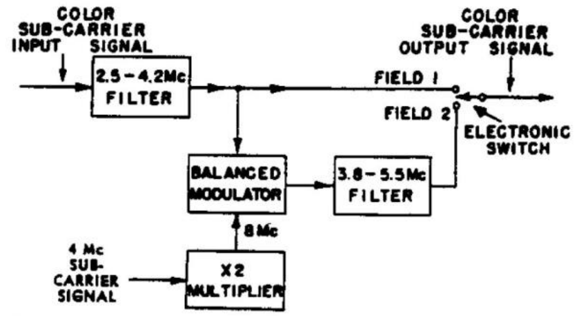


Fig. 21—Circuit for reversing phase sequence of color subcarrier.

It should be noted that the arrangement of Fig. 21 is rather universal. By adjusting the phase of the 8-mc signal applied to the balanced modulator, the phase of the axis about which the signal is inverted can be chosen. Also, the circuit can be used in the chromaticity channel of either the receiver or transmitter. In addition, the circuit can be used with OCS applied to the constant-amplitude system as well as to the simplified constant-luminance system just described.

B. Cancellation of Large-Area Color Errors

Consider the detailed operation of a system using OCS. Fig. 22 shows the vector relations in the receiver

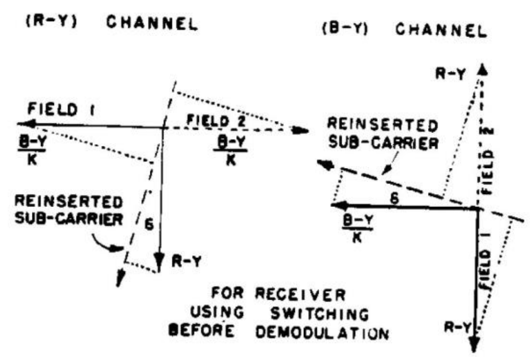


Fig. 22—Vector relations in system with OCS when reinserted subcarrier is at wrong phase.

of such a system when the reinserted subcarrier is at an incorrect phase. The relations existing in the $R-Y$ channel are shown by the left vector diagram. For illustration, it will be assumed that the receiver (such as the receiver in Fig. 20) uses switching before demodulation, and then the right vector diagram represents the

[18] Note that the phase of the beat note will retard when the phase of the original subcarrier is advanced.

relations existing in the $B-Y$ channel at the input of the $B-Y$ demodulator *after* switching. The phase of the color subcarrier signal is reversed after each field by the electronic switch so that the $B-Y$ component now appears at a fixed phase; this means, of course, that the $R-Y$ component appears to have opposite phase on successive fields. Thus, for this form of receiver, the $B-Y$ component at the input of the $R-Y$ demodulator appears to alternate in phase, and the $R-Y$ component at the input of the $B-Y$ demodulator also appears to alternate in phase.

From the above we can see that if the phase of the reinserted subcarrier is incorrect, the resulting cross talk has opposite signs on successive fields. Thus, the output signal of $(R-Y)$ modulator is

$$(R - Y) \cos \delta \pm \left(\frac{B - Y}{K}\right) \sin \delta.$$

The output signal of $(B-Y)$ modulator is

$$K\left(\frac{B - Y}{K}\right) \cos \delta \mp K(R - Y) \sin \delta,$$

where the + and − signs apply on alternate fields. If the system is linear, these opposite-sign chromaticity errors should visually cancel because successive fields correspond to adjacent lines in space. Then the only visual effect of misphasing should result from the cos δ terms which cause a gradual desaturation in the reproduced color due to a loss in detection efficiency for the desired color-difference components. Thus, in an *ideal linear* constant-luminance system using OCS the *phase* of the reinserted subcarrier should not affect the hue of the reproduced image, but should merely *change the saturation* of the color according to a cosine function. (Of course, when the cosine function becomes negative, this corresponds to a complementary color.)

Practical experience with a system using OCS (and $K=1.5$) has indicated that a misphasing of ± 20 to 30 degrees gives reasonably acceptable chromaticity reproduction. However, the permissible misphasing is frequently limited by flicker considerations. Because of the nonlinear characteristics of brightness versus voltage of the picture tubes, a 30-cycle flicker can result under conditions of large misphasing, even with the constant-luminance system. With the system just mentioned ($K=1.5$), this *may* restrict the permissible misphasing to ± 15 to 20 degrees.

C. Cancellation of Color Errors Near Edges

Color errors near edges due to vestigial sideband transmission of the color subcarrier have been previously described and illustrated in Fig. 17. When OCS is used, these color errors are opposite in sign on successive fields (i.e., on adjacent lines in space) and thus they tend to cancel visually. This effect is illustrated by Fig. 23.

The elimination of color distortion due to vestigial sideband transmission of the color subcarrier is the major advantage of OCS, and permits a substantial improvement of the color system. A higher subcarrier frequency can be used, thus improving compatibility. By changing the color subcarrier frequency from approximately 3.5 mc to approximately 4.0 mc, a very substantial improvement in compatibility may be obtained because of the relatively sharp cut-off characteristic of the IF amplifiers of most television receivers. Also, by using a higher subcarrier frequency, the spurious patterns produced in the color receiver can be minimized by a very slight reduction in bandwidth of the transmitted brightness signal. In addition, a higher subcarrier frequency permits a wider chromaticity bandwidth to be used.

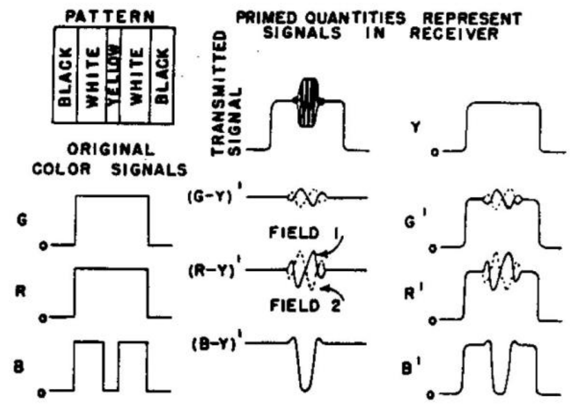


Fig. 23—Cancellation of color cross talk due to vestigial sideband transmission of subcarrier when using OCS.

IV. Summary of Advantages of OCS

The following is a summary of advantages obtained by using an oscillating color sequence:

1. Permits the use of a higher color subcarrier frequency.
2. Permits a wider chromaticity bandwidth.
3. Permits a greater tolerance on the phase of reinserted subcarrier at the receiver.
4. Simplifies the design of the IF channel of the color receiver since the IF characteristics need not be flat near the subcarrier frequency.
5. Makes color convertors more practical since good color can be obtained even when the color subcarrier is way down on the side of the IF characteristic.
6. Increases the probability of obtaining good color under conditions of multipath transmission.

V. Possible Values for a Practical System Using OCS

If desired, OCS could be directly applied to the improved system outlined in Part I of this paper. However, since vestigial sideband transmission of the color subcarrier is practical when using OCS, this possibility should be further explored. When vestigial sideband transmission of color subcarrier is used, sampling of the brightness signal at the transmitter (shown in Fig. 13) to reduce spurious patterns in the receiver is not very effective. This compensation scheme, which was described in Part I, relies on substantial double sideband transmission about the color subcarrier frequency. Thus, if the color subcarrier frequency is raised, when using OCS, some compromise other than the complete "20-db package," previously tabulated in Fig. 14, needs to be used. In a possible arrangement suggested below, the transmitted color subcarrier is only slightly reduced in amplitude (3 to 6 db) compared to the amplitude corresponding to the "dot-sequential" arrangement and the remaining improvement in compatibility is obtained by the higher subcarrier frequency. Then, to reduce spurious patterns, the constant-luminance system is used and the transmitted brightness component is slightly limited in bandwidth.

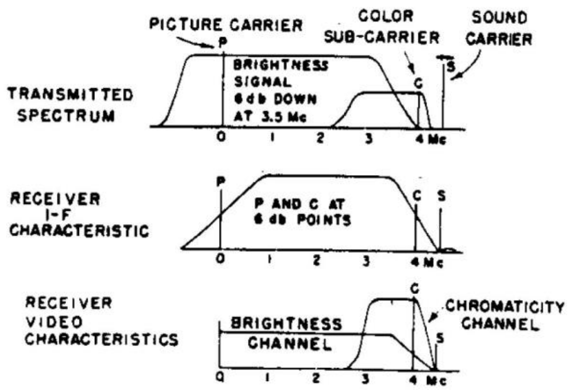


Fig. 24—Pass-band characteristics for suggested system using oscillating color sequence.

The pass-band characteristics for such a suggested system are shown in Fig. 24. Suggested system characteristics are the following:

1. Color subcarrier frequency about 3.99 mc (such as $507 \times 15.75/2$ kc$=3.99$ mc).
2. Subcarrier transmitted at a slightly reduced amplitude compared to the amplitude corresponding to the "dot-sequential" arrangement (such as 3 to 6 db down).
3. Brightness signal to be transmitted with slightly limited bandwidth—flat to 3 mc, 6 db down at 3.5 mc, substantially zero at 4.0 mc.
4. Color receiver designed to be 6 db down at color subcarrier frequency.
5. Simplified constant-luminance system used (with $K=1.5$).

VI. Conclusions

While the oscillating color-sequence principle can be applied to the constant-amplitude system, it appears most attractive when applied to the simplified constant-luminance system described in Part I of this paper. If OCS is applied to a constant-luminance system using a subcarrier of about 3.5 mc, the arrangement described in Part I of sampling the brightness signal to compensate for spurious patterns can be used. However, if OCS is used to permit a higher subcarrier frequency of about 4 mc, the compensation scheme is of little benefit; the combination of the constant-luminance system with slight bandwidth restriction of the brightness signal suffices to reduce the visibility of spurious patterns under conditions of adequate compatibility. While good, compatible, high-resolution color-television pictures can be obtained through a 4-mc bandwidth with either of the above proposals, further consideration may be required to determine which arrangement is most attractive commercially.

Bibliography

U. S. Patent No. 1,769,920; July 8, 1930; F. Gray (Band-shared TV System with Frequency Interleaving).

U. S. Patent No. 2,479,880; August 23, 1949; P. M. G. Toulon (Dot Interlaced System).

W. Boothroyd, "Dot system of color television," pp. 88–92, December, 1949; and pp. 96–99; January, 1950.

D. G. Fink, "Color fundamentals for TV engineers," *Electronics* pp. 88–93; December, 1950; pp. 78–83; January, 1951; and pp. 104–109; February, 1951.

D. G. Fink, "Progress in dot-sequential color TV," *Electronics*, pp. 80–81; February, 1951.

Barney Loughlin
1917 - 1988

It was with great sadness that Hazeltine employees received news that Barney Loughlin died on December 25, 1988. A brief six months had passed since his colleagues, family, and friends gathered at the Crest Hollow Country Club to pay tribute to him on the occasion of his retirement.

Barney joined Hazeltine in June, 1939. He served Hazeltine in many capacities, including Vice President of Research, Vice President of Technology, and was a member of the Board of Directors from 1972-1983. During his illustrious 49-year career, Barney contributed over 100 inventions to the electronics industry. He has been honored both nationally and internationally, especially for his contributions to the theory, understanding, and practice of color television. Barney earned a BEE degree from Cooper Union in 1939 and the MEE degree from Stevens Institute of Technology in 1946.

The seventeenth century poet and minister, John Donne, in his famous "no man is an island" sermon, wrote: "... when one man dies, one chapter is not torn out of the book, but translated into a better language; and every chapter must be so translated." Barney's legacy to the electronics industry and the Hazeltine community will continue to be a permanent memorial to his genius and character. To Cooper Union, he was "the house wizard"; to the world, he was "the grandfather of color television"; and to his colleagues, he was "a gentle man, a man of integrity, a teacher, a counselor, mentor, and friend." Barney's presence will be sorely missed.

The company expresses its deepest sympathy to his widow, Dorothy, and three children, David, John, and Mary Ellen.

Bernard Loughlin, 70, Helped Develop Color TV

By Robert Cooke

Electrical engineer Bernard D. Loughlin, an internationally respected inventor and theorist whose work helped make color television possible, died in Raleigh, N.C., on Christmas Day.

Mr. Loughlin, 70, had moved to Raleigh from Centerport in October after retiring from the Hazeltine Corp., where he had worked for 47 years.

"His biggest accomplishment was devising a television system that is now used around the world," said Tom Hana of Westbury, a longtime friend and colleague at Hazeltine. "He was in charge of Hazeltine's research laboratories, and was also vice president in charge of technical development."

Friends said Mr. Loughlin held 180 patents related to television systems and other broadcast devices, and he had received numerous awards for his accomplishments.

In addition to his professional achievements, Hana said, Mr. Loughlin "was a very considerate, modest person, well liked by everyone. He was a brilliant man."

Recently, Mr. Loughlin and his wife, Dorothy, traveled to China as members of a delegation of broadcast engineering experts.

A native of New York City, Mr. Loughlin earned his bachelor of science degree in electrical engineering from Cooper Union in 1939. He also earned a master's degree in electrical engineering at the Stevens Institute of Technology in 1946.

In a pamphlet prepared for Mr. Loughlin's retirement from Hazeltine, he commented that he "wrote the equations" for a television system devised by the RCA Corp. By using his approach, Mr. Loughlin said, "the effect on the [television] receivers and transmitters was that they were greatly simplified, were able to maintain stability and produced a better quality picture. RCA promptly changed its equipment over to our form."

Mr. Loughlin was a Life Fellow of the Institute of Electrical and Electronic Engineers, and in 1952 won the Vladimir K. Zworykin Award "for his outstanding contributions to the theory, the understanding and the practice of color television."

Mr. Loughlin is survived by his wife, Dorothy; two sons, David of San Diego and John of Raleigh; a daughter, Mary Ellen Milioto of Raleigh; a sister, Vivian Vadurra of Maplewood, N.J., and three grandchildren.

A funeral service is to be held at the Millbrook United Methodist Church in Raleigh with burial in that city. Memorial services were planned for today at 11 a.m. at the Centerport United Methodist Church. Friends were asked to send contributions to the American Heart Association.

Harold Lax, Executive, Pioneer Zionist

Harold Lax, 64, of Old Westbury, founder of Autronic Plastics Inc. of Westbury and longtime activist in behalf of Israel, died of heart failure Monday at the Texas Heart Institute in Houston.

Mr. Lax launched his firm, which manufactures plastic components for office, lighting and computer products, in the Bronx in 1953. He relocated Autronic Plastics to Westbury in 1964, and it now has a workforce of approximately 70 people.

Mr. Lax was on the national board of directors of the American Jewish Congress. A pioneer Zionist, he had lived and worked as a toolmaker in Israel from 1948 to 1950. Despite the debilitating effects of heart disease, he traveled to Israel, Jordan, Egypt and the Vatican to help foster good American-Israeli relations.

Mr. Lax grew up in Harlem, and during World War II, he served with the Army Rangers.

He had lived in Westbury for more than 20 years before moving to Old Westbury 11 years ago. He also had a home in Boca Raton, Fla. He was a member of the Society of Plastics Engineers and the Old Westbury Golf & Country Club.

Mr. Lax is survived by his wife, Charlotte, to whom he had been married 38 years; two sons, Steven of Woodbury and Michael of Oyster Bay Cove; a daughter, Michelle Lax-Garber of Baltimore, and five grandchildren.

A service is to be held at 1 p.m. today at Gutterman's funeral home in Woodbury; burial in Beth Moses Cemetery, Pinelawn. — Tony Schaeffer

Gwendolin J. Brimlow, 69

Gwendolin J. Brimlow, 69, formerly of Seaford Harbor, died Friday in Humana Northside Hospital, St. Petersburg, Fla.

Mrs. Brimlow was a homemaker and the widow of Walter Brimlow, a retired Long Island Rail Road car inspector who died eight years ago. They also had lived in Merrick and had moved to Florida from North Babylon almost 20 years ago.

Mrs. Brimlow grew up in Ozone Park, had worked for several years at the Grumman Corp., and was active in the Order of the Eastern Star.

Mrs. Brimlow is survived by a brother, Stanley Williams of Pinellas Park, Fla., one grandchild and three great-grandchildren. Services were held Monday with burial in Serenity Gardens Cemetery, Largo, Fla.

Oilman G.H. McCarthy, 'King of the Wildcatters'

Houston (AP) — Oilman Glenn Herbert McCarthy, who rose from laborer to national fame as the multimillionaire "King of the Wildcatters" in the 1940s and inspired the best-selling novel "Giant," died in a Houston nursing home. He was 81.

Mr. McCarthy died Monday, according to George H. Lewis & Sons Funeral Home. The cause of death was not disclosed.

The son of an itinerant oil field worker, he struck it rich in his 20s and by 1945 his wealth was estimated at $200 million. He lost most of his fortune during the 1950s when wells came in dry and a government oil price ceiling reduced his earnings.

He is survived by his widow, Faustine, and four children. Funeral arrangements were pending.

DECEMBER · 1950

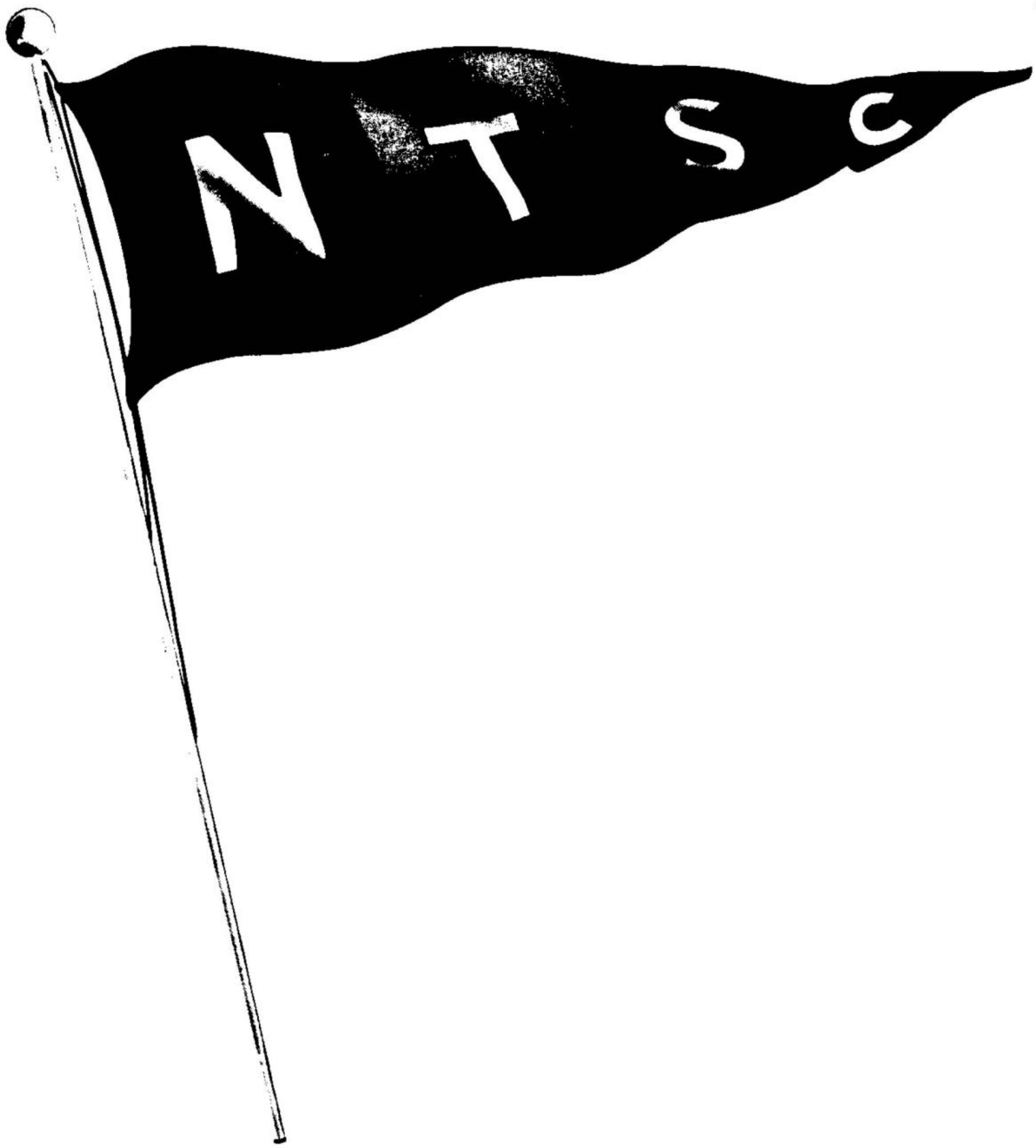
A McGRAW-HILL PUBLICATION

(A) SIMULTANEOUS TRANSMISSION—12-mc video band

(B) MIXED-HIGHS TRANSMISSION—4.2-mc video band

(C) COLOR COMPONENT of B, three 0.1-mc bands

(D) MIXED-HIGHS COMPONENT of B, 0.1 to 4 mc


NTSC