CONFIDENTIAL

RCA's Contribution to the War Effort Through Television 1937 - 1946

RCA Victor Division

Radio Corporation of America

Camden, New Jersey

FOREWORD

....The long waves generated by the massive high-frequency alternators that carried the messages of the First World War across the Atlantic have given way to globe-girdling, short-wave beams empowered by electron tubes. The crashing spark transmitters romantically served their day until the electron tube revolutionized all radio and made it a part of everyday life....Now music at the speed of light encircles the earth....

When the call to the Second World War trumpeted from Europe, radio was ready for its unprecedented role in global warfare. It became the Voice of Freedom; it coordinated the outposts and battlefronts of the AEF and the United Nations all around the world.... Today RCA is a symbol of radio progress throughout the world. The armed forces have found the RCA monogram on the apparatus that served them flying high over the "hump" to China; they have found its mark aboard the flying fortresses, on battlecraft of all types as well as on tanks and in the field. Radio has gone with them into the jungles, into the Arctic, into the skies, on the seas and beneath the seas.

RCA has always been dedicated to pioneering, in every phase of radio. Our men of research and engineering have combed the skies for nature's clues; they have deciphered the signposts of science that lead onward. Yet as they look back across the past twenty-five years they realize....how modest are their efforts to emulate nature in the transmission and reception of sound and sight. Their tools are electricity, the electron, and invisible waves. With them they have fashioned magic devices to harness the wonders of nature for the welfare of the people....

....Peace will find the world on the threshold of television -- one of the great realities of electronics. Again all radio will be changed. We shall step into our second quarter-century with new electron tubes, and radio scientists will blaze new trails in the enchanting realm of microwaves -- waves so tiny they are akin to light. These electron tubes will be the beacons of progress in that mysterious wilderness of the unknown, the electromagnetic spectrum of tomorrow....

(David Sarnoff
President, Radio Corporation of America
Upon RCA's Twenty-Fifth Anniversary, 1944)

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SECTION I

INTRODUCTION

Some Early Mechanical Scanning Methods: Historically, the scanning principle underlying present-day television systems can be traced for its origin to the early stages in the development of wireless telegraphy.

In 1884, fully a decade before Marconi radioed cricketlike sounds three-quarters of a mile across his father's estate, Paul Nipkow, in Germany, conceived the idea of flashing pictures in motion over the telephone wires. It was evident to Nipkow that a picture or moving scene could be transmitted by rapidly and systematically scanning the entire image with a finite exploring aperture or spot of light. Then, reasoned Nipkow, if the amount of light either revealed through the aperture, or reflected from the image as a result of the traversing spot of light, could be transformed into electrical impulses of proportionate strength, these impulses could be transmitted by wire over great distances. At the receiving end, the image could be reconstructed merely by converting the electrical impulses into light projected on a screen. He probably visualized a system such as diagrammed in Figure 1.

Nipkow, however, was ahead of his time; he lacked the neon lamps and light-sensitive cells to complete his television system. He nevertheless patented his whirling, perforated disk, and the Nipkow scanner (Figure 2), known today as the forerunner of mechanical scanning systems, was used for over a quarter of a century---in fact, even until Dr. V. K. Zworykin's invention and perfection of the Iconoscope, the television camera that made electronic scanning possible.

After Nipkow, other television pioneers with the desire to produce larger and clearer pictures, devised various mechanical scanners. Some of these were novel, employing rotating disks with lenses fitted into the apertures, and rotating or vibrating mirrors. Figure 3 shows one of these. A projector designed by Alexanderson and Kell reflected a cluster of seven lights on the screen, and when associated mirrors on a drum revolved, the spots of light gyrated and whirled to scan the entire screen with beams of light that virtually "painted" the picture. This system proved to be capable of projecting sevenfoot television pictures. At the same time, considerable progress was being made in the design of vacuum tubes and radio communication equipment, and as a result of several tests made over great distances, it was found that picture transmission could be applied as successfully to radio as to wire systems.

The problem of television in the earlier mechanical systems was to obtain an image that might be interpreted as a picture: The criterion of merit at that time was recognizability of the subject matter. Today, owing largely to the advent of the cathode-ray television systems, a recognizable picture can be taken for granted, and the problem is one of obtaining a high-definition picture.

The term high-definition picture originated when, through advances made in the art, it became possible to obtain a picture having a larger number of scanning lines, and, consequently, higher resolution than previously thought feasible. Since then, the term has come to mean not only a picture with a large number of scanning lines but also with low flicker level, sufficient brightness and correct contrast. Such a high degree of excellence in picture transmission has enhanced the entertainment value of television, but, more significantly, it contributed to the utility of television in the prosecution of the war.

For high entertainment value, the maximum picture definition required is determined by the resolving power of the eye, which is reasonably limited. If a picture is considered as made up of small elements of area, each uniform in size and brightness, there is a limit beyond which an increase in the number of elements per unit of area will not result in improved definition.

There is also a lower limit below which a decrease in the number of elements per unit of area will result in a loss of definition, as illustrated in Figure 4.

Measurements made, using projected pictures whose structure simulated that of a television picture, provide valuable information relative to visual acuity, image structure and picture size. This information, together with data from moving picture practice and experience, leads to the conclusion that for best results the television picture should have a width-to-height ratio (aspect ratio) of 4 to 3, and the minimum number of horizontal lines per frame should be approximately 400. The detail of the picture then appears to the observer as structureless. Actually, 525 lines per frame have been adopted by the Federal Communications Commission as a standard practice for this country.

The most satisfactory physical arrangement of the Nipkow disk, together with the object to be televised and the light-sensitive phototubes, is shown in Figure 5. This arrangement has been used successfully for closeups of small areas. The disk is illuminated with a high-intensity arc, or other powerful light source, so that the light passing through successive apertures in the revolving disk forms a narrow moving beam which rapidly scans the object being televised. Light reflected from the object is then picked up by a bank of phototubes which surround the scanner. These tubes convert the light rays into a train of

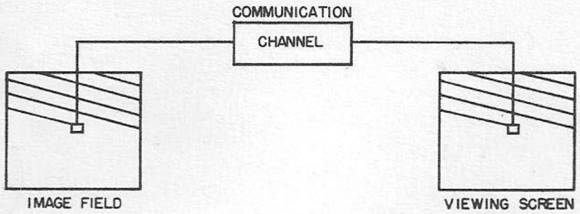

Figure 1. Functional Diagram of a Television System.

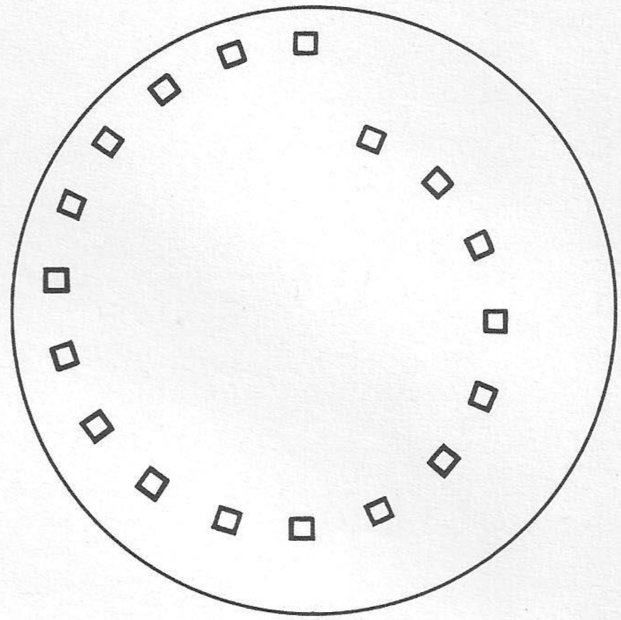

Figure 2. The Nipkow Disk, the Earliest Mechanical Scanner.

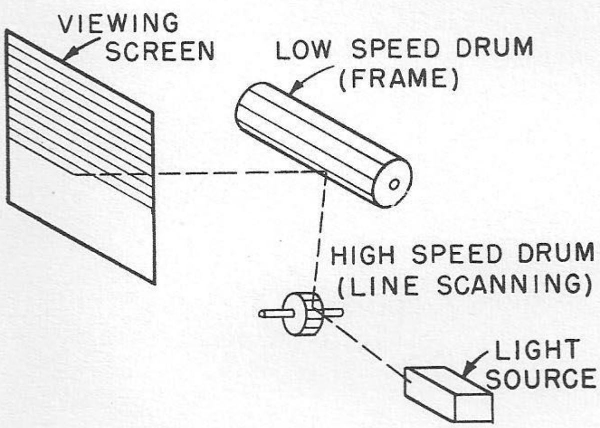

Figure 3. A Mechanical Scanner Employing Mirrors Mounted on Revolving Drums.

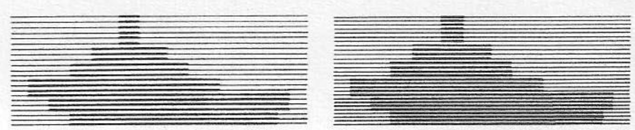

Figure 4. Picture Quality is related to the number of scanning lines used.

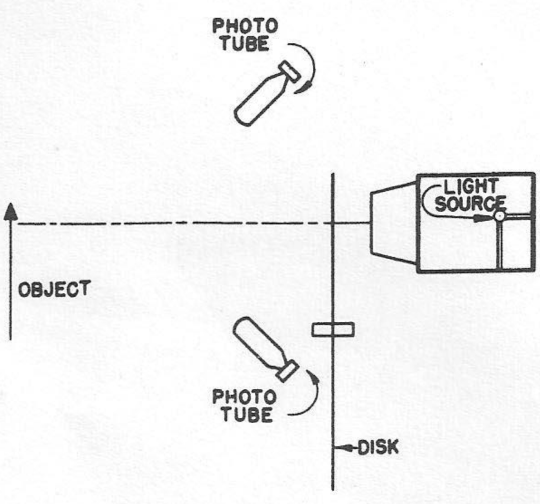

Figure 5. Scanning the Object with a Spot of Light.

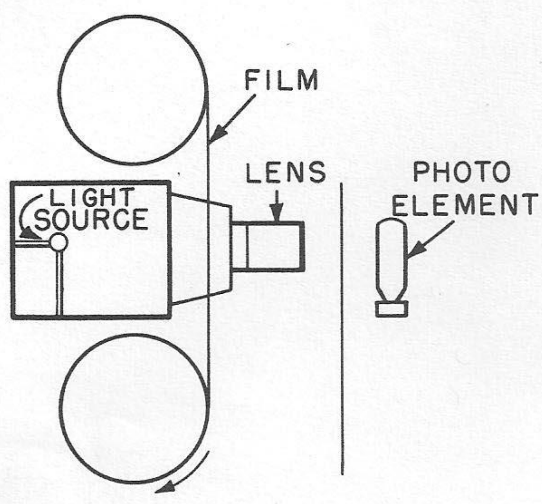

Figure 6. The Nipkow Disk Film-Scanner.

electrical pulses corresponding in amplitude to the intensity of the reflected light rays.

In a similar manner, the disk can be used to pick up the image from a moving picture film (Figure 6). Indeed, systems have been devised wherein the scene to be televised is photographed with a motion-picture camera, rapid development of the film then follows, and finally a mechanical film scanner converts the registered image into the picture signal (also called video signal).

The series of electrical impulses thus obtained from the phototubes, when transmitted in the correct sequence by wire or by radio, can be readily reconverted into light rays making up a picture. In the early mechanical receiving systems using the disk scanner, light from a bright lamp was focused on the revolving disk. As the light passed through the sweeping apertures of the disk, it was projected on a screen, scanning it with a number of horizontal lines. The incoming electrical impulses were applied to a light valve located between the lamp and the scanning disk, and thus the amount of light reaching the screen was modulated in accordance with the amplitude of the electrical impulses. To assure that corresponding elements of the projected picture and televised object occupied the same relative positions, the pickup and receiving disks were caused to revolve in the same direction and in synchronism.

<u>Electronic Scanning</u>: Electronic scanning in the viewing tube, as successfully demonstrated by Boris Rosing in 1907 and in the pickup tube as proposed by Campbell Swinton in 1908, were the first two steps leading up to the modern, electronic high-definition system. In many respects these as well as later proposals paralleled present-day systems, but the design of the pickup tubes lacked one important feature--the storage of the electric charge between successive scannings. This principle, which greatly increased the sensitivity of the pickup tube, was first employed by Dr. V. K. Zworykin in 1923, and publicly demonstrated in 1929.

Dr. Zworykin named his pickup tube "Iconoscope"; "eikon" in Greek meaning image, and "skopon", to watch. Therefore, the Iconoscope observes the scene to be telecast. His receiving tube he called the "Kinescope"; "kinema" being the Greek word for movement. So the Kinescope observes the motion.

The Iconoscope, illustrated in Figures 7 and 8, is strikingly like the human eye in performance. In Dr. Zworykin's own words:

"The new 'eye' is so sensitive that it sees the entire picture at once just like man's eye. In fact, it has 'electrical memory.' For example, look at something and shut the eyes. You imagine you see the scene; that is persistence of vision.

The Iconoscope, because of a capacity effect on its 'retina', also holds the scene for a second or two.

"The electric retina is a mica plate having a metallized back. The mica is covered with millions of globules of light-sensitive material. There is an electron beam or 'paint brush' regulated by a 'gun' that plays upon the retina or fluorescent screen. That beam is what I call the optic nerve of television."

Thus with the invention of the Iconoscope and the Kinescope, a practical electronic means was established for the direct pickup and reproduction of high-definition pictures.

The ability of the Iconoscope in this respect arises from at least two important factors: The first factor is basic to all known electronic-pickup as well as viewing devices and lies in the fact that electrons emitted from a cathode can be focused into a very narrow scanning beam, making it possible to employ a larger number of picture lines and thereby improve the picture resolution; the second, which is characteristic of only the Iconoscope and later pickup tubes, is the use of the storage principle. With this principle, photoemission continues during the entire scanning period, being accumulated in the form of a charge at each image point. The result is an increase in the effective photocurrent by a factor equal to the number of picture elements, thus increasing the sensitivity of the tube. In the Kinescope, a similar storage action takes place due to the luminescent "persistence" of certain phosphors used in the fluorescent screen. This tends to increase the average brightness of the picture.

It should be stated that, even at the time of the invention of the Iconoscope, the mechanical method of scanning had been developed to the point of providing pictures with as many as 400 lines per frame. This is significant in so far that the approach to many of the television problems such as obtaining the required bandwidth in amplifier systems, increasing the efficiency of high-frequency transmitting and receiving equipment, and reducing the enormous bandwidth then required for transmitting high-definition pictures, had been partially solved. The adoption of the Iconoscope as the most efficient television pickup device of the time was based principally on its greater sensitivity, lower cost of operation and smaller size, factors against which no known mechanical system can compete.

With the evolution of the Iconoscope pickup tube and the Kinescope picture-reproducing tube, a new, all-electronic system of television was born. A system utilizing an invisible stream of electrons instead of a beam of light--a stream of electrons that could be hastened or slowed in its path, moved up and down or from side to side with equal ease and at great speed.

The possibilities of the new system were never pictured more vividly than after RCA's development of the projection Kinescope and the Orthicon tube. The new Kinescope permitted the projection of television pictures on an 8 x 10-foot screen. The Orthicon, a pickup tube based on the design of the Iconoscope, but one-third its size and ten times more sensitive, permitted the development of portable camera-transmitters, greatly extending the scope of television activity in presenting to the public educational as well as entertaining events.

In 1940 and 1941, Orthicon type field equipment was constructed for such organizations as the Bell Telephone Laboratories, Columbia Broadcasting System, National Broadcasting Company and the Don Lee Organization in California. It proved satisfactory and enjoyed a variety of uses, telecasting outdoor as well as indoor sporting events, spot news pickups, on-the-street interviews, concerts and world events. Such were the capabilities of RCA television before the United States entered the war.

SECTION II

QUALITY PICTURE TRANSMISSION AND RECEPTION

Picture Definition: In advancing television to its present stage, scientists aimed for a practical, compact system. A system that would offer the greatest possibility for improving the art. No known methods were left unexplored. Mechanical or electronic, they were tried and compared. Sensational developments in the performance of vacuum tubes, as an example, favored the adoption of the all-electronic system. Penetration of the ultrahigh-frequency spectrum promised a still further reduction in the size of the equipment, and permitted transmission of a wealth of picture information provided by the new, electronic pickup tubes. An electronic system of television was thus established. A system which was later to be adapted to military needs.

In spite of the small size of the most modern of these prewar units, the electronic television system as a whole was necessarily complex. The technical requirements for satisfactory picture transmission were (and still are) exacting. Any television system utilizing line scanning, whether it be mechanical or electronic, must carry on three distinct processes simultaneously: It must convey the necessary information from the image to the observer in a limited period of time; it must synchronize each element transmitted with an identical element received; and it must suppress spurious signals generated during the above processes.

The higher the picture definition employed, the more difficult it becomes to satisfy these processes. This can be exemplified by first expressing the relationship between the number of elements to be transmitted and the time required for their transmission, and then showing the significance of their electrical counterparts.

Compared to the average radiotelephone system, which conveys at the most approximately ten thousand (sound) elements in one second, resulting in a total bandwidth of 20 thousand cycles, a high-definition television system must transmit approximately four and one-half million elements in the same length of time, producing a total bandwidth of nine megacycles. These four and one-half million elements correspond, for the most part, to the varying shades of light encountered by the electron beam as it scans the image projected on the mosaic of the pickup tube.

Assuming an image of great detail with contrasting light and dark area, the number of picture elements to be conveyed over the channel, per second, depends upon the number of horizontal and vertical lines employed by the scanning system (Figure 9), and the number of frames scanned each second. These factors also determine the highest frequency to be passed by the system. If the scanning system provides N horizontal lines and m vertical lines, and the image is scanned at a repetition rate of r frames per second, the signal will go through m maxima and minima during each horizontal sweep, or, in other words, maxima will follow one another at a frequency of

$$f = mNr \text{ cycles per second}$$

Obviously, the frequency f varies as any one of the factors m, r, or N. For high definition, m and N are high, m being slightly higher than N due to the ratio of frame width to frame height (4/3). Also, the frame repetition rate, r, must be maintained high enough to give the illusion of continuous motion, with absence of flicker.

To create the illusion of continuous motion, the motion-picture industry has adopted a standard of twenty-four frames per second. This rate, possibly higher than absolutely necessary, insures smooth operation for all type pictures. Instead of twenty-four, thirty frames per second has been chosen as the most satisfactory repetition rate for television in this country, not because this high rate is essential for continuity of motion, but because of the relation it bears to the frequency of commercial power.

Although the eye is unaware of discontinuity of motion at frequencies above fifteen cycles per second, results of tests using sequential scanning indicated that it could detect flicker on bright television pictures at frame frequencies as high as fifty cycles per second.

This frequency being much higher than that required for continuity of motion, if employed as the frame repetition rate, would require an unnecessarily large communication band. In practice, economy of bandwidth is retained without reducing the effective field frequency by means of interlaced scanning.

In interlaced scanning, which is a form of straight line scanning, the spot, instead of moving across the horizontal lines in the sequence 1, 2, 3, 4, ..., covers the odd-numbered lines first, then the even-numbered lines, i.e., 1, 3, 5, ...; 2, 4, 6, ... The scanning beam has to complete two scanning fields, displaced by the width of one line, in order to cover the entire frame. Therefore the field frequency is twice the frame frequency. For this manner of interlacing, therefore, the beam must be deflected vertically at twice frame frequency, or 60 cycles per second.

Synchronization: Beside the enormous band of frequencies constituting the picture signal, still further information must be furnished to insure synchronism between the scanning pattern

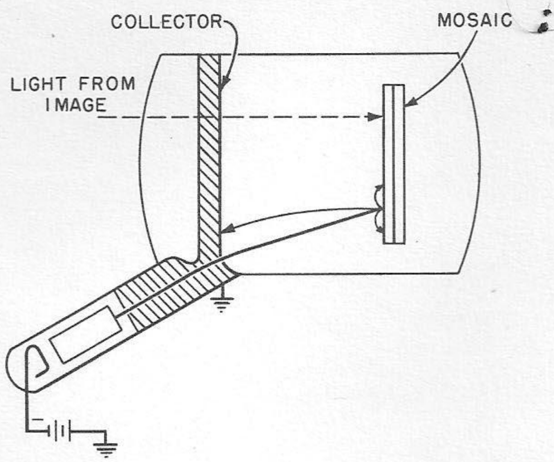

Figure 7. A Schematic Drawing of the Iconoscope.

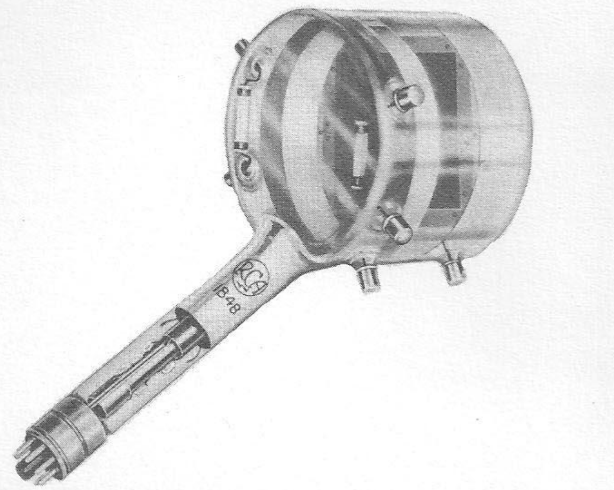

Figure 8. The RCA 1848 Iconoscope.

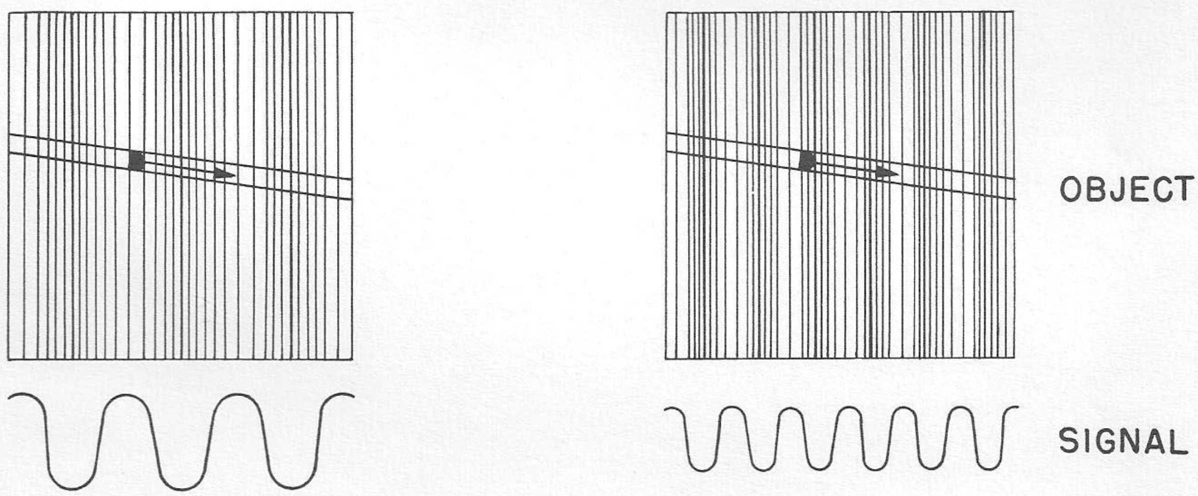

Figure 9. In line scanning, the transmission frequency becomes higher with an increase in the periodicity of the line pattern, as shown.

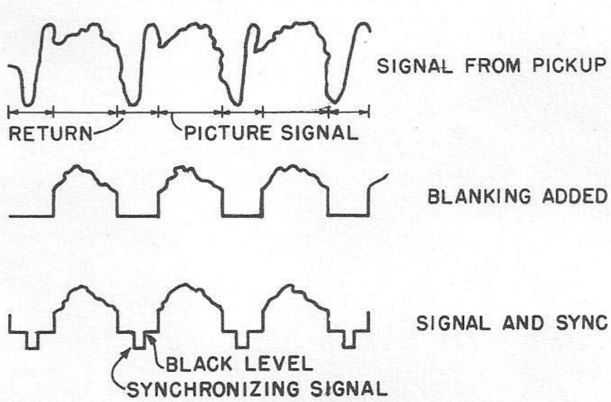

Figure 10. Formation of the Complete Video Signal.

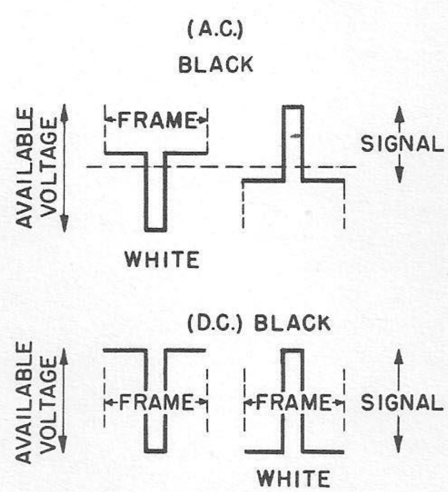

Figure 11. D-C Transmission utilizes to fullest extent the available carrier voltage.

at the transmitter and receiver. This is supplied to the transmitted signal in the form of properly shaped pulses, timed so that they occur after the end of each scanning line and before the beginning of the next. Similarly, a pulse or series of pulses is added between frames to insure vertical synchronization.

Synchronizing pulses are added to the signal in the amplifier chain. This is performed by rendering the amplifier inactive, ahead of the point of injection, for a period equal to or slightly in excess of that occupied by the synchronizing signal, and injecting the pulse during this interval. The purpose of this attendant "blanking" process is to prevent any possible signal from the pickup device from interfering with the synchronizing signal, and to erase the retrace lines on the Kinescope at the receiver. Steps performed in making up the video signal are illustrated in Figure 10.

Horizontal and vertical synchronizing pulses must meet certain requirements: They must not interfere with the picture signal; they must be easily distinguishable from one another and from the picture signal; and they must be capable of controlling the deflection oscillators in the presence of ordinary interference.

The first condition is met by originating the horizontal pulses during the return time of the scanning beam, and the vertical pulses at the end of each frame.

Because these pulses cannot be distinguished from the picture signal by their frequency content, they must be given some other attribute which will provide for their distinction. They are characterized by their time of occurrence and their amplitude. Time of occurrence cannot be used as a means of selection, because it is the pulse which times the system itself. Therefore of necessity amplitude selection is used, and the amplitude of the synchronizing signal is, in practice, made greater than that of the picture signal. This serves also to reduce loss of synchronism through random noise, when the amplitude can be made greater than that of the noise.

In order that a distinction can be made between the horizontal and vertical pulses, these pulses are usually characterized in the system by different lengths of duration, the vertical pulse being much longer in duration than the horizontal pulses. It can, therefore, be seen that the generation of properly shaped synchronizing signals for a television system transmitting as many as four million picture elements per second is an exacting process. It will also be apparent that the higher the definition, or the greater the number of elements to be transmitted in a period, the more critical becomes the duration and shape of the synchronizing impulses, since the synchronizing process also requires time allotments in the pattern of the television signal.

Television Transmitters: The difference between the type of transmitter required to radiate high-definition television signals and that used for sound broadcasting is so great as to be almost fundamental. The reason for this difference is the tremendous frequency band needed for picture transmission. Not only does the wide frequency band present a technical obstacle in itself, but it also makes necessary the use of the ultrahigh-frequency spectrum if more than one television station is to function at any one time.

Early in 1939, the Federal Communications Commission made a tentative frequency allotment of the ultra short wave region of the spectrum, assigning seven six-megacycle bands lying between 44 and 108 megacycles for television broadcasting. Frequencies between 150 and 300 megacycles were assigned for television relay purposes. At that time, television broadcasting was confined to the lower frequencies of the ultra short wave band because of the technical difficulty in generating wide-band radio signals of high power at extremely short wavelengths. This was due to the limitations of the power amplifier tubes available.

Like the transmitter used for sound broadcasting, the ultrahigh-frequency television transmitter consists of a carrier-frequency generator, a modulator, and an antenna.

The carrier frequency generator, which is usually a crystal oscillator working on a submultiple of the desired carrier frequency, is followed by frequency multipliers, where required, and a class C power amplifier. The design of these components follows the latest principles in the design of ultrahigh-frequency transmitters.

The video signal modulating the carrier of the television transmitter can be of either polarity, giving rise to either positive or negative modulation. With positive modulation, the amplitude of the radio frequency is a maximum for white portions of the picture, while with negative modulation the black regions of the picture increase the radio frequency amplitude.

Practical considerations dictate the use of synchronizing pulses in the direction of a black signal. Therefore, if positive modulation is used, the synchronizing signal causes the radio frequency signal to drop to a very low value (usually zero amplitude), while negative transmission results in a maximum signal for the synchronizing pulses.

The choice of positive or negative transmission is not very clear-cut, as there are reasons favoring each. It can be said, however, that an interfering signal in positive transmission produces a white flash on the viewing screen, while corresponding interference in negative transmission produces a dark spot. Since bright flashes are more objectionable than dark spots of similar size, negative transmission might be considered to be more desirable. It is favored in this country.

The signal, whether positively or negatively modulated, can be radiated from the transmitter in the form of either a-c or d-c transmission. A-c transmission, as the name implies, means that the video signal supplied to the modulator has been amplified by an amplifier passing only its alternating-current components. Because of this, the signal at the modulator represents the voltage variation about an axis or reference voltage which is the time average of the signal. Thus, if the picture consists of a narrow white line on a black background, the carrier envelope for negative modulation will vary from approximately half value for the background, to zero carrier at the white band, while a black band on a white background leads to a carrier which varies from approximately half value for the white background to maximum value at the black line. It will be apparent that the instantaneous magnitude of the radio-frequency signal has, therefore, no real meaning in terms of picture brightness.

On the other hand, the video signal may be amplified up to modulation level by means of a d-c amplifier or its equivalent. If this is done, the magnitude of the r-f signal has absolute significance in terms of picture brightness. For negative modulation, a black area, irrespective of size, results in maximum carrier amplitude (exclusive of the synchronizing signal), while a white area leads to zero or minimum carrier.

Considerable economy can be effected with d-c transmission. A given transmitter has available a certain maximum voltage range for the carrier envelope. This range, for convenience, can be referenced to the voltage applied to the modulator, and is shown in Figure 11 by the double-headed arrow, whose ends represent maximum and minimum carrier.

The reference axis, about which the video signal-voltage swings in a-c transmission, must be at or near the midpoint of the modulator voltage range in order to transmit a white line on a black background, or a black line on a white background. It will be seen that the voltage change from black to white is only about one-half the total available voltage swing. On the other hand, if a d-c video signal is applied to the same modulator, a "black" signal will correspond to a maximum positive voltage, while white corresponds to a maximum negative voltage; hence, the full voltage swing of the modulator is available for the signal voltage. In other words, the useful voltage range with a-c transmission is only about half as great as it is with d-c transmission.

Modulation of the carrier by the video signal is one of the most difficult problems facing the television engineer. In sound transmission, the efficiency of the plate modulator can be made fairly high where the modulator stage is a class B, push-pull amplifier modulating the class C power amplifier. In television broadcasting, this a-c transmission is not economical, as has already been pointed out. As a consequence, if plate modulation is to be used, the power amplifier must be modulated by a single-ended class-A amplifier as illustrated in Figure 12, greatly reducing the efficiency of the system.

A second serious objection to this type of modulator for television transmission is the requirement placed on the coupling impedance. Like the interstage coupling of the video amplifier, it must be constant in magnitude and time-delay over the video frequency band. Furthermore, since the coupling impedance carries the entire d-c component of the power amplifier, a pure resistance can not be used without making the power loss prohibitive. The choice of coupling impedance is limited to a filter network which will include the tube capacity.

Grid modulation (Figure 13) is somewhat better suited to television. In the grid circuit, the direct current is low and consequently an impedance network containing resistance can be employed without serious loss of power. The modulator power output requirements are also lowered with grid modulation.

<u>Television Antennas:</u> As is well known, ultrahigh-frequency radio waves are quasi-optical in their propagation characteristics. In other words, they behave similar to rays of light, travelling in nearly straight lines through space, being reflected and diffracted by obstacles in their path. The television transmitting antenna may be compared to a lighthouse, radiating television signals in all directions as the lighthouse radiates light. The higher the lighthouse, the fewer obstacles lie in the path of light and the greater the distance over which it can be seen. This "line of sight" distance is limited to about forty miles by practical heights at the lighthouse and the observer. Likewise, the "coverage" by the television antenna is confined to about the same distance. Very little ultrahigh-frequency energy is reflected from the ionic layers of the upper atmosphere, so that reception at great distances, while not impossible, is a rare occurrence.

If the television receiving antenna is not within a line-of-sight path to the television transmitting antenna signals received will be those reflected from nearby trees, buildings or other objects. This might not prove objectionable if the reflection occurs over one reliable path. However, if reflection takes place from two or more obstacles located at different distances from the receiving antenna, the signals will arrive at the antenna over paths of different lengths (Figure 14). This multipath interference produces "ghosts" in the received picture,

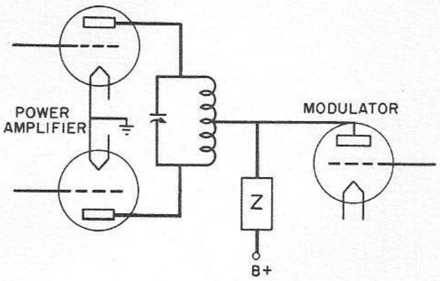

Figure 12. Plate Modulator.

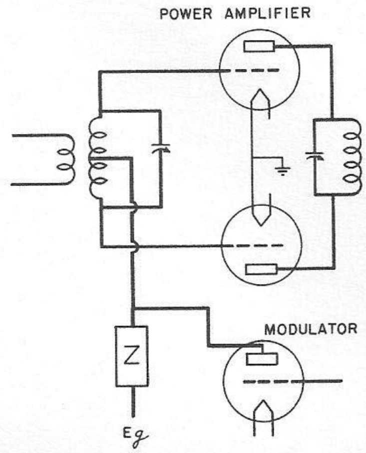

Figure 13. Grid Modulator.

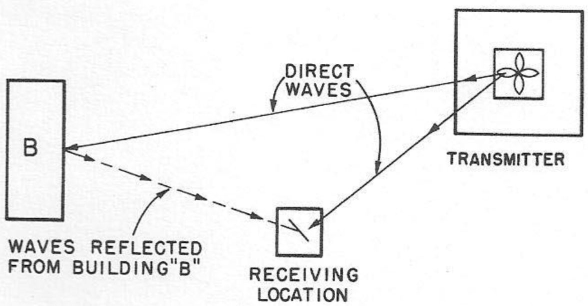

Figure 14. Direct and Reflected Transmission Paths.

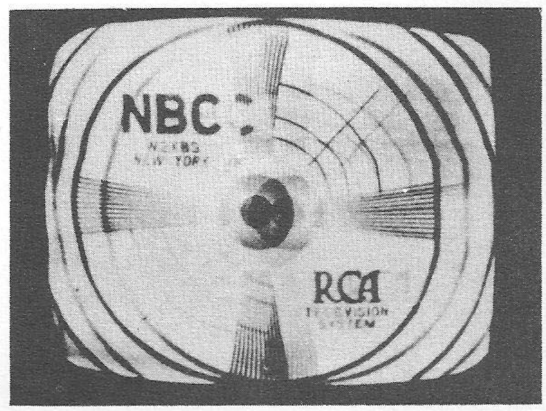

Figure 15. A Television Test Pattern Marred by a Multipath Signal.

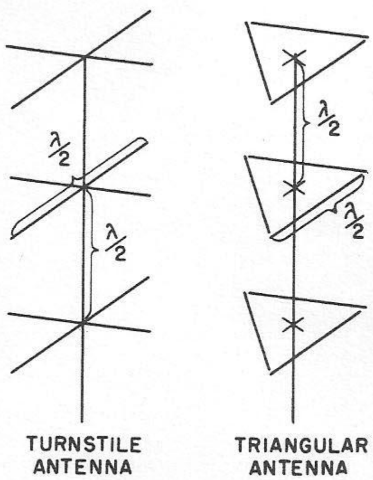

Figure 16. Turnstile and Triangular Antennas.

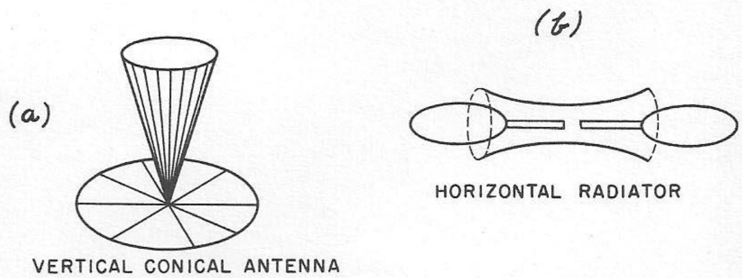

Figure 17. Special Wide-Band Television Antennas.

as shown in Figure 15.

Usually, the higher the antennas are erected the greater will be the coverage and the stronger the received signal. In metropolitan areas, increased height at the receiving antenna also reduces auto ignition interference which is particularly severe at these frequencies.

The requirement for a wide-band antenna in television transmission presents a formidable difficulty in antenna design. The electrical properties of a half-wave dipole are essentially those of a resonant circuit. As the length is increased, the radiation impedance increases. A large inductive component goes through a maximum and then decreases, until at one wavelength the antenna is a parallel resonant circuit presenting an almost purely resistive impedance. At three half wavelengths, the antenna is again series resonant having doubled the radiation resistance over that of a half-wave length. Decreasing the length of an antenna from a half wavelength increases its impedance by adding a capacitive component.

Varying the frequency produces an effect on the impedance similar to lengthening or shortening the antenna. This variation in magnitude and phase of the impedance of the antenna with frequency introduces a mismatch between the antenna and its transmission line at frequencies adjacent to the resonant frequency of the antenna. To overcome this for wide-band transmission, either special matching circuits or an antenna with a flatter impedance characteristic must be employed. In actual practice both methods are used.

There are many types of ultra-high-frequency antennas, chosen to give the desired radiation pattern and load characteristics. A large class is made up of arrays of linear dipoles suitably spaced and oriented, and fed so that currents in the various elements have a definite phase relationship to one another. Two antennas of this class are the "triangular array" of the type used for some of the television transmission tests made from Empire State Building, while the second is a so-called "turnstile" antenna. Both antennas, which are roughly illustrated in Figure 16, are made up of stacks of parallel, horizontal dipoles, excited so that the currents in the elements constituting each stack are equal and in phase. This directs the radiation strongly in a horizontal plane and consequently the power emitted upward, where it would be wasted, is very small. The current fed to the two stacks is in quadrature in the turnstile antenna. In the triangular array the current supplied to the three stacks is in phase. Both these antennas produce a fairly uniform pattern confined to a horizontal plane. Like the single horizontal dipole, they are both strongly resonant and require a special matching element to couple them to a coaxial line.

Another class of antennas is constituted of those whose radiating elements are not simple linear conductors. The calculation of the performance of this type of antenna is much more difficult because a simple sinusoidal current distribution cannot be assumed. The impedance characteristics of these wide-band antennas (Figure 17) are much less dependent upon frequency. The vertical conical antenna (a) produces a vertically polarized wave which is directed uniformly in a horizontal plane. Horizontally polarized radiation is obtained from the horizontal radiator shown in (b). In order to obtain a uniform pattern with this radiator, the antenna must consist of two such elements placed at right angles.

The design of ultrahigh-frequency antennas and their coupling systems are complex. Only the nature of the problem can be presented here.

<u>RMA Standards for Television:</u> The complex nature of television systems, the numerous processes involved, and the diverse ways in which each might be carried out, called for a standard, nation-wide system of television transmission. Without such a standard system, receivers of one manufacturer, for example, might not operate properly with a transmitter manufactured by another. Or undue space in the radio-frequency spectrum might be unfairly occupied by transmitters requiring greater bandwidth than others. To avoid difficulties such as these, and in an effort to establish a standard system which would be acceptable to all manufacturers, the Radio Manufacturers Association, in 1939, set up certain standards for television transmission, a revision of which was later adopted by the Federal Communications Commission.

In addition to proposing the use of d-c negative transmission, these standards specified the number of horizontal lines to be employed, the frame repetition rate, and the shape and duration of the synchronizing, equalizing and blanking signals to be used.

The wave shape of an FCC standard signal, appearing at the input of the modulator, is shown in Figure 18. The drawing illustrates the region near the vertical synchronizing pulse. The radiated signal, of course, would appear in opposite polarity to that shown.

These wave shapes are for 525 lines per frame, 30 frames per second, 60 fields per second, interlaced.

At the left are shown the last few lines of each field. At the end of each line is shown the horizontal blanking pulse, which biases the Kinescope grid to cutoff during the return sweep of the line deflection. The vertical blanking pulse,

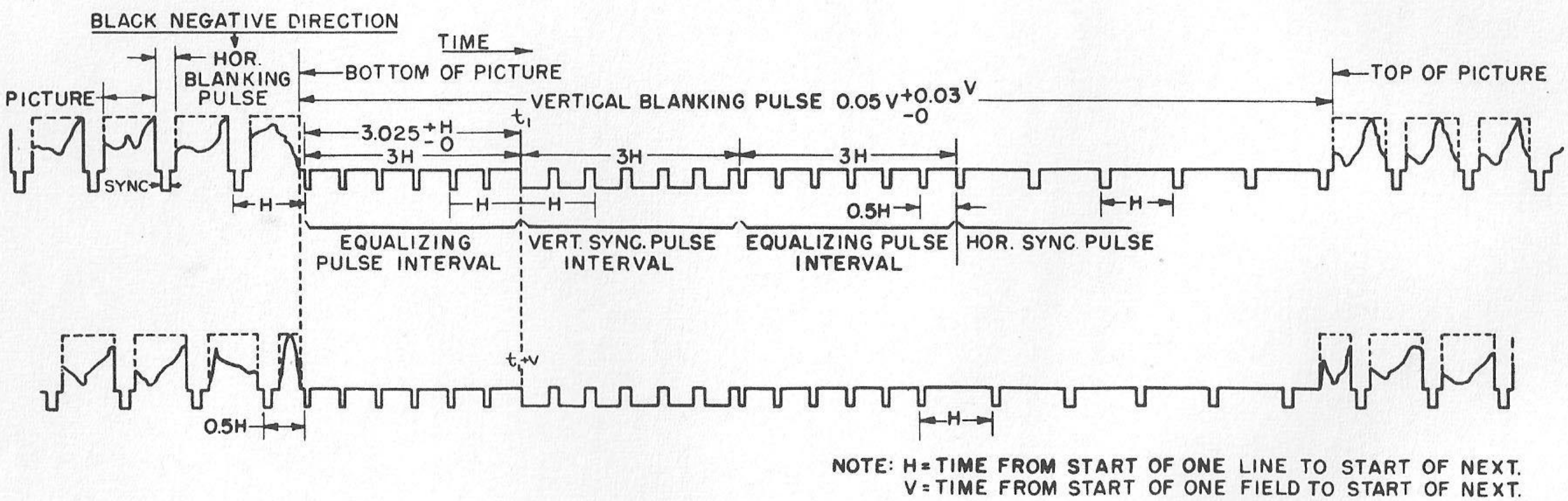

Figure 18. The Standard Television Signal Approved by the Federal Communications Commission. The modulator input signal is shown.

which maintains the Kinescope bias at or beyond cutoff during the vertical return sweep, occurs between the bottom of one picture field and the top of the next. Superimposed on these two types of blanking pulses are the synchronizing pulses, which extend from the black level in the direction of black.

The horizontal signals consist of nearly rectangular pulses of short duration. The vertical pulse is rectangular and has a duration of three line periods. In order to maintain horizontal synchronization, the vertical pulses are serrated. Actually the serration occurs at twice line frequency but since the horizontal oscillator, by its design, is insensitive at the half periods, it responds only at line frequency. For about three lines before and three after the vertical signal, the horizontal pulses occur at double frequency, forming what are known as equalizing pulses. This also has no effect on horizontal synchronization, but makes the vertical signals for the odd and even field traversal of the interlaced pattern identical as far as an integrating circuit is concerned. Such similarity is essential since the vertical synchronization must be accurate in order to maintain interlacing.

The total duration of the vertical synchronizing signal is sufficiently longer than that of the horizontal signal to allow them to be separated by wave shape discrimination at the receiver.

Keystone Correction: Due to the physical layout of the Iconoscope, the electron beam strikes the mosaic at an oblique angle. Thus, if the beam is deflected through the same angle at the gun for each horizontal line, those lines at the top of the mosaic will be longer than those at the bottom, the top of the mosaic being further away from the gun. The picture, therefore, will be compressed at the bottom and spread at the top.

Distortion of this kind, known as "Keystoning", is corrected by modulating the horizontal deflection with a vertical sawtooth wave. In this way, a decrease in the angular amplitude at the top and an increase toward the bottom can be made to overcome the trapazoidal distortion in the pattern. Actually, the gain of the deflection amplifier must be linearly increased periodically at vertical frequency, and the vertical sawtooth wave component present in addition to the modulated horizontal sawtooth must be removed.

Television Receivers: A superheterodyne receiver at the observer's end of the television system transforms the radiated signal into a picture. This is done by separating the picture signal from the radio-frequency carrier, amplifying it and applying it to a cathode-ray picture-reproducing tube. The television receiver is similar to the sound broadcast receiver except that in the television receiver, amplifiers are designed to pass a much wider band of frequencies. Then, of course, the sound

Then, of course, the sound receiver is equipped with a speaker which converts electrical impulses into sound waves, while in the case of the television receiver the electrical impulses are converted into light waves which are made to reproduce the original image or scene.

The picture reproducer, or Kinescope, is a glass vacuum tube containing an electron gun and a flat viewing screen on which the scene received is reproduced. The electron gun is similar to that used in the Iconoscope pickup tube, and projects a stream of electrons onto the rear of the viewing screen. The viewing screen of the cathode-ray tube is somewhat larger than the mosaic of the pickup tube, and the electron spot is also somewhat larger. The viewing screen, which is coated on the inside with a thin layer of fluorescent material, glows when struck by electrons, producing a spot of light which is visible through the glass face of the tube. The intensity of the beam, and hence the brightness of the spot, is regulated by the received picture signal.

The electron beam is in reality an electric current passing from the cathode to the screen and may be deflected to one side or the other of its course by the influence of an electric or magnetic field. To scan the entire viewing screen from top to bottom, the spot must be moved across the screen in horizontal lines and slowly downward so that each horizontal line starts directly below the previous line. When the end of the bottom horizontal line is reached, the spot returns quickly to the top of the screen to begin another series of horizontal lines. Horizontal deflection and vertical deflection is produced by separate sets of magnetic coils or electrostatic plates. Output from deflection oscillators similar to those used to deflect the beam in the pickup tube is applied to the deflection coils or plates to obtain the proper speed for horizontal and vertical deflection.

SECTION III

PREWAR STATUS TELEVISION

The requirements for high-definition picture transmission discussed in the preceding section were not out of keeping with resources available to fulfill them. Prior to 1940, RCA and its NBC subsidiary had set up an extensive television installation in New York City. This system, the largest of its kind, provided for many tests and public demonstrations carried on by RCA in its endeavor to evolve the highly satisfactory and practical system we have today. This particular installation will be briefly described later.

A typical television system may be divided into three functional groups, namely: The camera, the transmitter, and the receiver. Each of these groups may be further sub-divided as follows:

Camera	Pickup tube Deflection generator Video amplifier
Television transmitter	Carrier-frequency generator Power amplifier Modulator Antenna
Television receiver	Receiver amplifier Deflection and synchronizing separator circuits Viewing device Antenna

The pickup tube, of course, is the element in the system which converts the light image into the train of electrical impulses making up the video signal.

As in the viewing device of the receiver, the electron beam of the pickup tube is caused to scan both horizontally and vertically by correctly varying associated electrostatic or magnetic fields. Whether deflection of the beam is accomplished by electromagnetic or electrostatic means depends largely upon the application of the equipment; both methods have their role in television. In applications where economy of space is most important, electrostatic deflection is usually used.

As explained in Section II, according to FCC standards each frame (complete picture) consists of 525 horizontal lines. In order to sustain the impression of motion, the frames are reproduced at the rate of 30 per second. One method of interlaced scanning requires that each frame be scanned twice, the electron beam in each case following alternate lines. Therefore, the rate of vertical scanning is equal to twice the number of frames or 60 per second. The rate of horizontal scanning is equal to 525 (lines per frame) multiplied by 30 (frames per second), or 15,750 per second. This means that in both the transmitter and receiver, the horizontal scanning frequency is 15,750 cycles per second, while the vertical scanning frequency is 60 cycles per second.

A control oscillator, a sawtooth generator, and often a deflection amplifier were used to produce each of these deflection fields. The control oscillator when in use was not allowed to run free, but was triggered by a series of synchronizing pulses which served to coordinate the timing of the patterns at the transmitter and receiver. The sawtooth generator included circuit elements in common with the oscillator in the simpler deflection units, but in general, they were considered as separate entities. It was frequently necessary to amplify the output of the sawtooth generator to obtain a current or voltage of sufficient amplitude to deflect the beam.

Usually, a blocking type oscillator was employed to trigger the sawtooth generator. The blocking oscillator shown in Figure 19 operates as a conventional feedback oscillator, the frequency being determined by the inductance and distributed capacity of an iron-core transformer connected between its plate and grid circuit. The value of the circuit constants of the transformer are so chosen that this frequency is much higher than the desired repetition rate of the pulses. With a large resistance shunting a capacitance in the grid circuit, as soon as oscillations start, rectification by the grid builds up a negative voltage across the capacitor sufficient to block the tube. As soon as the capacitor is discharged, the cycle starts again. The frequency of repetition is dependent chiefly upon the time constant of the r/c circuit.

The synchronizing pulses which triggered the control oscillators of the horizontal and vertical deflection generators also accompanied the picture signal.

In early design, these pulses were formed by a chain of suitable multivibrator oscillators and shaping circuits, and were added to the picture signal by means of keying or mixing tubes. The highest pulse frequency in the system was twice line frequency. Therefore, the primary oscillator delivered pulses at a rate of 31,500 per second. From this, a multivibrator, adjusted to respond to every other pulse, produced 15,750 pulses per second. Another chain of multivibrators responded to 5, 7, and 15 pulses (i.e., 5x7x15 = 525 lines) and provided a

60-cycle pulse for the vertical scanning signal. The primary oscillator of the synchronizing chain was controlled by the frequency of commercial power (60 c-p-s) serving the transmission area.

Later, the inherent instability of the multivibrator synchronizing generator was overcome by the substitution of new design. There were essentially two parts to the new generator. The first part produced the timing information without any attempt to provide the correct wave shapes; the second part properly shaped the pulses. The timed pulses were produced by a master oscillator operating at twice the horizontal scanning frequency, or 31,500 cycles. This was followed by a system of frequency dividers which produced two other frequencies, 15,750 cycles and 60 cycles, both being integral submultiples of the 31,500-cycle master oscillator frequency. In operation, the 60-cycle signal from the final divider circuit was compared to the 60-cycle power-supply frequency in an automatic phase control circuit. A slowly varying d-c voltage from this circuit was then applied to the grid of a reactance tube across the tank of the master oscillator. In this manner, the master oscillator was kept at 31,500 cycles (on an average), and there was only sufficient phase shift between the 60-cycle output of the generator and the 60-cycle power source, to provide control voltage for the reactance tube.

Each frequency divider was a type of electronic counter, sometimes called a "stair" counter---its output resembled the cross-section of a flight of stairs. These counters exhibited very good stability and independence of vacuum-tube characteristics. Actually, the counter circuit is a variation of a common voltage doubler, or peak-to-peak rectifier. A discussion of its operation would be too lengthy here; it should be sufficient to state that, with the application of successive grid pulses, the output of the counter circuit increases exponentially in discreet steps, finally approaching a level which triggers a restoring circuit; whereupon, it starts a new cycle to produce another pulse.

At the receiver, a limiter tube was used to separate the synchronizing pulses from the video signal. Often the tube was biased at such a point that the plate was just starting to draw current at the black level of the picture signal. Only the blacker-than-black peaks, as represented by the synchronizing pulses, were passed. The separation of the two types of pulses was carried out by suitable filter circuits, a differentiating network to pass the horizontal synchronizing pulses, and an integrating network for the vertical synchronizing pulses.

<u>Picture Amplifiers:</u> The width of the frequency band required

to transmit a picture imposed severe demands upon the amplifying system. Constant frequency response and time delay were to be obtained over a band several megacycles wide. The degree of amplification required, and the difficulty in obtaining high gain per stage with uniform amplification over the band, resulted in the use of a chain of several stages illustrated by Figure 20.

Picture amplification for the transmitter, for convenience, may be divided into three parts. Located at the camera was a preamplifier with a gain of about one thousand. The final stage of this amplifier was fed through a fairly low-impedance cable to the input of a monitoring amplifier, where the signal was further amplified to operate a Kinescope monitor. From the monitoring amplifier, the signal was fed through another coaxial cable to the modulation amplifier, which amplified the signal to such an extent that it could be used to modulate the transmitter. Resistance-coupled amplifiers, because of their more nearly uniform transmission characteristics, played an important role in the transmitter video amplifiers. Tunable iron-core peaking coils were usually used to improve the high-frequency response of the amplifiers.

At the superheterodyne receiver, the incoming signal was again amplified. Here the problem was somewhat different in that a large part of the amplification took place in the radio fre- and intermediate frequency stages of the receiver. However, the output of the second detector was usually amplified by a picture amplifier, similar to that used at the camera, before the signal could be used to operate the Kinescope control grid (Figure 21).

<u>Transmitters:</u> RCA television transmitters, with power outputs ranging from 25 watts to several kilowatts, were designed to operate on assigned television channels between 70 and 350 megacycles.

The r-f exciter circuits, because they generated relatively low frequencies, utilized conventional coil and condenser tank circuits. Buffer and power amplifier stages, however, were provided with tuned "lines" in which major frequency changes were effected by changing the settings of shorting bars.

In most instances, a black, positive video signal was employed to grid-modulate the power amplifier, resulting in a d-c negative r-f signal. D-c insertion was often accomplished by shunting the modulator input with a diode, to rectify the picture signal. The diode was connected so that rectified video voltage opposed a fixed grid bias, causing a net decrease in modulator bias in proportion to the amplitude and the brightness content of the video signal. The fixed bias was set to near cutoff, which was blacker-than-black, or top synchronizing-

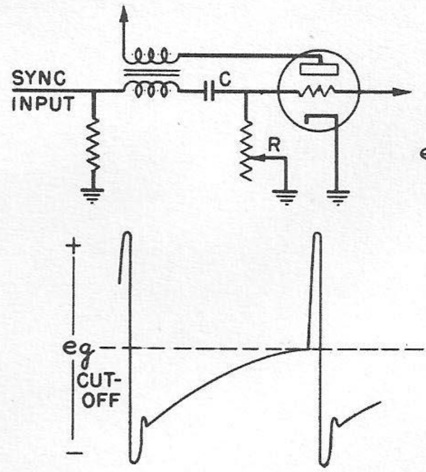

Figure 19. *Blocking Oscillator and Waveforms.*

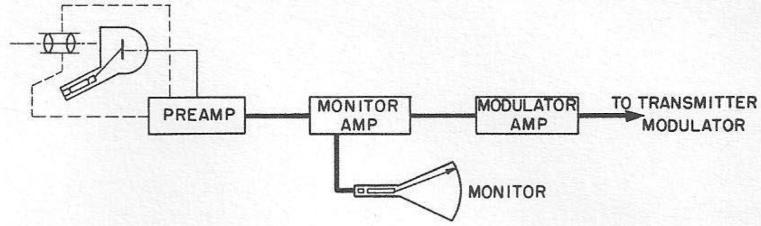

Figure 20. Video Amplifier Chain at Transmitter.

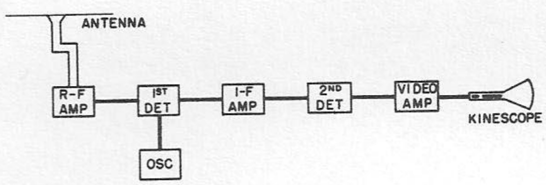

Figure 21. Amplifiers of Superheterodyne Receiver.

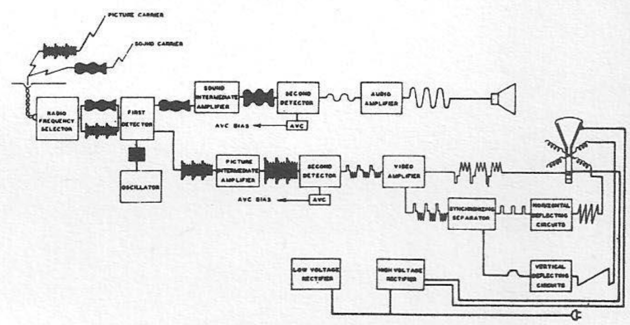

Figure 22. Block Diagram of a Typical Television Receiver.

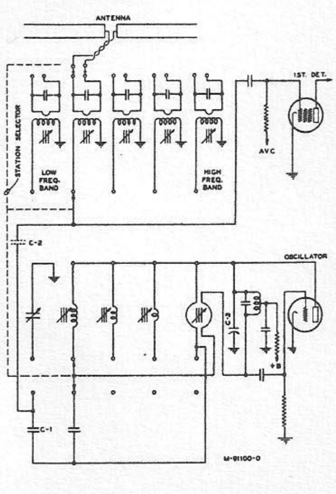

Figure 23. A Typical R-F Input and Oscillator.

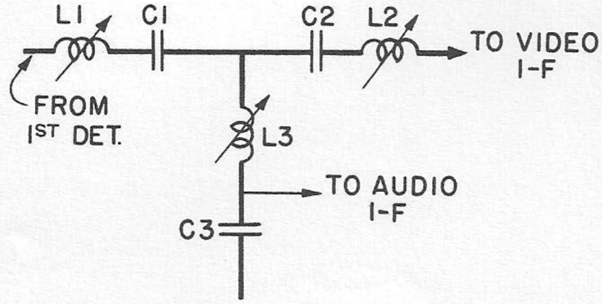

Figure 24. Selector for Separating Video and Audio I-F Signals.

signal level.

Although the transmitters were designed to develop a nine-megacycle, double-sideband signal, a lower-sideband suppression filter was interposed between the transmitter and the antenna so that the radiated signal conformed to RMA and FCC standards.

Receivers: Second only to obtaining a picture of high quality, the aim of television receiver design was simplicity. This made it necessary to place the burden of producing a nearly perfect video signal upon the pickup and transmitting equipment, in order to eliminate receiver controls such as required for shading, etc. The sole duty of the receiver, then, was to convert the corrected video signal into a picture.

In spite of this simplification, the television receiver was much more complex than a broadcast receiver. All but the least expensive commercial television receivers were equipped to handle the accompanying sound as well as the picture. Thus, except for a common input stage and detector, the instrument was actually two receivers: one for sound, the other for picture reproduction. The picture receiver, in addition to performing the functions of a normal superheterodyne receiver, employed circuits for d-c insertion, synchronization and deflection. A block diagram of the typical receiver is shown in Figure 22.

From the standpoint of tracking and frequency stability, better results were obtained using a separate oscillator with the first detector, rather than by employing a single tube to perform the functions of both oscillator and mixer (Figure 23). The oscillator circuit was of conventional form, the Hartley circuit being widely used.

To decrease the likelihood of image interference, and to reduce the ratio of video bandwidth to carrier frequency, the frequency of the local oscillator was usually chosen higher than the frequency of the signal. Since the video intermediate frequency was 12.75 megacycles, the oscillator frequency was variable over a frequency range of approximately 50 to 125 megacycles to cover the television broadcast region.

Since the first detector received both the sound and picture carriers, separated by 4.5 megacycles, two intermediate-frequency carriers were produced, likewise separated by 4.5 megacycles. The audio intermediate carrier was the lower in frequency, being 8.25 megacycles. The separation of these two i-f carriers was usually made at the output of the first detector. A circuit used extensively for this purpose consisted of a T-bandpass section, like that shown in Figure 24. The branches containing L_1C_1 and L_2C_2 were tuned to the video carrier. L_3C_3 was tuned to the audio carrier, so that a large audio voltage developed across C_3.

The i-f amplifier system passed a band up to four megacycles. An amplifier which will pass a band of this width must necessarily have low gain per stage. Consequently, five stages were used in the typical receiver. To permit use of an economical number of stages in securing sufficient gain and bandwidth, it was necessary to develop special, high mutual-conductance amplifying tubes such as the RCA 1852.

In discussing the picture i-f amplifier, it may be of interest to consider briefly the type of i-f coupling transformers used in a typical receiver. It will be noted from Figure 25, that the primary and secondary sections of the first detector, and the first and second i-f transformer assemblies were mounted within separate shields. The primary and secondary were not coupled magnetically, but through an impedance common to both circuits. At the frequencies involved, stray capacities and the input and output capacities become very important factors. These capacities were actually utilized to resonate the circuits at the proper frequencies.

Use of automatic gain control (automatic volume control, avc) in the picture channel of a television receiver has several advantages: It maintains the signal level at the second detector substantially constant for wide variations in the signal input; it makes manual adjustment of controls unnecessary when tuning from one station to another; and it simplifies the problem of synchronizing-pulse separation.

The a-v-c system of the picture i-f amplifier differs considerably from that of the sound amplifier. In sound broadcast receivers, it is customary to use the filtered d-c drop across the diode resistor as the source of a-v-c voltage. This is satisfactory because the d-c voltage thus obtained is directly proportional to the average carrier amplitude at the diode. In the transmission of television pictures, however, the average carrier amplitude varies greatly with picture content, as previously mentioned, and an a-v-c system operating to maintain a uniform carrier amplitude through the amplifier, therefore, is not suitable.

In picture transmission, although the average carrier amplitude varies with picture content, there is a maximum carrier amplitude which is always reached with the transmission of the synchronizing pulses. Thus if there is no fading of the signal, the peaks of the synchronizing pulses will always represent some constant amplitude, forming a convenient reference level for operating a satisfactory picture a-v-c system.

In Figure 26, the a-v-c rectifier, which is essentially a peak voltmeter, furnishes a d-c voltage which is amplified by a d-c amplifier, designated a-v-c amplifier. The voltage drop across the plate resistor of the amplifier is used as a-v-c bias, which is applied to the grids of two or more i-f amplifiers.

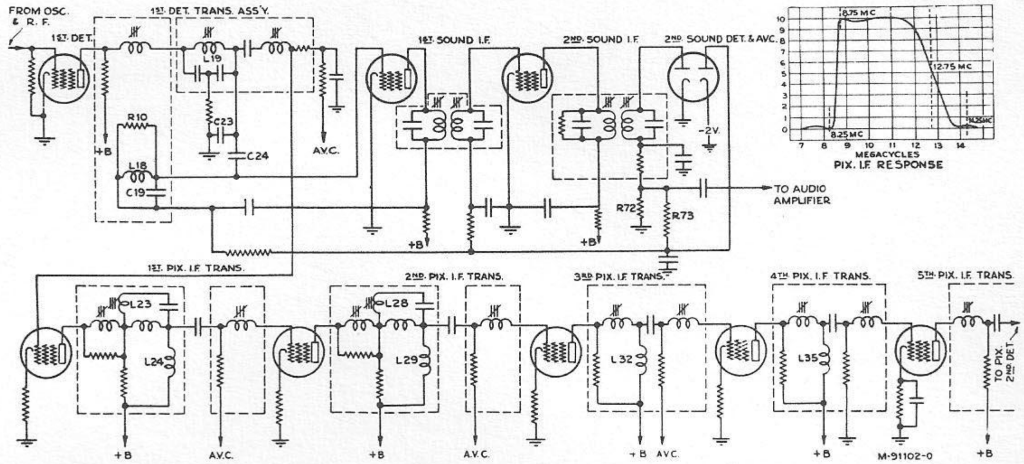

Figure 25. First Detector and I-F Amplifier.

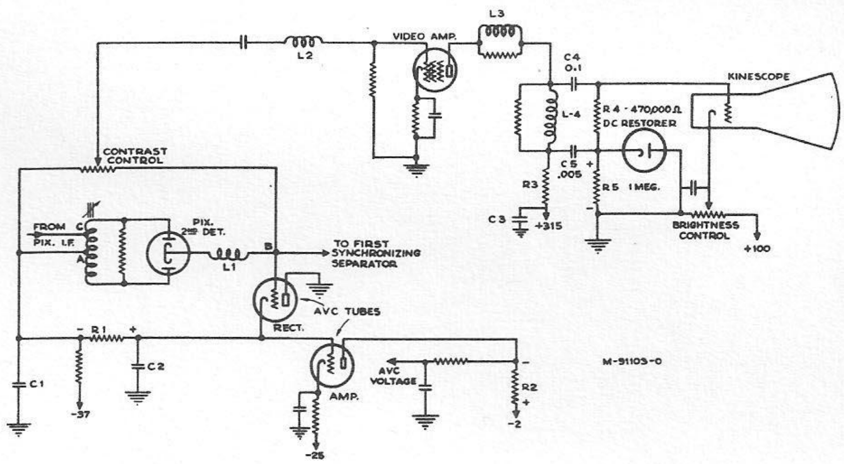

Figure 26. Picture Second Detector and A-V-C System.

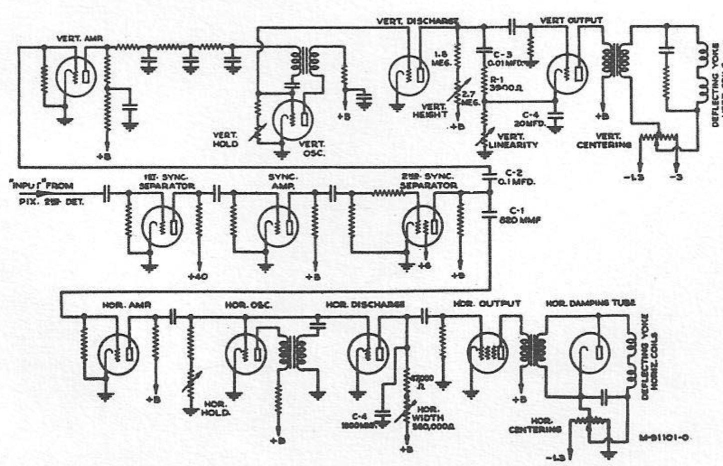

Figure 27. Synchronizing Separator and Deflection Circuits.

It was not considered economical to secure voltage directly from the i-f amplifier to operate the Kinescope. A stage of video amplification was employed. In high-quality receivers, the frequency response of this amplifier was excellent up to four megacycles. Linear phase shift and uniform time delay were other factors given consideration in the design of the amplifier. The peaking coils L_1, L_2, L_3, and L_4, together with stray capacities produced by tubes and wiring, formed a wide bandpass network that assured uniform response over the video band.

Since the video amplifier is an a-c amplifier, the d-c component of the picture signal that represents the average illumination of the scene will not be passed. Consequently, unless some means is provided to restore it, the Kinescope will not receive any information as to the average brightness of the scene. Restoration of the d-c component was accomplished by the use of a diode as a d-c restorer or automatic brightness control tube. This tube, operating as a rectifier, regulated the d-c bias of the Kinescope so that it was always driven to cutoff by the blacker-than-black synchronizing pulses.

Before the synchronizing pulses can control the deflection generators, they must be separated from the picture signal. Furthermore, the horizontal and vertical pulses must be separated from one another. Two limiter stages and an integrating circuit were used to carry out these processes. The first limiter tube was operated with low plate voltage, and was grid-leak biased to a point where only the synchronizing pulses had sufficient amplitude to cause plate current to flow. This stage, therefore, eliminated nearly all the picture elements from the signal. The second limiter stage was usually a tetrode, grid-leak biased and operated at low plate voltage and relatively high screen voltage. Thus, the second limiter operated as a dynatron, clipping the tops of the synchronizing pulses as well as effecting further separation of the remaining picture elements.

Filters responsive to wave shape served to separate the horizontal pulses of short duration and the vertical pulses of longer duration. A form of high-pass filter was used to separate the horizontal pulses, and a low-pass filter for the vertical pulses. Equalizing pulses at twice horizontal line frequency were part of the vertical synchronizing pulse. The purpose of the equalizing signals, as has already been pointed out, was to make the synchronizing pulses corresponding to the odd and even fields of interlaced scanning identical. This precaution was necessary to maintain interlacing.

A typical deflection and synchronizing circuit is shown in Figure 27. The horizontal and vertical selector circuits are designated as "First and Second Sync Separators." The "Sync Amplifier" serves to amplify the horizontal synchronizing pulses. It also serves as a buffer to prevent interaction between the horizontal deflection circuits and the separator filters.

The deflection generators for both vertical and horizontal components of the scanning pattern consist of a relaxation oscillator, a sawtooth generator and discharge tube, and a deflection amplifier.

Blocking oscillators of the type needed to produce pulses to actuate the discharge tubes are indicated as Vertical and Horizontal Oscillators in the diagram. The oscillator shown is a feedback oscillator, arranged with a grid leak and capacitor so that its grid is driven to cutoff after a half-cycle of operation. The grid remains below cutoff until the charge resulting from grid rectification leaks off through the grid leak, permitting another cycle of normal operation. The operation of this type oscillator has been described in a preceding section.

The sawtooth wave shape is formed by charging a capacitor through a large resistance and discharging it through a tube whose grid is driven positive by the pulse from the blocking oscillator. In practice, the sawtooth wave was applied either to the deflecting plates in the viewing tube, or to the coils of a magnetic deflecting yoke.

Two principal voltage sources were needed in the television receiver. One of these supplied the Kinescope voltages; the other furnished power required by the amplifiers, deflecting units, etc.

The high-voltage supply was divided into two parts, one which supplied the second anode and screen grid or accelerating voltages, the other the first anode voltage. The former was capable of delivering about one-half to one milliampere at 6000 to 8000 volts. While filtering was required in this rectifier, a greater percentage of ripple could be tolerated here than in the rectifier supplying the amplifier. Usually, one filter stage consisting of two 0.03-microfarad condensers and a 30-henry choke, was ample. The other part of the Kinescope power supply had a potential output of 1200 to 1500 volts. This voltage was variable to permit adjustment of the Kinescope focus. The filtering problem here was identical to that of the second anode voltage supply. The negative ends of both these power units were made low in potential so that the output of the video amplifier supplying the control grid would be near ground potential.

The voltage source for the amplifiers resembled that used in sound work. Its output, however, was more thoroughly filtered than that of the units just described.

Television Demonstrations: Many elements that go to make up the television system, previously described, emerged only after years of research and development. The notable outcome was the founding of what is probably the greatest "proving ground" in television history---a complete working example of a modern television system: NBC's television installation at Radio City.

The magnitude of the work involved in carrying out this endeavor, and its inestimable contribution to television science merit an account of the problems which arose and a brief description of the equipment designed to meet them.

Actually, RCA field tests began at a time when the mechanical scanner was the heart of the television system. Moreover, they served not only for the development of the television equipment, but also for improving the studio and operating technique so necessary to a picture of high entertainment value. For brevity in the following discussion, neither the earlier tests with mechanical systems, nor the developments in programming will be discussed. The subject matter will directly concern only the television equipment embodying all-electronic principles.

Among the first of these electronic television demonstrations were those carried out in 1933 at Camden, New Jersey, using a picture transmitter with a carrier frequency of 49 megacycles. The accompanying sound was transmitted at 50 megacycles. The studio from which the picture signals originated was located about 1000 feet from the transmitter and connected by a coaxial line. Iconoscopes were used to pick up the scenes both in the studio and out-of-doors. A scanning pattern of 240 lines produced a picture with fairly good definition, but a frame frequency of 24 cycles, without interlacing, was used resulting in a quite noticeable flicker. The results of these tests were so encouraging that it was decided to continue them. New York City, the site of earlier RCA tests using a mechanical scanner, was selected as the location because studies were possible under more nearly the conditions to be encountered in actual broadcasts, particularly with respect to noise and reflection from buildings. This move was made in 1936, tests by the National Broadcasting Company starting in June the following year.

The New York studios were located in Radio City. The transmitter was installed in one of the upper floors of the Empire State Building, with the antenna on the mooring mast 1285 feet above the street level. Two links interconnected the studio and the transmitter. One of these was an underground coaxial cable approximately a mile in length. An ultra-high-frequency, radio-relay link operating at 177 megacycles served as an alternative method of interconnecting the two units. To increase the flexibility of the system, and to permit outdoor and indoor pickup from remote points, a mobile unit consisting of a pickup truck and a transmitter, which also operated at 177 megacycles, was placed in service in 1938.

Approximately one hundred receivers were built and located at various points within a radius of 50 miles of the transmitter. These, together with field strength measurements, gave details as to the effect of the terrain on the received pictures.

The television equipment then in use at Radio City may be conveniently divided into three units. The direct pickup studio was located on the third floor together with its associated control room equipment. Above it on the fifth floor was the film studio with its projectors, cameras and control apparatus. Also located on this same floor was an equipment room containing the line amplifiers, and the synchronization and deflection generators for the entire system.

The lighting equipment for the studio was planned to give the greatest flexibility possible. In order to obtain an optimum picture and yet permit stopping down the camera lens sufficiently to obtain a large depth of focus, it was found expedient to use a fairly high level of illumination, that is to say, 1000 to 2000 foot-candles. Banks of 300-watt lamps were mounted on metal frames suspended from the ceiling of the studio by cords and pulleys. The frames were suspended in such a way that the lamps could be tilted or moved laterally.

Dollies with rubber-tired wheels carried the cameras. The wheels were interconnected by a chain drive, and steered by means of a lever located half way up the pedestal. To enable the operator to follow the action and keep the camera in constant focus, each camera was provided with a "finder": a pair of identical lenses, one of which focused the scene onto the mosaic, while the other focused it onto a ground glass. The operator, by watching the ground glass of the finder, could manipulate both lenses by a single control and obtain a sharp image on the mosaic.

Inside the camera head was the Iconoscope with its associated deflecting yoke, a blanking amplifier and a picture pre-amplifier. The pre-amplifier consisted of a cathode-follower first stage, two compensated resistance-coupled stages, and a final low-impedance output stage, matched to the video cable. A thirty-two wire cable, approximately one and one-half inches in diameter and sixty feet long connected the camera with the control booth. This cable supplied the constant potentials needed for the Iconoscope, vertical and horizontal deflection, blanking signals, and also included a low-capacity video cable to carry the picture signal output from the pre-amplifier.

For each camera used in the studio, a separate picture amplifier was provided in the control room. These amplifiers were compensated, resistance-coupled amplifiers, working at an input level of about 0.1 volt. Both the input and output impedances were low, the former to match the camera cable and the latter to permit feeding a concentric cable to the line amplifier. Each amplifier was equipped with a gain control and a brightness or background control which regulated the pedestal height between lines, giving the d-c level. Also associated with each amplifier was a shading circuit. This circuit provided the waveform required to compensate for the spurius signal generated by the Iconoscope. Since the waveform of the spurious signal differed for various Iconoscopes, and varied with operating conditions, the compensating waveform was under control of the operating engineer. The simplest circuit for this compensation employed two horizontal and two vertical wave components, one of these being a sawtooth wave, the other a parabolic wave. These could be added with any amplitude or sign. Another shading circuit made use of sinusoidally-shaped components providing a sine half-wave, a full-wave and three half-waves, all of which could be controlled in amplitude and phase. The output from the shading circuit, after being amplified, was added to the picture signal by means of conventional injector circuits in the video amplifier.

The plate supply for the resistance-coupled amplifier had its source in a large central storage battery. The amplifiers were connected to this battery by low resistance lines, in some instances having lengths of 100 or 200 feet. Also located in the control room were two nine-inch monitoring Kinescopes. Accompanying each Kinescope was a five-inch oscilloscope which displayed the waveform of the video voltage. Each Kinescope had its own picture amplifier, which operated on a minimum peak-to-peak video level of approximately 0.5 volt.

The line amplifiers and synchronizing generators which were common to both the live-talent studio and the film studio were installed in a main equipment room. These amplifiers were fed by the output from either of the studios. Operating at an input level of about one volt. They produced ten volts in a 75-ohm coaxial line which was connected either directly to the Empire State transmitter, or switched to the radio relay link.

Blanking, deflection, and synchronizing pulses for both studios were produced by the synchronizing generators, either one of which could be used, insuring against any breaks in the program due to the failure of this essential equipment. To provide synchronism between the television system and the power lines supplying the receivers within the service area, the generators were locked into the 60-cycle outside power line supplying the building.

Programs originating from Radio City were transmitted from the Empire State Building. The ten-kilowatt transmitter in service at the time was located on the eighty-fifth floor. The transmitter consisted of two units, one for sound and the other for the pictures. Originally, these two units fed a coaxial transmission line leading to the antenna which served to radiate both carriers. Three stacks of horizontal dipoles arranged in an equilateral triangle constituted the antenna. Coaxial filters at the points where the transmitters joined the transmission line prevented interaction between the two elements. At first, double-sideband transmission was used for both audio and video. However, early in 1939 the system was changed over to single-sideband operation for the video signal. At the same time, separate transmission lines were installed for sound and picture. A coaxial filter in the transmission line removed the unwanted video sideband. This filter and the video antenna will be described later.

In locating the transmitting equipment it was desirable to place it as near the antenna as possible. However, account had to be taken of the structural limitations of the building, because the total weight of the two units was nearly 35 tons. Finally, with no compromise in efficiency, and with but a slight sacrifice in convenience, the installation was spread over considerable area in a single large room 75 feet by 20 feet. The transformers and motor generators supplying the power were located in adjoining rooms on the same floor. These occupied a space about equal to the transmitter room. Power for the transformers was brought through several commercial 13,000-volt feeders.

The video transmitter employed a temperature-controlled crystal oscillator operating at 2.828 megacycles. Suitable frequency multipliers fed a push-pull RCA 833 carrier amplifier stage, which in turn fed a pair of RCA 846 tubes serving as intermediate power amplifiers. The final power amplifier stage consisted of two grid-modulated RCA 899 tubes, whose plate tank was coupled to the antenna feeder. Two RCA 899 tubes were used in parallel as class A modulators. Approximately 9000 volts was supplied to the final r-f stage, and 6000 volts to the modulator.

The amplifier preceding the modulator consisted of four stages, the first of which contained two RCA 807 tubes in parallel. This was followed by a stage consisting of three parallel RCA 807 tubes. These two stages were coupled with pi networks to separate the plate and grid capacities of the successive tubes, and the signal traversed them as an a-c signal, the average value of picture illumination being transmitted as pedestal height. The third stage consisted of three RCA 831 tubes connected in parallel. Here, the d-c component was reinserted by

Figure 28. The Mobile Television Unit.

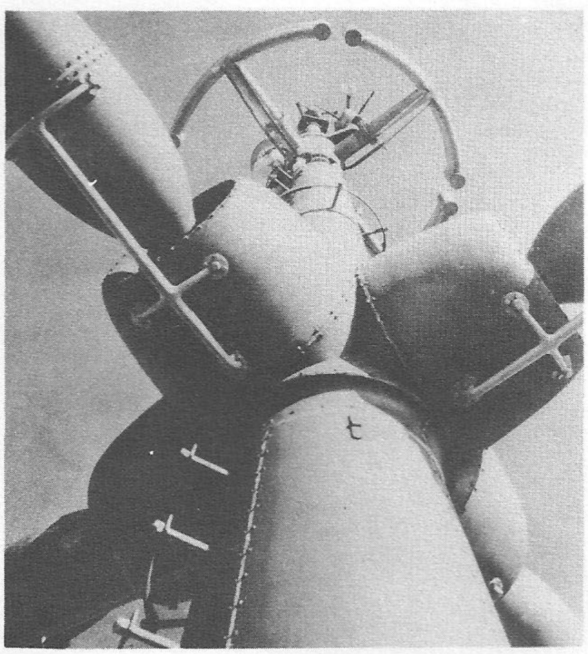

Figure 29. Prior to the war, this broad-band antenna atop the Empire State Building radiated sight and sound programs originating in NBC's Radio City.

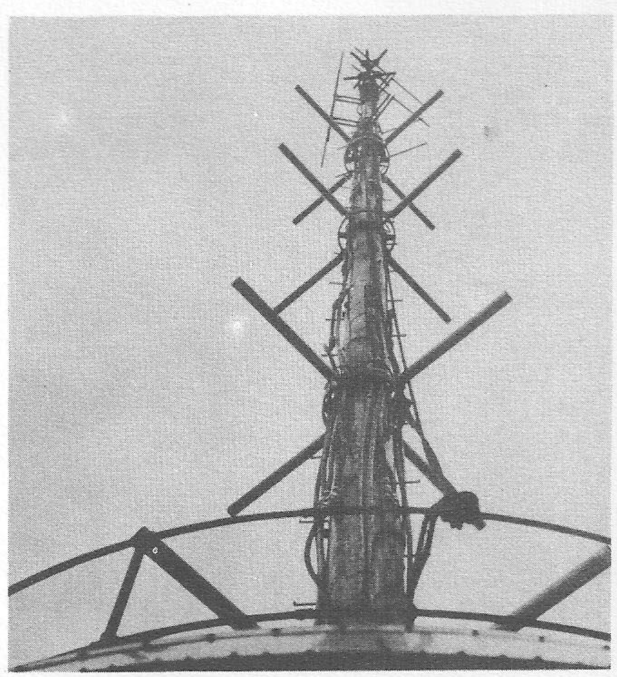

Figure 30. In 1946, the antenna was replaced with this specially-designed 61-foot television antenna. The extensions at the lower end radiate the television signals. Above them are the T-shaped f-m radiators, and at the top are antenna elements for a 288-megacycle experimental television transmitter. By 1946, RCA alone had spent several million dollars in television research.

means of an RCA 1-V diode whose cathode was connected to the grid of the video tube and whose anode was essentially at ground potential. Coupled to this stage was an RCA 891 tube, where the direct current was again reinserted; but since the polarity was reversed, the anode of the 1-V was connected to the grid, and the cathode to ground through the bias supply. The d-c component was, of course, reinserted in the class A modulator stage with another reversal of polarity.

As previously stated, the lower of the two 4.5-megacycle side-bands generated by the transmitter was partially suppressed by a filter in the 72-ohm coaxial feeder of the antenna. The filter used for this purpose consisted of six elements. Three of these were cascaded, high-pass dissipative elements, the cutoff of which was not sharp enough to meet the requirements of the band shape. Therefore, three narrow bandpass elements were needed to complete the filter.

The antenna itself was formed of two pairs of radiating elements whose axes were at right angles in a horizontal plane. These elements were fed in quadrature through an interconnecting quarter-wave line. The form of these radiators is illustrated in Figure 29. An antenna designed by RCA engineers and recently installed is shown in Figure 30.

It has already been mentioned that two video communication links were provided between the studios at Radio City and the transmitter at the Empire State Building. One of these consisted of an ultrahigh-frequency radio-relay transmitter and receiver. A carrier frequency of 177 megacycles was chosen for the radio link because this frequency did not coincide with possible harmonics of the main television transmitter. It was desirable at the time to employ as high a frequency as possible so that radiation could be directed effectively, and so that there would be a minimum of interference either from existing radio services or man-made static. The upper limit was determined by the efficiency of available vacuum tubes. Like the Empire State system, the link equipment was later remodeled to transmit a single-sideband signal.

Located on the south side of Radio City, at the level of the fourteenth floor, was the link transmitting antenna consisting of two half-wave horizontal radiators fed in phase and mounted on a large copper reflector to give the desired directivity. On the north wall of the Empire State Building, at the eighty-fifth floor, so placed as to have an unobstructed path to the Radio City end of the link, was the receiving antenna. The receiving antenna was constructed like the transmitting antenna. The actual distance between the antennas was 4600 feet.

In spite of the many possibilities for reflection as suggested by the terrain over which the relay signal had to pass, the transmitted radiation was so beamed that very little interference of the kind existed. The variation in the received signal over a band from 176 to 182 megacycles was nearly constant, although a few irregularities were recorded owing to reflected radiation.

The link transmitter was made up of video amplifiers, a modulator, a master oscillator, power amplifier, and a monitor. The master oscillator was controlled by a concentric tank, the center conducting member being a copper tube two and one-quarter inches in diameter and 0.2 of a wave in length. One end of the concentric line was short-circuited by a disc, which was silver-soldered to both, insuring a good electrical path. To maintain temperature stability, an invar rod fastened to the disc ran through the center of the inner member. A sylphon bellows about an inch long, which formed part of the inner conductor, was attached to the other end of the invar rod. Since the length of the invar rod is practically invarient with temperature, the effective length of the controlling inner member was constant. The ratio of the diameters of the cylinders was 3.5, and the theoretical Q of the tank was nearly 12,000.

Two RCA 834 tubes were used in the oscillator circuit, the grids being inductively coupled to the center member of the controlling tank. The plate tank circuit was formed of a concentric line tuned by a balanced condenser. The power amplifier, which also employed two RCA 834 tubes, operated as a grid-modulated neutralized push-pull amplifier. The plate inductance for this stage was in the form of two balanced lines connected in parallel. Coarse tuning adjustments were made by means of sliders on these lines, and fine adjustments by a small movable-disc condenser. The modulator employed two RCA 802 tubes connected in parallel.

A loop coupled to one branch of the power amplifier plate inductances provided the output terminal of the transmitter. The ends of this loop were connected to the antenna feeder circuit. A half-wave coaxial line matched the unbalanced feeder to the balanced output of the transmitter.

The link receiver at the Empire State Building was a superheterodyne using an intermediate frequency of 21 megacycles. The detector consisted of a pair of push-pull RCA 954 acorn tubes. The 21-megacycle intermediate frequency appearing at the output of this detector was coupled to a six-stage i-f amplifier. An RCA 955 tube, connected as a diode rectifier, served as second detector and fed a video output tube (RCA-42). Automatic control of the i-f amplifier gain was effected by the output of a d-c amplifier driven from a voltage divider across the diode load resistance.

A signal of the order of 30 millivolts-per-meter was picked up at the receiver. Because the transmitting and receiving antennas were both directive, the signal-to-noise ratio was high. Measurements of this ratio showed that the noise level was approximately 44 decibels below a signal corresponding to 85 per cent modulation of the transmitter. The overall response of the television relay link was within 1.5 decibels from approximately 20 cycles to 1600 kilocycles.

The mobile unit was an adjunct to the direct pickup and film studios at Radio City. It was an essential part of the television project, permitting the direct pickup of events of current interest. The unit consisted of a complete pickup system and an ultrahigh-frequency link transmitter.

Two streamlined buses, each 26 feet long, and capable of a ten-ton load, housed the equipment. Along the top of the video bus was a catwalk equipped with four camera and microphone placements, allowing the camera and parabolic microphones to be placed well above any spectators watching the scene to be televised. The camera could also be placed on the ground at any distance up to 250 feet from the bus. Prior to operation, a 24-foot collapsible antenna was erected on the roof of the bus.

The Iconoscope cameras, like those in the studio, contained the video pre-amplifier, a horizontal deflection amplifier and a vertical blanking amplifier. The picture amplifier and the deflection and synchronizing circuits were rack-mounted inside the bus. Telephone circuits were employed to link the video operator with the men handling the cameras and other equipment.

Like the main link transmitter, the mobile transmitter operated on a frequency of 177 megacycles. It produced a double-sideband signal corresponding to a video channel of three megacycles. A resonant, concentric tank controlled two push-pull RCA 887 tubes as master oscillator. The grid-modulated output stage utilized RCA 887 tubes operating class C.

There were many important problems to be solved in carrying out an installation such as that of the Radio City and Empire State Building television system. Some of these problems were both instructive and interesting, and while they are now common knowledge among communication engineers and technicians, a few of them associated with ultrahigh-frequencies can be briefly considered for whatever historic value they might have.

Where ultrahigh-frequency energy was handled, symmetrical, push-pull stages were practically essential. Otherwise, it was virtually impossible to establish a common ground, because the mounting frames, metallic enclosures, etc., were an appreciable fraction of a wavelength in size. Not only was the problem of fixing a ground facilitated by the use of push-pull circuits, but also, by making these circuits symmetrical with respect to their metallic enclosures, the unavoidable stray capacities could be considered as symmetrical circuit elements, simplifying the almost impossible problem of neutralization. At these very short wavelengths, transmission lines became practical as circuit elements, and replaced lumped inductances and capacitances as tank circuits, impedance transformers, etc. To give a well known example, the filament leads on power amplifiers, because of their length, made it impossible to ground the cathodes directly as is necessary in a push-pull stage. However, by extending the filament leads of each tube so that they were a half-wave long, and by grounding the far end, the filaments themselves were effectively grounded.

The property commonly known as "skin effect" made it possible to use concentric circuit elements plated with a thin, highly conducting metal such as copper or silver on an underlying metal having the desired mechanical properties, regardless of the specific resistance of the latter. Where high frequency stability was required, concentric tank circuits were made of invar steel and coated with thin silver plate, giving it the same conductivity as though the entire structure was of silver. This has been described in connection with the link oscillator.

The problem of obtaining suitable capacitors for use with high power at ultrahigh frequencies was rather serious. The small variable capacitors needed for neutralizing and tuning were conveniently made in the form of pairs of copper discs whose separation could be varied to adjust the capacity. These discs were usually mounted directly on the circuit elements to which the capacitors were to be connected, avoiding the need for insulating supports. A most difficult task was to supply condensers for interstage coupling. The current in such circuits reached values as high as 30 or 40 amperes, and because of the relatively low reactive impedance of the tubes, the reactance of the capacitors was not to exceed 15 or 20 ohms. This meant that a capacity of at least 200 micro-microfarads was required, and the capacitor must be capable of withstanding more than the normally applied plate voltage of 10 kilovolts. Dielectric losses in capacitors, using mica insulation, were found to be very high at these frequencies. Air as a dielectric was satisfactory but air-insulated capacitors of this capacity were bulky and did not lend themselves to good circuit design.

Sulphur-insulated capacitors were found most satisfactory, and promising possibilities were shown by both compressed-air and vacuum type capacitors. The vacuum capacitor takes the form of close-spaced concentric cylinders assembled in a highly evacuated glass cylinder. Thus a high-voltage rating can be obtained without the need for large dimensions.

Satisfactory ultrahigh-frequency resistors, because of their reactance, presented another problem. At extremely high frequencies, the capacity of the grains in carbon resistors practically amounts to a short circuit. Thin coatings of a high-resistance metal on glass or ceramic were found suitable for low power. Resistors made by depositing carbon on glass or ceramic cylinders, through which water could be circulated, when used as the center conductor of a concentric line, proved satisfactory over quite a broad frequency band and handled large amounts of power.

In the design of the ultrahigh-frequency circuits of the transmitter, an attempt was made to dispense with supporting insulators wherever possible. However, some insulators were unavoidable. Where insulators could not be located at voltage nodes, they presented certain difficulties because of the high displacement current that necessarily flows through the dielectric material. Special precautions in avoiding all imbedded points, such as screws, were required because the current density in the vicinity of sharp intrusions would be high, and the heat developed might cause the insulator to shatter. Electrostatic shielding was found useful in reducing the current in the dielectric.

A wealth of valuable information on television technique has been gained through the tests made on the installations at Radio City and the Empire State Building. The special problems discussed, together with many others which space does not permit describing, have been solved at least to the extent that they do not impair the efficiency of the equipment in its present form. The installation has long since ceased to be experimental, and has become a practical, modern broadcasting unit, not only as far as the equipment is concerned, but also from the operating standpoint. As new and better equipment is made available, it replaces the old at these locations.

Programs of high entertainment value and interest, smoothly transmitted have been assured by the Radio City plant. In 1938, scenes from the Broadway play, "Susan and God," starring Gertrude Lawrence were telecast from these studios. The following year, RCA and NBC introduced television as a service to the public at opening ceremonies of the New York World's Fair, featuring President Roosevelt as the first Chief Executive to be seen by television. The same year, major-league baseball was telecast for the first time. So was the first college football game -- Fordham vs Waynesburg -- televised by NBC in New York.

NBC's television station ceased to be pioneer experimental W2XBS when, in 1941, it became television station WNBT, the first commercially licensed television station to go on the air. During the war, WNBT trained thousands of air-raid wardens in the New York area. The station completed its wartime service to the public by telecasting films of the Japanese signing surrender documents aboard the USS Missouri.

Figures 31 to 47 illustrate some of the television equipment manufactured by RCA prior to the war.

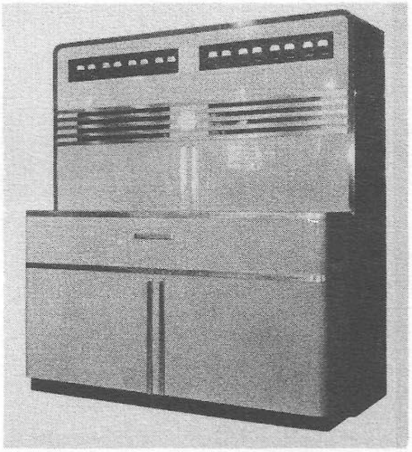

Figure 31. This RCA Type T1 Television Transmitter generated a standard, one kilowatt signal.

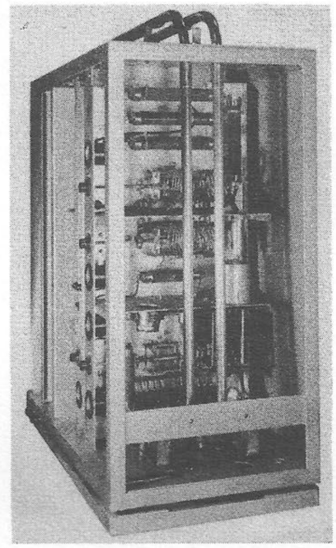

Figure 32. The r-f unit employed a temperature-controlled crystal oscillator. Push-pull RCA 889 tubes were used in the final amplifier.

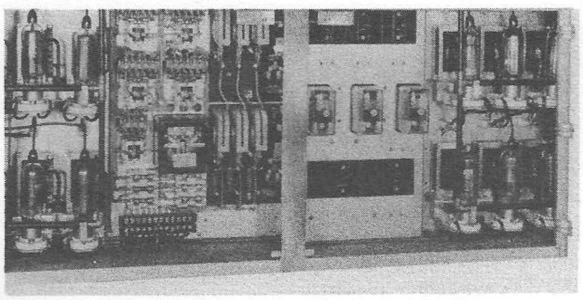

Figure 33. The High-Voltage Rectifier Compartment. A total of 12 RCA 872A tubes in three-phase circuits supplied transmitter voltages.

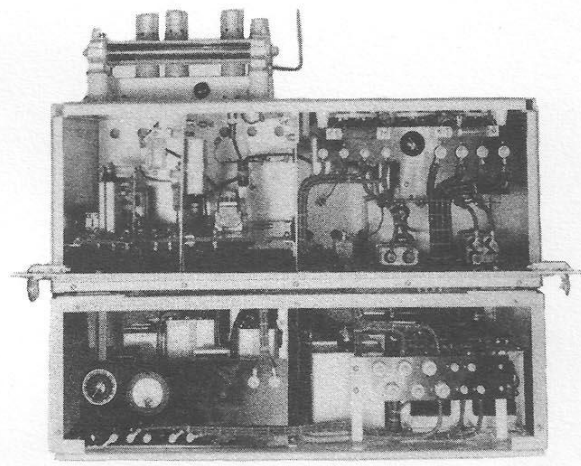

Figure 34. The modulator used ten RCA 813 tubes in parallel to grid-modulate the power amplifier.

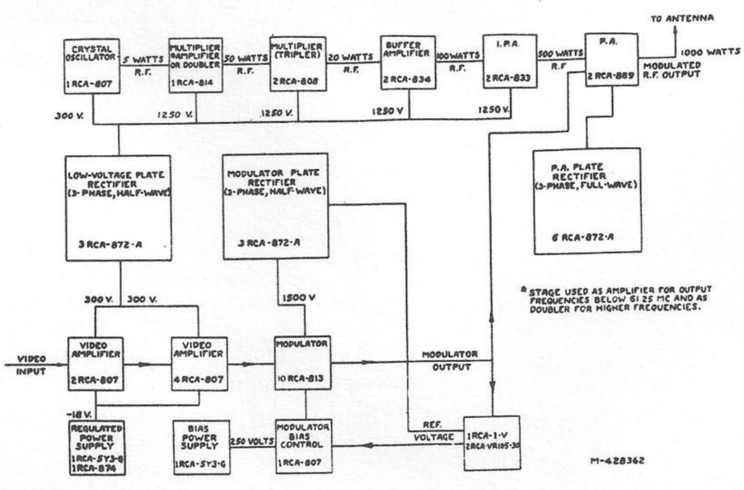

Figure 35. A Block Diagram of the Type T1 Television Transmitter

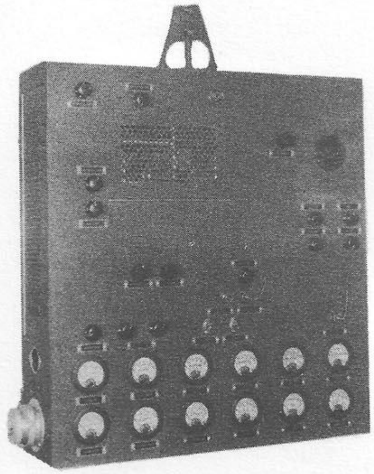

Figure 36. The RCA Mobile Television Transmitter, Type M-25, consisted of two units—the transmitter and power-supply. The 25-watt transmitter (this photo) was crystal-controlled and operated on specified frequencies between 288 and 346 megacycles.

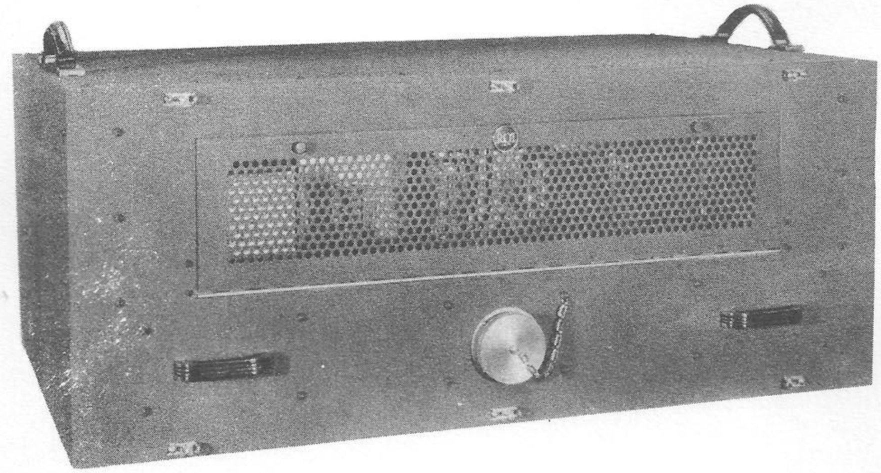

Figure 37. The power supply used four RCA 866 tubes in the high-voltage circuits. Operation was from a generator supplying 120 volts 50/60 cycles, 600 watts.

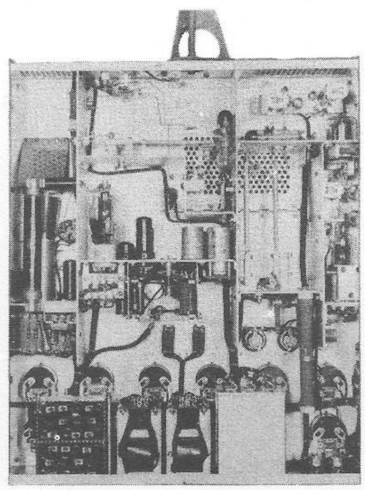

Figure 38. A Rear View of the M-25 Transmitter. The push-pull (2074G tube) power amplifier is in the top center of the picture. Below it is the video modulator, two RCA 807 tubes in parallel.

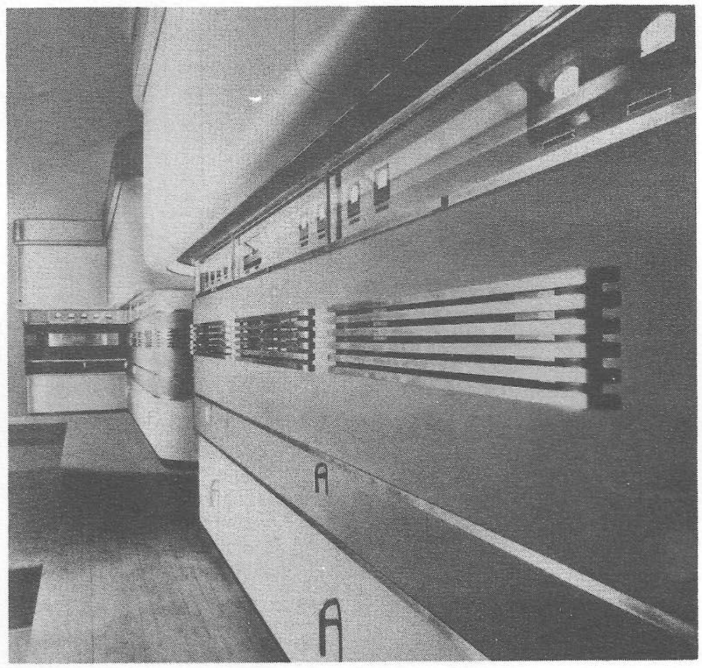

Figure 42. High-Power Television Transmitter Manufactured by RCA Before the War.

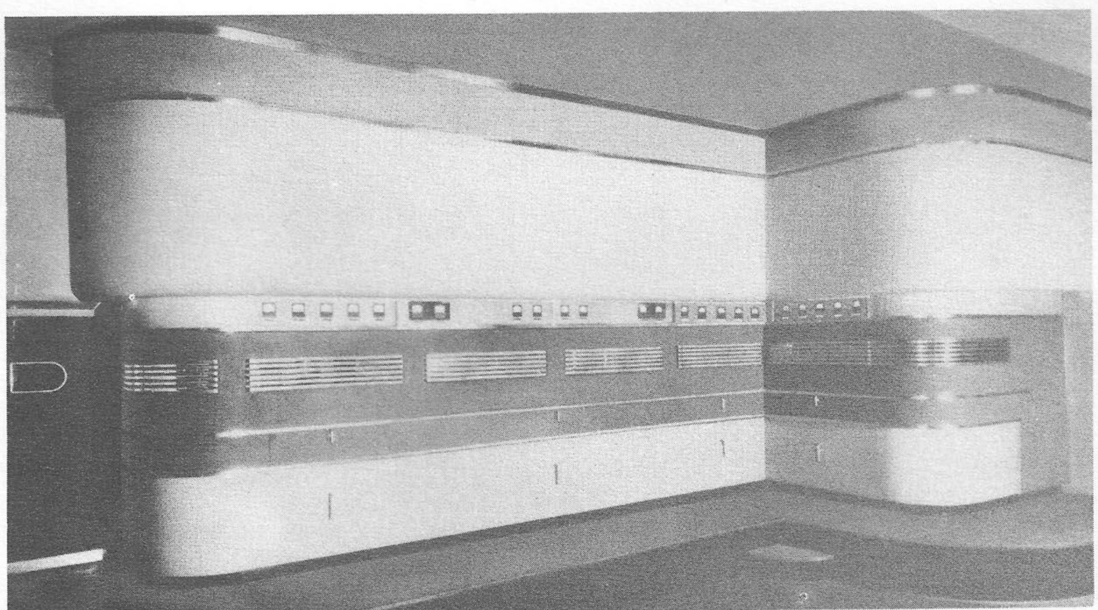

Figure 43. One of RCA's Early Field Cameras Using the Type 1848 Iconoscope.

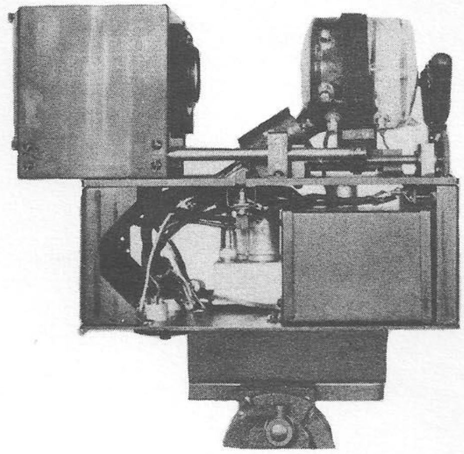

Figure 44. An Interior View of the Iconoscope Camera. Lamps placed behind the Iconoscope provided background illumination, increasing the pickup tube's sensitivity.

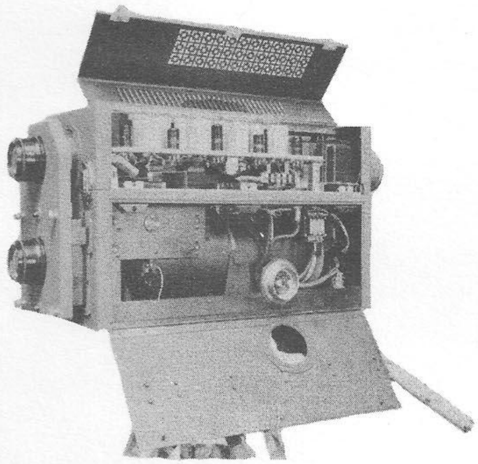

Figure 45. Later, RCA developed the Orthicon Camera, pictured here, permitting scenes to be telecast under low illumination. In the upper compartment is the five-stage video amplifier.

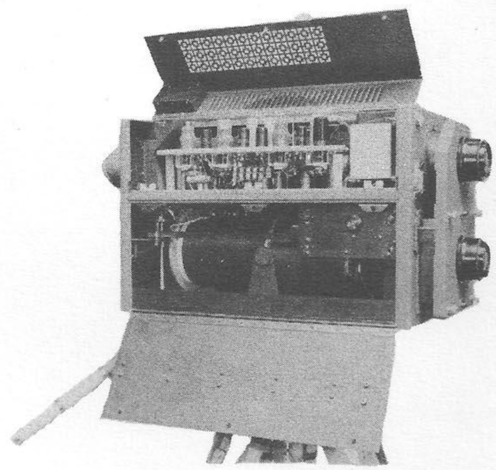

Figure 46. Another View of the Orthicon Camera. Beside the video amplifier, the top compartment contained the deflection and blanking amplifier.

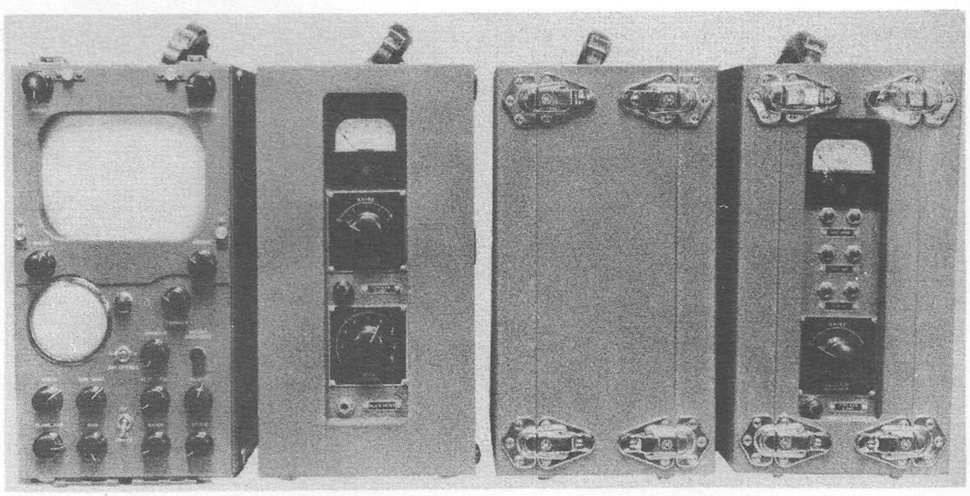

Figure 47. These four units—Camera Control, Power Supply, and the Shaping and Pulse units of the synchronizing generator were used with the Orthicon Camera. The picture amplifiers of this equipment featured three unusual circuits: The clamp circuit; the linear clipper; and the gamma control.