Radio Transmission System for Television[1]

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SYNOPSIS: Starting from the general requirements imposed on the transmitting medium, this paper discusses the engineering of a radio system for television purposes and describes the radio facilities actually employed for the recent Bell System demonstration. The tests to which the system was submitted to determine its suitability are outlined and the measured frequency-response characteristics are shown. An interesting phenomenon due to multi-path transmission, the production of positive and negative secondary images, is reported. A brief series of experiments concerned with the transmission of both voice and image "on a single wavelength" is also described.

IN other papers of this symposium, the general nature of the television problem has been discussed, the scope of the recent Bell System demonstration has been outlined, terminal apparatus for television has been described, and the general requirements to be met by the transmitting agency have been formulated. This paper is concerned with the problem of engineering a suitable radio system for television purposes and with a description of the radio facilities actually employed for the demonstration.

Requirements Imposed on the Radio System

The radio experiments were conducted from the Bell Telephone Laboratories' Experimental Station 3XN at Whippany, New Jersey. Between this point and the main Laboratories Building at 463 West Street, New York City, some 22 miles distant, three separate communication channels were required—one for the picture, a second for synchronizing, and a third for speech and music. The demonstration being of a three-cornered nature involving New York, Washington and Whippany, it was deemed to be highly advantageous to transmit the necessary synchronizing currents for both the wire and radio systems from a master generating set located in the auditorium of the West Street Building. Hence the synchronizing channel was required to operate from New York to Whippany, while the picture and speech channels necessarily transmitted in the reverse direction.

From the radio standpoint, the problem presented for solution may be described as follows:

1. There is given television transmitting and receiving apparatus designed to work into and out of specified impedances at stated signal

[1] Presented at the Summer Convention of the A. I. E. E., Detroit, Mich., June 20–24, 1927.

energy levels. Signal components ranging in frequency from 10 to 20,000 cycles must be transmitted with as little discrimination with respect to either amplitude or phase as reasonable design practices will permit. It is required that a suitable radio system be designed to afford satisfactory transmission between terminals when operated under prevailing conditions with respect to static, other radio traffic, and local electrical disturbances. The maximum allowable "noise" level is probably somewhat arbitrary but it has been found that if the ratio of signal to interference current is 10:1 the results are satisfactory. The variation of amplitude with frequency should probably not exceed $\pm$ 2 TU at any point in the required signal band. The equivalent of the circuit must be substantially constant; in other words, no fading effects can be tolerated. In this respect a variation of perhaps 3 TU is the maximum allowable.[2]

2. For synchronizing purposes, a second channel must be provided to transmit 17.7 and 2125 cycles, the impedances and the signal energy levels at both ends of the circuit being known. The grade of transmission required in this case is probably considerably lower than that needed for the picture circuit but stable operation must be assured.

3. Arrangements must also be made for a high quality telephone channel to transmit speech and music for loud speaker reproduction.

4. All of these channels must, of course, be capable of operating simultaneously without mutual interference and without effect on established radio services.

Preliminary Survey

In the vicinity of New York, an assignment of this type is surrounded with unusual difficulty due to the serious congestion which exists in the ether. Operations were started, therefore, by undertaking a survey of available frequency bands at periods of the day during which transmission might be required.

The pioneering nature of the project and the character of the apparatus available led to an early decision to base the system on the transmission of the carrier and both sidebands. Since the upper limit for the signal was specified as 20,000 cycles, an interference-free band somewhat greater than 40,000 cycles in width was, therefore, required. The unusual width of this band indicated the desirability of fixing upon a relatively high carrier frequency. No readily available

[2] Definitely agreed on limits were essential to proper coordination of the various development activities and figures of the order mentioned were assumed for design purposes.

substitute for the ordinary type of tuned circuit was at hand and such circuits discriminate seriously against side frequencies differing by more than a few per cent from the frequency to which they are adjusted.

The results of the survey disclosed two bands somewhat wider than that required centering approximately about 1575 and 1750 kilocycles. It was also conclusively demonstrated that the operation of the synchronizing channel at a frequency above the broadcasting

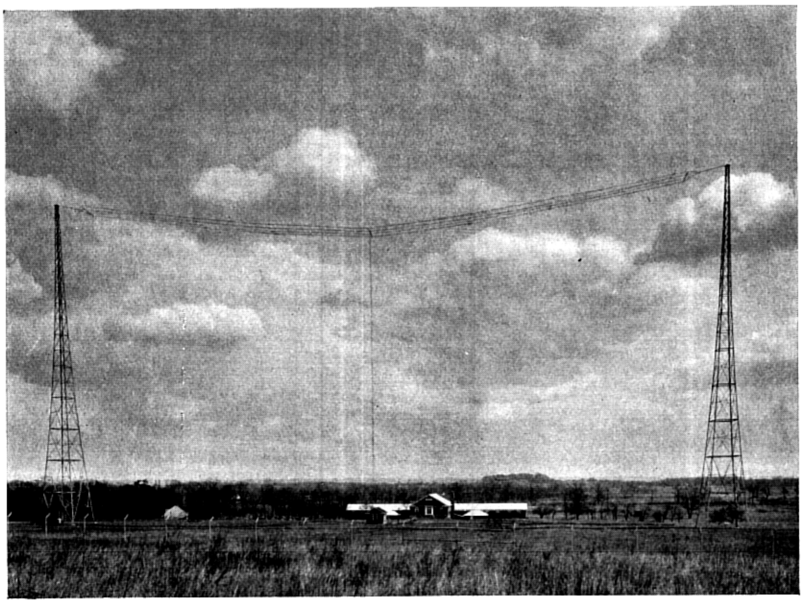

Fig. 1—General view of the Whippany Station, 3XN

band was entirely out of the question. With two broadcasting stations located in the immediate neighborhood, one producing a field strength of perhaps 50 millivolts per meter and the other several volts per meter, the operation of a third transmitter on an adjoining frequency with the maximum obtainable separation between antennae, resulted in an almost continuous interference spectrum. It was decided, therefore, to transfer the synchronizing channel to a frequency of the order of 185 kilocycles, which would be sufficiently remote to remove interference from this source, and to make further studies in the regions about 1575 and 1750 kilocycles based on transmission from Whippany. No difficulty was anticipated in making suitable arrangements for the speech channel on account of the narrower band required and the well-known nature of the problem.

The Whippany Station, 3XN

A general view of the station site at Whippany is shown in Fig. 1. The property consists of some 47 acres. The main laboratory building, which is located near its center, is a two-story structure affording approximately 18,000 square feet of floor space. The principal antenna system involves two 250-foot steel towers with a suitable buried ground system, which is placed some 500 feet out in front of the building in order that the latter may be clear of the denser portion

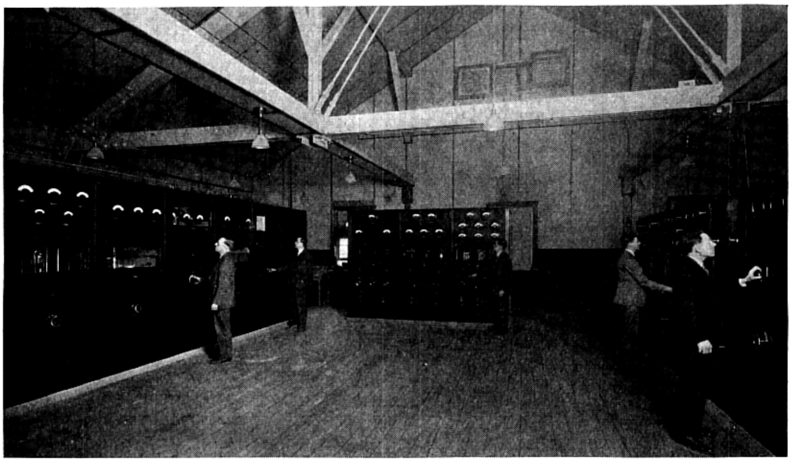

Fig. 2—Operating room at 3XN. Transmitter for television channel on the right. Power supply unit and radio transmitter for the speech channel in the center and on the left, respectively.

of the electric field. This antenna was assigned to the picture channel. For the voice channel, a separate structure located 500 feet in the rear of the laboratory building or approximately 1000 feet from the other was employed. The original supports in this second case were 60-foot wooden masts but subsequently metal topmasts were added, bringing the total height to 100 feet. Both antennae were energized by means of radio-frequency transmission lines. The antenna tuning and coupling apparatus was housed in small buildings placed under the center of each antenna, that for the larger structure having a copper roof which was securely connected to the ground network.

This type of installation is thought to afford a number of advantages. By separating the building and the antenna it becomes a much simpler matter to control the electrical factors which enter into the design of the latter. Removing the building from the field tends toward reduced dielectric and eddy current losses and consequently toward higher antenna efficiency. The resulting improvement may be expected to more than compensate for the slight loss in the line, which should not exceed 3 per cent. Removing the field from the building is equally advantageous in that it simplifies the precautions which normally have to be taken to prevent the radio-frequency energy from affecting the performance of audio amplifiers and other supple-

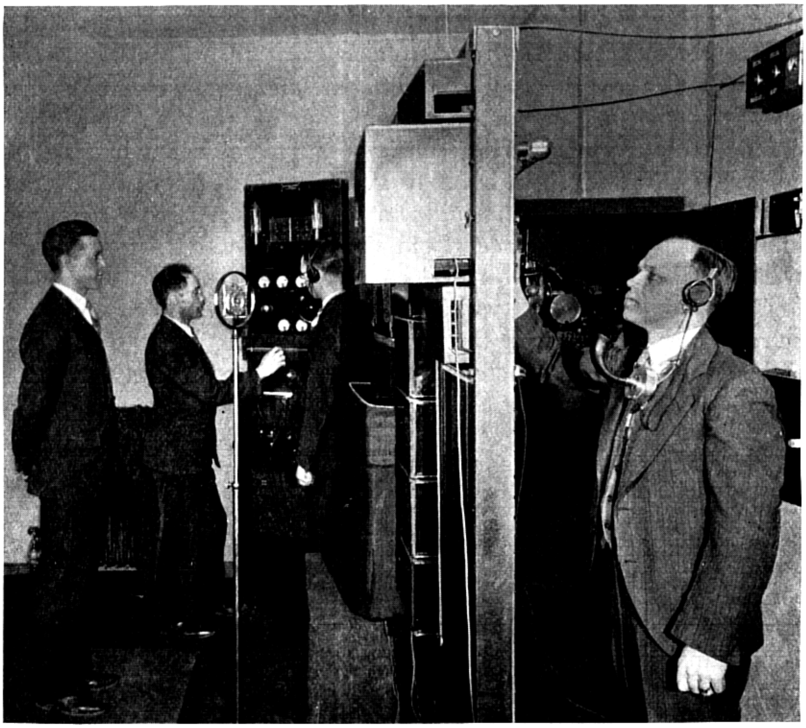

Fig. 3—Television transmitting apparatus in the studio at Whippany

mentary vacuum tube apparatus. The most serious disadvantages arise from the fact that the antenna must be tuned and the current in it measured at a point remote from the transmitting apparatus proper.

In spite of the fact that the station building was not directly under either antenna, some difficulty was anticipated from radio-frequency fields produced within the transmitting equipment due to the relatively high amplification employed with the photoelectric cells. In order to minimize trouble of this nature a special shielded studio was constructed in one of the wings of the building to house the television terminal apparatus. Walls, ceiling and floor were completely covered with No. 24 gage sheet copper lapped about one inch and carefully soldered. The windows were covered with fine copper gauze. The door was covered with sheet copper which was carried around the edges so that in closing it made a firm wiping contact with the surrounding frame. Circuits for lighting and miscellaneous power service were led in through two specially constructed transformers fitted with grounded copper shields between the primary and secondary windings. The picture circuits leading to the radio transmitter, the microphone circuits, and the necessary studio signal and control circuits were run in lead cable and in most cases were brought into the room through suitable radio-frequency filters enclosed in metal boxes attached to the copper sheathing. In order to avoid the possibility of the heavy current leads to the arc bringing in radio-frequency energy, and to eliminate the noise and heat from the arc, provision was made for mounting the latter in its metal cabinet outside of the room. The circular opening through which the light beam was projected into the room was protected by the lamp cabinet which was also grounded to the sheathing. Satisfactory acoustic conditions within the studio were obtained by applying celotex wall board over the copper and by the use of suitable floor coverings.

Transmitting and Receiving Apparatus

For the television channel, arrangements were made to install a standard Western Electric 5-B Radio Broadcasting Transmitter and to modify it for the purpose. This transmitter is a 5-kilowatt unit (carrier output without modulation) designed for high quality telephone transmission in the 500–1500-kilocycle band. It will transmit signal components ranging from 50 to 5000 cycles without noteworthy discrimination. At 30 cycles and at 10,000 cycles there is some loss in efficiency and beyond these points the characteristic curve falls rapidly. The necessary changes, therefore, involved both the radio and audio circuits, the latter phase of the problem being perhaps the more difficult.

The schematic circuit of the modified transmitter is shown in Fig. 4. The revised radio frequency circuits were very similar to the standard arrangement, the changes mainly affecting the magnitudes of various coils and condensers. The output circuits were, of course, redesigned to meet the conditions imposed by the transmission line. The circuit was of the master oscillator—modulating amplifier—power amplifier type. The master oscillator employed a 50-watt tube operating in a

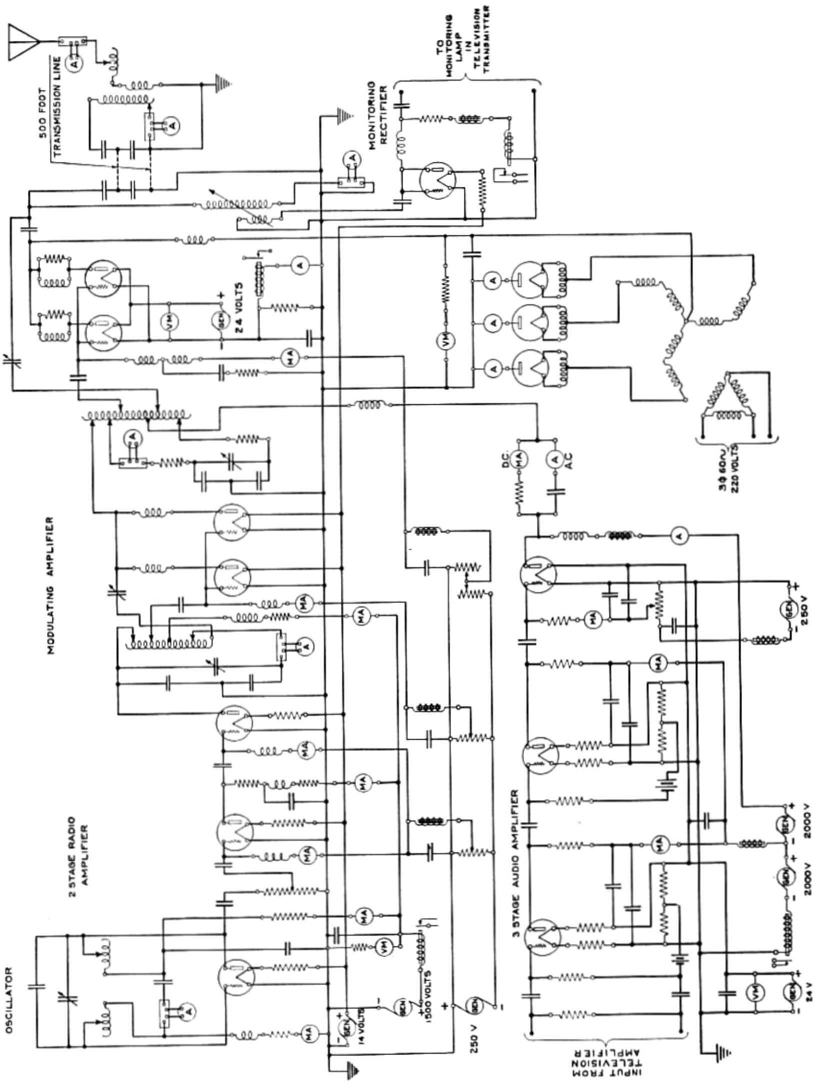

Fig. 4—Schematic of radio transmitter for television channel

circuit designed to afford a high degree of stability. This was connected to the input of the modulating amplifier through two radio-frequency stages, also employing 50-watt tubes. These two stages precluded the possibility of the oscillator frequency being appreciably altered by effects due to modulation. The modulating amplifier employed two 250-watt tubes in parallel and operated on the Heising system. In the standard equipment, the audio stages involve one 50-watt tube and two 250-watt tubes in parallel. To meet the more rigorous requirements of television with an ample factor of safety, this portion of the transmitter was removed from service and a specially constructed three-stage amplifier was substituted. As shown in the drawing, the latter consisted of two 50-watt resistance-coupled stages and a final power stage based on a 5-kilowatt water-cooled tube which raised the signal currents to a power level of approximately one half kilowatt.

In order that it might be possible to check the performance of the radio transmitter under all operating conditions, a suitable monitoring rectifier was constructed and coupled to the output circuit of the radio-frequency power amplifier. A circuit was run back to suitable switches on the television control panel so that either the output of the photo-electric cell amplifiers or the rectified output of the radio transmitter could be impressed on the pilot lamp of the television transmitter. By comparing the two images, it thus became a relatively simple matter to detect any serious maladjustment in the radio apparatus.

The problem of providing a suitable transmitter for the speech channel was rendered quite simple by the fact that at the time there was in process of development at Whippany a 50-kilowatt equipment intended for broadcasting applications. The detailed description of this transmitter is beyond the scope of the present paper. It may be said, however, that it consists of a piezo-electrically controlled master oscillator employing a 50-watt tube directly followed by a 50-watt modulating amplifier. Modulation is by the Heising system, employing one 50-watt and one 250-watt tube in the audio stages. The output of the modulating amplifier is amplified by three push-pull, neutralized, radio-frequency stages the last of which employs six water-cooled tubes at approximately 17,000 volts. This set is capable of delivering 50 kilowatts (unmodulated carrier) to the antenna and during modulation instantaneous peaks approaching 200 kilowatts are attained.

The radio receiver employed at Whippany for the reception of the synchronizing signals at 185 kilocycles presents no features of unusual interest. A double-tuned input circuit was used followed by three stages of radio-frequency amplification, a detector, and two audio stages of conventional design employing transformer coupling. No serious difficulty was encountered in obtaining ample selectivity to insure satisfactory operation in the face of the strong local signals but care was necessary in locating the receiver and in laying out the antenna in order to avoid the inductive type of interference which is almost always experienced in the immediate vicinity of a large radio station. The receiving antenna was located approximately 700 feet from the two transmitting radiating systems.

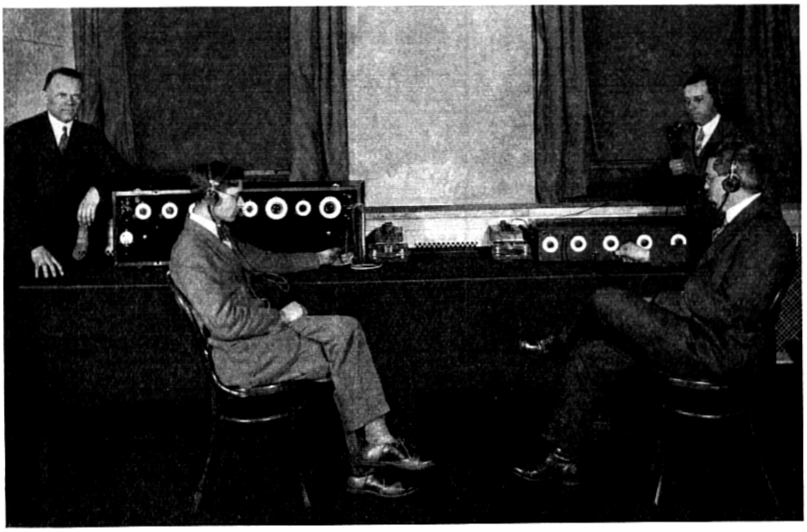

Fig. 5—Radio receiving equipment for the television and speech channels in the auditorium of Bell Telephone Laboratories, New York

The receiver employed at the New York terminus of the television channel presented a somewhat knotty problem on account of the relatively wide frequency band which it was required to pass while providing the maximum discrimination against interference. The width of the required band pointed very definitely toward the superheterodyne. This type of circuit is also very stable, permits of all the amplification that may be needed or that may be employed under ordinary noise conditions, and is very selective against interference immediately adjacent to the desired band. It is quite susceptible, however, to interference from components differing from the desired carrier frequency by an amount approximately equal to the intermediate frequency. If the interfering component lies in the neighborhood of the frequency of the oscillator, beats will be produced which may or may not pass the intermediate-frequency amplifier and the associated filters depending on their design. If the interfering component lies on the opposite side of the wanted carrier from the oscillator and differs from the former by the intermediate frequency, it will be passed by the receiver, subject only to the attenuation due to the radio-frequency circuits (the input circuits tuned to the wanted

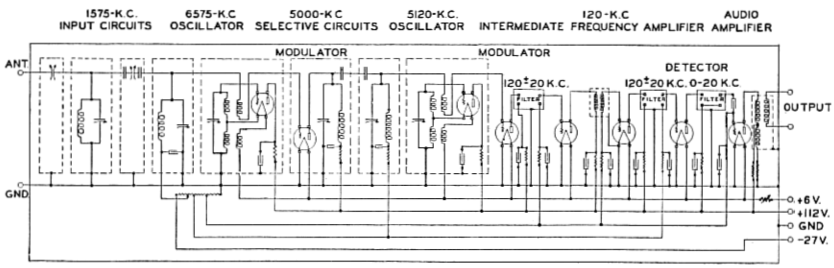

Fig. 6—Schematic of triple detection receiver for television channel

carrier). This characteristic must be given careful consideration in the design of selective receivers of the superheterodyne type and has led to the introduction of carefully designed, loosely coupled, input circuits or an initial tuned radio-frequency stage for this purpose. Neither of these expedients were possibilities in the television receiver, however, because of the extraordinary width of the required transmission band. Recourse was had, therefore, to a triple detection arrangement. Speaking somewhat in the vernacular, the desired signal was "beat up" to 5000 kilocycles where it was passed through sharply tuned coupled circuits, then "beat down" to 120 kilocycles, amplified, filtered and rectified, finally passing through a suitable low pass filter, audio amplifier and output transformer to the television reproducing apparatus.

The circuit arrangement is shown schematically in Fig. 6. Two tuned circuits with capacity coupling were connected to the input of the first detector or modulator. A relatively tight coupling was employed to produce the well-known double-peaked resonance curve capable of affording the required band width. The antenna was not tuned but was loosely coupled to the selective circuits by means of an adjustable capacity. The incoming radio signal was impressed upon the grid of the modulator tube along with a suitable voltage from an oscillator operating at 6575 kilocycles. The 5000-kilocycle components which resulted were selected by means of two carefully designed tuned circuits also capacity coupled. The purpose of this stage in the process will be evident if it is appreciated that at 1575 kilocycles, $\pm$ 20 kilocycles represents a 2.6 per cent band while at 5000 kilocycles the same side frequencies represent only a 0.8 per cent band. In the latter case, therefore, it is possible to employ materially sharper circuits without discriminating against the higher signal components. The 5000-kilocycle circuits connected to the grid of a second detector or modulator tube upon which suitable voltages from a 5120-kilocycle oscillator were impressed. The 120-kilocycle components in the output of this modulator were selected by means of a band-pass filter which worked into a two-stage intermediate-frequency amplifier. A second band-pass filter led to the third or final detector. A 20-kilocycle low-pass filter was employed in the plate circuit of the latter. This filter was designed for a low input impedance at 120 kilocycles in order to meet the necessary condition for efficient rectifier action and it also served as a coupling element for the audio stage which followed. A special output transformer with a permalloy core was provided to step down to the relatively low impedance of the line leading to the television apparatus proper.

A superheterodyne receiver of more conventional design was employed for the speech receiver. The circuit arrangement involved a double-tuned input circuit, one tuned radio-frequency stage, oscillator and modulator, two intermediate-frequency stages, detector and one audio stage. It was highly selective and afforded substantially distortionless transmission for signal frequencies ranging from 50 to 5500 cycles.

The transmitting equipment for the synchronizing channel consisted of a Western Electric 6-A Radio Broadcasting Transmitter modified to operate at 185 kilocycles. In order to avoid the necessity of transmitting directly the 17.7-cycle component required for synchronizing purposes, a 760-cycle carrier was modulated at 17.7 cycles by means of a relay and impressed upon the input of the radio transmitter together with the steady 2125-cycle component. At the receiving end, the 2125- and modulated 760-cycle components were separated by means of suitable filters, and the latter rectified to produce the desired 17.7-cycle current.

Tests of the System

As soon as the various apparatus units could be made ready for service, a comprehensive series of transmission tests was undertaken. In order to determine the relative suitability of the 1575- and 1750-kilocycle bands disclosed by the preliminary survey, transmissions from Whippany at intervals throughout the day were arranged. Field strength measurements were taken at the receiving point employing apparatus of the type described by Englund and Friis[3] and observations on the relative strength of the received signals were made by inserting a sensitive microammeter in the plate circuit of the third detector of the television receiver. These data indicated that the lower frequency band suffered considerably less attenuation and also afforded much more stable transmission. In spite of the comparatively short distance (approximately 22 miles), marked fading was experienced beginning with the sunset period and increasing in amplitude as the night advanced. The high frequency band proved to be particularly disadvantageous in this respect. It was decided, therefore, to fix upon the lower frequency band and to confine the demonstration to the afternoon when reasonably stable transmission conditions prevailed.

Following the choice of a definite operating frequency, a number of modifications were made in the transmitting antenna to improve its efficiency and increase the field strength at the receiver. This work finally resulted in a measured field strength of approximately 2500 microvolts per meter for an antenna input of 5 kilowatts.

Further consideration of the available data on transmission and traffic conditions and the performance characteristics of the apparatus units involved lead to a choice of 1450 kilocycles for the speech channel. In spite of an antenna input of approximately 30 kilowatts, the initial tests at this frequency were very unsatisfactory due to inadequate field strength at the receiver which necessarily resulted in an abnormally high noise level. The height of the antenna was, therefore, increased from 60 to 100 feet by installing iron pipe topmasts. This change brought the field strength at the receiver to approximately the same value as that obtained for the television channel (2500 microvolts per meter) which was considered to be satisfactory for the purpose.

In order to insure that the reproduction of the picture might not suffer from serious discrimination against essential frequencies at some point in the radio system, very careful tests were made on the individual units and on the system as a whole.

The frequency characteristic of the transmitter was determined by connecting a vacuum tube oscillator producing a relatively pure wave to its input terminals through a suitable network involving a thermal milliammeter and an adjustable artificial line. A rectifier of known characteristics and a second thermal meter protected against radio-frequency currents by means of a low-pass filter were coupled to the

[3] "Methods for Measurements of Radio Field Strengths," C. R. Englund and H. T. Friis. Presented to the Spring Convention A. I. E. E. at Pittsfield, Mass., May 25, 1927.

output circuit of the water-cooled tubes. Employing a frequency of 1000 cycles, the input was adjusted to produce normal modulation and the readings of the input and output meters noted. The oscillator frequency was then changed by a convenient amount while holding the input reading constant and the artificial line readjusted, if necessary, to produce constant output current. Under these conditions, any change in the setting of the artificial line indicates an equal variation in the transmission efficiency of the transmitter which is evaluated by this method directly in TU.

The characteristic of the receiver was determined in a similar manner. A low power transmitter of known characteristics was connected to it through a suitable attenuating network which, in so far as the receiver was concerned, simulated the receiving antenna. The radio-frequency input to the receiver was adjusted to approximately the normal value and a series of measurements taken with variable audio-frequency inputs as indicated above.

The overall measurements were also based on a similar procedure impressing a constant input on the 600-ohm input terminals of the transmitter through a suitable artificial line and adjusting the latter to give a constant current into a 600-ohm load at the output of the receiver, taking necessary precautions, of course, to preclude overloading at any point in the system.

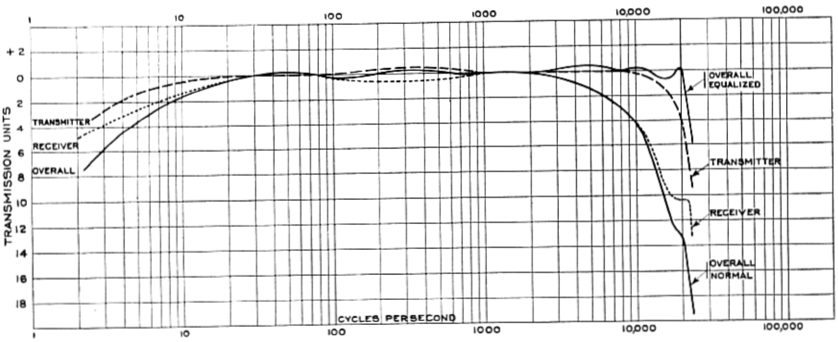

Fig. 7—Measured characteristics of television channel

The experimental characteristic curves thus obtained are shown in Fig. 7, where the abscissæ represent cycles per second and the ordinates departure from the 1000-cycle value in TU. As will be noted, at the lower frequencies exceptionally good performance was obtained, the overall characteristic being only 2 TU down (or deficient) at 10 cycles and only 6 TU down at 3 cycles. The results for the higher frequencies, however, were not so satisfactory, a loss of approximately

13 TU being observed at 20,000 cycles, probably due to the tuned circuits in the receiver. Since modification of these circuits to obtain a flatter characteristic would have been difficult and would have occasioned a noteworthy sacrifice in selectivity, a compensation network was designed for use in the 600-ohm output circuit of the receiver which introduced a negligible loss at 20,000 cycles, a substantially constant loss of 13 TU at frequencies below 2000 cycles, and for intermediate frequencies losses represented by the height of the "normal overall" curve above the horizontal line representing − 13 TU. With this network connected between the receiver and the television equipment, the average level throughout the band was, therefore, reduced some 13 TU but the resulting characteristic as measured beyond the network was that which has been designated "overall equalized." Above 20,000 cycles the characteristics all fell very rapidly which is an indication of the degree of selectivity attained. This was contributed to by the radio-frequency tuned circuits, the band-pass filters in the intermediate-frequency amplifier and the 20,000-cycle low-pass filter between the final detector and audio amplifier. The individual characteristics of the various filters were designed to be 60 TU down 20 kilocycles from the specified cut-off frequency.

Similar measurements were made upon the speech channel but a less thorough study was deemed sufficient in that case due to the existing background of experience.

Effects of Fading

With the system as outlined above, very satisfactory performance was obtained during the afternoon and early evening hours when reasonably stable transmission conditions were prevalent. Later at night, however, when marked fading became evident, some rather unexpected but easily explainable phenomena were observed which may be of sufficient interest to warrant brief mention.

When marked fading occurred, the normally clear reproduction was accompanied by "ghosts" or additional images which faded in and out in an erratic manner, sometimes appearing as positives and sometimes as negatives. The effect was most clearly observed when using one of the various types of test screens employed, a white card bearing a black diamond-shaped outline, approximately a square with its diagonals vertical and horizontal. With this simple type of pattern, it became evident that the secondary images were additional reproductions which were "out of frame" by a greater or less amount. In other words, each of these additional images consisted of a portion of two diamonds placed side by side with the corners just touching. Images "out of frame" along the vertical axis are frequently seen on the motion picture screen.

The explanation is fairly obvious. The present more or less generally accepted view of fading is that it is a manifestation of transmission along two or more paths, at least one of which is variable, producing a continually changing phase relationship between the components and a corresponding waxing and waning of the resultant signal. In the present case, the major image was probably produced by the so-called "ground wave." The secondary images probably resulted from components which were transmitted upward at a relatively sharp angle and turned back to the receiving station from the Heaviside layer, the difference in framing being due to the longer time of transmission.

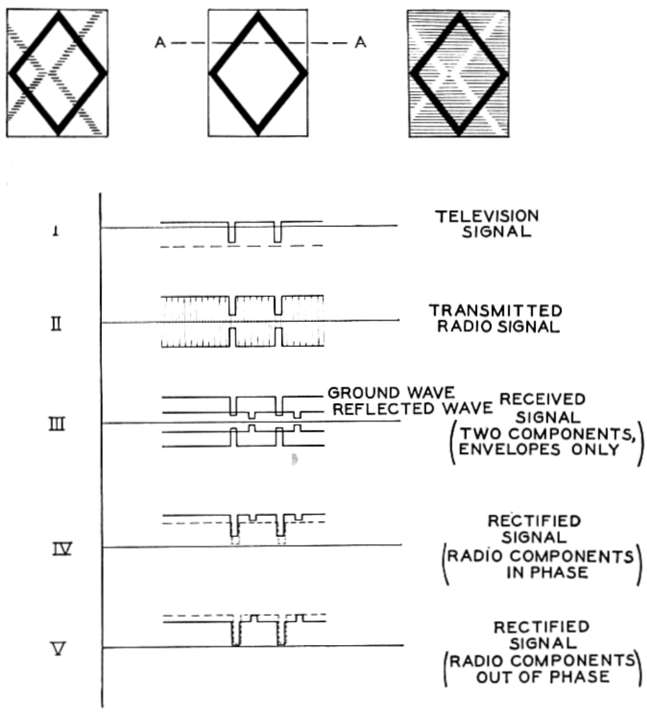

Fig. 8—Production of positive and negative secondary images due to multi-path transmission

The production of negative secondary images is a most interesting phase of the phenomena. This effect may be explained quite easily by means of a series of signal diagrams such as is shown in Fig. 8.

If attention is confined to the interval during which scanning takes place along the line *AA*, it is evident that the television signal will have the form shown. Amplitudes above the dotted line indicate the current through the photoelectric cell. Since transformer-coupled amplifiers are employed in the television apparatus, however, the direct component is eliminated and the zero axis for the input to the radio transmitter is the solid line. Sketch II shows the modulated output of the radio transmitter. The received signal, shown in III, is assumed to consist of two components, the larger due to the "ground wave," and the smaller due to reflected energy from the Heaviside layer. The latter lags somewhat because of the greater length of the transmission path. The resultant of these two components will necessarily depend on the relative phase of the two carriers at the receiving point. Two cases are considered: when the components are exactly in phase, and when they are exactly out of phase. The effect at intermediate positions may be readily evaluated from these examples. With the components in phase, the detector output is proportional to their sum which is shown in IV. It is evident that this will result in a major image and a secondary positive image. If the components are out of phase, the rectified signal shown in V results. It is simply a matter of subtracting amplitudes. This resultant consists of the desired signal with the amplitude somewhat reduced which will produce a gray background. The secondary image will be formed by the two small peaks shown and will be lighter than the background, in other words a negative.

A pattern frequently observed was the diamond with a cross through its center due to a secondary image. This represents a change in framing of approximately one half line. With 17.7 pictures per second and 50 lines per picture, this corresponds to a difference in transmission time of $1/17.7 \times 1/50 \times 1/2$ or 5.65×10^{-4} seconds. A rough computation of the height of the reflecting layer based on this figure and a distance of 22 miles between transmitting and receiving stations gives 100 kilometers, which is substantially in agreement with determinations made by other methods.

Transmission of Voice and Image with a Common Carrier Frequency

Following the demonstration, a brief series of supplementary tests was arranged to obtain some appreciation on experimental grounds of the problems involved in transmitting both voice and image with a single radio transmitter. The system employed may be considered as the extension of carrier current technique to radio, but has been described in various other terms: "multiplex radio," "double modulation," "the Hammond system," etc. The output of a 30,000-cycle oscillator was modulated with the speech signal. The resulting carrier and sidebands were selected by means of a suitable filter passing frequency components ranging between 25,000 and 35,000 cycles and impressed on the input terminals of the radio transmitter along with the 10 to 20,000-cycle signal from the television apparatus. A suitable low-pass filter was employed in the line to the latter in order to preclude "crosstalk" due to 25,000–35,000-cycle energy working back into the final amplifier stages. The input to the radio transmitter thus consisted of a band extending from 10 to 20,000 cycles together with a 25,000 to 35,000 band, with a particularly strong component at 30,000 cycles representing the low-frequency carrier.

In order that it might be capable of handling this wider band without discrimination, further modifications in the radio transmitter were required. In the case of some of the radio-frequency circuits, which were required to pass a 70,000-cycle band, it was found to be necessary to insert resistance to reduce the sharpness of resonance. On account of lack of time, it was not possible to obtain a complete series of characteristic curves for the transmitter under these conditions. Isolated measurements with a single-frequency input of 35,000 cycles indicated, however, that components of this order could be transmitted without serious loss and the subsequent performance of the system as a whole confirmed this conclusion.

It is well known that if a sinusoidal alternating current $i = I_0 \sin \omega t$ is modulated with a signal of frequency $f = \Phi/2\pi$, the resulting modulated current may be represented by the expression:

$$i = I_0 \sin \omega t + \frac{kI_0}{2} \sin (\omega + \Phi)t + \frac{kI_0}{2} \sin (\omega - \Phi)t,$$

where k is a fraction indicative of the degree of modulation. In other words, a modulated current, or wave, may be resolved into three components: (1) a steady component, known as the "carrier," which has the amplitude and frequency of the original unmodulated current, (2) an "upper sideband" which is equivalent to the signal spectrum with each individual frequency increased by an amount equal to the carrier frequency, and (3) a "lower sideband" which is an inverted reproduction of the signal spectrum, that is, each individual signal component is laid off in the downward direction from the carrier frequency, or subtracted from it. Hence, assuming a carrier frequency of 1575 kilocycles and a signal input to the radio transmitter of the type described above, the antenna current, or the transmitted wave, may be represented diagrammatically as shown in Fig. 9.

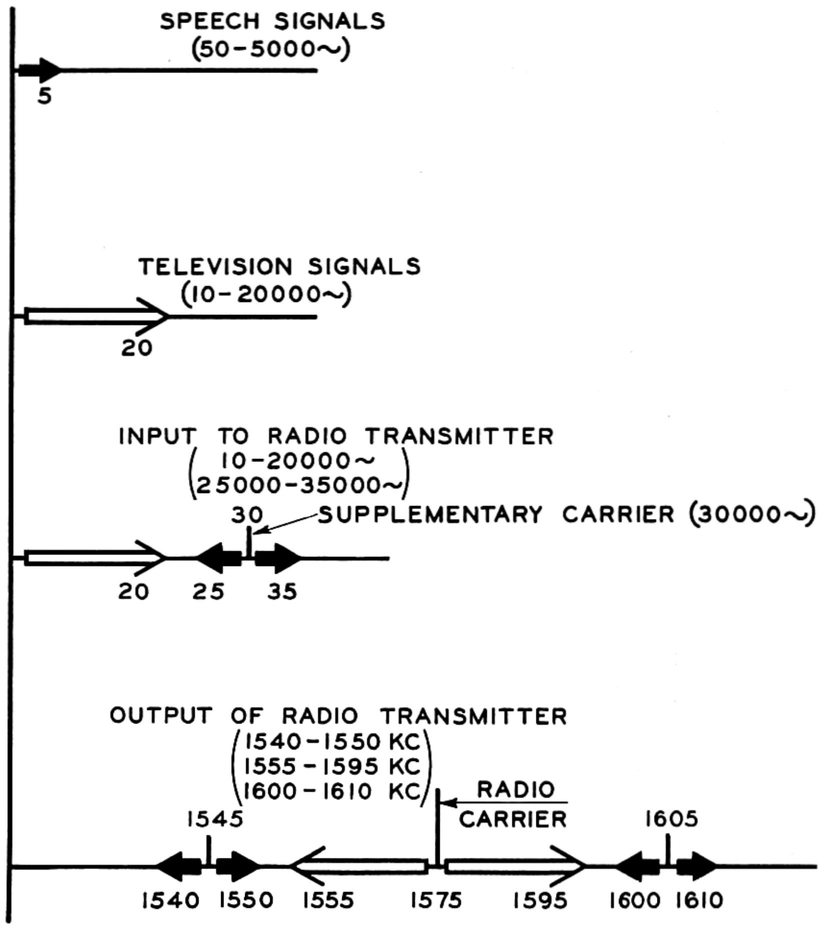

Fig. 9—Diagrammatical representation of frequency conversions in multiplex radio system

It is evident that this type of radio signal can be received by employing an arrangement which will accept the entire band and subject it to rectification in the usual manner. If this is done, the television signal and the 30,000-cycle supplementary carrier modulated with speech will appear at the output of the detector. Branch circuits with suitable filters will enable these two components to be separated and the television signal passed on to the reproducing apparatus. The other component must be rectified to derive the original speech signal, which may then be impressed on the loud speaker amplifiers.

The reception scheme actually employed during the experiments was somewhat different. The television signal was received separately by means of the triple detection set employed for the demonstration. The speech signal was received in a similar manner employing the set utilized for the speech channel during the demonstration. This latter receiver was tuned to 1545 kilocycles. That reception in this manner is feasible, is evident from the diagram. The 1540–1550-kilocycle zone contains two speech sidebands and a carrier of 1575 − 30 or 1545 kilocycles. It is quite possible, therefore, to demodulate in one step, instead of "beating" the various components against the main carrier (1575 kilocycles) to produce a 30-kilocycle supplementary carrier which must be rectified a second time to derive the speech signal. The 1600–1610-kilocycle band was ignored. The receivers were sufficiently selective that, with the 5-kilocycle interval which existed between the two bands, no noteworthy crosstalk was experienced.

The results obtained in this manner were not as satisfactory as those to be had with the other system described. This can be attributed to two factors, both concerned with the transmitting apparatus: (1) In order to transmit both signals with the same transmitter, that is, the same vacuum tubes, the individual current amplitudes had to be reduced to at least one half, resulting in too weak a radio signal to clear the prevailing noise levels in New York, (2) In spite of the reduced amplitudes, a certain amount of inter-modulation was experienced in the transmitter which resulted in "crosstalk" between the channels. Notwithstanding these deficiencies, however, it was possible to recognize the speaker and to understand his remarks; but a short time ago, the performance would have been considered a very noteworthy achievement.

Experiments of this nature, although not new, are of particular interest where television is concerned, since, as Dr. Ives has indicated, the logical trend of development is toward a finer picture structure involving the transmission of much wider frequency bands, or what is more likely, the use of parallel scanning schemes and multi-channel transmission. The work, while necessarily somewhat cursory, may, therefore, be of value in affording an indication of the significance of multi-channel radio transmission in this connection. From a popular standpoint, these tests have been described as the transmission of both voice and image "on a single wave-length." To what extent this statement falls short of actually representing the facts in the case is obvious from Fig. 9. It will be seen that a wider frequency band is actually employed with this system than was required for two separate channels. Furthermore, this wider band is much less effectively utilized. Two bands are required for the voice channel in place of one. At the receiver, one of these bands was disregarded. To have received both would have required apparatus accepting twice the band width and the gain in signal would have been offset by the corresponding increase in noise level. For all useful purposes, therefore, the energy radiated in the form of the second band is wasted.

To proceed further with a discussion of multi-channel radio transmission is beyond the scope of the present paper. Whatever the system employed, however, one conclusion illustrated by these experiments may be pointed to with confidence: television by radio requires a discrete and fairly wide frequency band. Hence the frequently predicted introduction of television as an adjunct to radio broadcasting without extensive changes in existing channel arrangements is extremely unlikely.