# TELEVISION COAXIAL CABLE


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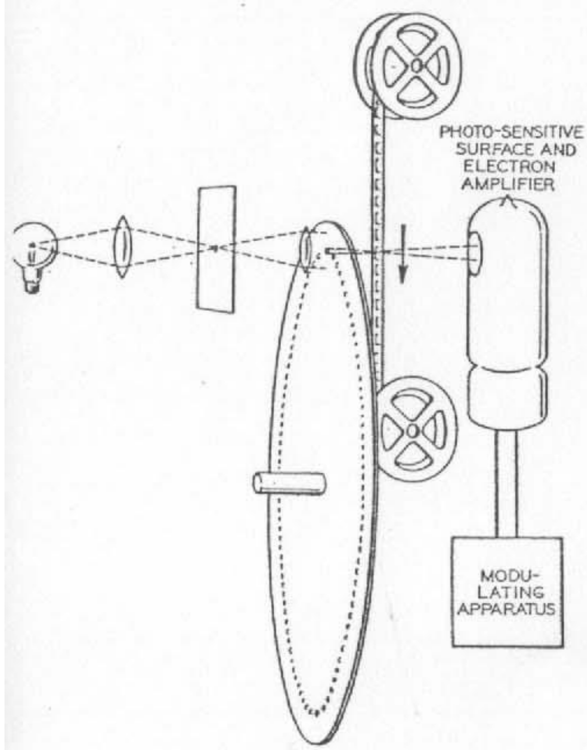


FIG. 1

Schematic representation of the scanning arrangement at the sending end of the television system.

SATISFACTORY television transmission requires a very wide band of frequencies. According to present indications a width of several million cycles will be employed for ordinary commercial broadcasts and such a great spread of radio frequencies—wider than the total band now set aside for broadcasting sound programs—can be made available only in the ultra-high frequency part of the radio spectrum. The area of satisfactory reception from an ultra-high frequency broadcast transmitter is comparatively small. In order to reach a large audience simultaneously the same program therefore would have to be broadcast from a number of stations all connected together. A similar scheme is employed in the broadcasting of sound programs at the present time, but with television a greater number of stations than is now used in the sound programs would probably be involved.

the broad-band systems for wire-line communication service, the Laboratories have accordingly been studying the problem of transmitting television signals. Such transmission over wire lines was first demonstrated in 1927* but the frequency employed at that time was only a little over 20 kc wide, which was narrow enough to permit the use of existing types of circuits and methods. With bands several thousands of kilocycles wide as now proposed for commercial television a radically different system is required.

## NEED OF SHIELDED CIRCUIT

Because of the necessity of reducing outside disturbances to a minimum, a shielded circuit seemed desirable, such as the coaxial conductor now installed† between New York and Philadelphia. The original equipment of this cable provided for the transmission of a band about a million cycles wide, and although this was somewhat narrower than the band that would be required to transmit the type of television images now proposed, it seemed desirable to provide the necessary terminal apparatus and circuits for television transmission over this line as a first step in an orderly process of development aimed at higher quality lines for commercial television networks.

Although television implies the transmission of an actual scene, it is much more satisfactory for engineering studies to transmit a motion picture, since exactly the same picture can then be transmitted over and over again as the circuit elements are changed or adjusted. Moreover, it was decided to use mechanical scanning to obtain the most nearly perfect signal possible, and with this form of scanning a film rather than an actual scene gives much better results. Because of these various factors a motion picture film was employed as the material for the recent experiments.

## HOW SCANNING IS DONE

The film is "scanned" by passing a beam of light across it in successive rows one below the other. The smaller this pencil of light and thus the greater the number of lines required to cover the picture, the finer will be the detail that can be transmitted and the higher will be the upper frequency required. Besides this very

* Bell Laboratories Record, May, 1927, p. 297.

high frequency, determined by the finest detail to be transmitted, other components over the whole frequency range down to zero will be required to reproduce the larger areas of light and shade in the picture. The direct-current, or zero-frequency, component controls the general level of brightness of the picture, and where this changes slowly, it results in a component of very low frequency. The scanning arrangement used for the recent demonstration provided for a picture of 240 lines, which for the shape of picture used, a square scanning beam, and twenty-four frames per second results in an upper frequency of 806 kc, and other components over the entire frequency band from 0 to 806 kc.

For scanning the picture a six-foot disk was employed with a circle of 240 holes near its outer edge. The arrangement is indicated schematically in Fig. 1, and a photograph of the scanning apparatus is shown in Fig. 2. Each hole has a lens mounted in it, and light from a powerful incandescent lamp behind the disk, passing through one hole at a time, is focussed by the lens to form on the film a small dot of light about three thousandths of an inch square.

## SPACING OF LENSES

The lenses in the disk are spaced by a distance equal to the width of the picture, or a little less than an inch, and as the disk rotates, each spot is moved rapidly across the picture. The film is carried at a uniform rate downward behind the disk at such a speed that the successive holes throw their light in succession one below another. A photosensitive surface mounted behind the film picks up the light transmitted through it, and produces a complex electric current corresponding to the variations of light which appear in the picture.

No small factor in the success of the recent demonstration was the cathode-ray tube, designed by C. J. Davisson and used at the receiving end to display the transmitted picture. Some of the features of this tube are indicated schematically in Fig. 4, and the tube itself is shown in Fig. 3. A stream of electrons from the cathode of this tube passes through a series of electron lenses which focus a narrow beam on a square aperture. Between the lenses and the aperture, however, are two modulating plates connected to the incoming circuit in such a way that there appear on these plates potentials proportional to the voltage of the incoming signals. The effect of potentials on these plates is to deflect the electron beam, and the conditions are such that at maximum strength of signal practically the entire stream of electrons passes through the hole and forms a brilliant spot of light on the front of the tube. As the signal decreases in strength, the electron stream is more and more deflected; so that fewer electrons pass through the aperture, and the illumination on the sensitized end of the tube decreases.

## CONTROLLED POTENTIAL

In addition to these modulating plates, and placed between the aperture and the front of

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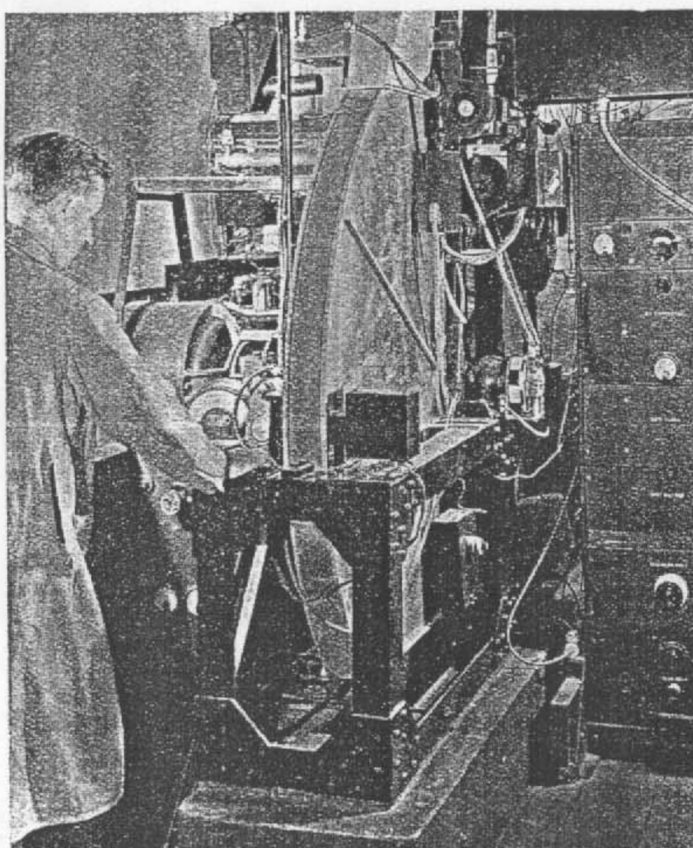

FIG. 2
The scanning apparatus used for the recent television demonstration was developed under the direction of H. E. Ives

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tube, are two other pairs of plates mounted lanes at right angles to each other. The poial on one of these sets of plates, conled by a frequency of 5760 cycles, which is frequency at which successive lines are nned, varies in such a way that the beam electrons passing through the aperture is pt across the front of the tube from left right, exactly in synchronism with the scang beam at the sending end. After the beam ches the farther side of the picture, the ential on the plates is suddenly changed, l the beam is rapidly moved back to begin next line.

Due to a black mask down the far side of film being scanned, there is no signal during very short period while the voltage on the tes is changed, and thus the electron beam deflected from the aperture and is not visible the front of the tube during its return.

The potential on the other pair of plates is ntrolled at a frequency of twenty-four cycles second, which is the rate of scanning sucsive frames. The effect of the potential on se plates is to deflect the electron beam wnward in synchronism with the motion of the n at the sending end. This results in the ssage of the electron beam across the front the tube in successive rows, one below other.

## VOLTAGE CHANGED

After the last row has been scanned, the volte on the plates is changed and returns to the lue that causes the beam to appear at the top e of the tube. A properly synchronized nking out pulse is introduced between sucssive frames of the film, so that no signal is ceived during this interval, and thus the passge of the electron beam from the bottom to e top of the frame is not visible.

The sharpness of the image over the entire ld and the wide range of brightness secured due to the superior design of this cathode-ray be. The chief factors are the sharp focusing the electron lenses, the linear deflection of e beam at the aperture, and the great length the tube, which makes it necessary to deflect e electron beam over only a narrow angle cover the seven by eight inch field. Since is trial was a test to determine the capabilities the coaxial system, such matters as size and st, which would be important with commercial ceivers, were not controlling.

The coaxial cable system used could not transit the frequency band from 0 to 806 kc, beuse repeaters were not designed to pass frerencies below about 60 kc. This limitation was corporated in the original design because the ble offers insufficient shielding to various disrbances at low frequencies. It was necessary, erefore, to raise the television band to a higher equency position for transmission over the ne. A number of considerations led to the ecision to raise the upper frequency to 950 c for transmission over the coaxial cable, hich required raising the entire frequency band by an amount less than the width of the band itself, a single modulation is not generally satisfactory. The products of modulation include the original frequency band as well as the upper and lower sidebands, so that there will always be a confusing jumble of frequencies in the modulator output unless the modulating carrier is greater than the highest frequency of the band. For this reason a system of double modulation was used for the recent experiments.

FIG. 3.
The cathode-ray receiving tube used for the recent television demonstration held by C. F. Calbick who took an active part in its design.

## THE TWO MODULATING STEPS

The modulating scheme employed can be followed with the help of Fig. 5, which shows the two modulating steps at the sending end and the two demodulating steps at the receiving end in four lines beginning at the top. A ... of 2376 kc is used for the first modula-

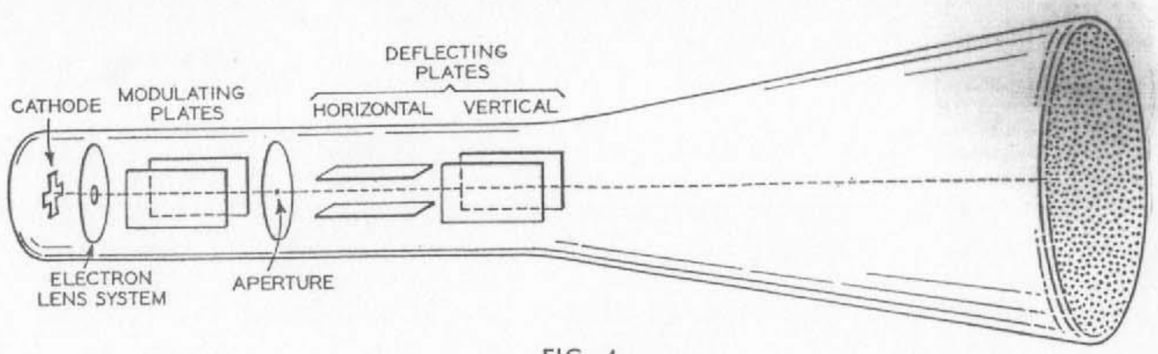


FIG. 4
Schematic representation of the cathode-ray equipment at the receiving end.

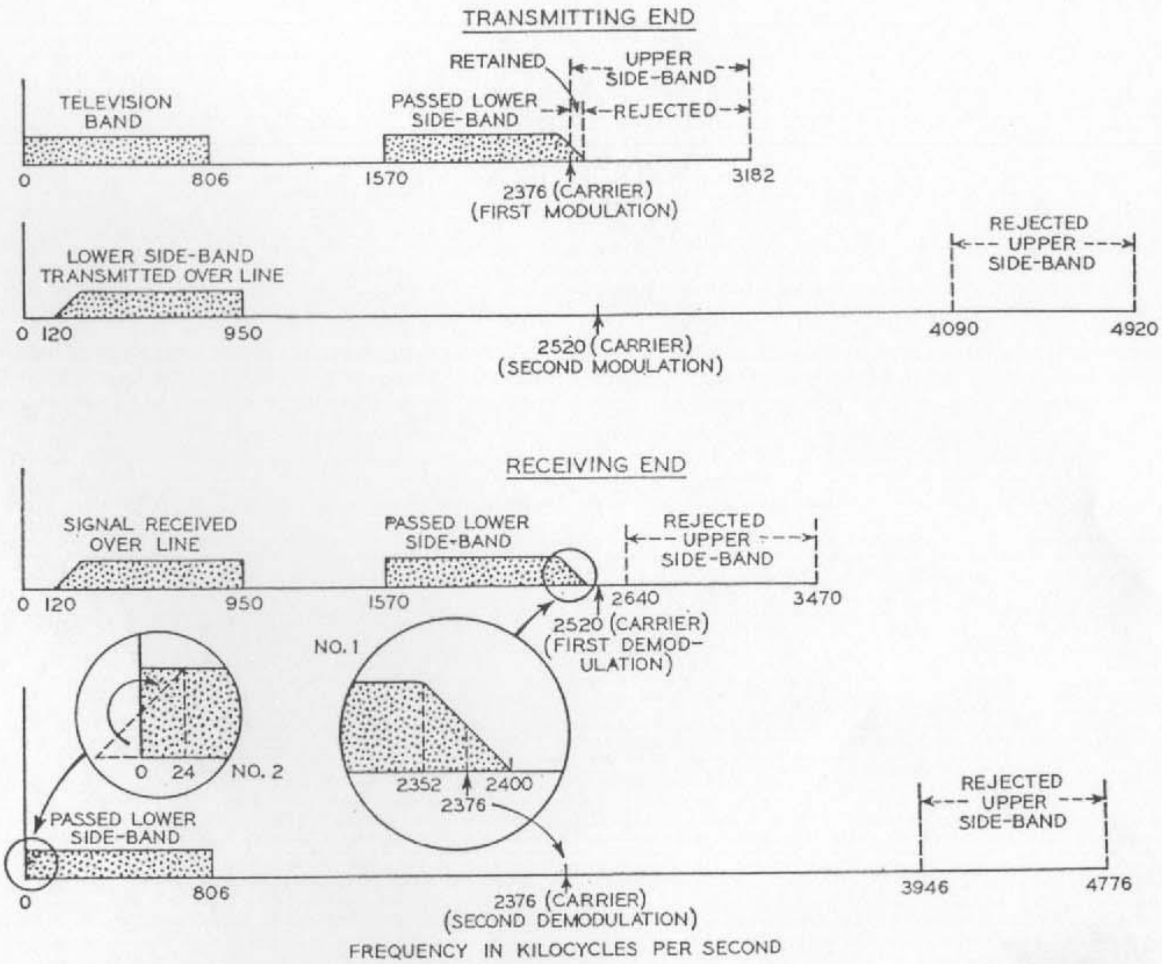


FIG. 5
Modulating and demodulating scheme for the recent television transmission, beginning with the first modulation at New York, above, and ending with the second demodulation at Philadelphia, below.

1570 to 2376 kc and an upper sideband from 2376 to 3182.

The carrier itself is eliminated in the balanced modulator. The output of this modulation is passed through a filter, but because the two sidebands touch each other at 2376 kc, the filter cannot cut off all the upper sideband. At the output of the filter there is thus the lower sideband plus a small amount of the lower part of the upper sideband. The upper readily eliminated by the following filters because of the wide separation.

The carrier for the second modulation is 2520 kc, and the lower sideband extends from 950 down to 144 kc plus the vestigial upper sideband remaining from the first modulation which extends below 144 kc.

The lower edge of the filter following this modulation is accurately designed to attenuate slightly a group of frequencies just above 144

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and to pass with controlled attenuation the stigial upper sideband, which then extends om 144 to about 120 kc. The resulting single leband, extending from 120 to 950 kc, is then ssed over the coaxial cable to Philadelphia.

## EQUALIZERS INTRODUCED

Here the transmitted band, together with a rrier of 2520 kc, is applied to the first demodu- ;or, and the lower sideband, from 2400 down 1570, is passed to the second demodulator iere a carrier of 2376 kc is applied. The west frequency of the lower sideband, 1570

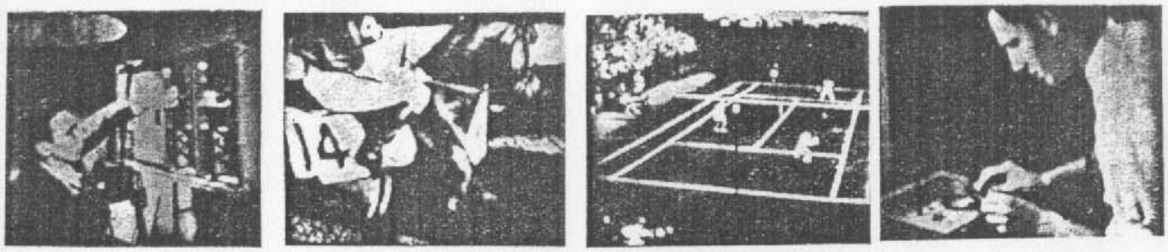

FIG. 6

**Photographs of the receiving tube during transmission. In the tennis match the ball itself shows and its movement could be followed. The race horse is interesting because of the way the half-tones were reproduced.**

:, is converted to 806 kc, becoming the highest equency of the final demodulated band. The equencies from 2352 to 2400 kc of the side- ind before the second demodulation are some- hat attenuated as a result of the filter follow- ig the second demodulator, and the second emodulating carrier, 2376 kc, falls in the mid- e of this attenuated band as shown in inset o. 1. Frequencies extending about 24 kc above ie carrier are inverted by the demodulation, id superimposed upon the corresponding fre- uencies just below the carrier. The magnitude id phase of these components are proportioned y the filter and equalized so that the overall re- ilt, when they are superimposed, is an essen- ally flat transmission band from 0 to 806 kc.

Besides this carefully planned modulating and emodulating arrangement at the terminals, it as necessary also to provide networks and jualizers to insure that the coaxial line did ot distort the ultimate image due to unequal at- nuation, resulting in amplitude distortion, or unequal time of transmission, causing phase istortion. The actual attenuation character- tics of the line, the line plus repeaters, and the verall result are shown in Fig. 7.

## REGISTERING THE DETAILS

The attenuation requirements are not particu- ırly severe, but those for phase distortion are ifficult to meet. The details in the scanned icture result in the various frequencies of the lectrical signal, and if these details are to ap- ear in the reproduced picture in the same rela- ve position as in the scanned picture, it is ssential that all frequencies be received in ...lative time relationship

but consideration of certain factors led to the decision to hold frequencies between 806,000 and 5760 cycles to a delay of about 0.3 micro-second, and frequencies below 5700 cycles to a delay of about forty micro-seconds. The actual circuit roughly met these requirements as indicated by Fig. 8, which shows the phase delay characteristics of the line, repeaters and equalizers, and of the overall circuit including the phase equalizers.

Noise or interference is very annoying in television transmission; and pattern, or single-frequency interference, is particularly objectionable. The permissible noise or interference depends does not lead to any well defined requirements, on the amplitude range of the reproduced picture. During these experiments, it was found that a substantially linear response could be obtained over a current range of 30 db—corresponding to a brightness range of 15 db. The actual

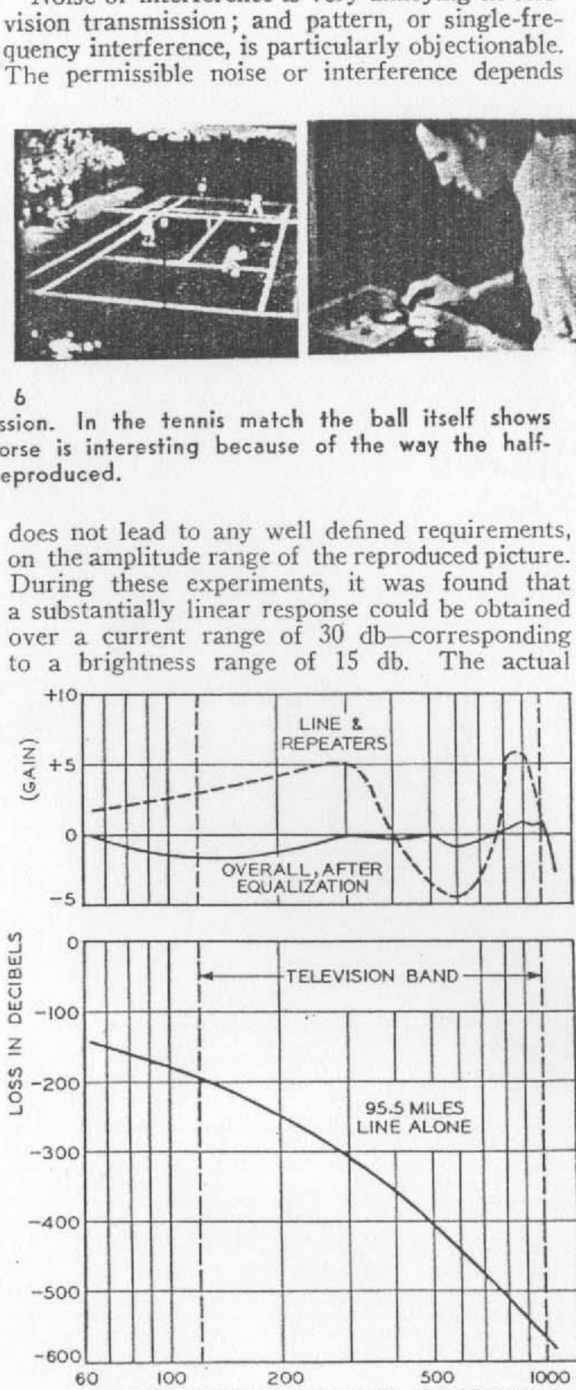


FIG. 7

Attenuation of the coaxial circuit between New York and Philadelphia as arranged for the telerange of the reproduced pictures extended somewhat beyond the range of linear response. It

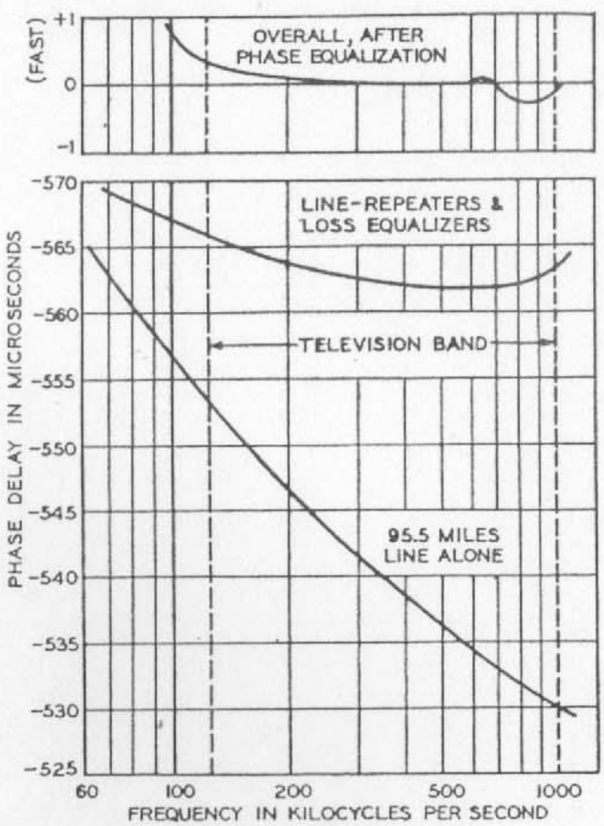


FIG. 8
Phase delay of the coaxial circuit during the recent experiments.

was found desirable to hold random interference down about 40 db below the maximum signal, and pattern interference down at least 15 db more.

The terminal equipment besides providing modulators, amplifiers, filters, and equalizers, New York, thus showing that the cable system itself introduced no appreciable distortion. must also provide for the generation of the two modulating carriers accurately spaced. This is accomplished by deriving all carriers from a 4000-cycle reference frequency at the transmitting end. From this source a 72 kc frequency is first obtained, and is then used for deriving the modulating carriers of 2376 and 2520 kc through harmonic generators. The same 72-kc frequency is also transmitted over the coaxial line to Philadelphia, where exactly synchronous carriers are derived from it for demodulating. These are adjusted for phase manually by observing the picture. To synchronize the scanning arrangements at the sending and receiving terminals, a frequency corresponding to the speed of the scanning disk is also transmitted. The appearance and arrangement of the terminal apparatus are shown in Fig. 9.

Many of the engineers who worked on the system, and outside experts who observed it, expressed the opinion that the reproduced pictures in Philadelphia were substantially the same as those seen on a similar receiving device in

## CAN MEET REQUIREMENTS

The opinion was also expressed that in spite of the use of only 240 lines, the pictures were remarkably clear and distinct. The photograph at the head of this article shows the end of the reproducing cathode-ray tube at Philadelphia, with C. L. Weis monitoring. The actual illumination on the tube was of such low intensity that it was difficult to secure photographs in the time interval of one frame. The tennis match scene shown here, however, is an actual

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FIG. 9
Modulating terminal equipment at the New York end of the coaxial circuit.