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Television Over the Coaxial Cable

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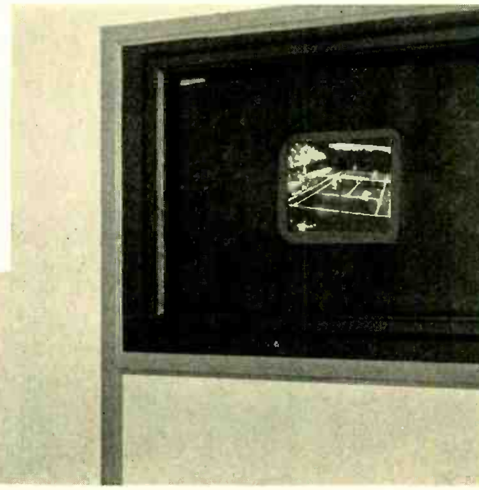


SATISFACTORY television transmission requires a very wide band of frequencies. According to present indications a width of several million cycles will be employed for ordinary commercial broadcasts and such a great spread of radio frequencies—wider than the total band now set aside for broadcasting sound 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.

As part of the general program of developing 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 band 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.

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

*RECORD, *May*, 1927, *p.* 297.
†RECORD, *May*, 1937, *p.* 274.

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.

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 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 Figure 1, and a photograph of the scanning apparatus is shown in Figure 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

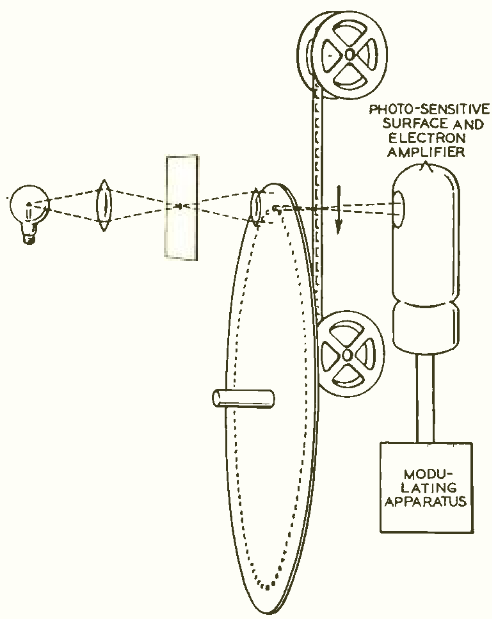


Fig. 1—Schematic representation of the scanning arrangement at the sending end of the television system

dot of light about three thousandths of an inch square. 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

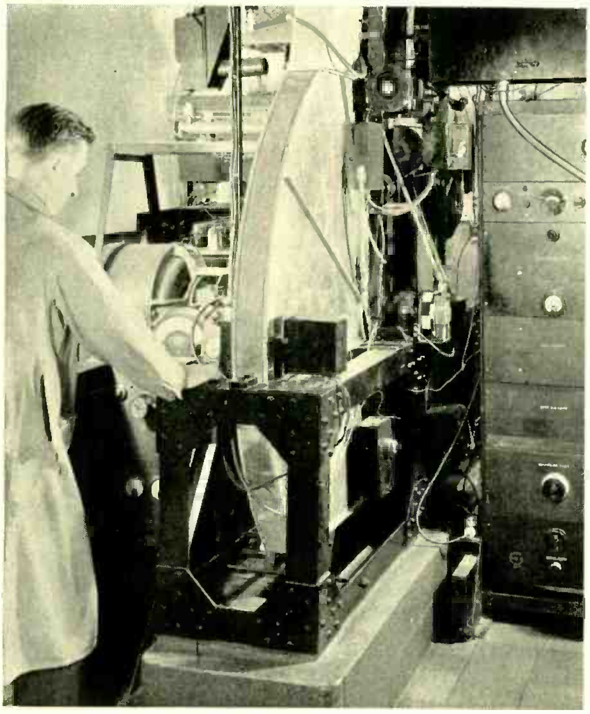


Fig. 2—The scanning apparatus used for the recent television demonstration was developed under the direction of H. E. Ives

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 Figure 3, and the tube itself is shown in Figure 4. 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.

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 successive rows across the picture 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

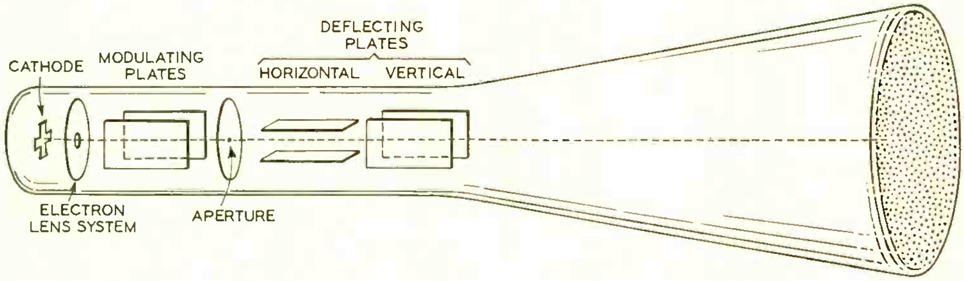


Fig. 3—Schematic representation of the cathode-ray equipment at the receiving end

In addition to these modulating plates, and placed between the aperture and the front of the tube, are two other pairs of plates mounted in planes at right angles to each other. The potential on one of these sets of plates, controlled by a frequency of 5760 cycles, which is the frequency at which successive lines are scanned, varies in such a way that the beam of electrons passing through the aperture is swept across the front of the tube from left to right, exactly in synchronism with the scanning beam at the sending end. After the beam reaches the farther side of the picture, the potential on the plates is suddenly changed, and the beam is rapidly moved back to begin the next line. Due to a black mask down the far side of the film being scanned, there is no signal during this very short period while the voltage on the plates is changed, and thus the electron beam is deflected from the aperture and is not visible on the front of the tube during its return.

The potential on the other pair of plates is controlled at a frequency of twenty-four cycles per second, which is the rate of scanning successive frames. The effect of the potential on these plates is to deflect the electron beam downward in synchronism with the motion of the film at the sending end. This results in the passage of the electron beam across the front of the tube in successive rows, one below another. After the last row has been scanned, the voltage on the plates is changed and returns to the value that causes the beam to appear at the top line of the tube. A properly synchronized blanking-out pulse is introduced between successive frames of the film, so that no signal is received during this interval, and thus the passage of the electron beam from the bottom to the top of the frame is not visible.

The sharpness of the image over the entire field and the wide range of brightness secured is due to the superior design of this cathode-ray tube.

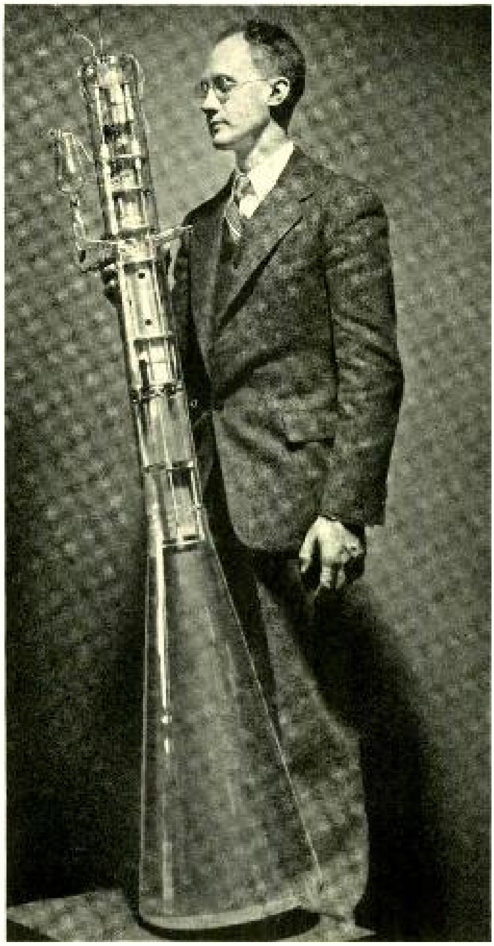


Fig. 4—The cathode-ray receiving tube used for the recent television demonstration held by C. J. Calbick who took an active part in its design

The chief factors are the sharp focussing by the electron lenses, the linear deflection of the beam at the aperture, and the great length of the tube, which makes it necessary to deflect the electron beam over only a narrow angle to cover the seven by eight inch field. Since this trial was a test to determine the capabilities of the coaxial system, such matters as size and cost, which would be important with commercial receivers, were not controlling.

The coaxial cable system used could not transmit the frequency band from 0 to 806 kc, because repeaters were not designed to pass frequencies below about 60 kc. This limitation was incorporated in the original design because the cable offers insufficient shielding to various disturbances at low frequencies. It was necessary, therefore, to raise the television band to a higher frequency position for transmission over the line. A number of considerations led to the decision to raise the upper frequency to 950 kc for transmission over the coaxial cable, which required raising the entire frequency band 144 kc.

Where such a frequency band is to be raised 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 by at least the width of the band. For this reason a system of double modulation was used for the recent experiments.

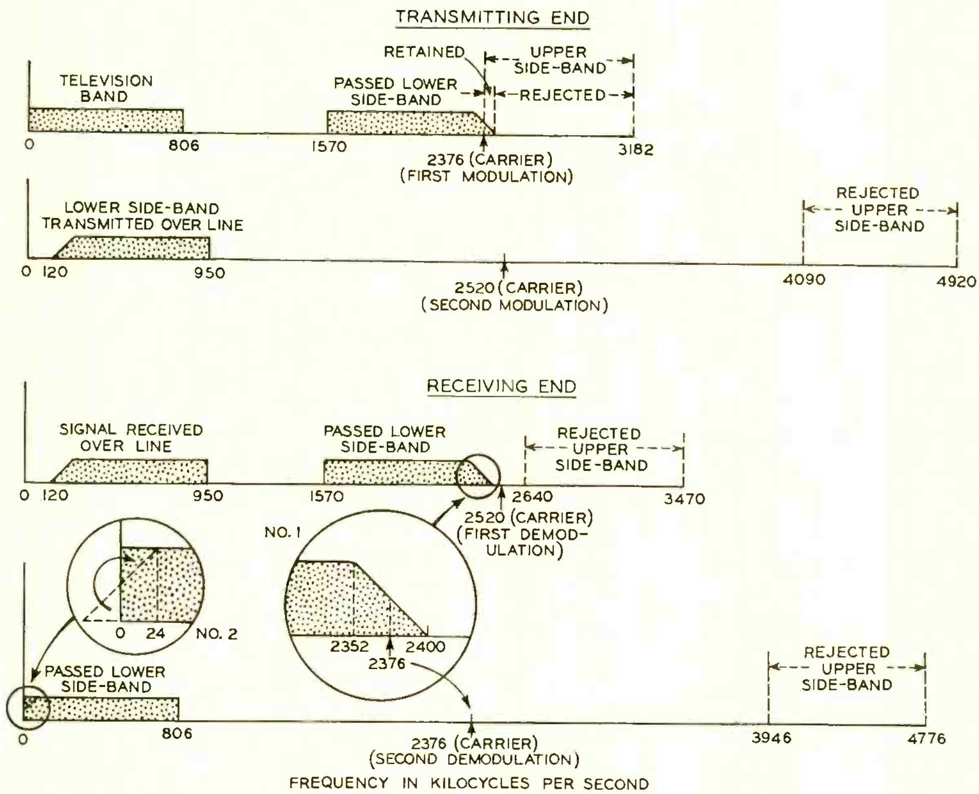


Fig. 5—Modulating and demodulating scheme for the recent television transmission, beginning with the first modulation at New York, above, and ending with the second demodulation at Philadelphia, below

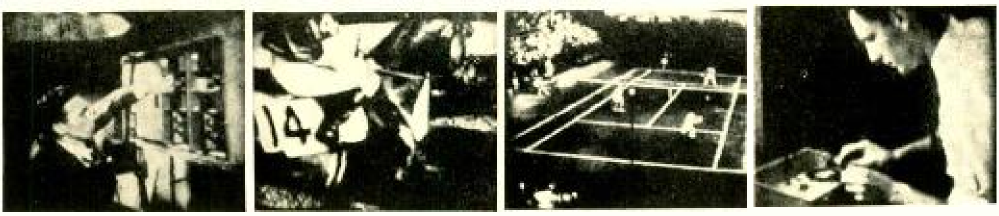


Fig. 6—Photographs of the receiving tube during transmission. In the tennis match the ball itself shows and its movement could be followed. The race horse is interesting because of the way the half-tones were reproduced

The modulating scheme employed can be followed with the help of Figure 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 carrier of 2376 kc is used for the first modulation, which results in a lower sideband from 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 sidebands from all subsequent modulations are 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 kc and to pass with controlled attenuation the vestigial upper sideband, which then extends from 144 to about 120 kc. The resulting single sideband, extending from 120 to 950 kc, is then passed over the coaxial cable to Philadelphia.

Here the transmitted band, together with a carrier of 2520 kc, is applied to the first demodulator, and the lower sideband, from 2400 down to 1570, is passed to the second demodulator where a carrier of 2376 kc is applied. The lowest frequency of the lower sideband, 1570 kc, is converted to 806 kc, becoming the highest frequency of the final demodulated band. The frequencies from 2352 to 2400 kc of the sideband before the second demodulation are somewhat attenuated as a result of the filter following the second demodulator, and the second demodulating carrier, 2376 kc, falls in the middle of this attenuated band as shown in inset No. 1. Frequencies extending about 24 kc above the carrier are inverted by the demodulation, and superimposed upon the corresponding frequencies just below the carrier. The magnitude and phase of these components are proportioned by the filter and equalizer so that the overall result, when they are superimposed, is an essentially flat transmission band from 0 to 806 kc.

Besides this carefully planned modulating and demodulating arrangement at the terminals, it was necessary also to provide networks and equalizers to insure that the coaxial line did not distort the ultimate image due to unequal attenuation, resulting in amplitude distortion, or to unequal time of transmission, causing phase distortion. The actual attenuation characteristics of the line, the line plus repeaters, and the overall result are shown in Figure 7.

The attenuation requirements are not particularly severe, but those for phase distortion are difficult to meet. The details in the scanned picture result in the various frequencies of the electrical signal, and if these details are to appear in the reproduced picture in the same relative position as in the scanned picture, it is essential that all frequencies be received in very closely the same relative time relationship as they were generated. Theoretical analysis does not lead to any well defined requirements, 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 microsecond, and frequencies below 5700 cycles to a delay of about forty microseconds. The actual circuit roughly met these requirements as indicated by Figure 8, which shows the phase delay characteristics of the line, repeaters and equalizers, and of the overall circuit including the phase equalizers.

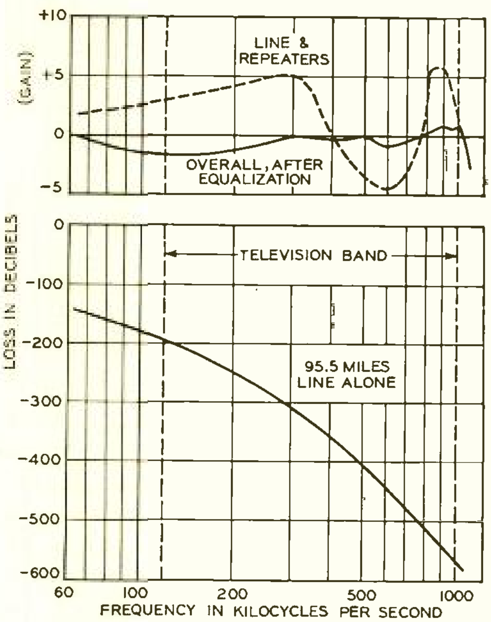


Fig. 7—Attenuation of the coaxial circuit between New York and Philadelphia as arranged for the television experiments

Noise or interference is very annoying in television transmission; and pattern, or single-frequency interference, is particularly objectionable. The permissible noise or interference depends 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 range of the reproduced pictures extended somewhat beyond the range of linear re-

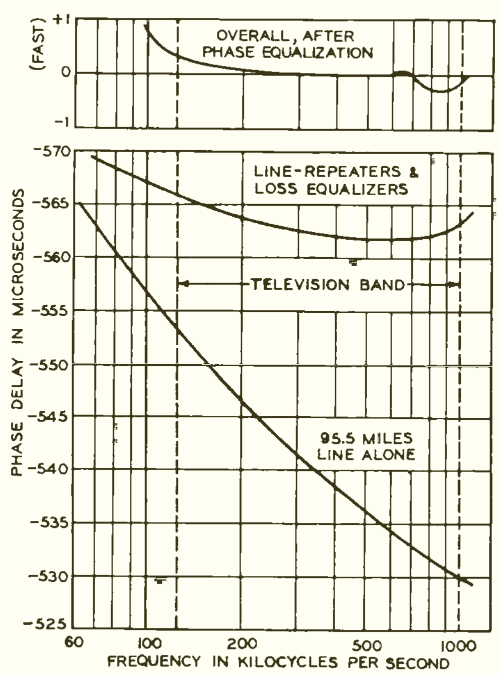


Fig. 8—Phase delay of the coaxial circuit during the recent experiments

sponse. It 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, 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 is shown in Figure 9.

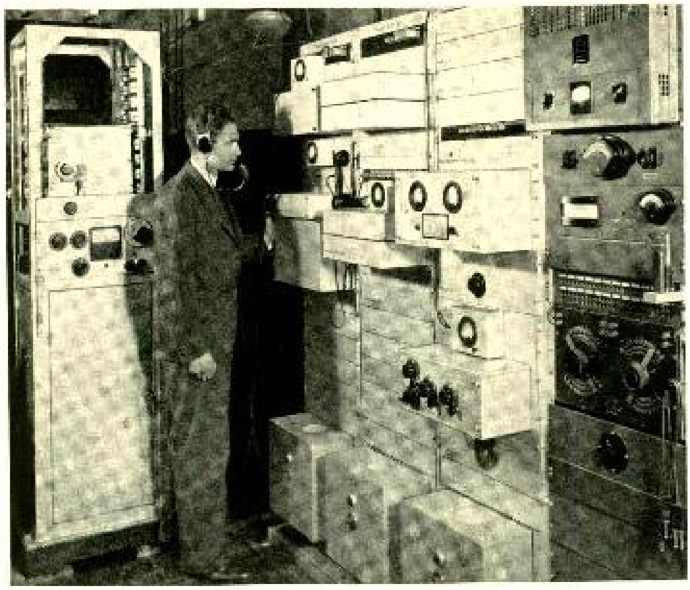
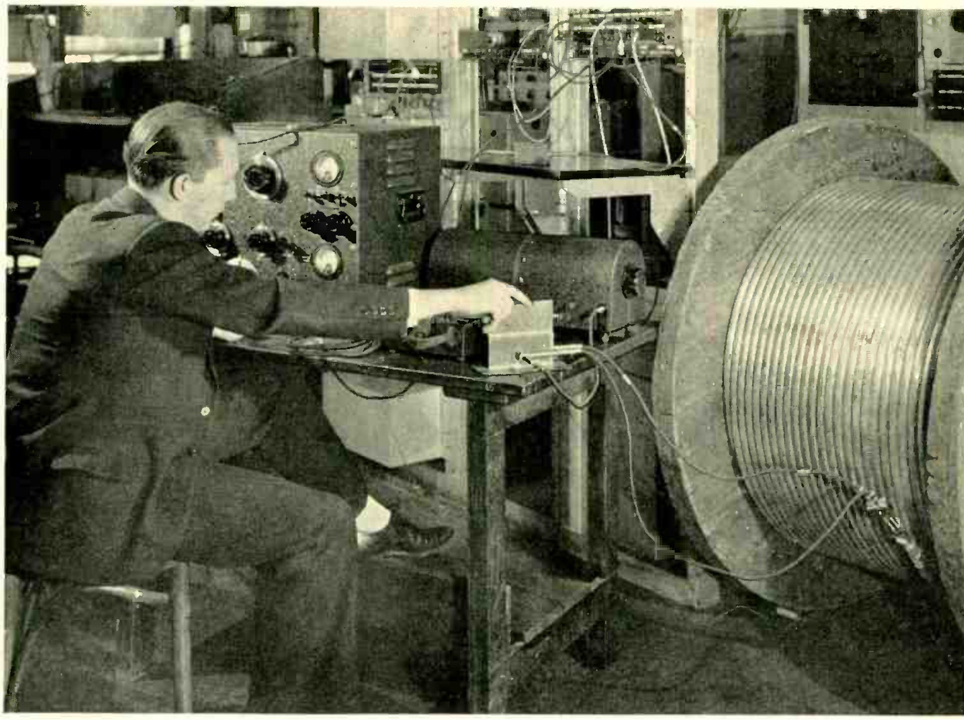


Fig. 9—Modulating terminal equipment at the New York end of the coaxial circuit

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 New York, thus showing that the cable system itself introduced no appreciable distortion. 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 photograph of the end of the tube, although not taken under the conditions shown.

These experiments have proved that a wide-band signal of the type required for television can be satisfactorily transmitted over a coaxial system. Work is already under way on repeaters and terminal apparatus for transmitting wider bands of frequency to meet the standards now envisioned by the television industry.



Transmission Characteristics of the Coaxial Structure

By J. F. WENTZ
Transmission Development

THE very earliest telephone lines consisted of only one wire with the earth as a ground return. It was soon discovered, however, that not many such lines could be operated simultaneously in the same neighborhood. The large separation between the wire on a pole and its ground return formed a large loop which was ideal for transferring energy to other similar loops by induction. In addition the voice currents from all such grounded circuits flowed in the common ground which also tended to increase the crosstalk between them. By using another nearby wire for the return path of each circuit, most of this trouble disappeared. Since then ungrounded or metallic-return circuits have been employed almost exclusively, either as open-wire lines on poles or as paper insulated pairs in cables. With the coaxial structure,* however, which has been tried out experimentally between New York and Philadelphia, the outer conductor is grounded; and thus on a circuit carrying a far wider range than the early voice-frequency circuits there is a reversion to the grounded circuit that proved so impracticable.

*RECORD, *June*, 1937, *p.* 325.

This anomalous situation is explained by the peculiar nature of the coaxial structure. The fact that the outer conductor is grounded does not mean that the return current of the circuit passes through the ground, and thus over the same path as the return of adjacent circuits. The reason for this is the phenomenon commonly known as "skin effect," which has more and more influence as the frequency becomes higher. Skin effect is an inductive reaction that—as the name implies—causes the current to flow in the skin or near the surface of a conductor. With an ordinary circuit consisting of round wires, this means that the current tends to avoid the center of the wire and flows mostly in the outer layers. At very high frequencies it flows in a very thin surface layer or skin of the conductor.

In the coaxial circuit, the current flows largely in the outer skin of the central conductor and along the inner surface of the outer conductor. Even though the outer conductor is grounded, therefore, there is no appreciable mingling of the return currents of two adjacent conductors if the frequency is sufficiently high, because the return current of each structure is held to the inner surface of its own outer conductor, and is thus separated from the return currents of adjacent structures. Furthermore, in the case of lightning and power line interference, the currents induced are, by the same skin effect, forced to flow on the outside surface of the outer conductor. These induced currents are physically in the same conductor as the return currents of the coaxial circuit but are electrically separated from them by the intermediate metal of the outer conductor. The higher the frequency the greater will be the separation between the signal and the disturbing currents. At very high frequencies, as a result, the signal currents of the coaxial structure are almost completely isolated from the disturbing currents.

The interference in a telephone circuit from other similar circuits is known as crosstalk, and the effectiveness of the coaxial circuit in eliminating it at high frequencies is indicated by Figure 1, which shows the relative crosstalk coupling between ordinary cable pairs not individually shielded, and between two coaxial structures in the same sheath. It represents the ratio of the output of a disturbing circuit to the output of a disturbed one of the same type when the former and the latter are measured at the same end. With a rising crosstalk characteristic, as in existing cable, a frequency would be reached sooner

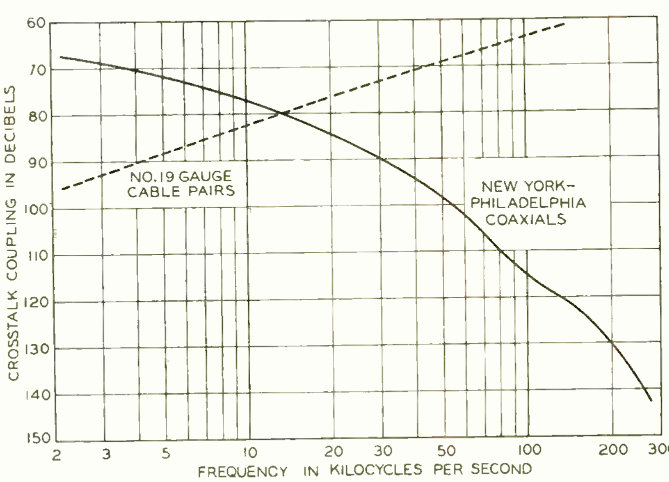


Fig. 1—Typical crosstalk values for ten miles of nineteen-gauge cable pair and the coaxial structure

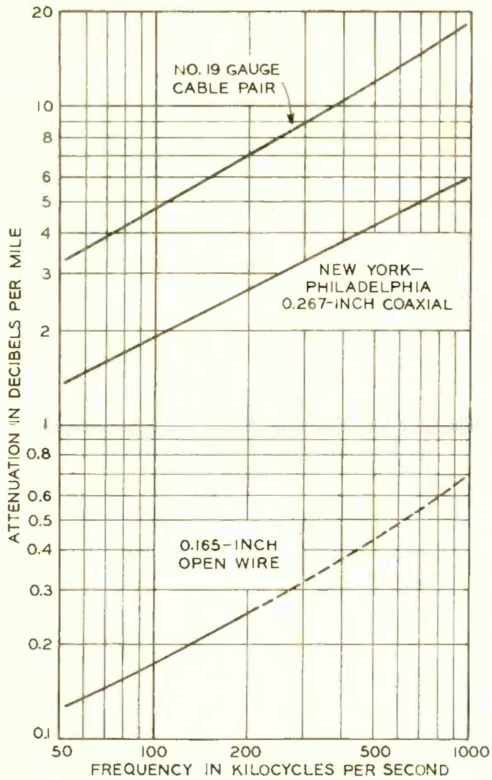


Fig. 2—Typical attenuation values per mile for nineteen-gauge cable pair, open-wire lines, and the coaxial structure

or later where the disturbances become so great as to cause impairment of secrecy; but with a falling characteristic, as exists with the coaxial structure, the higher the frequency, the smaller becomes the chance of secrecy impairment. This shielding effect of the outer conductor makes the coaxial structure particularly suitable for the transmission of very high frequencies. Long before the top frequency of the present frequency band is reached, the crosstalk volume drops below the level of the thermal noise from the cable itself, and is thus always below the requirements for very quiet circuits.

The other transmission characteristics of the coaxial structure are not so unusual as the shielding, and depend primarily on the size and relative spacing of the conducting elements. The attenuation for the coaxial structure in db per mile is shown in comparison with the equivalent values for typical cable and open-wire circuits in Figure 2. The values are roughly proportional to the size of the conductor employed, which for the cable pair is 0.036 inch, for the coaxial is 0.072 inch, and for the open-wire line

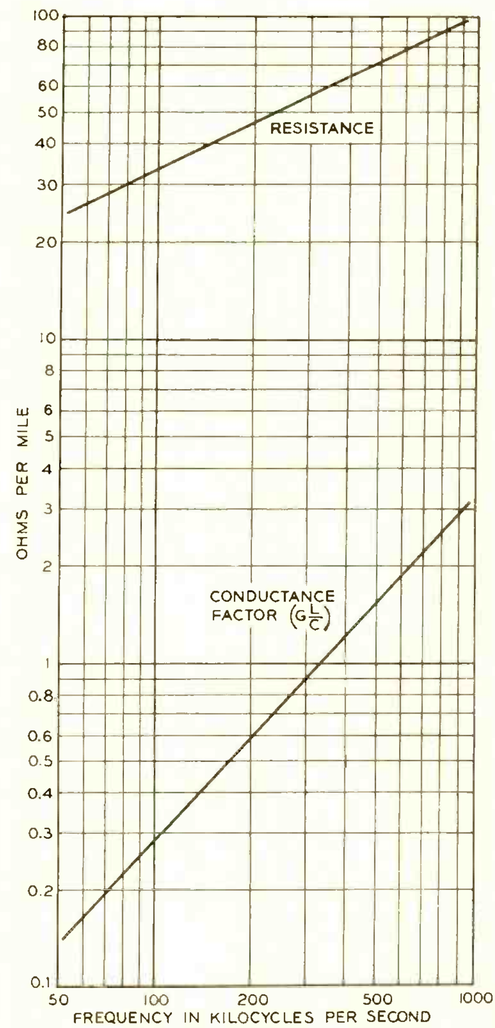


Fig. 3—Resistance and conductance factors for the coaxial structure

is 0.165 inch. This attenuation in terms of the four primary constants of the circuit is given very closely by the expression,

$$\alpha = 4.343\left(R + G\frac{L}{C}\right)\sqrt{\frac{C}{L}}$$

in db per mile,

which is a part of the solution of the differential equation of transmission.

The largest contribution to the attenuation is the resistance, R. Due to the skin effect it increases with frequency, and at 1,000 kc is many times the d-c value. The conductance, G, sometimes called the leakance, acts as though the insulators were resistance shunts across the line. In the equation above, the conductance factor that causes attenuation is $G(L/C)$ and is equivalent to a resistance that absorbs the same amount of power as the insulators. In the coaxial structure it is only a few per cent of the conductor resistance. Values for both, over the frequency range involved, are shown in Figure 3.

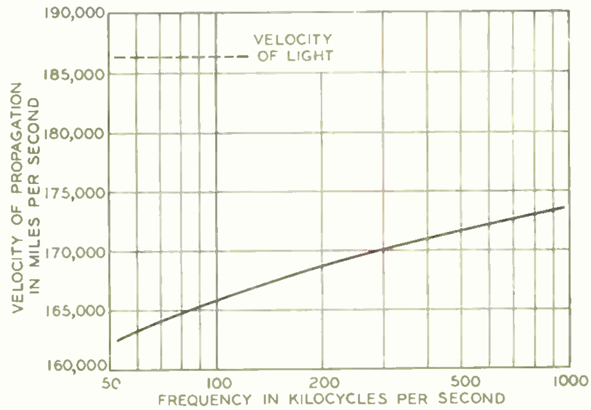


Fig. 5—Velocity-frequency characteristic for the coaxial structure

Values of the capacitance, C, and inductance, L, are given in Figure 4 for the same range of frequencies, but as is evident from the formula, it is the ratio of these two factors rather than their absolute values that is of importance so far as attenuation is concerned. It is the ratio of these two factors that also determines the characteristic impedance of a long cable, which is the impedance it offers to a steady frequency applied at one end. The expression for the characteristic impedance is also obtained from the transmission equation, and is found to be $Z_0 = \sqrt{\frac{L}{C}}$ ohms. It is practically a pure resistance, although actually there is a slight capacitance component at the lowest frequencies we use.

The velocity of propagation over the coaxial cable may also be calculated from the transmission equation, and turns out to be $v = \frac{1}{\sqrt{LC}}$. Again L and C are the important factors, but this time as a product. If the capacitance were air alone,

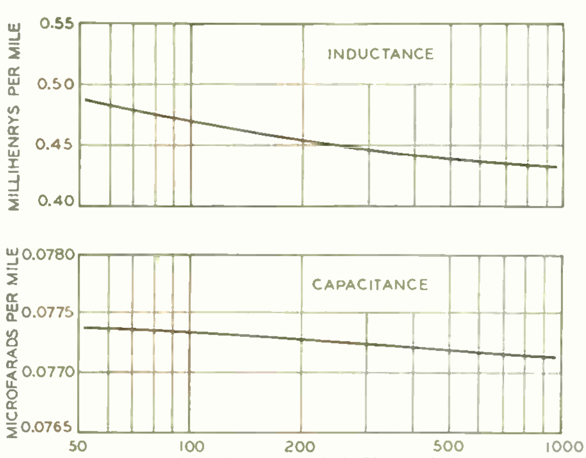


Fig. 4—Inductance and capacitance characteristics for the coaxial structure

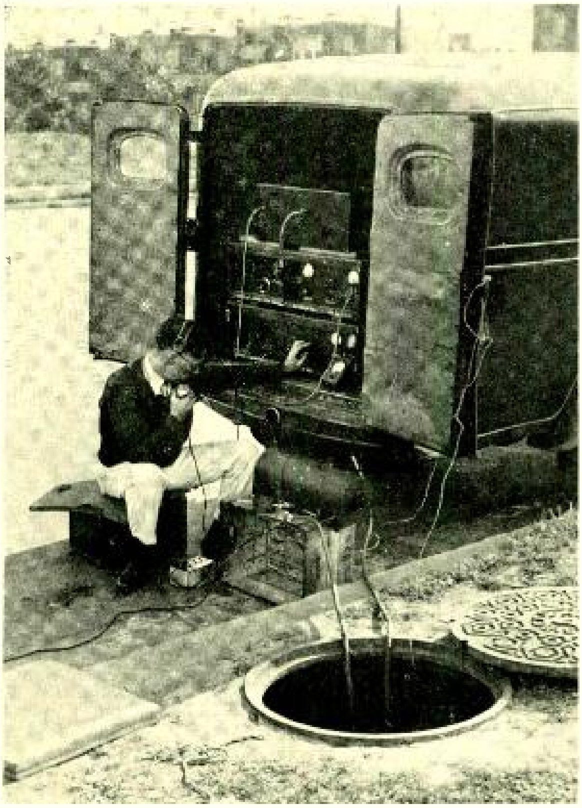


Fig. 6—A field test being made of the coaxial cable after it was installed

Thus, the velocity varies from 163,000 to 173,000 miles per second as shown in Figure 5.

The difference in the time of transmission of different frequencies is called delay distortion. It is not very large over one of the 4,000-cycle bands used as a voice channel, and causes no distortion in speech that the ear can detect. Over a very wide band, however, such as was used for the transmission of television, the delay distortion amounts to a fraction of a microsecond in every mile, and if not corrected produces a distortion that the eye can detect. For our television demonstration special apparatus was constructed to measure this distortion so that equalizers could be built to correct it.

All of these characteristics were calculated before the cable was actually manufactured, but measurements of the primary constants were also made during manufacture, in the laboratory, and in the field after the cable was laid. A laboratory test is pictured in the photograph at the head of this article, and a field test, using a special truck equipped for the purpose, is shown in Figure 6. Measurements made after installation check the calculated values closely.

without any insulators, and if the conductors were very thin cylinders, the velocity for all frequencies would be equal to that of light, or about 186,000 miles per second. Actually the insulators used add about thirteen per cent to the capacitance, and the conductors are so thick that they add from two to fourteen per cent to the inductance.

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An Anti-Static Loop for Aircraft

By J. E. CORBIN
Radio Development Department

AIRWAY radio beacons and other radio aids to safe air travel increase in their usefulness and importance as the flying conditions become poorer. Unfortunately, however, rain, snow, sleet, or thick dust clouds sometimes produce a "static" disturbance that makes reliable radio reception impossible just at those times when it is most needed. This interfering effect, called "rain static," is apparently caused by the high potential charge picked up by the surface of the plane and the antenna from the charged particles in the air.

It has been found that this rain static can be considerably reduced by using a shielded loop antenna. In the interest of safe flying, therefore, a shielded loop antenna, shown in Figure 1, has been designed for airplanes to be used with weather and beacon radio receivers instead of the usual rod or wire antenna when the rain static becomes objectionable. Advantage has been taken of the non-uniform field pattern of the loop to make the new antenna available for direction finding as well, and in recognition of this use it has been called the "6004A Radio Compass Antenna Outfit."

What was particularly desired was to secure a simple and inexpensive loop that could be readily adapted to the radio receiver, and be "gang tuned" with it. Loops in the past have been wound with many turns so as to secure as large an induced voltage as possible, and as a result have had a high impedance. The new loop is unique in that it is wound with a relatively few turns, which results in a correspondingly low impedance. This permits mounting it at a distance from the radio receiver, connection between the two being made by a concentric transmission line. The usual high-impedance loop is mounted very close to the radio receiver with which it is to be used.

A step-up transformer for matching the low impedance of the loop and

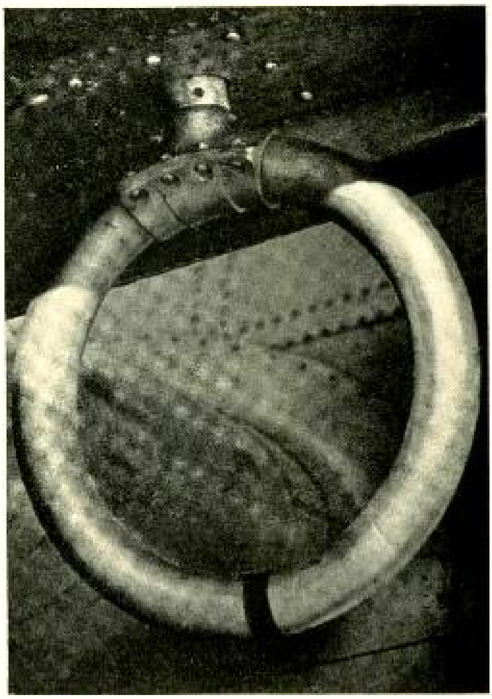


Fig. 1—One of the new Western Electric anti-static loops mounted beneath the wing of an air transport plane

transmission line to the high impedance of the antenna circuit of the radio receiver is mounted in or adjacent to the radio receiver. By adjusting the secondary inductance of this transformer, the impedance of the loop-circuit may be made to agree with that of the regular antenna at all frequencies in the band. The loop may therefore be used interchangeably with the regular antenna, no supplementary tuning arrangements being required.

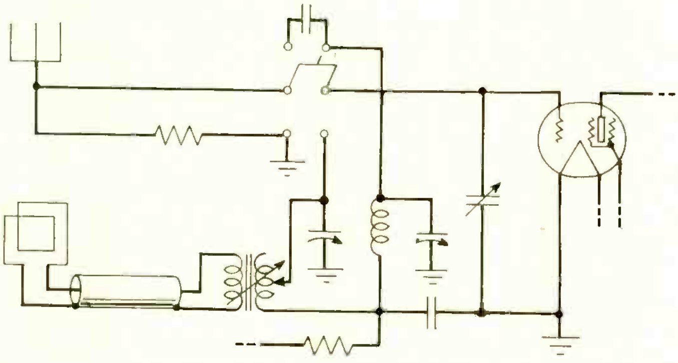


Fig. 2—Circuit arrangement used with the anti-static loop

Since the loop is to be added to the existing equipment of the plane, a switch is provided to transfer the receiver from the loop to the open-wire antenna as desired. The circuit arrangement is shown in Figure 2. Twenty or more feet of transmission line may be used with only a small transmission loss.

To assist in its use as a direction finder, the loop is equipped with a remote-control worm drive; and a dial, calibrated in degrees, is used at the control point to indicate the angle the axis of the loop makes with the center line of the plane. This dial is calibrated to read up to 180 degrees in each direction from the neutral point. The pilot determines the bearing by rotating the loop until no signal is heard in the head phones, and then reading the setting of the pointer on the control unit. The receiver is normally operated without automatic volume control when taking a bearing so as to increase the sensitivity of the null indication.

Since the loop must be mounted on the outside of the plane where it is exposed to severe weather conditions, it has been made moisture proof by placing the winding in an impregnated fabric cover. This structure is then coated with a non-corrodible metal to provide the electrostatic shielding. This assembly is clamped into a mounting, and connection is made to one side of the loop through a jack and plug to facilitate removing the loop. The other terminal of the loop is grounded.

With this simple but effective equipment, the pilot will be able to hear his weather and beacon signals under conditions that would otherwise result in their being lost in a continuous roar of noise. By the use of this anti-static loop, therefore, the usefulness of his radio receiving equipment will be considerably increased.

Engineering of a telephone system with all its thousands of individual apparatus units and thousands of unit assemblies requires not only careful design, but experimental installation of new equipment. Sometimes these installations are made in the field, sometimes in the Laboratories. Four such laboratory installations are shown.

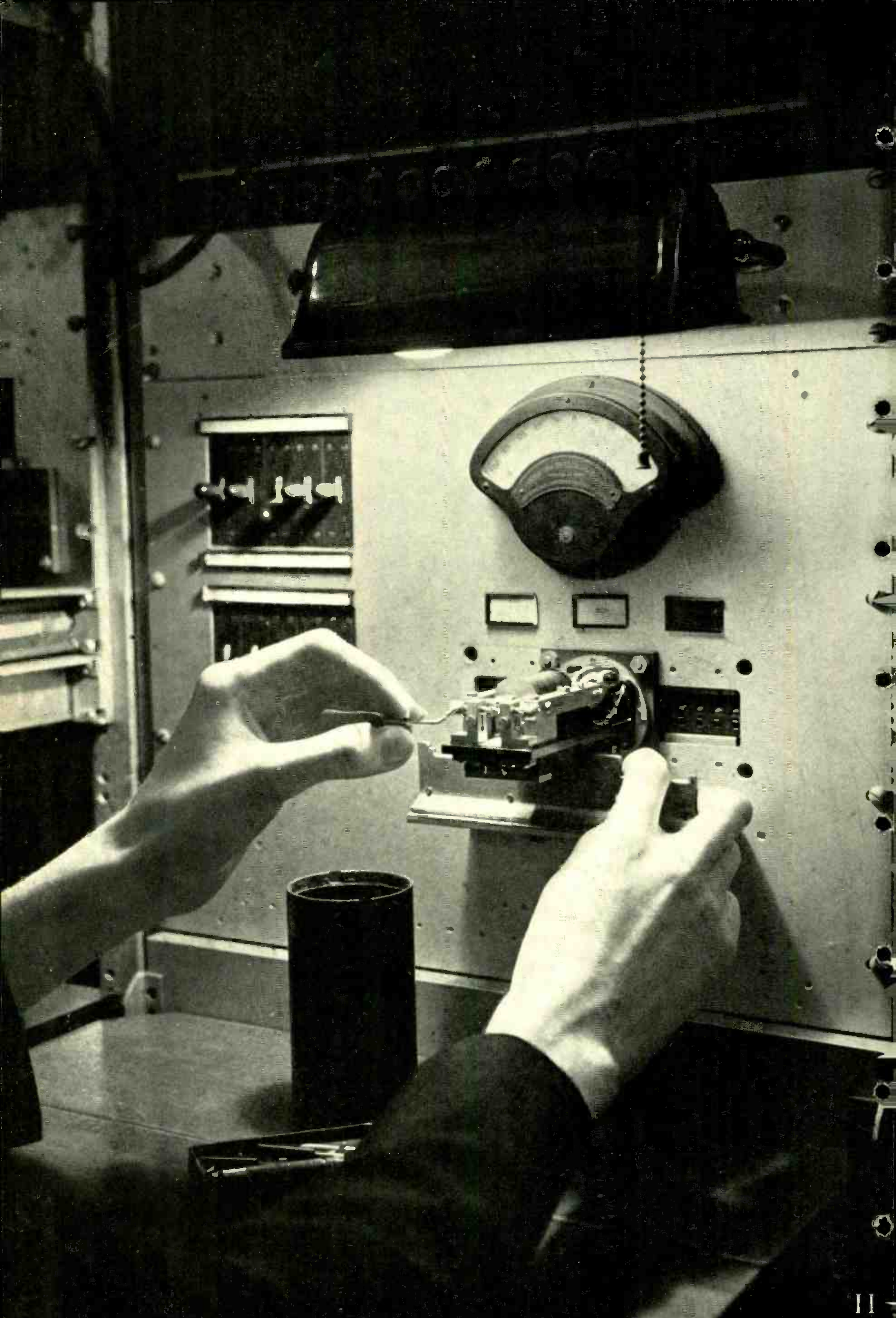
I
Oscillators for voice-frequency carrier telegraphy

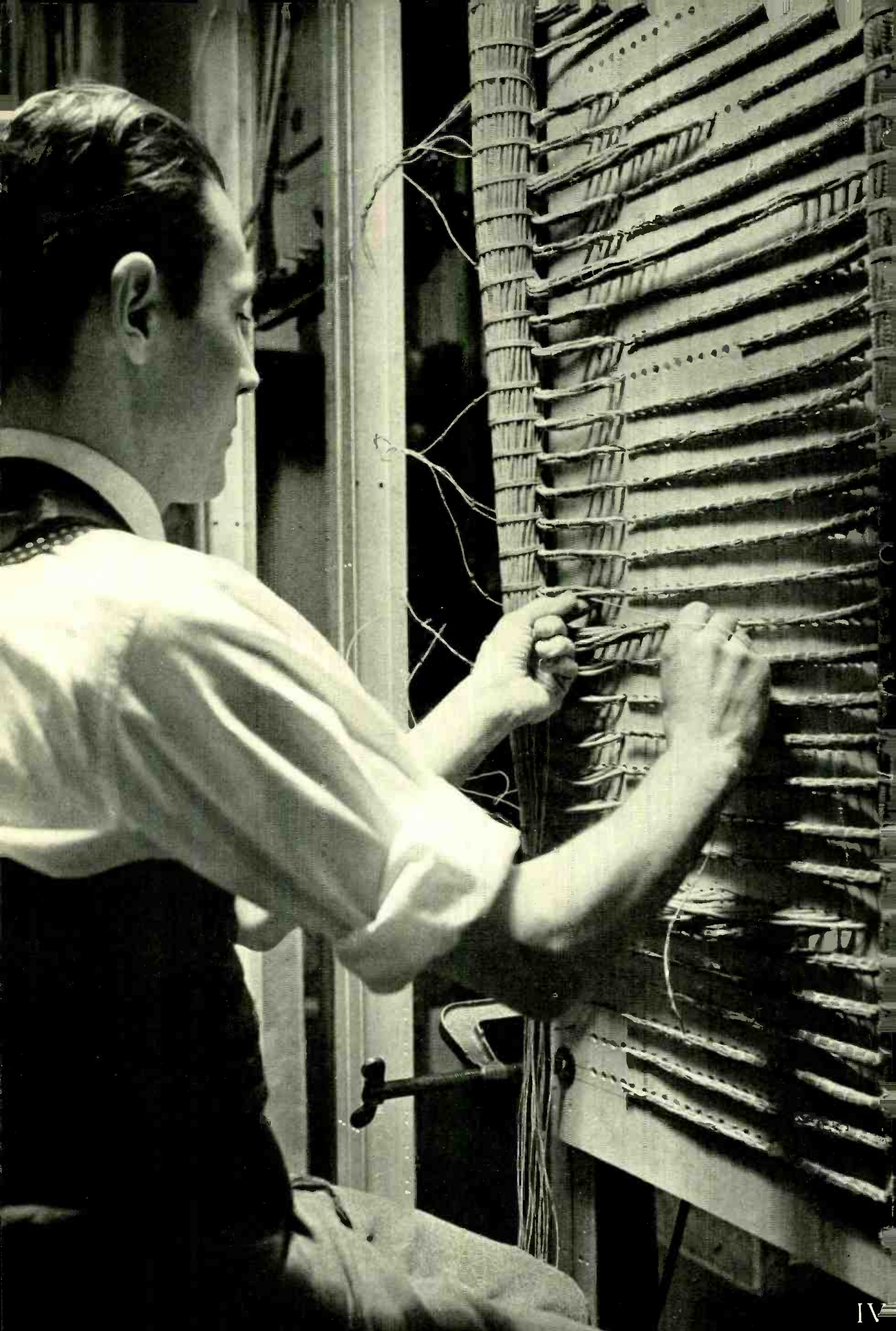
II
Satisfactory operation of a telegraph relay requires careful adjustment at a special testboard

III
Voltage indicator which records transient voltages on telephone lines

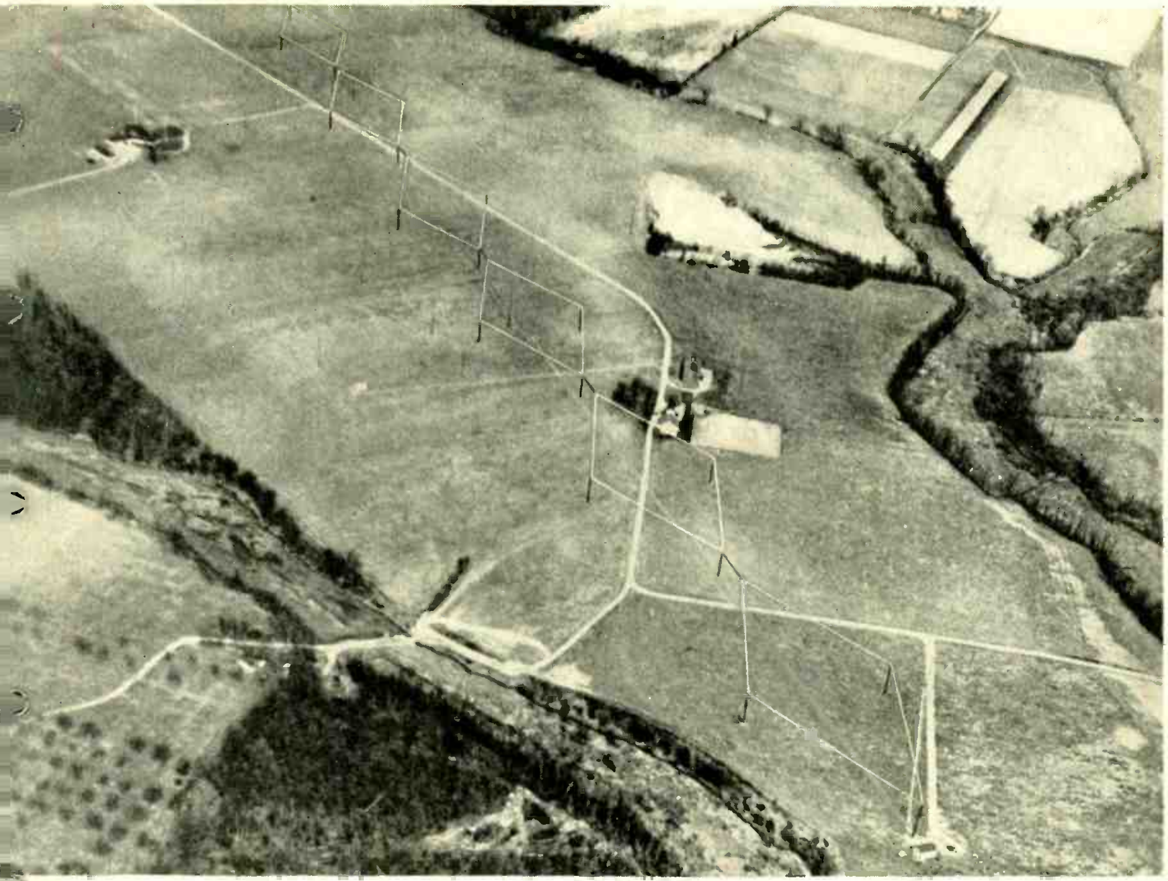
IV
Cabling a power board in the crossbar toll switching laboratory


I





IV



The Musa From the Outside

By L. R. LOWRY
Radio Research Department

THE array of poles and wires that one would see if flying over the Holmdel radio laboratories, is the tandem group of six rhombic antennas of the experimental musa. These equally spaced antennas, with their individual coaxial transmission lines running underground to the receiver building shown in Figure 1, comprise the outside plant of the system. Within this building is the musa terminal equipment; and the six coaxial lines may be seen inside the sloping wood casing, on the right-hand side, from which one side has been temporarily removed.

The coaxial lines are constructed of sixty-foot lengths of one-inch copper pipe, joined with screw-type unions. The inner conductor consists of a quarter-inch copper tube supported at ten-inch intervals by isolantite insulators. A trench running down the middle of the array carries all six lines; and at each pole one of the lines turns up and runs to the top of the pole where it is connected to one end of the antenna through a coupling unit. A photograph of this coupling unit is shown in Figure 2, and its circuit schematic is given in Figure 3. At the other end each antenna is terminated in its characteristic impedance, which takes the form of three spaced resistance units. The arrangement of these units is shown schematically in Figure 6, and as actually installed, in Figure 4. The arrangement at each of the five intermediate poles is identical, and is shown in Figure 4.

Although there is nothing particularly unusual in the antennas themselves, in the coaxial lines, or in the method of coupling, there are a number of requirements of unusual severity that must be met if the array is to act properly as a musa. As has been discussed in a previous article,* the phase differences between adjacent antennas must be alike; and along each transmission line the phase shift must be proportional to the length. To meet these conditions the antennas and coupling transformers must be exactly alike, and the coaxial lines must be accurately terminated. Final tests must then be made in order to verify the behavior of the outside plant.

One of the incidental requirements is that the coaxial lines be electrically smooth; in other words their characteristics—resistance, capacitance, and inductance—must vary uniformly with distance. If they are not smooth, standing waves will be formed even though the lines are correctly terminated, and as a result their impedance will vary with frequency. As a test for smoothness, the longest coaxial line—about a thousand meters—was terminated at its remote end by its characteristic impedance and then the near end impedance of the line was measured over a wide range of frequencies. The resistive and reactive components thus obtained are shown in

*Record, *January*, 1938, *p.* 148.

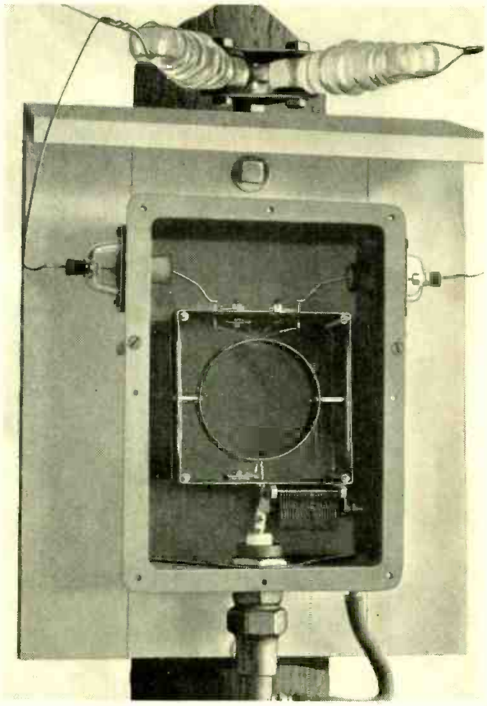


Fig. 2—Coupling unit designed for the musa antenna structures

Fig. 1—The musa terminal building and the incoming coaxial transmission lines

Figure 5. For most of the frequency range, as will be noticed, the impedance variations are within ±10 ohms. Variations of this order do not appreciably affect the satisfactory operations of the musa, and are not objectionable.

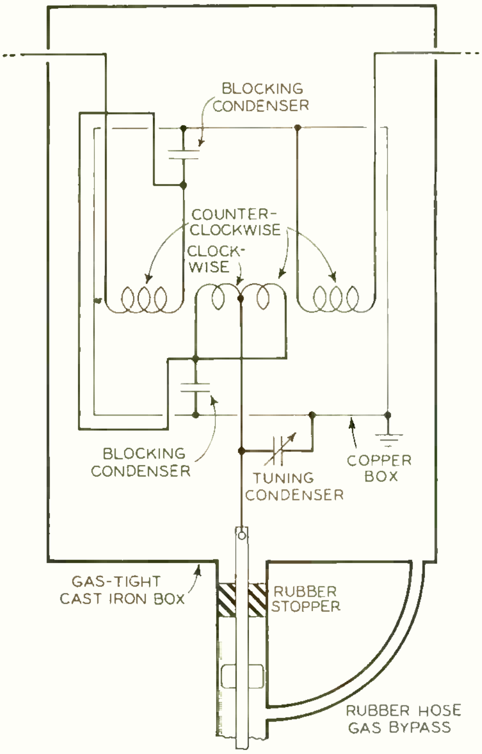


Fig. 3—Circuit schematic of the coupling unit, which is designed to permit checking the continuity of the termination resistance by means of direct current measurements at the terminal building

At 7.7 and 15.4 megacycles, however, much larger variations were found. These are believed to be due to a slight irregularity in the line at each joint, which adds a small shunt capacitance. When located at regular intervals, these small capacitances have a cumulative effect at frequencies for which the distance between joints is a multiple of a half wavelength. For the sixty-foot sections of the existing lines and for their actual velocity of propagation, these critical frequencies would be 7.7 and 15.4 megacycles—exactly as found. Since the musa is not required to operate at these two particular frequencies, the regular sixty-foot sections are satisfactory; but if it were to receive at these frequencies, the sections would have to be made of different lengths to avoid this cumulative effect.

The musa can be controlled over its steerable range and operated in the designed manner without the phase

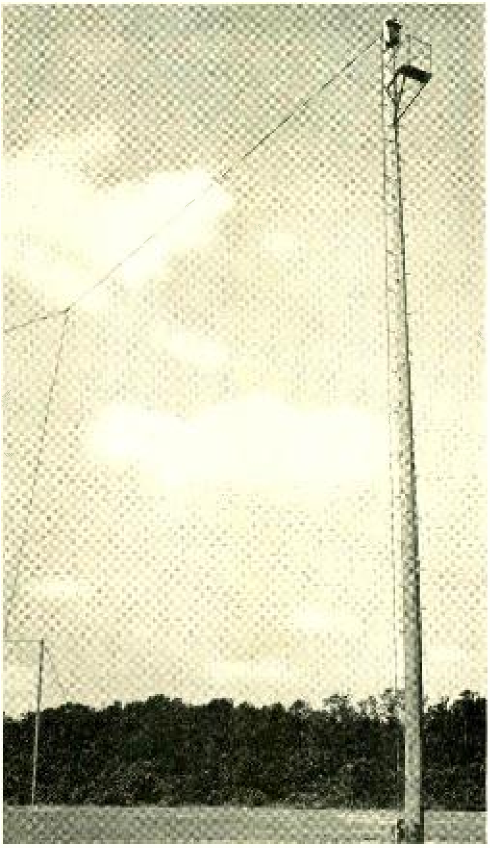


Fig. 4—At their output end each antenna is connected directly to a coupling unit, and at their termination end, the wires of each antenna are connected through three terminating resistances

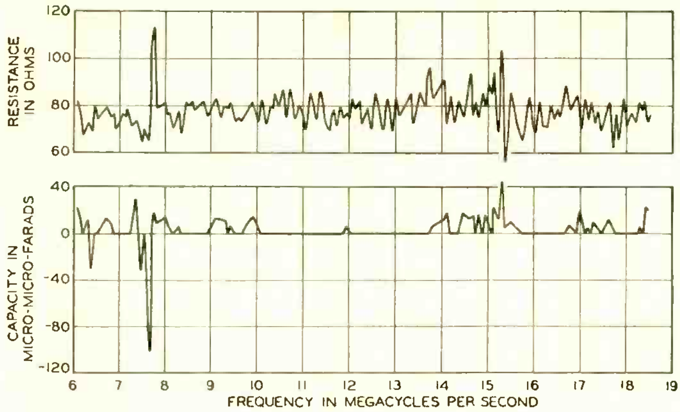


Fig. 5—Resistance component, above, and reactance component, below, of the coaxial transmission lines of the musa

this variation is satisfactory, experience with the system suggests that the actual variations are considerably less than this. The antenna outputs were found to differ by less than 0.5 db over the working range of frequencies.

Another requirement for the satisfactory operation of the musa is that the coupling, or crosstalk, between adjacent antennas be negligible. Results of measurements on the experimental musa are indicated in Figure 6. The small amount of crosstalk current, 0.001I, measured at the transmission line end of the musa and the larger current, 0.16I, at the termination end, indicates the unidirectional characteristic of the antenna. To a first approximation, the current in such an antenna increases progressively toward the output end, and under this condition the effective crosstalk current is probably less than 0.08I, that is half of (0.16I + 0.001I), and is thus less than ten per cent of the signal current, I. Antennas at greater spacing, either ahead or behind, contribute relatively nothing. These measurements were made at eighteen megacycles, at

velocity of the transmission lines being known. To be able to determine the angles of the incoming waves, however, the velocity must be accurately determined. The velocity of the existing coaxial line was therefore calculated and also measured. The calculated ratio of the velocity of the line to that of light was 0.941; and the measured ratio was 0.933 ±0.004. Experience with the system indicates that the value is 0.937.

Measurements were also made at the receiver input of the phase difference between adjacent antennas. At the highest frequency the maximum variation, in these measurements including the experimental error, was found to be only 0.4 per cent of the total phase difference between adjacent antennas. Although

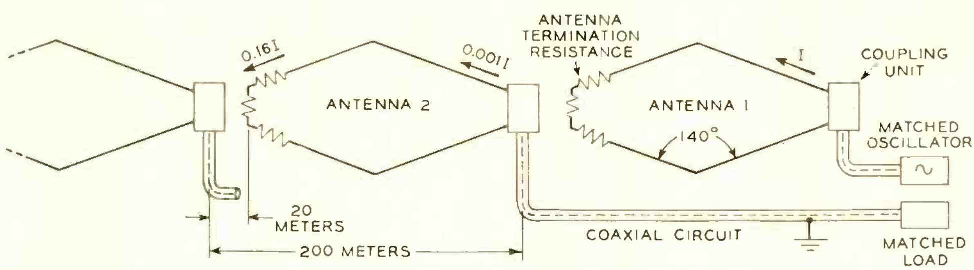


Fig. 6—Values of crosstalk current measured in the experimental musa vary at different parts of the antenna as indicated

which frequency the antennas are proportioned to give maximum radiation approximately end-on. At lower frequencies, the crosstalk is probably less. Since the directional pattern of any antenna is the same for transmitting and receiving, the crosstalk will have less than ten per cent effect when the antenna is receiving.

A further requirement for the musa is that the ground on which it is erected should be electrically flat, so that the reflected waves and the direct waves will combine similarly at all parts of the system. This requires that the reflecting plane of the earth should be approximately horizontal. Although the actual surface contour of the ground is not necessarily an indication of the position of the reflecting layer, tests and experience over the last few years have both indicated that the location of the Holmdel site meets this requirement.

The Washington Award for 1938

has been conferred on Dr. Frank B. Jewett by the Western Society of Engineers. In making the announcement, the Society stated: "It is generally recognized that America has led the world in the development of the art of telephony; and in this development Dr. Jewett and his research staff have had an important part in making it possible to converse not only from coast to coast but from this country to all other principal countries in the world. These contributions, which have been most important in the development of telephony, have also resulted in important advances in the fields of telegraphy, radio broadcasting, telephotography and television. They have brought increased comfort, enjoyment, security, and aid to the daily lives of millions of people, and have promoted friendly relations between nations."

Established in 1916 by John W. Alvord, the Washington Award is for "recognition of devoted, unselfish and pre-eminent service in advancing human progress," and is granted annually by a committee representing the American Society of Civil Engineers, the American Institute of Mining and Metallurgical Engineers, the American Society of Mechanical Engineers, the American Institute of Electrical Engineers and the Western Society of Engineers. Among its recipients have been Herbert Hoover, Orville Wright, Michael I. Pupin, Bion J. Arnold, Ambrose Swasey and Charles F. Kettering.

The Carrier Telephone Alphabet

By M. M. BOWER
Toll Transmission Development

THE use of carrier telephone systems has been increasing rapidly during recent years; and as a result of the increased use, new types have been developed to meet new applications, and older types have been improved to obtain better performance and lower cost. It now appears that a large part of the growth in the future will be provided by carrier methods. Each new system has been designated by a letter with the result that systems are now represented by an alphabet of letters from A to K. Although some of the earlier systems have nearly disappeared from use in the telephone plant, they all are of historical interest.

The first carrier system, designated as type A, was developed during the War. The purpose of this system, as with the carrier systems which followed, was to provide telephone channels in addition to the existing voice channels without increasing the number of physical pairs. The type A system provided four two-way channels above the voice channel on open-wire pairs in the frequency range between five and twenty-five kilocycles. Each channel used the same frequency for both directions of transmission; directional discrimination was secured by hybrid-coil balance at terminals and repeater stations as with two-wire repeaters. The lower sidebands of carrier frequencies at ten, fifteen, twenty and twenty-five kilocycles were employed, with the carrier suppressed. This system provided good service, but the number of systems that could be placed on a pole line was limited by near-end crosstalk, and the repeater gains were limited by the degree of balance obtainable from the hybrid coil, so that the utility of the system for very long circuits was reduced. Seven type A systems were installed, but only one of these is now in regular service and is between Merced and Yosemite Valley, California.

The type A was followed by the type B carrier system, which provided three channels above the voice channel. This new system could employ higher repeater gains because different frequencies were used for transmission in opposite directions, making it possible to rely upon filter selectivity instead of impedance balance to separate the directions of transmission. This system transmitted a single sideband and the carrier frequency, using the lower sidebands of carrier frequencies at six, nine and twelve kilocycles, in the East to West direction, and the upper sidebands of carrier frequencies at fifteen, eighteen and twenty-one kilocycles in the West to East direction. Although this system was a distinct improvement over the type A, it was soon found that the band width obtainable in each channel was somewhat narrower than was desirable, and that the transmission of the carrier placed an unnecessarily large burden on the load-carrying capacity of the repeaters. Of the score of type B systems placed in service, only one is now in operation, between Spokane and Lewiston in the state of Washington.

The type C* system, which followed, embodied the best features of the types A and B systems. It employed filter selectivity to separate the different frequencies used for opposite directions of transmission, transmitted a top frequency of about thirty kilocycles, with a single sideband for each channel, but suppressed the carrier. This system has been very successful, and is now employed on many of the longer open-wire circuits in the toll plant, some of which are over two thousand miles in length. Over five hundred of these systems have been installed throughout the country up to the present time.

Where a number of carrier systems are employed on the same pole line, special carrier transpositions must be used to reduce carrier crosstalk. In addition it has been found desirable to shift slightly the frequencies used on carrier systems being transmitted over adjacent pairs to obtain a so-called "staggering advantage," and thus reduce the crosstalk. Type C systems having three slightly different frequency allocations were developed, and were designated as the types CN, CS, and CT systems. As progress was made in the art, improvements were incorporated in these systems, and successive models were standardized which were designated as the C2, C3, and C4, with a letter added to indicate the frequency allocation used in each case, as CN4, CS4, and CT4.

During recent years there have been a number of new developments such as copper-oxide modulators and demodulators, and filters employing molybdenum-permalloy coils, which have made it possible to reduce materially the cost and physical size of the equipment. In addition to these, new types of vacuum tubes have become available, having higher gains than those used heretofore, and the feedback type of amplifier has been developed, which is much more suitable for carrier use than the types previously employed. A new type C system, known as the C5, is now under development in which all of these improvements will be incorporated. It will be provided in the CS frequency allocation and a new frequency allocation known as the CU.

Although the types A, B, and C systems had found ready acceptance for application to long circuits, there were many places in the toll plant where carrier could be used to advantage for shorter circuits in areas of slow growth on open-wire lines. To fill this need the type D* system was developed. This system provided one two-way telephone circuit on a pair of wires in addition to the voice-frequency circuit already in use. Like the type C system, the type D employed single-sideband transmission with the carrier suppressed, and used different frequencies for opposite directions of transmission, employing the lower sidebands of carriers at 10.3 and 6.87 kilocycles. The type D system was well received, and was soon followed by the DA system employing a transmitting amplifier, which extended the length of circuit to which the system could be applied to about two hundred miles. As on the type C system, later models were designated as the D2 and DA2. About 550 of these systems have been installed.

The type E† is a single-channel system for power lines. It transmits a

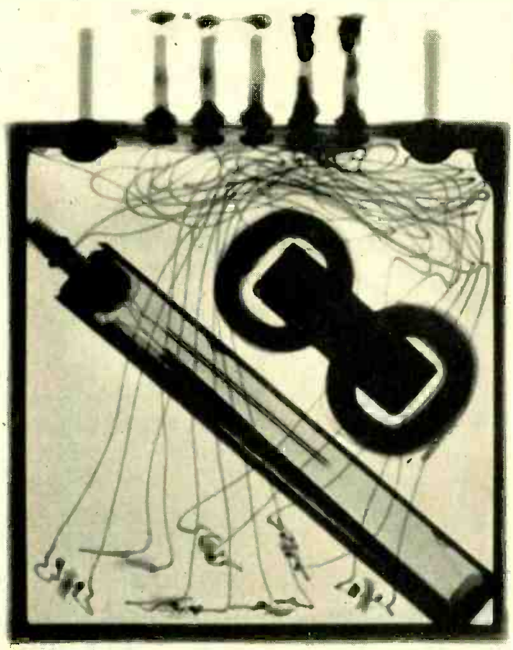
*The types A, B, and C systems are briefly described in the Record for *December*, 1925, *p.* 154.

*Record, *July*, 1928, *p.* 353.

†Record, *July*, 1929, *p.* 451; *June*, 1932, *p.* 350.

The type K system for cables, a trial installation of which has recently been placed between Toledo and South Bend, provides twelve four-wire telephone channels in the frequency range between twelve and sixty kilocycles, using non-loaded pairs in separate cables for opposite directions of transmission. A cable with a group shield may also be used. Unlike the open-wire systems, which were superposed on existing voice circuits, the cable system requires that the voice channels be removed before carrier is applied. At present, the frequency space below twelve kilocycles on these pairs is not used except for d-c pilot wires and d-c testing of the pairs. It is expected that the type K system will find a large use in the long-haul cable plant.

In the coaxial—or balanced shielded pair—system, to which as yet no alphabetical definition has been given, two shielded transmission paths are provided, one for each direction of transmission. Frequently inserted amplifiers associated with distortion-correcting and transmission-stabilizing arrangements make each transmission path capable of transmitting unbroken frequency ranges more than a million cycles wide. By the application of suitable terminal apparatus, hundreds of telephone circuits may be obtained from a single system. These lines will also be suitable for the transmission of television signals.



X-Ray photograph of 23A equalizer

Noise Measurements and the International Conference on Acoustics

By HARVEY FLETCHER
Physical Research

MEASUREMENTS of noise in rooms and out of doors have been made by the Laboratories and the operating telephone companies for over twenty years in connection with telephone problems. For the most part these measurements have been confined to the vicinity of telephone stations and to the laboratory for research studies, but Laboratories engineers have also taken part in surveys made to find ways of eliminating unnecessary noise in New York City. These studies have been carried out either with sound-level meters which showed on an indicating instrument the magnitude of the sound picked up by a microphone, or with audiometers which measured how much louder a test tone must be to be heard in the presence of a noise than in its absence.

Before noise could be measured at all, however, a unit had to be chosen in terms of which to express the physical intensity of a sound and the loudness with which a person's ear hears it. At the time the New York Survey was made in 1929 the decibel had already been adopted both in this country and in England as the unit for measuring the intensity level of a sound above the threshold of hearing. Since then this unit has been used very extensively in this country for defining the intensity level of a noise. The values obtained by the early workers in the field differed, however, because they chose different values for the threshold intensity. This difficulty was solved when the American Standards Association took up the problem and obtained agreement by engineers and physicists in America to use as the reference sound intensity a value of 10^{-16} watts per square centimeter and as the reference pressure 0.0002 dyne per square centimeter. This made it possible to express accurately the physical intensity of any type of sound in decibels above the recognized standard reference level. This intensity, however, does not correspond to the loudness of the sound as heard by the ear.

To obtain a quantitative measure of the loudness of a sound as distinguished from its physical intensity the Laboratories proposed in 1927 that the loudness be defined as numerically equal to the intensity in decibels above 10^{-16} watts per square centimeter of a 1000-cycle pure tone, which sounded equally loud. The intensity level of the 1000-cycle reference tone was defined as the loudness level of this tone, and any other sound which is judged by listeners to be equally loud is said to have an equal value of loudness level.

Other laboratories saw the advantages of this scale and began to use it. In 1932 it was adopted by a committee of the American Standards Association as a tentative American standard. Several countries in Europe also used a reference tone to measure loudness, but in some instances they chose one having a frequency of 800 cycles per second and in most cases they selected a zero which differed from that adopted by the American Standards Association. In Germany and in some of the smaller countries the word "phon" was used instead of decibel for designating units on the loudness level scale. They also chose a reference level about four decibels higher than that of the American standard. Great Britain joined them in using the word "phon," but chose as the reference pressure 0.0002 dyne per square centimeter.

It was principally because of these differences that an acoustical conference on standardization of noise measurements was called in Paris in July of last year. Although originally called under the auspices of the International Electrotechnical Commission, it was decided later that the conference belonged more logically under the sponsorship of the International Standards Association. Under this organization, members of the International Electrotechnical Commission, however, assumed the responsibility for one of the most important committees, namely, that in charge of units and methods of noise measurement (including noise meters).

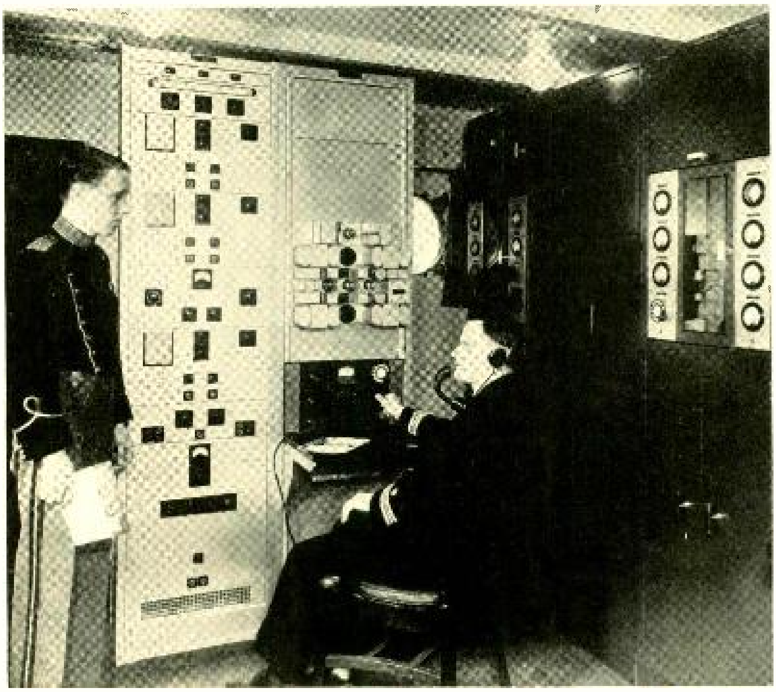
The meetings were held at the headquarters of the Association Française de Normalisation and were attended by about forty delegates from fourteen different countries. At the close of the conference, which lasted a week, a luncheon was given at the Maison X, one of the distinctive old cafés of Paris. Through the committee on noise measurements, of which the author was chairman, it was possible to bring about agreement concerning the fundamental standards for noise measurement and the following international standards were adopted.

The reference sound and the scale for sound level measurement are characterized as follows: (1) the reference sound is to be produced by a plane, sinusoidal, traveling wave with a frequency of 1000 cycles per second; (2) the reference zero shall correspond in round numbers either to an intensity of 10^{-16} watts per square centimeter or to an acoustical pressure of 2×10^{-4} baryes (dynes per square centimeter); (3) in each case the intensity scale or the pressure scale is to be graduated in decibels with respect to reference zero.

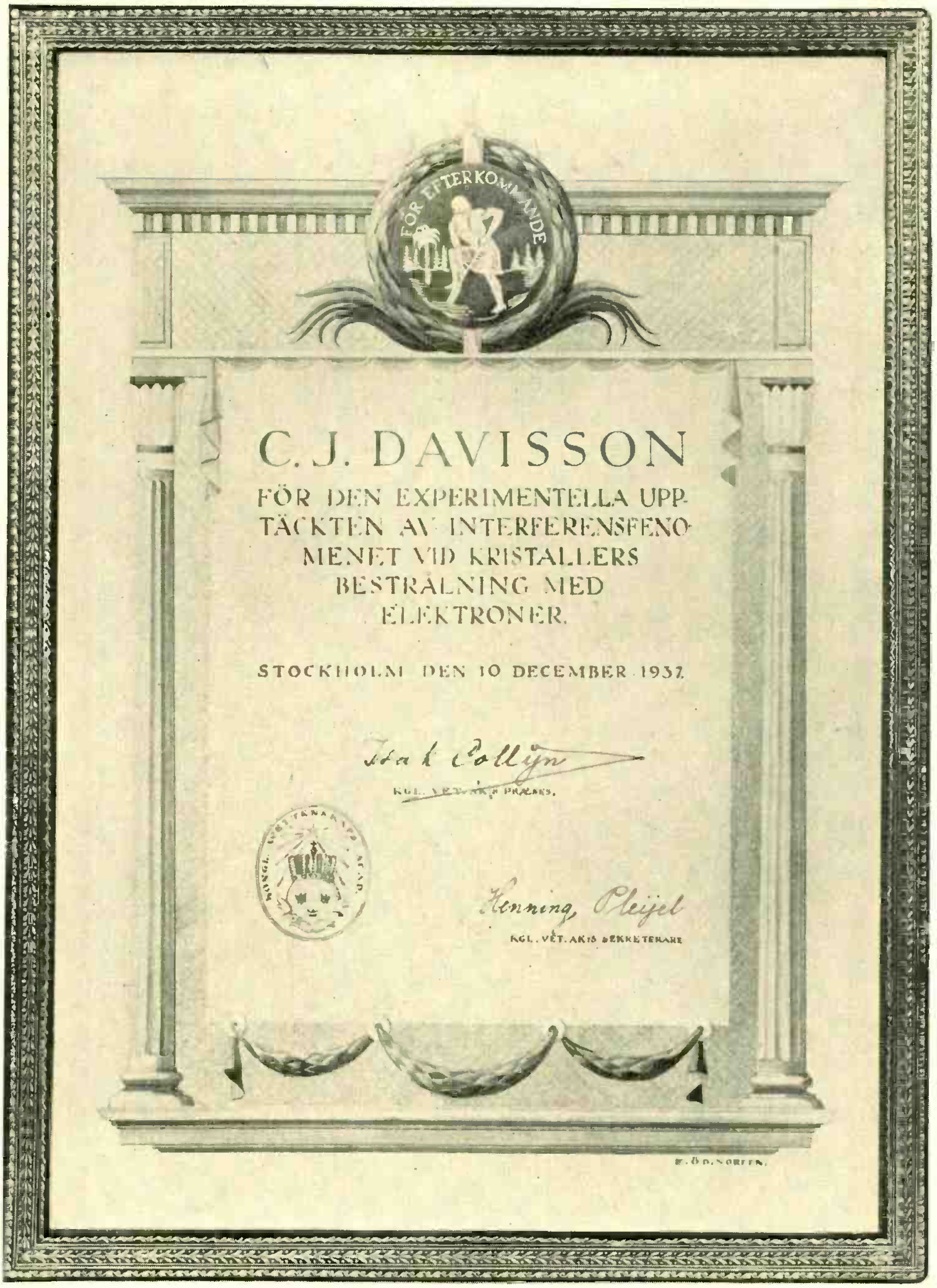
The unit to be used for intensity level measurements is the decibel, but the unit to be used for the equivalent loudness level measurements is the phon. Loudness measurements are to be made by listening to the reference sound and the sound to be measured alternately with both ears, while the intensity of the reference sound is regulated until an ordinary observer considers that it has the same loudness as the measured sound. Whenever possible the reference sound and the one measured should be listened to for practically the same length of time. This period should never be shorter than one second when listening to the reference sound. When, under these conditions, the intensity level, or the pressure level, of the reference sound (the pressure being that of the free wave before the operator's head is in the acoustical field) is "n" decibels above the reference zero, it is said that the sound measured has a loudness level of *n* phons. Primary loudness measurements are made in a very dead room or outdoors where there is no reflected sound. The intensity of the reference tone, which is generally produced by an oscillator and loud speaker, is usually measured with a calibrated condenser microphone.

This committee appointed a subcommission to report on the possibility of reaching an agreement about specifications for sound-level meters. The subcommission reported that such an agreement could not be made now; but a number of the representatives undertook to send available material concerning the construction of sound-level meters which are now being used and the data obtained with them.

The International Standards Association broadened its scope to include four other subcommittees besides the one on units and methods of measurement. These dealt with an international vocabulary on acoustics; electroacoustics and musical acoustics; architectural acoustics; and noise abatement, vibration, and medical acoustics. The first-named committee brought in a report which will probably be adopted internationally. It deals with a set of definitions of acoustical terms. The other committees are just beginning active work with the hope that further agreement in standards can be obtained.



Western Electric radio-telephone installation on the S. S. Washington *of the United States Lines*



Diploma of the Nobel Prize in Physics
awarded to Clinton J. Davisson

Contributors to This Issue

Since Harvey Fletcher came to the Laboratories in 1916 he has been identified with many important investigations which have made him one of the foremost authorities in the field of speech and hearing. As Acoustical Research Director he was in charge, for a number of years, of groups working on fundamental problems relating to sound, including aids to the hard-of-hearing. Dr. Fletcher is now Physical Research Director and in this capacity has charge of research work in acoustics, electronics, magnetism and vibrating systems. He graduated from Brigham Young University in 1907 and received the Ph.D. degree from the University of Chicago in 1911.

M. M. Bower received the B.S. degree in electrical engineering from the California Institute of Technology in 1927. After two years with Westinghouse, he joined the staff of M. I. T. as a research assistant. The following year he received the M.S. degree from M. I. T., and then joined the Department of Development and Research of the A. T. and T. Company to engage in the development and field testing of carrier telephone systems for open wire and cables. He has continued this work since the consolidation of D. & R. with the Laboratories in 1934.

Harvey Fletcher

After receiving an A.B. degree from Colorado College in 1914, M. E. Strieby studied at Columbia and at Massachusetts Institute. In 1916 he received the B.S. degree in Electrical Engineering from M. I. T. and Harvard, and at once joined the Engineering Department of the New York Telephone Company. He served as Captain with the Signal Corps overseas until 1919, when he joined the D. and R. Department of the American Telephone and Telegraph Company. Here he engaged in various phases of toll transmission work. In 1929 he transferred to the Laboratories where he has engaged in studies of new high-frequency carrier apparatus and technique, and their application in particular to the development of coaxial systems.

M. M. Bower

J. E. Corbin received the degree of B.S. in Electrical Engineering from Pennsylvania State College in 1930 and im-

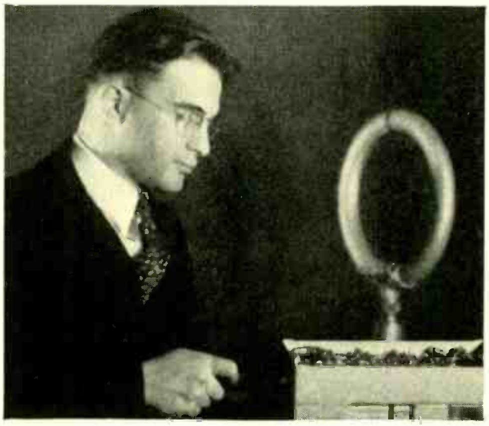
M. E. Strieby

J. F. Wentz

mediately joined the technical staff of the Laboratories. Here as a member of the radio development group he has engaged in the design of radio-frequency distribution systems, and of radio receivers for broadcasting stations and aircraft.

J. F. WENTZ was graduated from Lehigh University in 1917 with an E.E. degree. He then served as first lieutenant in the 35th Infantry before coming to the Western Electric engineering department in 1919. Here he worked for two years on high tension fuses and protectors, and then transferred to the research department. During 1921-1922 he did part-time graduate work at Columbia, receiving an A.B. degree in Physics in 1923. During the development of loaded submarine cables Mr. Wentz worked on cable design and permalloy loading technique. From 1931 to the present time he has had charge of development of coaxial structures, and transmission tests on the New York-Philadelphia coaxial installation.

LEWIS R. LOWRY received the B.S. degree in Electrical Engineering from the University of Washington in 1927, and joined the Laboratories the same year. During college vacation periods he had worked with the Pacific Telephone and Telegraph Company, in machine-switching central-office maintenance and electrolysis surveys. In the Laboratories he has been engaged in the design, erection, and testing of short-wave directive antenna systems.



J. E. Corbin

L. R. Lowry