BELL LABORATORIES RECORD

RADIO ECHOES AROUND THE WORLD
A. C. PETERSON, JR.

G-1 CARRIER SYSTEM
E. C. BLESSING

FIELDS FROM THUNDERSTORMS
K. E. GOULD

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In this Issue

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In verifying mathematical studies of telephone trunking, counters representing telephone trunks are drawn at random from the hopper, to remain on the moving belts during various holding times

MARCH, 1937

VOLUME FIFTEEN—NUMBER SEVEN

Modulation in the G-1 Carrier System

By E. C. BLESSING
Toll Development Department

A NEW member of the carrier family, christened the "G-1 Carrier Telephone," is a single-channel system designed for open-wire circuits ranging from about five to twenty-five miles in length. Power is required and carrier is generated only at one terminal, which for this reason is called the "active" terminal to distinguish it from the other or "inert" terminal. Carrier is transmitted to the inert terminal over the open-wire line for both modulation and demodulation. The general features of the system are shown in the simplified schematic of Figure 1. At the active terminal, voice currents for the carrier channel travel first through a low-pass filter, then through the "modem" unit where they are modulated by carrier from a vacuum-tube oscillator, then through the line filter, which separates the carrier from the voice frequencies, and thence out over the line. Transmission in the opposite direction takes place in a similar manner, the same modem serving both as a modulator and demodulator. The inert terminal is similar to the active terminal except that it has a phase corrector, and the oscillator and power supply are absent.

One of the major developments that have made this simple system possible is the copper-oxide modem unit—a set of copper-oxide varistors which, through their non-linear resistance characteristic, modulate and demodulate by a process of rectification. This unit consists of four varistor assemblies, which are three-quarters of an inch square and three-eighths of an inch thick. The copper-oxide elements used in the modem units are small disks of copper, about three-sixteenths of an inch in diameter and one-thirty-second inch thick, with a layer of cuprous oxide on one side. Such disks have the peculiar property of presenting a low resistance when connected to a source of emf of one polarity, and a high resistance when the polarity of the source is reversed. A typical characteristic of such a disk is shown in Figure 2.

A number of these disks are arranged in a series-parallel group to form a varistor element, and four of these elements are arranged in the form of a Wheatstone bridge as indi-

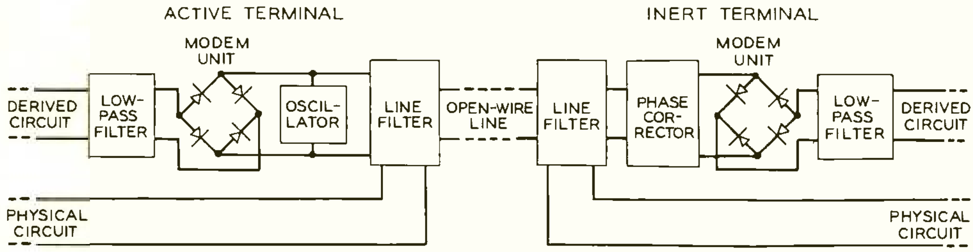


Fig. 1—Simplified block schematic of the G-1 carrier telephone

cated in the illustration. Stripped of all but the bare essentials required for modulation, the circuit would be as shown at the top of Figure 3. Here the oscillator is represented by a high-frequency a-c. generator, and another generator, serving as the source of the voice currents, may be considered as generating a pure tone, giving a simple sine wave. The high-frequency generator has the higher potential, and thus controls the action of the varistors. In explaining the action of the circuit, the varistor elements may be considered as ideal, that is, as offering no impedance with a potential of one polarity across them, and as offering infinite impedance with the opposite polarity. Current will flow through the varistor assembly only when the base of the triangle, which is used as the symbol for the varistor element, is positive.

The two sides of the line are connected to opposite vertices of the bridge, and the varistors in the two branches leading from these vertices are arranged with opposite polarities toward the vertex. Thus in one branch the base of the triangle is toward the vertex, and in the other, the apex is toward the vertex. Only one of these branches can thus be conducting at a time, and the flow of current shifts from one branch to the other with a change in the line polarity. The two conducting paths are indicated by the two lower diagrams of Figure 3. The modem unit thus acts as a two-pole double-throw switch connected as a reversing switch and operated by the oscillator. If the voice generator were a battery, for example, the modem unit would reverse the current flow in the line with each change in polarity of the oscillator, but due to the synchronized action of the modem unit at the other end of the line, the current into the receiving resistance would remain in the same direction.

Through this rough analogy, the modulation and demodulation process may be easily understood. In Figure 4, the two modem units are replaced by two-pole double-throw reversing switches, and the oscillator may be considered as a motor-driven mechanism (not shown on the sketch) to operate the two switches in unison and at oscillator frequency. The generator representing the voice at the transmitting end gives a sine wave, indicated at the lower left, which causes a current to flow to the upper and lower terminals of the reversing switch. This switch, which is being moved back and forth at a much higher frequency than that of the voice-frequency generator, reverses

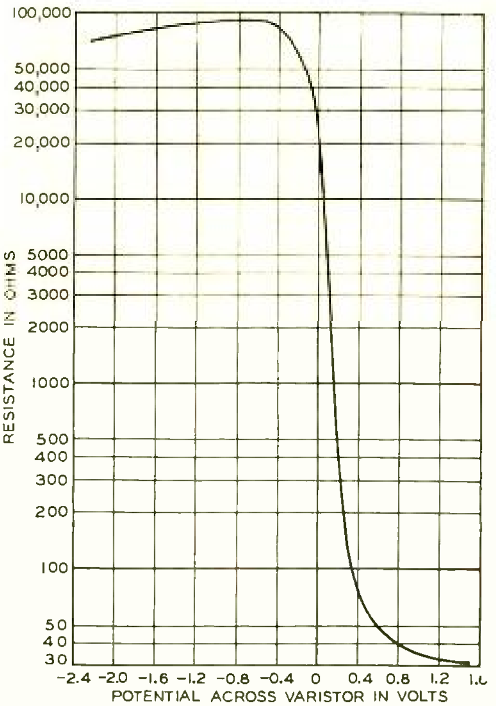


Fig. 2—Typical resistance-voltage characteristic of a copper-oxide disk

the current flow into the line, and gives a wave form as shown in the center of the illustration.

An analysis of this wave into a Fourier series would show that the principal components were an upper and lower sideband of the carrier—or switching—frequency. The action of

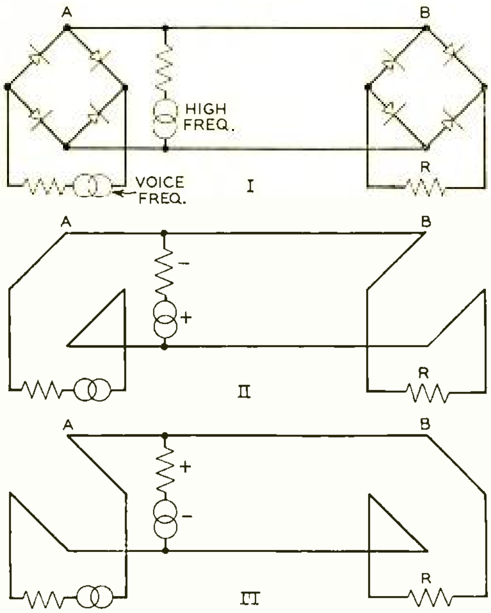


Fig. 3—Through its rectifying properties the modem unit acts as a two-pole double-throw switch

this switch, and of the modem unit it represents, is thus a simple modulation—producing a carrier and two sidebands from a carrier and voice frequency. At the receiving end of the line, however, the switch, operating in unison with that at the sending end, acts as a demodulator, and results in a current flow into the receiving resistance of the same frequency as that of the voice-frequency generator at the sending end. If the transmitting generator and the receiving resistance are interchanged, transmission in the opposite direction will take place in an exactly similar manner.

In this example it has been assumed that the two switches move in exact synchronism. In the actual circuit, however, the driving power is the output of the oscillator, which must be transmitted over the line to control the action of the modem unit at the inert terminal. In passing over the line, the carrier current suffers a phase shift, with the result that the modem unit at the inert terminal does not change its operating condition at the same instant as that at the active terminal, but at some later time. Since the sideband frequencies suffer the same average phase shift, however, this does not cause any difficulty, because the change in condition of the modem unit at the inert end is made at the correct time with respect to the sideband frequencies.

When the inert terminal is transmitting, however, the situation is different. Assuming that the phase shift over the line is θ degrees, the modem unit at the inert terminal will act θ degrees behind that at the active terminal. This phase difference has no effect on the signals put on the line at the inert terminal, and, ignoring the switching or carrier-frequency component, the line current will be identical to I_1 of Figure 4. This current also suffers a phase shift of θ degrees in passing back to the active unit, with the result that there it is 2θ degrees out of phase with the switching action of the modem unit. If θ is 45 degrees or any odd multiple of 45 degrees there will be no output of signal frequency received at the active terminal. If it is 90 degrees or any multiple of 90 degrees the full output of signal current is received at the active terminal.

The reasons for this may be seen by

studying the result of operating switch A (Figure 4) out of phase with switch B. Typical possibilities are shown in Figure 5 where the upper left curve corresponds to the central one of Figure 4. This current, supposed to have been formed by the action of the reversing switch (or the modem unit) at the inert terminal, has passed over the line to the active terminal and is ready for demodulation. With perfect synchronism between the two switches (no phase shift in the line) the switch will operate at positions A, B, C, D, etc., and by reversing the direction of flow at those points will give the true signal current shown immediately below it, where the reversed sections of current are shown dotted.

With a 45-degree phase shift in the line, the inert unit operates 45 degrees behind the active unit because of the phase shift suffered by the carrier. The modulated wave, already shifted 45 degrees because of this fact, is shifted another 45 degrees in transmission back to the active terminal and thus arrives there 90 degrees behind the operation of the switch. Instead of operating at points A, B, C, etc., therefore, the switch operates at a, b, c, etc., that is, 90 degrees ahead of these points. In operating at "a" it reverses the section of current from "a" to "A." At "A" it does not operate but the current on the line reverses at that point, which gives the effect of a reversal. Operation at "b" again gives a reversal and so on. The result, shown at III of Figure 5, is a current whose principal components are sidebands of double the carrier frequency, and no signal frequency is present since at signal frequency each positive pulse of current is offset by an approximately equal negative pulse.

When the phase shift of the line is 90 degrees, however, the modulated current will arrive at the active terminal 180 degrees behind the switch (or modem) action. Thes witch operation that took place at "A" with perfect synchronization (curve II) will now take place at "O," so that the first pulse of current will be reversed. The next switching operation

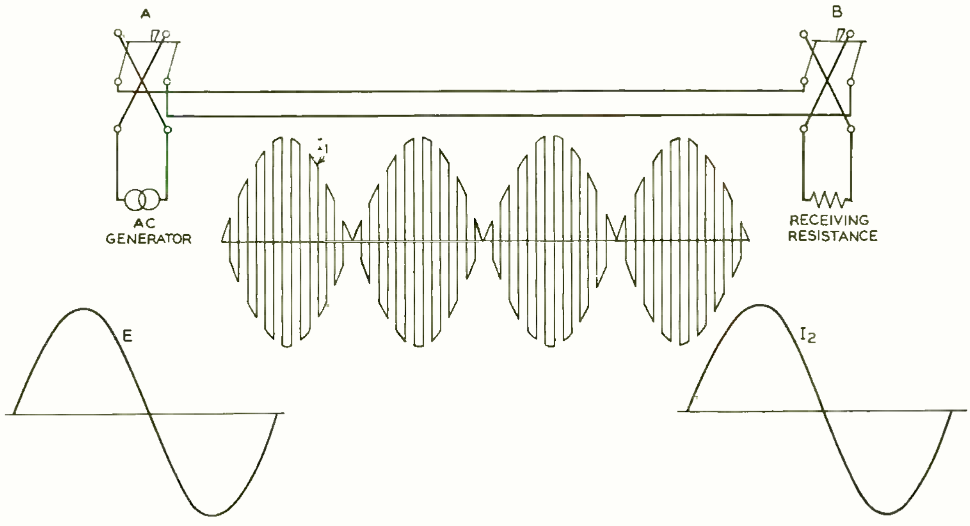


Fig. 4—Through the action of the modem units and the carrier, a voice potential E results in a current I_1 in the line and a current I_2 in the receiver at the other end

will take place at "A" but as the current in the line also changes direction at this point, the direction of flow will not change in the receiving circuit. The overall result is the curve shown at IV, which is the true signal current. It is shifted in phase 180 degrees with respect to the original signal, but this does not affect the sound received, which is a function of frequency rather than of phase.

Because of these facts, a phase shifter is incorporated in the inert terminal, and is adjusted to build out the phase shift of the line to approximately 90 degrees or some multiple thereof. The combination of line and phase shifter thus causes a phase shift of approximately 90 degrees, and as a result the maximum amplitude is always obtained in the output.

While the general principle on which the system operates is fairly simple, considerable development was required to meet the requirements placed for the class of service required of it. The G-1 carrier system employs no amplifiers, and as a result every effort has been made to keep down the losses. Since an appreciable proportion of the total loss occurs in the modem units, considerable time was spent by the Research Department in developing manufacturing methods that would produce varistors of high efficiency. An extended study was also required to determine the number, size, and arrangement of the copper oxide disks in the modem unit. Precautions had to be taken also to pro-

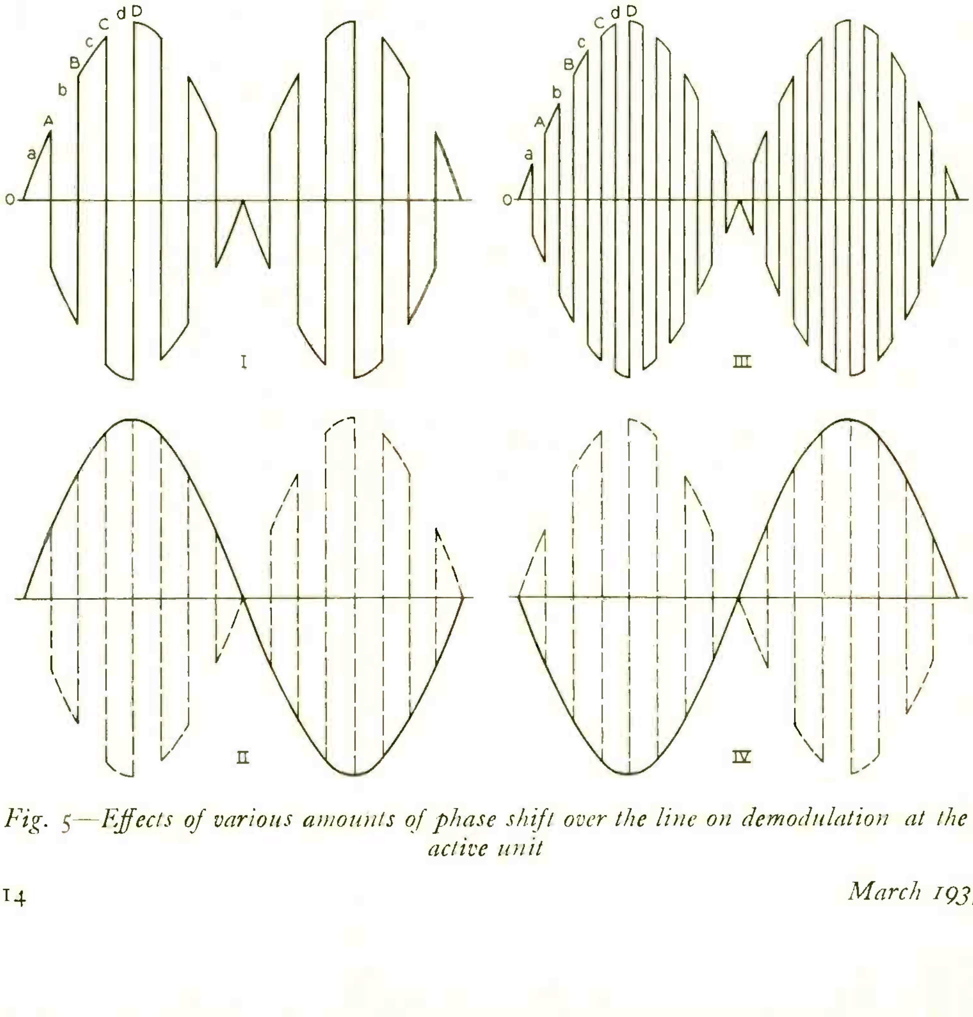


Fig. 5—Effects of various amounts of phase shift over the line on demodulation at the active unit

tect this unit from high voltages, which would break down the active surfaces. This is accomplished by a neon tube connected across the line side of each modem unit. These tubes cause practically no loss to the transmitted currents, but effectively short-circuit the modem units when the voltage on the line rises above a critical value.

Considerable study was also required to make the oscillator, which is bridged across the line, present a high impedance, and thus not to produce serious transmission losses. Power for the oscillator is obtained from the commercial a-c. supply through a copper-oxide rectifier unit incorporated in the active terminal. To prevent voltage variations in the commercial supply from causing undesirable variations in the carrier potential, a voltage stabilizing circuit was incorporated, consisting of a silicon-carbide varistor bridged across the secondary winding of the oscillator coil.

The G-1 carrier telephone system was designed primarily to provide a compact, inexpensive, easily installed system for operation over relatively short lengths of open-wire line. Its loss-frequency characteristic is indicated in Figure 6, which shows a typical characteristic for a system operating over a 25-mile open-wire line with 600 feet of 22-gauge cable at each end. Its simplicity, performance, and cost are such as to make it suited to short-haul applications.

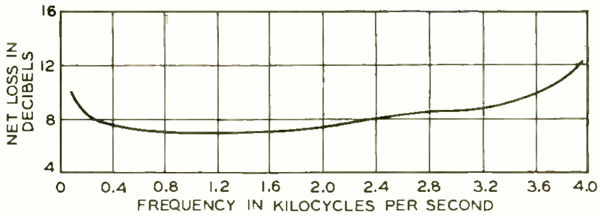
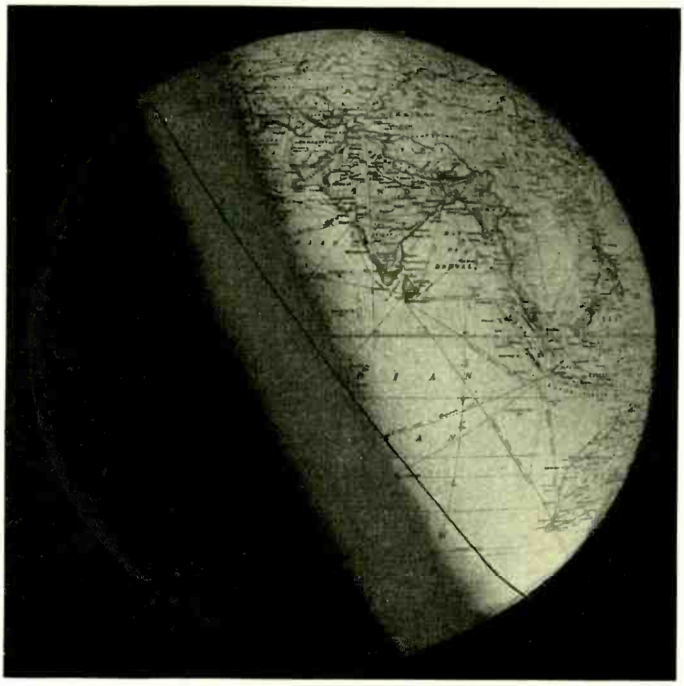


Fig. 6—Typical loss-frequency characteristic of the G-1 carrier telephone



Around-the-World Radio Echoes

By A. C. PETERSON, JR.
Radio Transmission Development

SINCE the earliest experiments with long wire telephone circuits, echoes have been a source of annoyance. They are normally caused by the reflection of energy at impedance irregularities along the transmission path. In radio transmission, where the signal energy is confined only by the earth and the ionosphere, echoes are caused by the signal arriving at the receiver after travelling over different paths. Since these paths may differ considerably in length, there is a corresponding difference in the time of arrival of the signals, and thus the effect on reception is similar to that of echoes caused by reflection on wire lines.

Radio waves passing between two points on the earth follow great circle paths, that is, paths lying wholly in a plane determined by the two points and the center of the earth. For any two points which are not diametrically opposite each other there is only one such plane, but there are two directions that a radio signal can take in passing from one point to the other. This is illustrated at the left of Figure 1 for transmission from London to New York. One path extends westerly from London in the great circle plane, and the other follows a reverse track around the earth in an easterly direction from London. The direct signal, having much the shorter distance to travel, reaches New York first, while the reverse-path signal, travelling farther, arrives later, and appears as an echo.

Besides these two paths in opposite directions there are also echo paths due to signals passing the receiver, completely encircling the earth one or more times, and being received again on each transit at a diminishing intensity. A signal may start easterly from London, reach New York, and then continue on around the world one or more times before it becomes inaudible. Such echo paths are illustrated in the center of Figure 1. A signal may also start westerly from London, and after reaching New York continue on around the world as indicated at the right of the illustration. From the point of view of the receiver, echoes fall into two groups: one group, called front around-the-world echoes, reaches the receiver from the same direction as the direct signal; the other group, including the reverse-path and rear around-the-world echoes, is received from a direction 180 degrees from the direct signal.

Short-wave transmission over long distances depends largely on the reflection of the waves back and forth between the earth and the ionized layer high overhead. The reflecting behavior of the ionized layer is a function of both the frequency of the waves and the exposure of the layer to light from the sun. When the ionized layer is in darkness, frequencies above about 10,000 kilocycles are not reflected for the most part, and thus long-distance transmission at these higher frequencies becomes poor. When the layer is illuminated, however, these frequencies are reflected, and long-distance transmission becomes possible. As a result of these facts it is common practice in radio transmission to use the higher frequencies for daylight conditions over the transmission path, and the lower frequencies for nighttime conditions. For the transition period between dark and daylight, frequencies in the neighborhood of ten thousand kilocycles are employed.

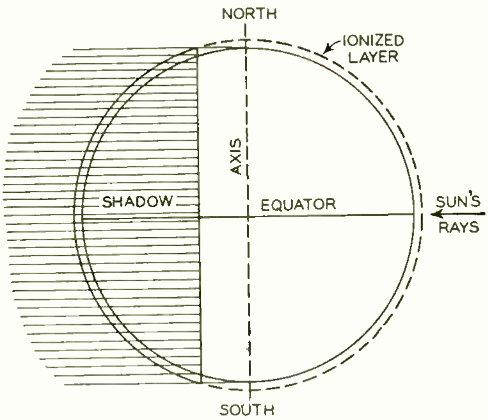


Fig. 2—One-half of the surface of the earth is always illuminated by the sun, but at an altitude of 150 kilometers the illumination extends about 12 degrees beyond the illuminated surface of the earth, as shown above

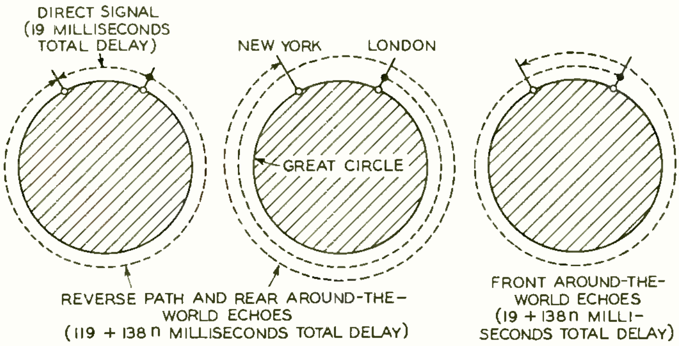


Fig. 1—A radio signal from London to New York may cause an echo by travelling around the world in either a westerly or an easterly direction, and in either direction it may encircle the earth one or more times

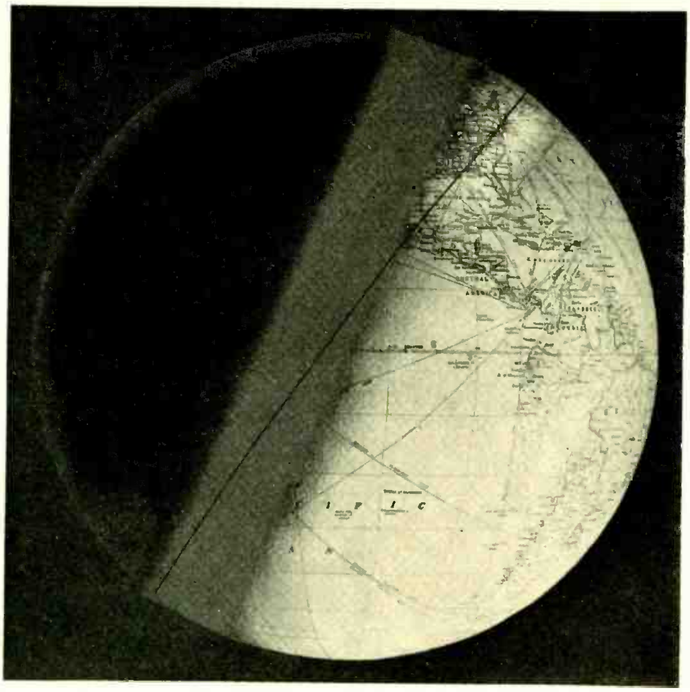


Fig. 3—Lighting conditions for the position of the earth at 1:30 *p.m. Greenwich Mean Time for December* 21

Since the altitude of the refracting layer is from 100 to 250 kilometers, an around-the-world signal path is never entirely in darkness so that frequencies much below 10,000 kilocycles seldom experience around-the-world echoes. On the other hand, there are times of the year when certain paths may be completely in daylight. Under these comparatively uniform and favorable conditions of illumination, there is every likelihood that around-the-world echoes will be prevalent at higher frequencies.

Illumination of the ionosphere beyond the shadow line at the earth's surface is illustrated by Figure 2, which represents conditions when the earth's axis is at right angles to the sun's rays. This occurs around March 21 and September 21. During winter in the northern hemisphere, the north pole is tilted about 23 degrees away from, and in summer the same amount toward, the sun. The tilt is such that only great circle paths passing within some 4000 kilometers of the poles are ever totally illuminated at ionized layer heights

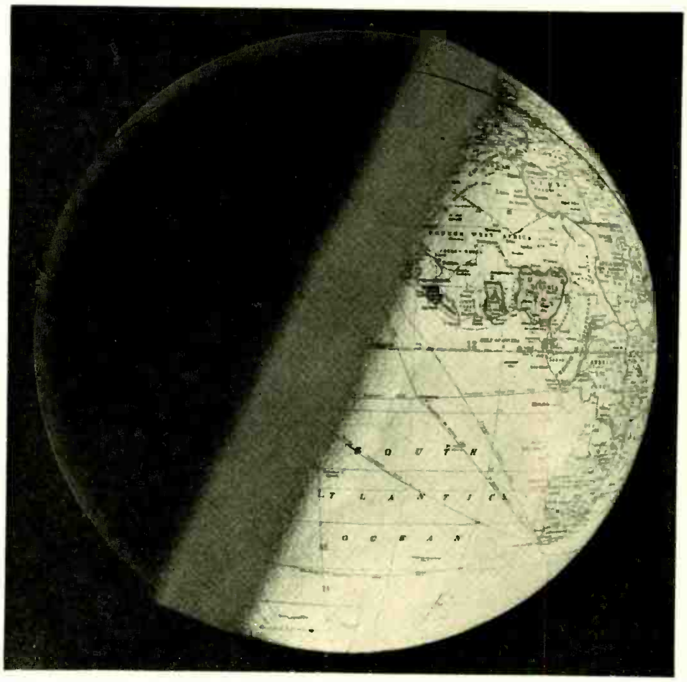


Fig. 4—Lighting conditions for the position of the earth at 7:30 *a.m. Greenwich Mean Time on December* 21

of 150 kilometers. It is not to be expected, therefore, that echoes will occur frequently on around-the-world paths that are more than this distance from the poles. The time of day and season of the year when they are most apt to appear on favorable paths may be readily determined by computation.

At an altitude of 150 kilometers the great circle path between New York and London is entirely illuminated around June 21 and December 21 at certain times of the day. The accompanying photographs of a globe illuminated by sunlight illustrates the seasonal shift of sunlight effects. The light areas in each case correspond to illumination at a height of 150 kilometers. The picture at the head of this article represents conditions at 1:30 A.M. Greenwich time on June 21, and Figure 3 shows conditions at 1:30 P.M. December 21. At both these times the great circle path between New York and London, which is marked on the globe, is entirely illuminated; around 7:30 A.M. and at 7:30 P.M. on any day of the year only about sixty per cent of the path is illuminated, as shown in Figures 4 and 5. Curves showing the percentage illumination of the New York-London path for the various months are illustrated by Figure 5. Observations indicate that the average intensity of the echoes varies in about the same way as the percentage illumination. Although total illumination occurs on paths through New York and Buenos Aires, around-the-world echoes are only rarely encountered here because

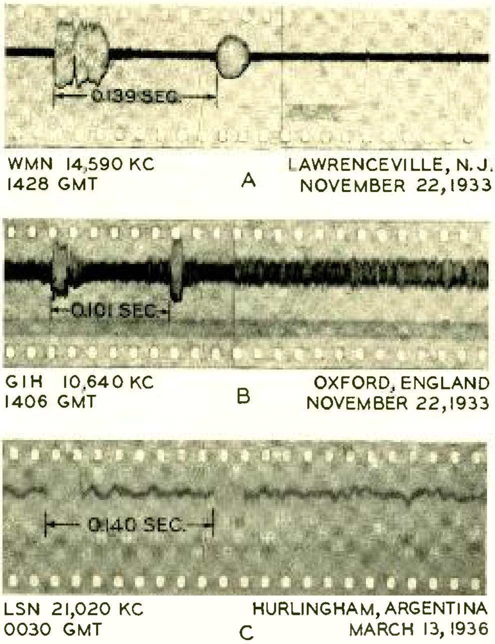


Fig. 6—Around-the-world echoes as they were recorded at Netcong, New Jersey

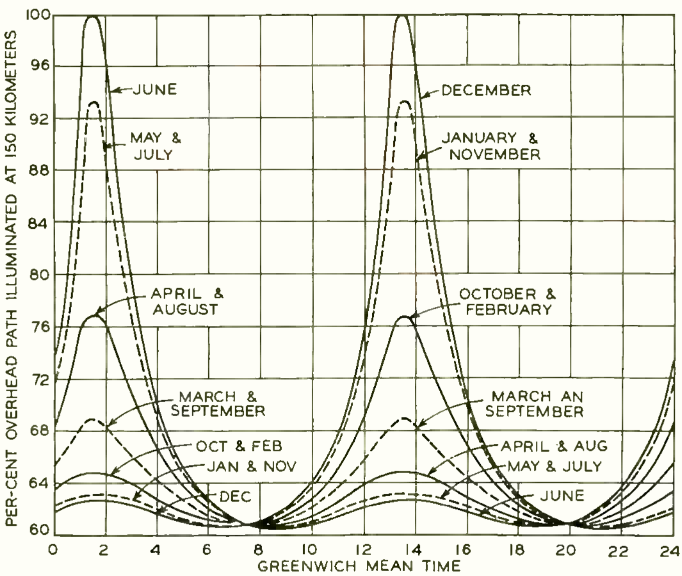


Fig. 5—Percentage illumination of the around-the-world great circle path from London to New York for various months of the year

these paths have to pass over the polar regions where the attenuation is great. The most likely time of occurrence is around the equinoxes, and echoes are then occasionally observed.

Due to the long around-the-world path, the echoes described above are considerably attenuated even on occasions when conditions are favorable for their transmission. The echo signal is rarely found to have a serious effect on the intelligibility of fixed-carrier radiotelephone circuits.

Oscillograph records made at Netcong, New Jersey, of around-the-world echoes received on various short-wave radio circuits are shown in Figure 6. When the receiver and transmitter are located close together, the direct signal will have a negligible time of transmission, while the around-the-world echo will be delayed by about 138 milliseconds. This is shown by A of the illustration. For a reverse-path echo, the difference in time of reception is the difference in the lengths of time required for the signal to go around the reverse path and along the direct path. For the London to New York circuit this amounts to the difference between 119 and 19 milliseconds or 100 milliseconds, and is illustrated at B. For a front around-the-world echo, illustrated at C, the difference in time of reception will be the time required for the signal to encircle the earth. Assuming that the signals travel at the velocity of light, the actual measured echo delays would require a path length about three and three-tenths per cent greater than the circumference of the earth.

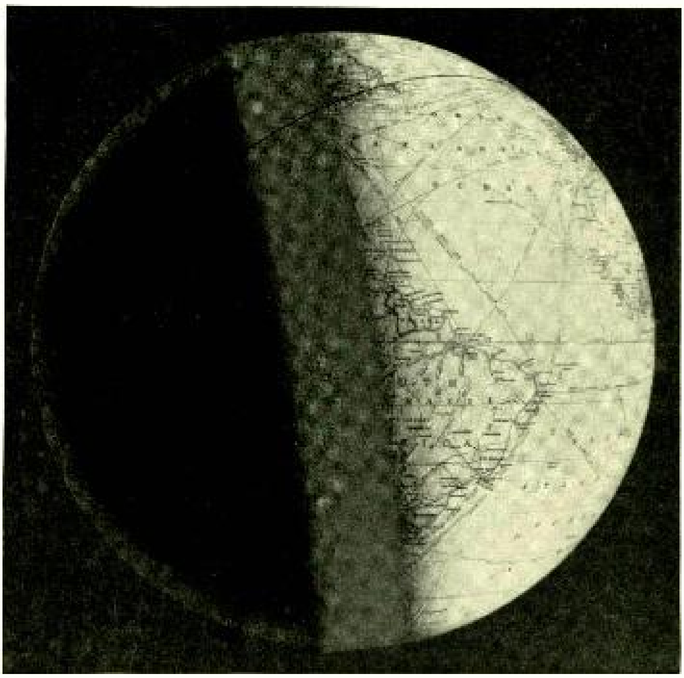


Fig. 7—Early morning in April or September

Fields Caused by Remote Thunderstorms

By K. E. GOULD
Protection Development

TELEPHONE lines are known to experience occasional disturbances from lightning and also from accidental short-circuits on power lines. Under some circumstances, it may be difficult to tell whether an observed disturbance comes from the one or the other. If there were no thunderstorms in the locality at the time, it might seem that the disturbance must have had its origin in a transitory upset of normal operating conditions in some neighboring power system. But this would not be a correct inference if thunderstorms at considerable distances are capable of producing, in telephone lines, disturbances of the same general character as those in question.

Thunderstorms set up transient electromagnetic waves which are propagated in all directions and which, if picked up by telephone wires, would appear as induced voltages. If these local disturbances are actually due to distant storms, it is reasonable to assume that this fact could be established by determining, with suitable circuit arrangements, the locality from which the disturbances come, and comparing the storm centers thus found with the storm areas shown on the weather map for the corresponding time. This was done in a recent investigation in which the writer participated.

The method of measurement used was to determine the voltages induced in grounded circuits by the distant storm. These circuits, or "probes," consisted of two wires several hundred

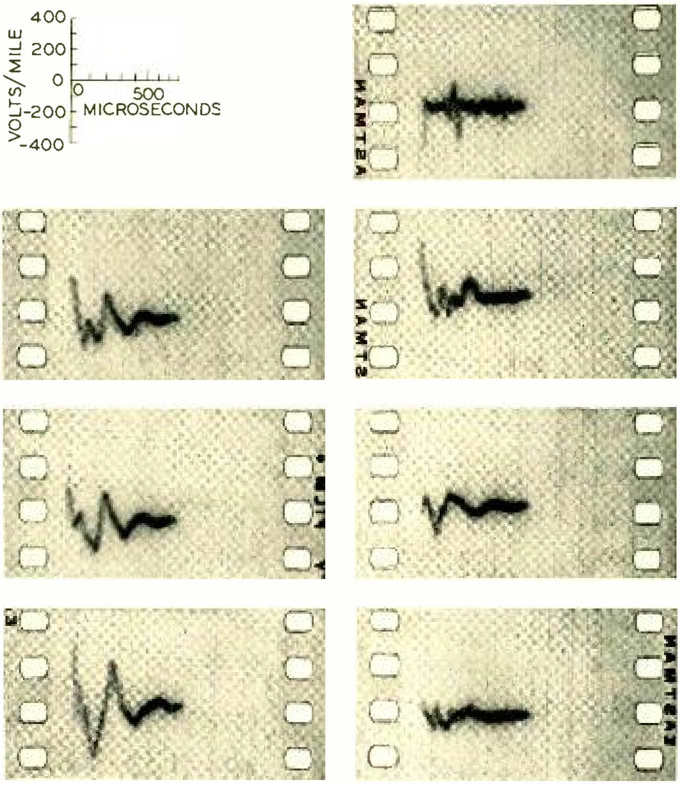


Fig. 1—Characteristic wave-forms of voltages which were induced in telephone circuits by distant lightning storms

feet long located at right angles to each other. The voltage induced in each line was applied, after amplification, to one of the pairs of plates of a

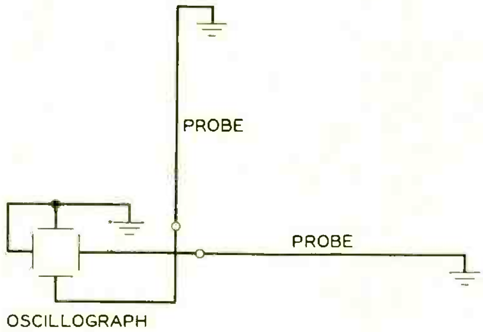


Fig. 2—The test circuits comprised two wires, called "probes," each several hundred feet long located at right angles to each other

cathode-ray oscillograph. The direction from which the disturbance came could then be determined by measuring the slope of the oscillograph image obtained, which was, in general, a straight line. By providing two sets of probes located several hundred miles apart and making directional measurements at both places simultaneously, a base line was established from which the location of the storm could be found by triangulation. It was principally in the use of the short earth-return circuits instead of loops or spaced aerials, and measuring equipment which responded to a wide band of frequencies, that the present work differed from that of other investigators.

In the summer of 1934, the measurements described were made at various pairs of points in different parts of the country. Whippany, New Jersey, was used in all the tests as one of the pair of test stations and for the second location points were chosen at which it was thought that the fields produced by remote thunderstorms would be particularly large. These

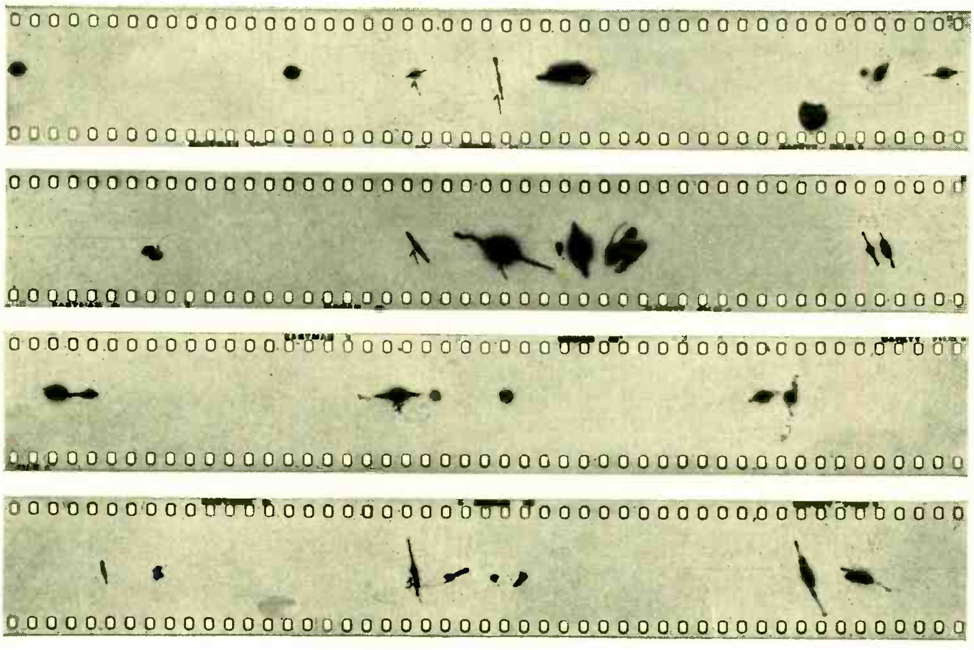


Fig. 3—Oscillographic records were made of the voltages induced simultaneously in the two test circuits

were at Cadillac, Michigan; Eau Claire, Wisconsin; Atlanta, Georgia; and Hagerstown, Maryland. Base lines in substantially different directions were thus made available for the triangulation measurements.

The essential features of the equipment employed in making these directional measurements are illustrated in Figure 2. The probe lines were 2000 feet long at Whippany and 500 feet at the other points. Amplifiers were inserted between the probes and the cathode ray oscillograph, so that satisfactory oscillographic deflections could be obtained. These amplifiers were designed to have an almost constant gain for frequencies from 1 kilocycle to 40 kilocycles and the phase shifts of the two amplifiers used with a single oscillograph were practically the same at any given frequency in this range. The cathode-ray oscillograph was of a portable type with a sealed-off glass tube and it had an external photographic recorder.

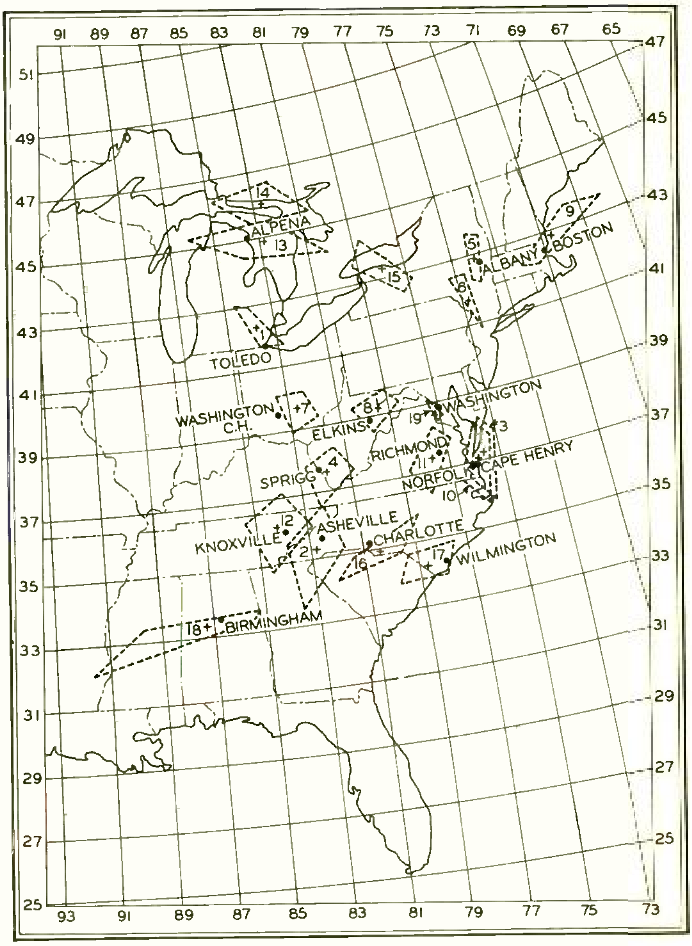


Fig. 4—Storm areas found by electrical measurements agreed with storms reported by the weather bureau

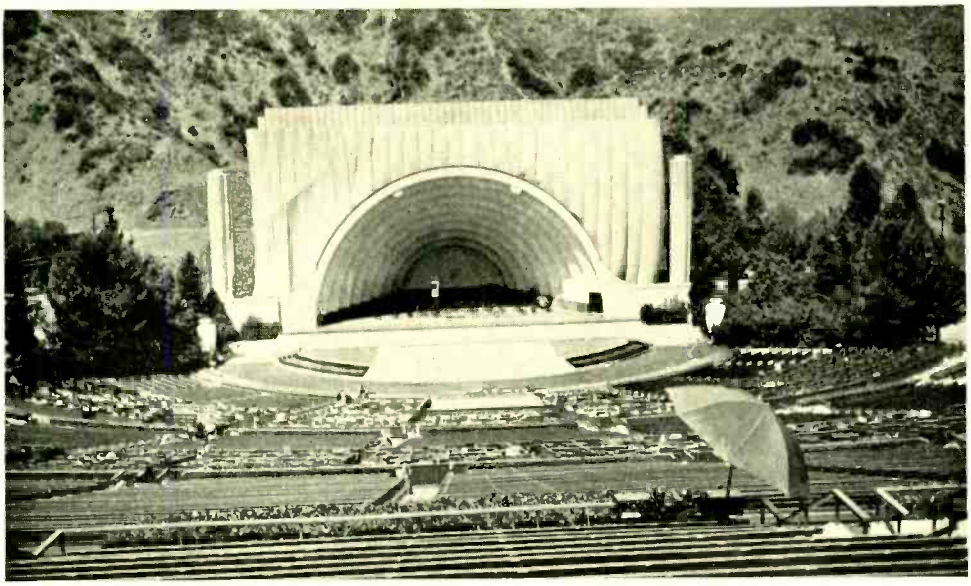
Some typical oscillographic records from the Whippany and Cadillac tests are shown in Figure 3. The direction of propagation of the transient field can be found from the slopes of the straight lines. Some of the records were open figures. These were caused by complex field changes and could not be used in the analysis of the data. The upper film gives the directional measurements at Whippany which were made simultaneously with those at Cadillac as shown on the second film. The third and fourth films are similar to the first and second, respectively.

Figure 4 shows, as crosses inside the dotted quadrilaterals, the locations of the storms found by the triangulation measurements. Each of these locations was indicated by a number of concurring records. The storms numbered 1 to 11, inclusive, were located from the Cadillac tests, 12 to 14 from the Eau Claire tests, 15 to 18 from the Atlanta tests and 19 from the Hagerstown tests. The quadrilaterals indicate the areas over which it seemed advisable to look for thunderstorms to correlate with the respective locations shown by the directional measurements. They represent areas bounded by the directions ±5 degrees from the average direction indicated by these measurements. Thunderstorms which agreed most closely in location and time of occurrence with the results of the triangulations are shown in Figure 4 by small circles. They were taken largely from detailed reports of the United States Weather Bureau. The correlation obtained between the triangulation measurements and reported thunderstorms was satisfactory, particularly since it was impossible to obtain complete thunderstorm reports from stations spaced closely enough to permit every thunderstorm to be reported and its location at any given time made known.

In the Cadillac tests, an intensive study was conducted for four days. Satisfactory testing periods occurred only occasionally, and even under the most favorable circumstances the only storms which could be located were the few which produced the larger disturbances at both triangulation stations. The locations shown by these measurements nevertheless could be correlated definitely with the changes in thunderstorm areas from day to day. When they were plotted on the daily weather maps for the corresponding days, it was found that they fell consistently within the thunderstorm areas shown by the maps.

These studies confirm the assumption that short-duration disturbances, which are occasionally met on telephone lines, may sometimes be caused by thunderstorms several hundred miles away. It is significant that, because of their short duration, these disturbances are limited in energy and would appear to have inconsequential effect on message circuits.

Medal of the American Institute of the City of New York, presented to the Laboratories on February 4, 1937



Sound Reinforcing System for Hollywood Bowl

By A. R. SOFFEL
Physical Research

ON the occasion of the first demonstration of the reproduction of orchestral music in auditory perspective at Philadelphia in 1933* Dr. Jewett said in part, "What we have done is to produce pick-up microphones, amplifiers, electrical filters, transmission lines and loud-speaking reproducers so perfect that the entire frequency and volume range of the most exacting orchestral and vocal music can be reproduced at a distance without impairment of quality. We have also worked out the arrangements by which substantially perfect auditory perspective is possible. . . . These new tools offer not only an enlarged field of possibility to the musician and the composer for the production of auditory effects, but likewise a great broadening of the audience which derives pleasure from such effects."

A new demonstration of the potentialities of this equipment was given at the Hollywood Bowl in California last August, when the reproduction of orchestral music in auditory perspective was heard for the first time out-of-doors with the orchestra present. The occasion was a concert presented by Paramount Pictures with Leopold Stokowski acting as the conductor. The special equipment required was developed by the Laboratories and installed by Laboratories and Electrical Research Products engineers.

The Hollywood Bowl is a natural amphitheatre situated in a hollow surrounded by low hills. Oval in form

*Record, *May*, 1933, *p.* 254.

with the stage at the lower end, its tiers of seats rise in curved rows up the sloping hillside at an inclination of about 12 degrees. It seats 22,500 persons. The orchestra plays in a large conical sound-reflecting shell on the stage. This shell raises the sound level effectively in the front and central portions of the seating area but not adequately in the side and back sections.

To correct these inequalities in sound distribution and to increase the general level of the music throughout the Bowl a multi-channel reproducing system was installed. This system also offered the additional advantages that special effects could be obtained with it by changing the volume and sound quality with manual controls and that the loudness of the singers or solo instruments could be increased relative to the orchestra.

In providing such equipment for the Bowl, conditions not previously encountered in indoor auditoriums had to be met. Since no walls or ceiling were present to reflect sound, arrangements had to be made to direct all of the low as well as the high frequencies toward the audience. Moreover, since the loudspeakers had to be placed near the orchestra to create the illusion that the sound all came from the orchestra, care had to be taken to prevent the sound from the loudspeakers from feeding back into the microphones, which would cause singing. These and a number of similar difficulties were overcome by using new equipment particularly designed for the demonstration.

The general plan of the system as installed was to provide three microphone positions in front of the orchestra: one at the left side, one in the center, and one at the right side. A separate amplifier-channel of high power was provided for each of these positions and the output of each channel was connected to separate loudspeakers mounted above the or-

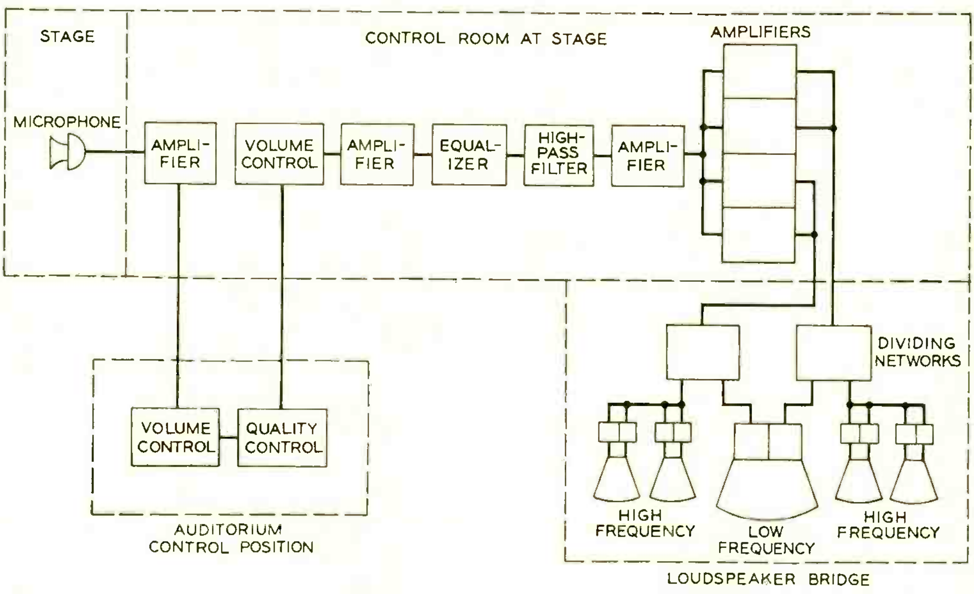


Fig. 1—A typical stereophonic channel—three like this one were used in the Hollywood demonstration

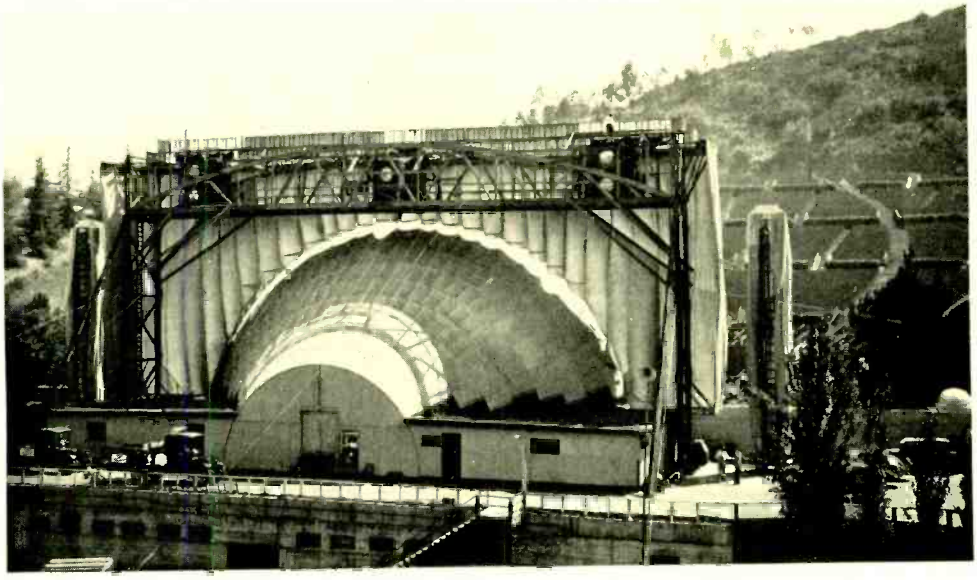


Fig. 2—A bridge structure was erected to hold the two and one-half tons of loudspeakers that were used in the Hollywood demonstration

chestra-shell in positions corresponding to the microphones. Six microphones were used on the three channels. Two were connected in parallel on the left channel to give a satisfactory balance for the cellos, harps and bass viols, because the microphones had to be placed close to these instruments to avoid feedback. Two were located at the center so that one would be available to switch in instead of the regular microphone for vocal soloists. At the right, in addition to the regular microphone, there was an extra one out in front of the shell. This was used for harp and cello solo numbers instead of the regular microphone. The volume controls were located in the center of the seating area about three hundred feet back from the shell, and at this position the gain of all three channels could be varied by one control. When the soloist's microphone was switched to the center channel, however, a separate volume-control was provided for it so that the level of the voice could be changed independently of that of the orchestra. Quality control made it possible to accentuate the low frequencies and temper the very high frequencies and an equalizer compensated for the characteristics of the loudspeakers, microphones, and air-transmission path. The amplifiers were adjusted to keep the system below the "singing" point at all times. The acoustic power output of the side channels was two hundred watts per channel and that of the center channel half that capacity.

The loudspeaker groups on the sides consisted of four multiple-unit high-frequency horns each driven by two receivers. These were mounted above two low-frequency units, like those used in the Philadelphia-Washington demonstration, which were placed one on top of the other with a common extension. This extension presented an area of ten by twelve feet at the mouth which made the low-frequency units directive down to fifty cycles. The sound beam of the

Fig. 3—Dr. Harvey Fletcher and W. B. Snow at the control station of the sound reinforcing system

horns, both low- and high-frequency, was about eighty-five degrees wide and fifty degrees high. The center loudspeaker group comprised two high-frequency horns and only one low-frequency unit, which was built out to ten by ten feet in mouth area. The field current supply to each side group consisted of three power units, while two units supplied the current for the center group.

To mount these two and one-half tons of loudspeakers above the orchestra shell it was necessary to construct a bridge structure 112 feet long and twelve feet wide, forty-five feet above the ground. The center speakers were directly above the center of the shell and the side speakers were each forty-five feet from the center of the bridge. The bridge was artistically draped and lighted, which added not a little to the appearance of the shell. All amplifier and circuit equipment was mounted in a room at the stage.

After the system had been installed, acoustical measurements were made with a high-speed level recorder at various places over the seating area of the Bowl and the horizontal angle of the high-frequency horns was adjusted to direct more of the sound to the back seats than to those in front. This resulted in a fairly even distribution of sound over the seats; 10 db was about the greatest difference between any two positions. The maximum gain settings were found with no audience in the Bowl. With an audience, however, four or five db more gain could be used without trouble from "singing."

In actual tests with the orchestra present an increase in sound power of forty times (sixteen db) was obtained when the gain of the system was set at maximum. Although ordinarily this much amplification was neither used nor desirable it was available to accentuate crescendos. Even in the first row of seats where the sound of the orchestra itself arrived a fraction of a second before that from the loudspeakers, the illusion that all the sound was coming from the performers was still strong. At the rear of the Bowl, one-tenth of a mile from the stage, the music level was at full volume; and for the first time vocal soloists could be heard satisfactorily.

This demonstration was a good illustration of how telephonic research can help to expand the horizon of music. The multi-channel reproducing system described here gives to an orchestra a covering power previously unattainable and makes possible fortissimo effects which could not be duplicated by the simultaneous efforts of hundreds of musicians.

A New Timing Motor for Oscillographs

By E. R. MORTON
Special Products Development

ONE of the problems in the design of oscillographs is that of providing an accurate timing scale. With the rapid record oscillograph* this is accomplished by a motor-driven timing disk which, by interrupting a light beam every thousandth of a second, superimposes timing lines on the oscillogram. For precise work it is customary to estimate time between the lines to 0.0002 second, so that it is essential for the lines to be very accurately spaced. The timing disk itself can be readily made to the desired accuracy; the chief difficulty is in securing a motor that runs at a sufficiently uniform speed. A synchronous impulse type motor is employed, and its speed is controlled by a hundred-cycle tuning fork which interrupts the current to the stator coils. Any motor of this type has a tendency to "hunt"—that is, to oscillate slightly from its mean position as it rotates. Although the motor that has been used for this purpose has proven fairly satisfactory, a new motor has recently been developed which has the advantage of greater ease of starting, and considerably greater torque and stability.

A diagrammatic representation of the original design of motor and its driving circuit is shown in Figure 1. Current from a battery is switched alternately back and forth to the windings of the upper and lower electromagnets by the action of the controlling tuning fork. With the motor running at synchronous speed, current is connected to the upper windings as two of the rotor poles are approaching the pole-pieces of the magnets. Flux induced by the current, indicated by the dotted arrows, attracts the rotor poles and thus provides a driving torque. As these poles reach the centers of the pole-pieces, the current is switched to the lower magnet winding, so that the two poles then approaching the lower pole-pieces will be attracted in a similar manner. This alternate switching of the stator current provides the driving torque and keeps the motor at the correct synchronous speed.

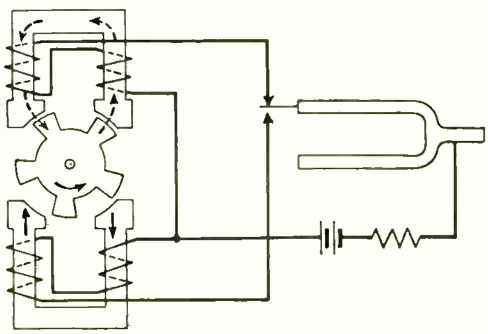


Fig. 1—Diagrammatic representation of the motor and circuit originally employed as a timing motor for the rapid record oscillograph

The appearance of the motor with front cover plate and bearing removed may be seen in Figure 2. Hunting was reduced by a "loose" flywheel on the rotor shaft, which tends to damp out changes in the rotor speed.

*Record, *August*, 1930, *p.* 580.

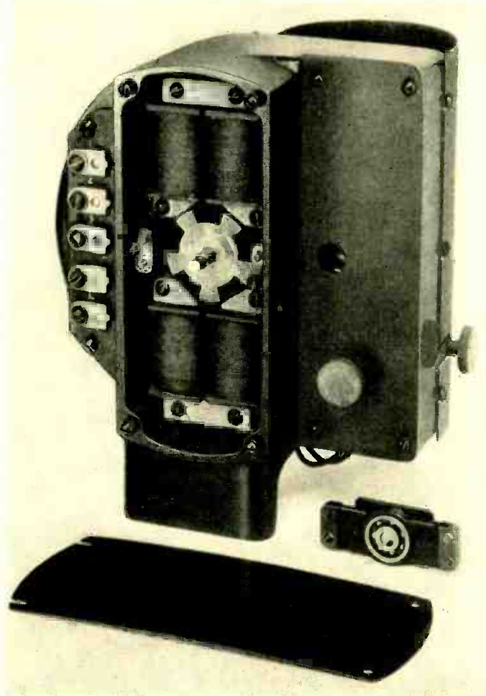


Fig. 2—Arrangement of the original timing motor

A resistance was used in series with the battery to protect the motor windings from burning out should the tuning fork contacts stick.

It had been discovered some years ago that a condenser connected in series with the winding of such a motor, of a capacity slightly less than that required for resonance, provided powerful electrical damping, and thus improved the stability of the motor. This principle was incorporated in the new motor. With a condenser in the circuit a transformer is employed to couple the rapidly reversed current of the battery to it. Instead of arranging the four windings into two parallel circuits, they are connected in series in a single circuit, as shown in Figure 3, but so poled that the flux in the two left-hand windings is in the same direction but opposite to that in the two right-hand windings. A permanent magnet field is employed to increase the efficiency and stability of the motor.

The flux due to this permanent field is always in the direction indicated by the solid arrows, while that from the electromagnets is alternately in the direction of the dotted arrows and in the reverse direction. Under the conditions shown, the flux due to the electromagnets assists that of the permanent magnets in the two left-hand poles and opposes it in the two right-hand poles. Since the maximum flux caused by the electromagnets is about equal to that of the permanent magnets, there is double strength flux in the two left-hand cores and zero flux in the two right-hand cores.

The spacing and positioning of the poles have also been changed so that two of the poles on the rotor are just approaching the two left-hand pole-pieces when the net flux tends to build up in the left-hand magnets. By the time the next reversal of current occurs, there will be two poles just approaching the right-hand pole-pieces. The general action is thus similar to

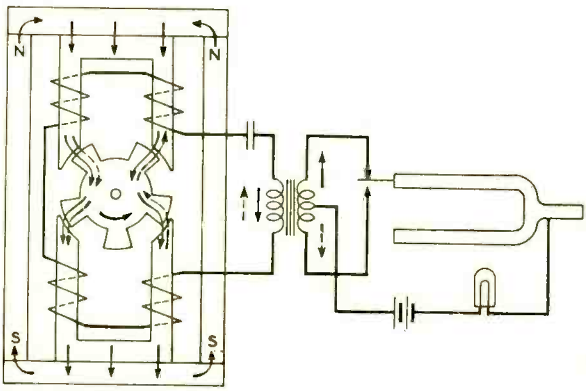


Fig. 3—Diagram for the new type of timing motor

that of the earlier motor except that driving action takes place at the two left-hand or the two right-hand poles instead of at the two upper or two lower pairs of poles. Since the force applied to the rotor is proportional to the square of the flux, this type of motor is materially more powerful than the earlier type because of the superposition of a permanent-magnet field on the electro-magnetic field.

Details of the design were worked out so that the new motor would fit into the housing of the former motor, and space was found for the permanent magnets as well. There are four of these in bar form, as shown in the lower part of Figure 4. They lie across the face of the motor, over the bearing, and are clamped by crossbars at the top and bottom. Besides the major changes in the new design, a tungsten lamp was substituted for the resistor in the battery circuit. The lamp has the advantage of having a low resistance at ordinary temperatures, but with the high temperature that would be caused by a short circuit, the resistance increases several fold. In this way adequate protection is provided without material loss in efficiency.

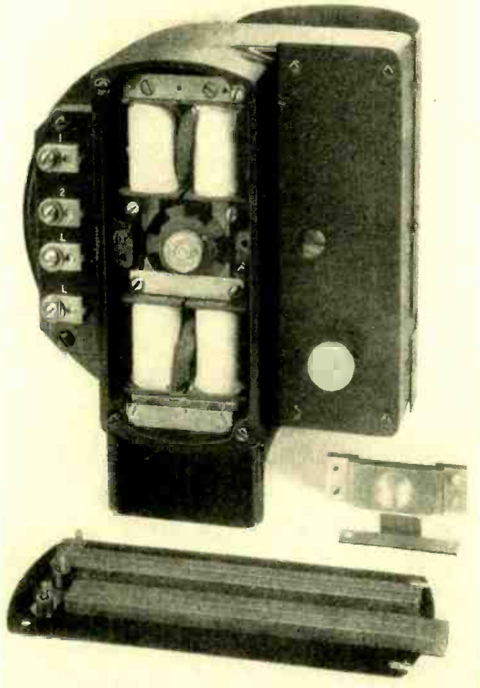


Fig. 4—The new timing motor employs permanent magnets, and the pole faces are differently shaped and positioned

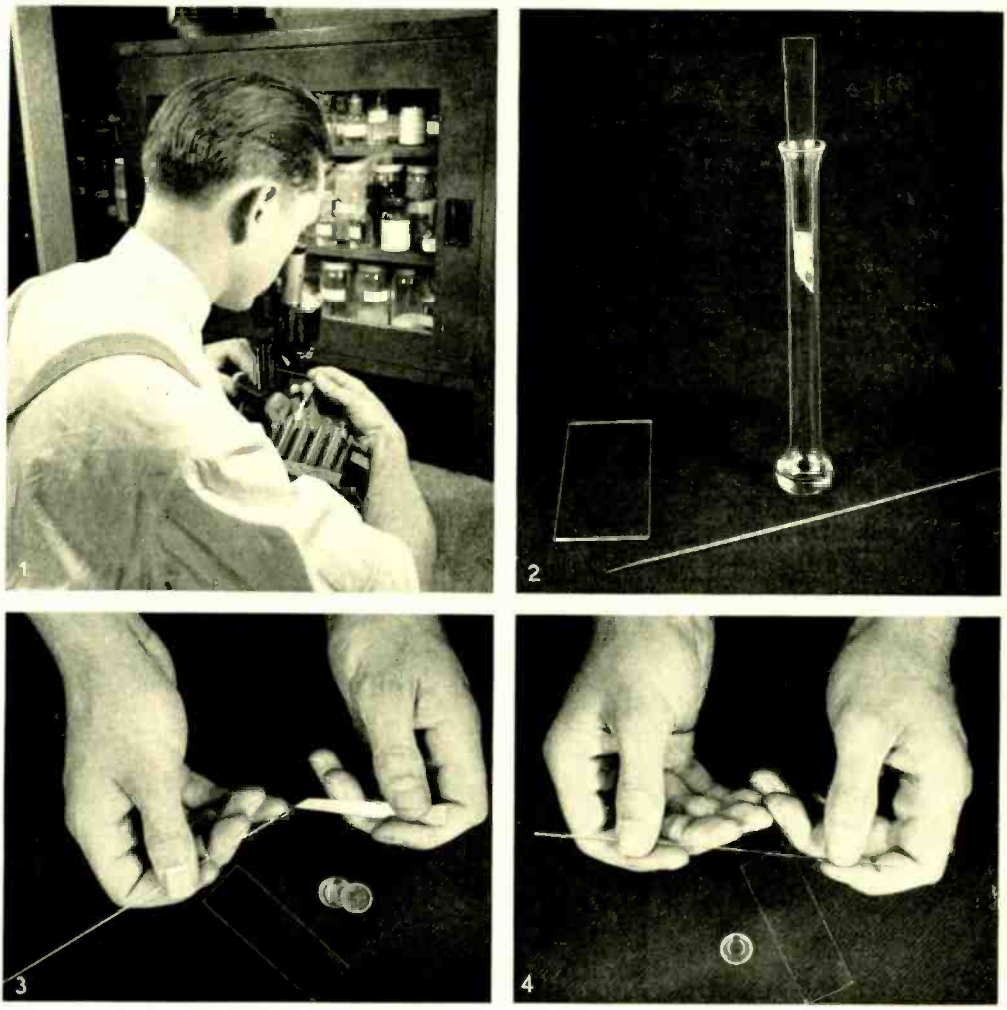
The new motor has been found to meet all performance requirements satisfactorily. It synchronizes easily and no sustained oscillation or hunting has been found.

An Aftermath of the New England Floods

"There could be no finer illustration of Bell System resourcefulness and unity than the coöperation rendered in this circumstance by the American Telephone and Telegraph Company, the Bell Telephone Laboratories and the Western Electric Company. The efforts of all were harmonious and unremitting toward the one objective of keeping service interruption at a minimum."

—Annual Report of the Southern New England Telephone & Telegraph Company for 1936.

MICROANALYSIS IN THE

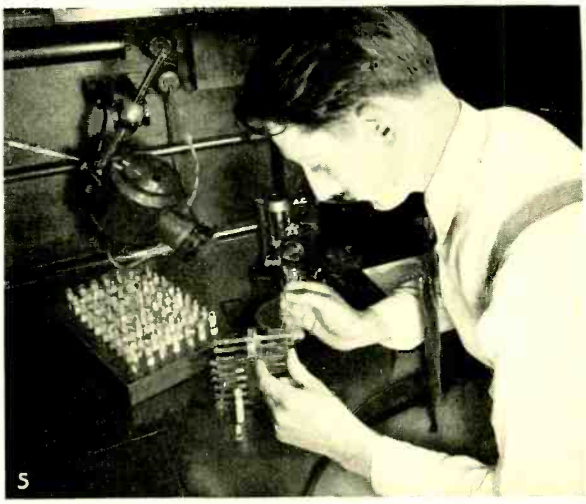


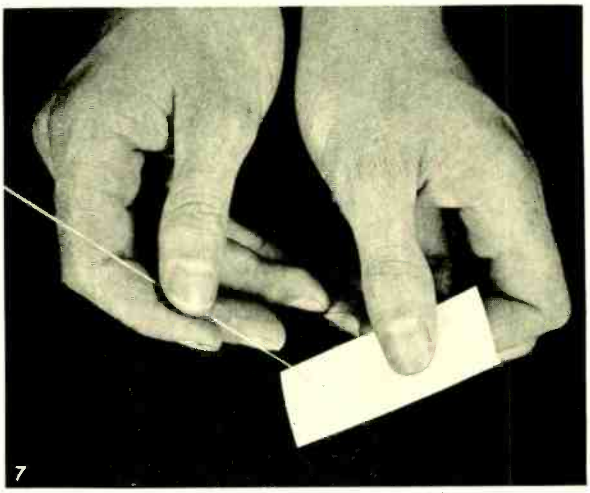
Millions of tiny bits of precious-metal alloys, called contact points, are used in the Bell System where circuits are to be closed or opened. Sometimes it is necessary to find out the composition of one of these contacts without taking enough material away from it to impair its operation. These pictures show how the Microanalytical Laboratory of Bell Telephone Laboratories goes about the job.

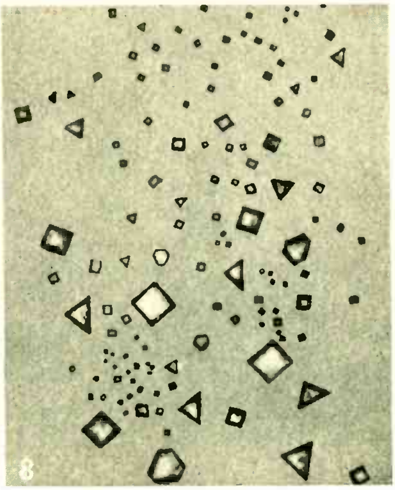
(1) *Taking a sample of metal from the contact point of a relay. A piece of glass, sand-blasted on one side, acts as a file to abrade a little of the contact metal.*

(2) *The glass slide is then put into the neck of a tiny flask in the bottom of which is a little aqua regia (hydrochloric and nitric acid). Vapors of this rising in the flask change the metals to their chlorides; hence the dark stain at the point of the slide.*

(3) *A minute drop of water from the capillary tube in the chemist's right hand is thrown on the stain, from which it dissolves all chlorides but that of silver. The solution is then drawn back into the capillary, and the gold chloride is separated from it*







by ether extraction. (This separation is not shown in the illustration.)

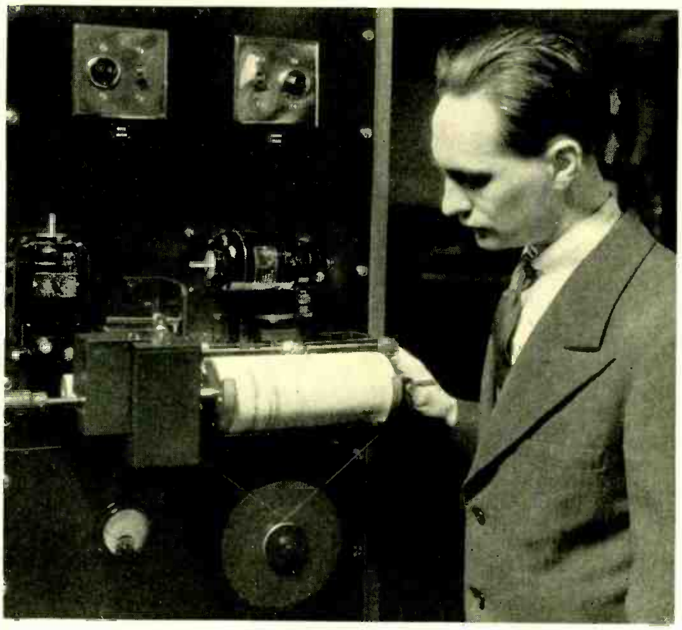
(4) *By a still smaller pipe the gold chloride is withdrawn from the tube.*

(5) *The gold chloride is then dropped onto a clean glass slide. This is placed under a microscope and a tiny fragment of thallium nitrate is added from the little bottle in the foreground.*

(6) *Crystals such as these show the formation of thallous gold chloride, a positive proof of the presence of gold in the solution.*

(7) *To confirm this, a portion of the solution is introduced into paper impregnated with mercurous chloride. Gold is reduced, forming a bluish black spot.*

(8) *These crystals prove the presence of silver in the original metal. They were formed by first dissolving the residue on the roughened slide in ammonia and were precipitated under the microscope when the ammonia evaporated.*



Measuring Loudspeaker Response Automatically

By H. F. HOPKINS
Transmission Instruments Development

THE measurement of response characteristics of loudspeakers is of major importance in their development because it shows how faithfully they reproduce the required range of frequencies. Single frequencies of known energy level are applied to the speaker and the intensities of the resultant tones are measured. To cover the frequency range may require as many as a hundred individual measurements. An electrical oscillator is used as the source of the single frequencies, and the intensity of the sound radiated by the loudspeaker is measured with a microphone whose output is amplified, rectified and then applied to an indicating instrument.

This procedure not only consumes time but is open to the objection that the selection of a series of discrete frequencies for measurement may miss narrow resonance peaks entirely. To avoid this difficulty an automatic system which makes a continuous record of the response throughout the frequency range has recently been developed by the Laboratories.

The elements of the new system are shown diagrammatically in Figure 1. The variable-frequency oscillator is connected either to the loudspeaker under test or to a calibrating circuit. The sound from the speaker is picked up by a condenser microphone, the output of which, after being amplified and rectified, is applied to a differential relay. This relay operates the magnetic clutches which control the attenuator to maintain a constant output for the amplifier. When the output of the amplifier increases the clutch moves the attenuator in the direction required to reduce the output, and vice versa. The amount the attenuator moves as the frequency is changed serves as a measure of the variations in the output of the loudspeaker; and this motion can be recorded by making the control lever of the attenuator operate a recording pen which is held in contact with a paper chart on a revolving drum.

The drum of the recorder is connected directly to the oscillator and both are rotated by a synchronous motor. Thus the record chart progresses under the recording pen at the same rate as the variable oscillator sweeps through the frequency range. The attenuator steps are in decibels and the oscillator has been specially constructed to synchronize the oscillator frequency settings with the frequency scale of the record paper. The result is a continuous record in decibels of the variations in output of the loudspeaker throughout the frequency range.

The oscillator used in this equipment is a 13A which has been modified to take heater type tubes. This does away with the necessity for storage batteries for filament supply and C batteries. A special variable condenser eliminates the need of cams or other complicated mechanical arrangements to synchronize the oscillator with the record chart on the rotating drum.

The calibrating circuit contains a variable attenuator network which puts a known voltage in series with the microphone to check the system and assure that the output level conforms to the scale on the chart. The calibrating panel includes a low-frequency equalizer to compensate for the drooping characteristic which is normally associated with condenser-transmitter amplifiers. Provision is also made for connecting an external frequency source to the calibrating circuit and for connecting an external input such as a special microphone to the amplifying system. These features are included to provide the system with as much flexibility as possible;

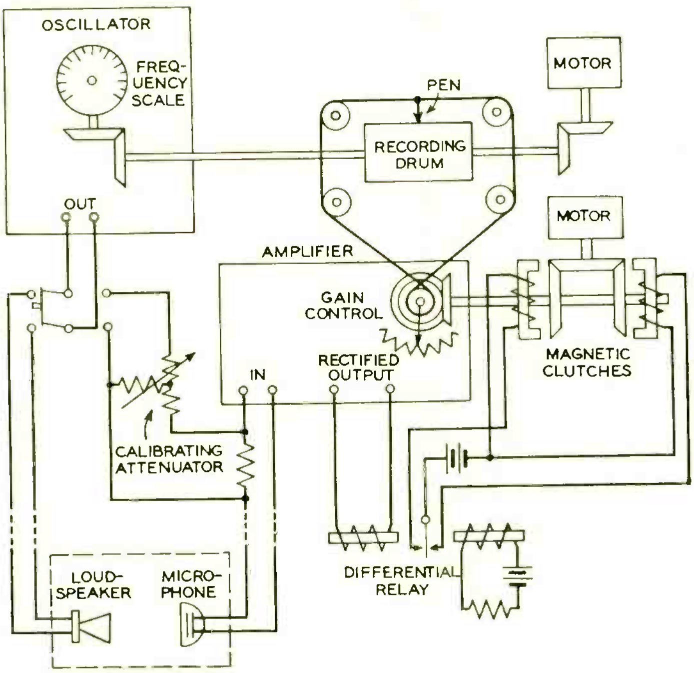


Fig. 1—The attenuation required to keep the output of the microphone amplifier constant is recorded as a measure of the variations in loudspeaker output

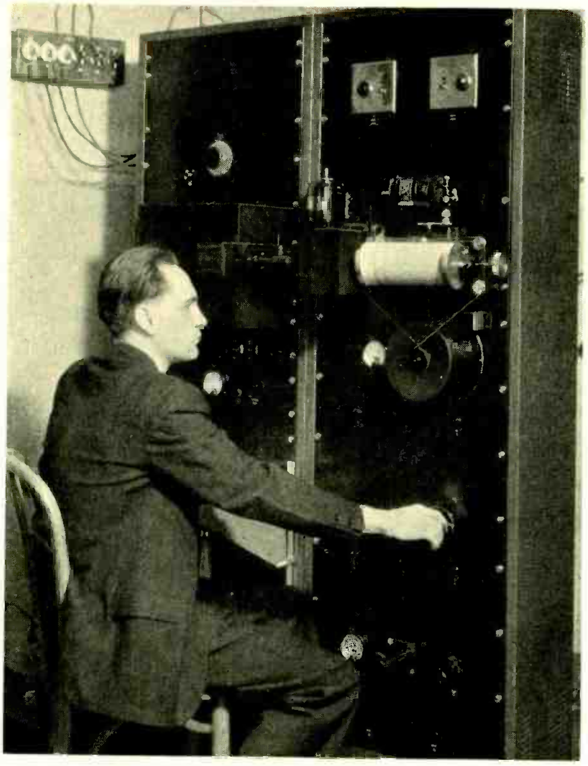


Fig. 2—A record of the output of a loudspeaker throughout its frequency range is made automatically on a chart. E. C. McDermott is the operator

with them it can be used to test devices other than loudspeakers, such as phonograph reproducers and amplifiers, or to measure transmission-line characteristics.

The amplifier has six resistance-coupled stages and the output is rectified to operate the clutch mechanism which controls the recording pen. The automatic attenuator has 120 half-db steps. This covers the full 60-db range of the record chart at 10 db per inch. A gear box with a shifting lever permits changing the speed of the recording drum so that the frequency range may be covered in approximately one minute or three or six. The release clutch will disconnect the motor and allow manual adjustment of the drum and oscillator.

The power supply includes a vacuum-tube rectifier which provides both oscillator and amplifier with plate voltage; a copper-oxide rectifier to supply heater current for the amplifier tubes and field current to the clutch magnets; and a transformer which provides heater current for the oscillator tubes. The voltages required for the condenser transmitter and the plate of the transmitter amplifier are supplied by batteries.

Before observations are made the pen is adjusted in its holder so that it is on the base line of the record paper when the automatic potentiometer is at the zero position. The clutch-release lever is then pressed and the drum and oscillator are rotated until the oscillator is set for 1000 cycles. If necessary the pen point is then adjusted to rest on the 1000-cycle line of the record paper. The drum and oscillator are then set at 50 cycles and the oscillator set for 50 cycles by timing with its reed.

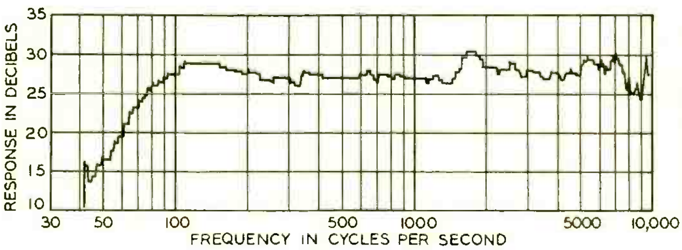


Fig. 3—Response-frequency characteristics are recorded in decibels. The frequency range of the apparatus is from 30 to 10,000 cycles

To adjust the amplifier system, the output key of the oscillator is thrown to the calibrating position and the amplifier gain is manually adjusted so that the pen rides at a predetermined response level which is dependent on the sound pressure calibration of the microphone. With the gain properly adjusted the base line will indicate a pressure of one bar for an oscillator output of one-quarter watt.

The system as thus adjusted will measure sound pressures at the microphone up to 150 bars (43 db above the base line) without overloading the amplifier circuit. This is adequate for most loudspeaker measurements but in special cases where higher pressures are encountered an input attenuator which brings the maximum reading up to 1000 bars can be inserted. In this case the base line indicates 10 bars for a quarter-watt oscillator output. The frequency range is from 30 to 10,000 cycles per second.

The equipment, excepting the loudspeaker and microphone, is installed in a double cabinet. On one side are the amplifier and recording mechanism and on the other the oscillator, the calibrating equipment and the power supply. The loudspeaker and microphone are usually installed in a separate room which is sound proof and whose walls, floor and ceiling are covered with extremely efficient absorbing material to minimize reflection effects.

This automatic response measuring system not only has the advantage that it gives a sweep-frequency record which practically eliminates the danger of missing narrow peaks, but also is much faster than making direct observations. The complete frequency range can easily be traversed in a minute with the automatic recorder while from half an hour to an hour were needed to make the large number of observations previously required.

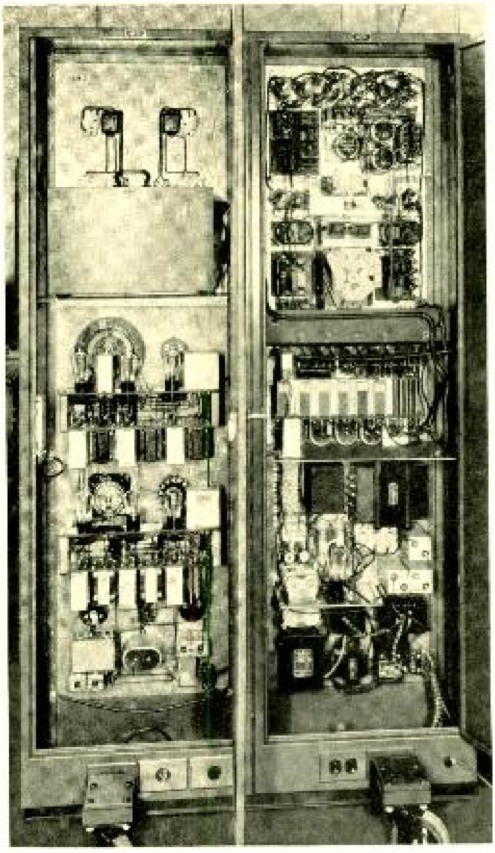
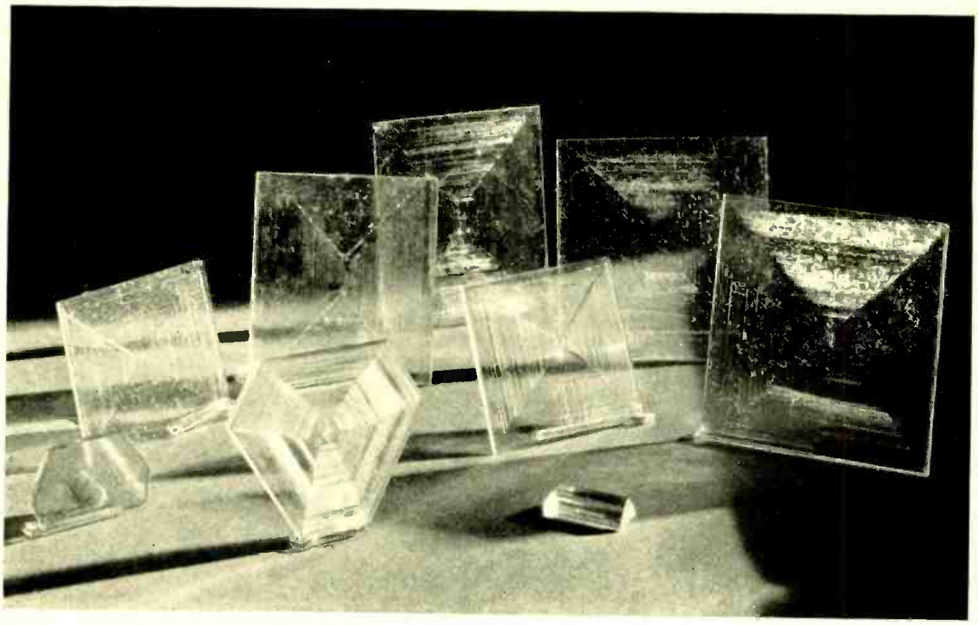


Fig. 4—The amplifier and recording mechanism are in the cabinet at the left and the oscillator, the calibrating equipment and the power supply are at the right



Thin Crystals

These thin crystals were grown between parallel glass plates from a water solution of the substance. They were formed by super-saturating the solution by cooling it after it had been inoculated with a seed crystal which was placed between the glass plates.

It is well known that all pure substances assume in the solid state a crystalline form which is characteristic of the substance. In that form the constituent atoms are arranged in a regular repetitive manner rather than at random as in a liquid. Most large crystals, however, are composed of many small ones which are oriented more or less at random. For the investigation of certain properties of crystalline substances it is necessary to avoid the effects of random orientation and the boundaries between the constituent crystals by making measurements on a single crystal, the larger the better. Large flawless crystals of some materials are difficult to produce but for most measurements only thin plates of known orientation are required. The method described here makes it possible to grow such plates, and in some cases it has been found easier to make them in this manner than to grow large complete crystals as is usually done.

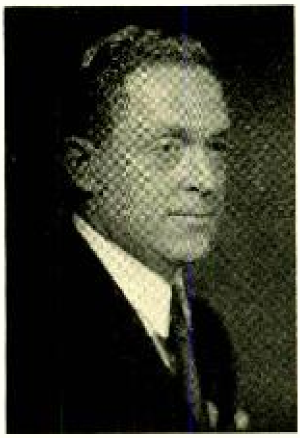
Contributors to this Issue

K. E. Gould, after graduating from Oklahoma Agricultural and Mechanical College in 1924 with the B.S. degree, spent three years at the Massachusetts Institute of Technology where he received the degrees of S.M. in 1925 and Sc.D. in Electrical Engineering in 1927. In June, 1927, he joined the D. & R. Department of the American Telephone and Telegraph Company and engaged in railway electrification and power system coördination problems until the department was consolidated with the Laboratories. His previous work was continued here, in the course of which considerable attention was given to the application of the cathode-ray oscillograph to interference problems. The studies on fields caused by remote thunderstorms described in this issue of the Record were carried out as part of an investigation undertaken to determine the nature and source of certain extraneous voltages which sometimes appear in telephone circuits.

A. R. Soffel has been engaged in studies on the fundamental characteristics of hearing and on problems relating to the transmission and reproduction of speech and music since he joined the Research Department of the Laboratories in 1928. He has completed the Laboratories' Student Assistant Course and is now attending New York University.

Since H. F. Hopkins joined the Laboratories in 1919 his efforts have been chiefly concerned with transmission instruments problems including loudspeaker development with which he has been associated for the last ten years. He has supplemented these activities with studies in the technical assistants' course and at Brooklyn Polytechnic Institute from which he received the E.E. degree in 1932.

A. C. Peterson, Jr., received the B.S. degree in Electrical Engineering from the University of Washington in 1928, and in December of that year joined the D. & R. Department of the American Telephone and Telegraph Company. With the later consolidation of this department with the Bell Laboratories, be became a member of the Transmission Development Department. With both organizations, Mr. Peterson has been concerned principally with problems dealing with short-wave radio transmission and development. He



K. E. Gould

A. R. Soffel

H. F. Hopkins

A. C. Peterson, Jr.

E. R. Morton

E. C. Blessing

recently received the E.E. degree from the University of Washington.

E. R. Morton was graduated from Stevens Institute of Technology in 1917 with the degree of M.E. During the next seven years he engaged in a variety of work, in electricity, optics, photography and mechanical design, including a year's graduate work at Harvard University and time in the army. In 1923 he joined the technical staff of the Laboratories and since then, with the Special Products Department, he has been chiefly engaged in the design and development of power apparatus. He worked on the motors for the television system developed by the Laboratories and also on those for sound-picture recording and reproducing. He has also worked on regulators for voice-frequency carrier telegraph generators and on other regulating apparatus.

E. C. Blessing received the degree of B.S.E.E. from Purdue University in 1922 and immediately joined the Technical Staff of these Laboratories. Prior to graduation he spent two years with the Ohio State Telephone Company in maintenance work. As a member of the Toll Systems Department he has worked principally on the development of carrier systems. At present he supervises the development of open-wire carrier repeaters.