# BELL LABORATORIES RECORD

GENERATING HIGH FREQUENCIES

R. A. Heising
H. J. Scott

NO. 12 SWITCHBOARD

H. W. Ulrich

FREQUENCY MONITOR FOR BROADCASTING

R. E. Coram

DECEMBER 1932 VOL. 11 NO. 4

# Bell Laboratories Record

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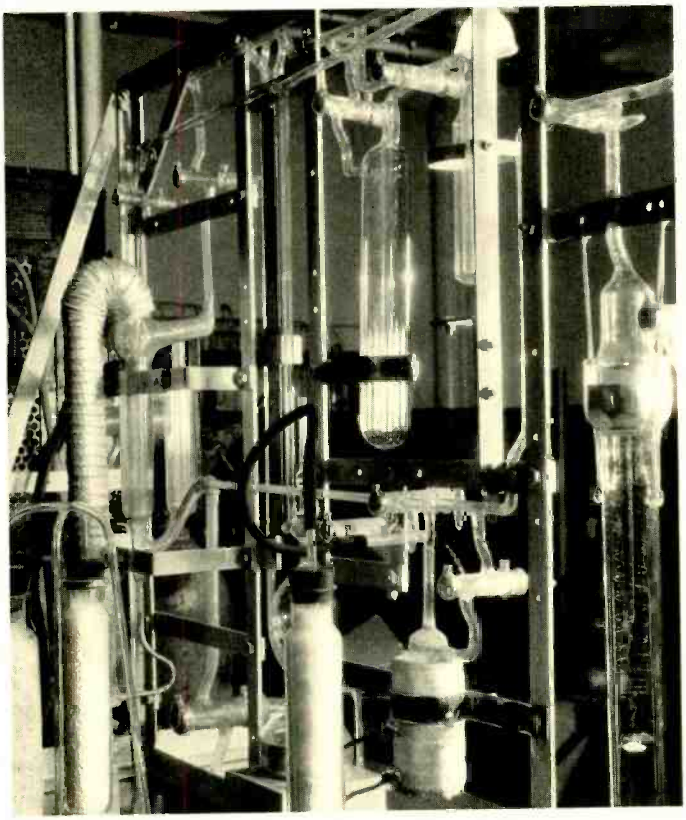
## *In this Issue*

# BELL LABORATORIES RECORD



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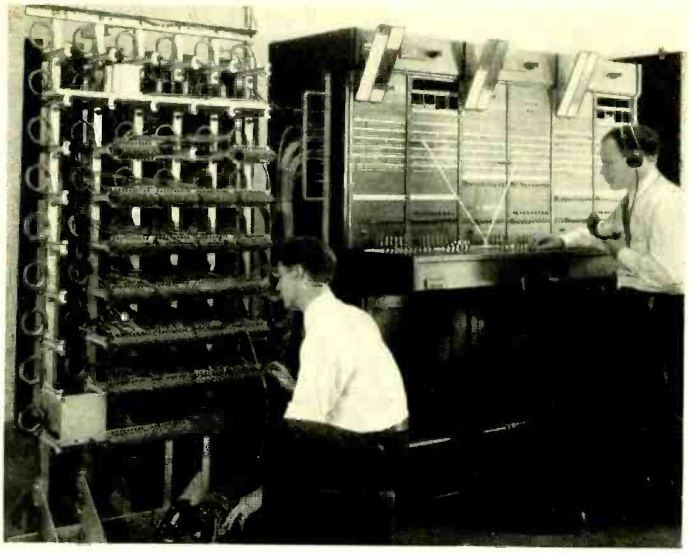


# A New Common-Battery Board for Small Offices

By H. W. ULRICH
*Local Systems Development*

THE largest telephone switchboards naturally have many features which are desirable and economical for the larger offices but which would not be justified for the smaller offices. There have been available, therefore, for some time a number of types of common-battery switchboards smaller and less expensive than those used in large central offices. Experience with these switchboards has indicated that there is a field for a still more inexpensive board, particularly one having low capacity. Accordingly the Laboratories in coöperation with the engineers of the American Telephone and Telegraph Company have developed a new common-battery board of low capacity and low cost, which is called No. 12. It has been designed to serve both magneto and common-battery lines and all positions are arranged for handling both types of local calls as well as originating and terminating toll traffic. With a capacity of 640 common-battery and 80 magneto lines, it is low in original cost and requires a minimum of maintenance effort.

The line circuits for the two types of service differ in arrangement both because of the necessity of placing a different indication on the sleeves of the jacks, and because a drop must be connected across magneto lines, and a lamp in series with common-battery lines, to indicate incoming calls. These two types of line circuits are shown in Figure 1. The jack sleeve of the magneto circuit has no connection to it, and so when a cord is plugged into

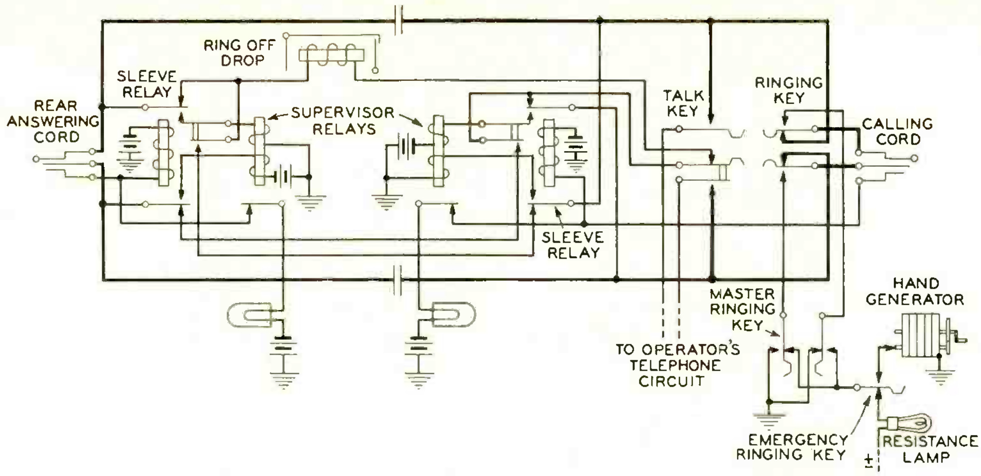



*Fig. 2—Universal cord circuit for the No. 12 manual board*

it none of the relays operate, and the conditions are right for magneto operation. When a cord is plugged into a common-battery jack, however, ground is connected to the sleeve, which operates relays in the cord circuit to supply the required common battery facilities.

The majority of the previous boards have required a line-and-cut-off relay

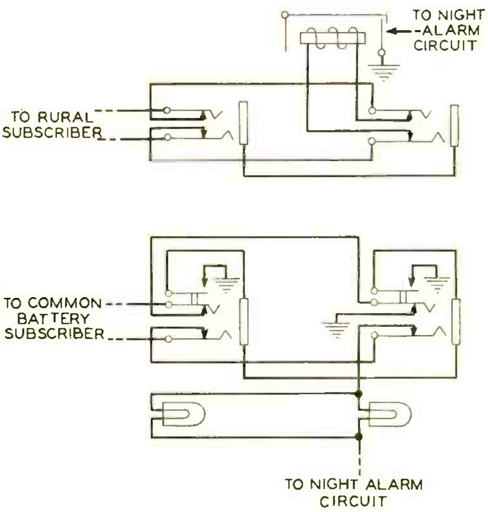



*Fig. 1—Line circuit of magneto line, above, and common-battery line, below. Two multiple appearances are shown, each serving two positions*

associated with the line-lamp of each line. The development of a new lamp, operable over a wide voltage range, has permitted placing the line-lamp of the new board in series with the line and has thus eliminated the line-and-cut-off relays. This has effected a saving in the cost and maintenance of the equipment.

For magneto and toll lines, and ring-down trunks, the only functions of the cord circuit are to provide a through connection for the talking currents, a ring-off drop to give an indication when either of the connected subscribers rings off or recalls, a key for ringing, and a key-operated connection to the operator's headset. All cord circuits are arranged to make this type of connection with none of their relays operated. For common-battery lines, on the other hand, the cord circuits must provide talking battery in addition to the through connection, and a lamp signal on each end of the cord for attracting the operator's attention instead of the ring-off drop. The operator's headset connection is the same for both types of connections. When connections are to be made between a common-bat-

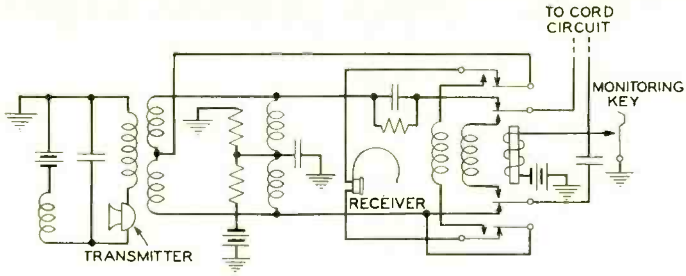



*Fig. 3—The operator's telephone circuit provides for high impedance monitoring by the operation of a monitoring key*

tery and a magneto line, the cord circuit must supply talking battery and a lamp signal to the common-battery-line end of the cord, and connect the ring-off drop to the magneto-line end. These different functions are all brought into play as required by a simple relay arrangement of the cord circuit, and by different conditions on the sleeves of the jacks of the two types of lines.

To each end of the cord circuit, shown schematically in Figure 2, are connected a pair of relays. One operates to supply talking battery when a ground connection is made to the sleeve, and the other controls the supervisory lamp. Each end of the cord circuit thus provides the proper type of service for the line to which it is connected, and so permits the interconnection of lines of the same type or of dissimilar types.

Since this new board is arranged for multiple operation, a busy test must be provided so that an operator about to make connection to a line can tell whether or not it is already in use. As is customary, this test is made by touching the tip of the cord plug to the sleeve of the jack while the operator's talk key is operated; and a busy jack is indicated by a click in the operator's receiver. This test is made possible for the two types of service by a condenser in the operator's telephone circuit, shown in Figure 3, which is normally charged to a potential between that of full battery and ground. The sleeves of busy jacks of common-battery lines have ground connected to them, and those of magneto lines have battery. Since the condenser is at a potential between battery and ground, however, either type of connection changes the charge on the condenser and produces the required busy click in the operator's receiver.

Ringing is provided by a small motor-driven ringing machine which rings through a resistance lamp to

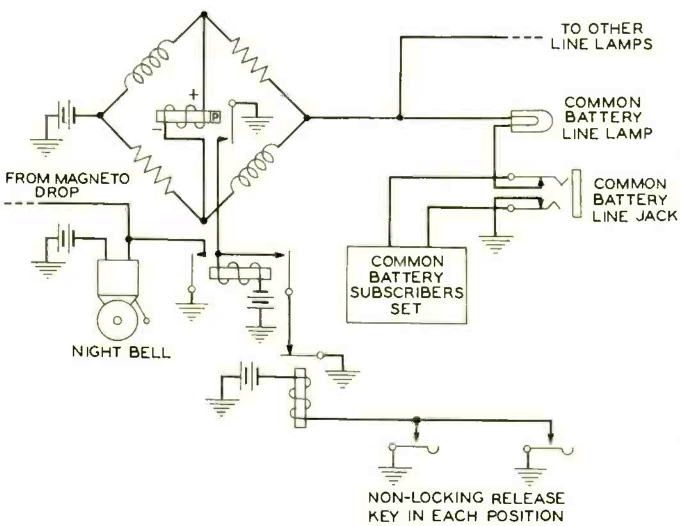



*Fig. 4—A Wheatstone bridge provides a night-alarm circuit that is unaffected by line leaks*

prevent making ringing ineffective at all positions should one operator ring on a grounded line. A key is provided to switch the connection from the power-driven ringing machine to a hand generator at each position in emergencies. For magneto lines, single party common-battery lines, or multiple party common-battery lines where ringing current is sent out over the "ring" conductor, signaling is accomplished by operation of a key in the cord circuit. For multiple party common-battery lines which are signalled over the tip conductor, a master ringing key is operated in addition to the cord ringing key.

Line lamps, on common-battery lines, are in series with the lines as shown in Figure 1. This arrangement has always made the operation of a night alarm difficult, since the line leakage on a large number of lines connected in parallel may be sufficient at times to operate the alarm falsely. This difficulty has been overcome by the "bridge" night-alarm circuit shown in Figure 4. Under normal conditions the bridge is balanced so that current flowing out on the various lines, because of leak conditions, does not operate the night-alarm relay, which is connected across the galvanometer points of the bridge. One arm on each side of the bridge is non-inductive, however, and the other is inductive, with the result that sudden changes in current momentarily unbalance the bridge and operate the relay. The sudden increase in current when a receiver is picked off the hook, thus operates the night-alarm relay, which locks itself in, and is released only by the operation of a release key at each position. Magneto lines operate the night-alarm relay directly through back contacts on their line drops.

In addition to these many circuit

*Fig. 5—A power plant forms one of the three units of the No. 12 board*

features that have made possible the production of an economical small common-battery switchboard, the equipment arrangement has also been simplified and arranged so that it can be manufactured and installed at a minimum cost. The No. 12 central office includes three separate, compact, equipment units: a switchboard, a main frame, and a power plant. One of the chief objectives in its design has been to reduce the installing expense as well as the engineering. So successful have these efforts been that very little engineering is required by the Telephone Companies and none by the Western Electric Company.

The line equipment is arranged in

units of twenty common-battery lines or ten magneto lines. By employing unnumbered jacks, it has been possible to make all units of any one kind alike regardless of where the lines appear in the panel. Designation strips are used for numbering the jacks. Each strip of jacks is connected by a cable to a terminal strip, which is mounted on the main frame adjacent to the left end of the board as shown in the photograph at the head of this article. These terminal strips are mounted in the same relative position on the main frames as the jacks are in the switchboard and all connecting cables are of the same length. A short looped section of cable between the board and the main frame allows for the different positions of the terminal strip on the main frame. This arrangement reduces the number of different items required since the same line unit can be used for any strip of lines in a given panel, and also permits all units to be wired and assembled in the shop, thus requiring a minimum of work on the part of the installer.

The third unit of the No. 12 board is the power plant shown in Figure 5. It consists of a 23-cell storage battery, with sealed glass jars equipped with charge indicators, and either one or two rectifiers for charging. Provision is also made for supplying a second set of storage batteries on a separate unit if the traffic warrants it. A motor-driven magneto generator for ringing is also mounted on the power frame. To make the equipment as inexpensive as possible, the usual

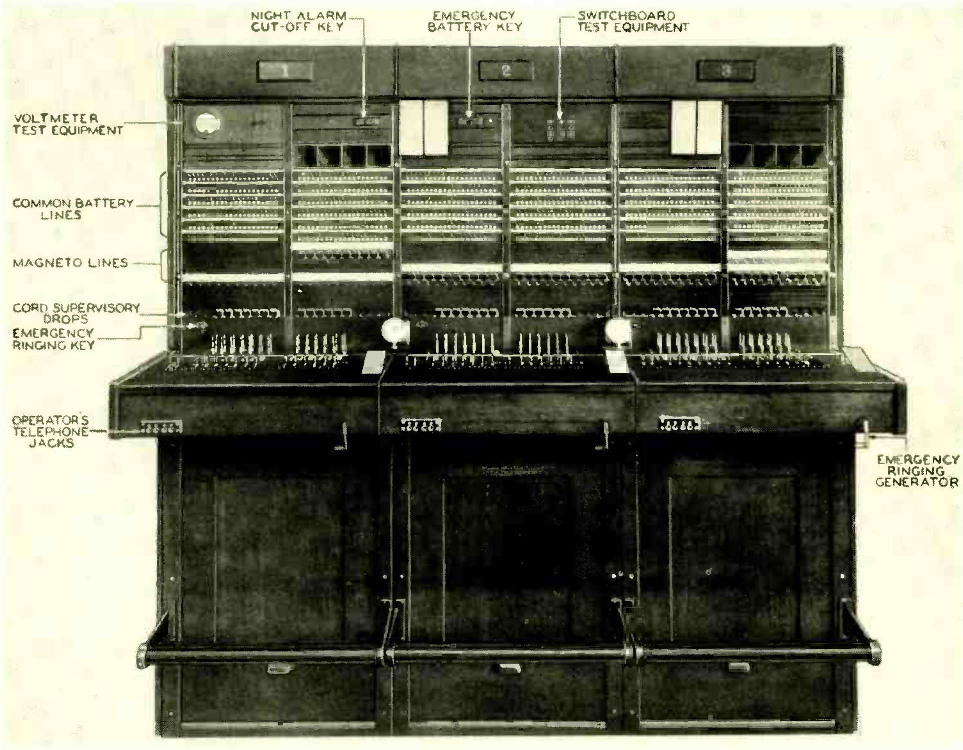



*Fig. 6—Each position of the No. 12 board is arranged for handling both toll and local traffic*

combination of starting switch and fuse is replaced by a single set of fuses mounted in a holder which is used as a switch for starting or stopping the motor. The power board is also equipped with a fuse and meter panel on which are mounted charge and discharge fuses, and a small meter to indicate the battery voltage.

Provision is made for an emergency power supply which, should the main supply fail, would be adequate for calling assistance. An emergency battery key is located above the multiple jack field, which when operated disconnects the main battery leads to one pair of cords and to the telephone circuit of a position designated for the purpose, and connects these circuits to an emergency dry battery. This battery will enable the operator to summon aid in the event of a complete failure of the main battery supply. A guard signal is furnished to prevent the possibility of draining the emergency battery by an accidental operation of the emergency key.

From the photograph of the No. 12 board, Figure 6, the relative positions of the equipment on the front of the board may be seen. Maintenance equipment consisting of a panel with voltmeter, key, jacks, and patching cords for testing line and substation equipment, and a jack panel for testing relays and drops in the switchboard, is provided as indicated in the upper part of the board. In addition to keys for the night-alarm release, monitoring, and master ringing already discussed, there is a grouping key which permits increasing the number of cord circuits available to any one operator during light load periods.

## *K. K. Darrow to Talk on Cosmic Rays*

*The Communication Group of the New York Section of the American Institute of Electrical Engineers will meet in the auditorium of the Laboratories at 7.00 p.m. on Tuesday, December 13, when members of the Institute and their guests will hear K. K. Darrow talk on* COSMIC RAYS. *Dr. Darrow's lecture will be devoted chiefly to the ways of observing cosmic rays and the actual and uncontested results of experiments. He will give especial notice to the discoveries of the past two years and to the photographic records of the paths of the cosmic corpuscles. Lantern slides will show examples of these paths, as well as the environment of the experiments and various sorts of apparatus used in them. Dr. Darrow will also allude to current theories of the nature and origin of cosmic rays.*

# Generating High Frequencies with Precision

By R. A. HEISING
*Radio Research*

FOR the study of mechanically resonant systems whose damping is extremely low, apparatus is required which will generate with high precision and stability any frequency within a considerable range. Figure 1 shows how the current through a certain quartz plate varied with the frequency at which it was driven. The entire region of interest, containing large current variations, was traversed within the brief frequency span of thirty cycles, at about a million cycles. Other such plates require equally detailed attention at quite different frequencies.

To build apparatus capable of making measurements such as are required to produce Figure 1 is by no means easy. The apparatus must have the precision and stability of the best fixed-frequency, temperature-controlled oscillators, and a variability over a range of from 400 to 1,200 kilocycles that can be controlled with an accuracy of about a cycle.

If the generator producing this frequency had a single variable condenser to cover the entire range and the dial had 100 divisions, adjacent divisions would correspond to frequencies 8,000 cycles apart. Getting any frequency in the range a cycle at a time would call for a condenser dial of very large mechanical dimensions so that individual cycles could be read. Such a dial is practically out of the question. Thus the possibility of obtaining by one condenser a frequency variation of accuracy great enough and in steps small enough to secure Figure 1 is so remote that it can scarcely be considered.

Another expedient suggests itself: that of providing a series of fixed condensers to be put in parallel with a single variable condenser of small range. This method would give the desired precision in adjustment, but now the accuracy of the frequency is dependent upon the accuracy with which the oscillator maintains its frequency as the voltage of the power supply varies, and as the condensers age. This accuracy is again insufficient for the investigation of quartz plates.

The apparatus which has actually been built, therefore, operates on a principle quite different, though somewhat analogous. Instead of putting fixed condensers in parallel with a variable condenser of small range, fixed frequencies are added to and subtracted from a frequency variable over a small range. Since the accuracy desired is that of good quartz oscillators, such an oscillator is used to control the fixed frequencies through sub-harmonic and harmonic generators, and the variable frequency comes from a source of like accuracy.

The number of steps necessary to build up the desired frequency, and thus to some extent the amount of equipment required, are determined in large part by a single familiar fact. This is the fact that the limit of the accuracy with which most electrical equipment can be made to do what is expected of it, is not a fixed number of cycles per second but rather is at best a fixed percentage of the frequency at which the equipment is operating. Thus, as the operating frequency is increased, it is more difficult to build apparatus whose error will not exceed a given number of cycles. It is for this reason that the variable frequency is taken from between three and four kilocycles, a range low enough in frequency so that a variable oscillator can be made accurate to about one cycle.

The best means at our disposal for adding and subtracting frequencies is the modulator, whose output contains, among other frequencies, the sum and the difference of the two frequencies applied to it. When, as in this application, only one of these frequencies is desired, it must be separated from the others by a filter. Like oscillators, variable filters become more difficult to build to a given absolute accuracy as the frequency is increased.

The consequences of this difficulty can be illustrated by the problem of producing the frequency 1,003,456 cycles. If a million cycles from the fixed quartz oscillator were modulated with 3,456 cycles from the variable oscillator, the desired frequency would be present in the output of the modulator. Both the carrier and the difference frequency would also be present, however, and would be separated from the desired frequency by much less than one per cent. Filters cannot be built with sufficiently sharp cutoffs to make the desired selection.

The desired frequency is therefore built up by two summing steps instead of one. In the first step, 50,000 cycles is modulated with 3,456 cycles. The 53,456-cycle component of the output is distant from the carrier by more than six per cent, and can readily be isolated by a filter. It is then made to modulate 950,000 cycles, and the sum-frequency, being more than five per cent distant from the carrier, is again readily isolated.

The availability of any frequency between 800 and 1,200 kilocycles is

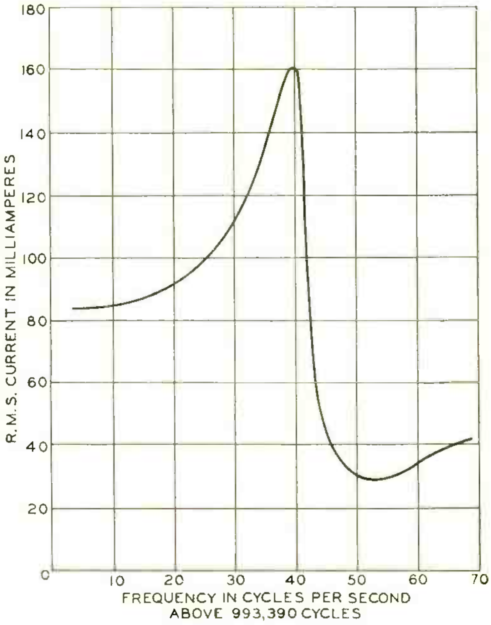



*Fig. 1—A typical response-frequency curve of a quartz plate shows large variations in a small frequency span*

brought about by providing many fixed frequencies through harmonic generators all ultimately controlled by a single million-cycle source. The single-cycle variability of the audio-frequency oscillator between 3,000 and 4,000 cycles is thus spread out into single-cycle variability over a far greater range of far higher frequencies.

Practical apparatus for laboratory use which accomplishes this purpose has been designed by H. J. Scott and I. E. Fair of the Radio Research group, and is described in the following article.

# A Precise Radio-Frequency Generator

By H. J. SCOTT
*Radio Research*

If a quartz plate is vibrating at a frequency of a million cycles per second, and is illuminated by a neon lamp flashing a million-and-one times per second, the surface of the plate can be viewed stroboscopically, and the complex and beautiful pattern of its vibration can be observed as it goes through all its phases. By flashing the neon lamp a million times per second instead of a million-and-one, the shift of the pattern can be arrested and the stationary pattern can be critically examined at leisure.

Such a procedure would be merely pastime if the rotation of the dial controlling the flashing lamp were not accompanied by the assurance that the lamp was really doing what the dial said it was. To give such assurance in this and many less spectacular methods of studying the behavior of quartz plates, a variable high-frequency generator of great accuracy was designed and built in these Laboratories*. The principal frequency source is a temperature-controlled, quartz-plate oscillator. Sub-harmonics of this appropriately combined with one another and with the output from an audio-frequency oscillator, as shown in Figures 1 and 2, produce a frequency which can be continuously varied over the range from 400 to 1,200 kilocycles.

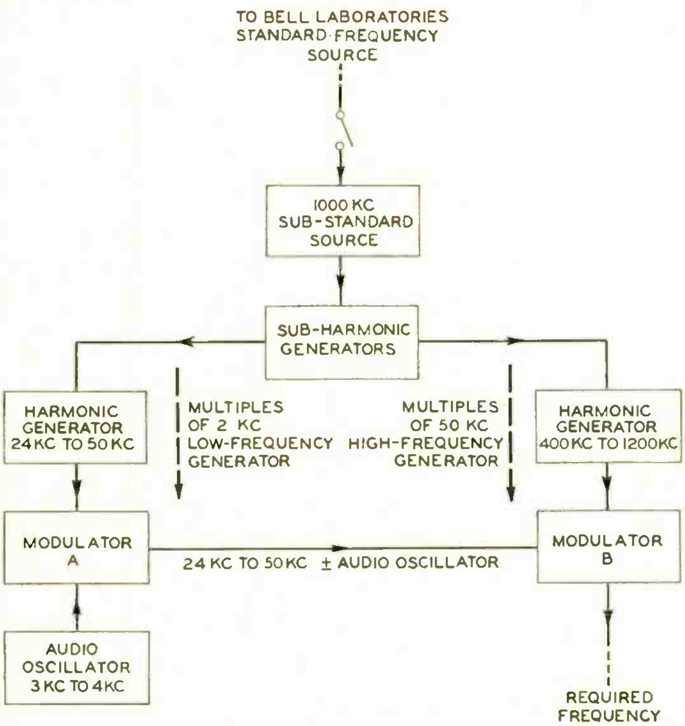



*Fig. 1—The major steps in the generation of a desired frequency*

In generating 1,135,475 cycles, for example, this frequency is considered as the sum of three frequencies: 3,475 cycles, 32,000 cycles, and 1,100,000 cycles, obtainable from

*I. E. Fair has been associated with Mr. Scott in the design and construction of this equipment.

the audio-frequency oscillator, the low-frequency generator and the high-frequency generator respectively. The two lower frequencies are combined in modulator A to produce 35,475 cycles, which in turn is combined in modulator B with the higher frequency to produce the required 1,135,475 cycles.

In general, the quartz oscillator supplies 1,000 kilocycles from which sub-harmonic generators derive 100 kilocycles and one kilocycle. The one-kilocycle output controls the low-frequency generating unit, which can produce all the multiples of two kilocycles between twenty-four and fifty kilocycles. The 100-kilocycle output controls the high-frequency generating unit, having an output range from 400 to 1,200 kilocycles in steps of fifty kilocycles. Independent of these is an audio-frequency oscillator. One modulator combines the outputs of this oscillator and the low frequency generator, and another combines the output of the first modulator with the output of the high-frequency generator. Thus it is possible to produce any desired frequency within the range of the apparatus.

The accuracy with which these frequencies can be produced is very high. The frequency of the audio oscillator can easily be adjusted to within one cycle. Since the frequency of the quartz oscillator can be maintained to within three parts in ten million, the overall accuracy of any single reading is of the order of ±1.3 parts in a million.

The million-cycle frequency source is similar to that used in the radio-frequency measuring equipment at Holmdel,* but incorporates two quartz oscillator units instead of one. The two are adjusted to zero beat at the beginning of any series of measure-

*Record, *August*, 1931, *p.* 585.

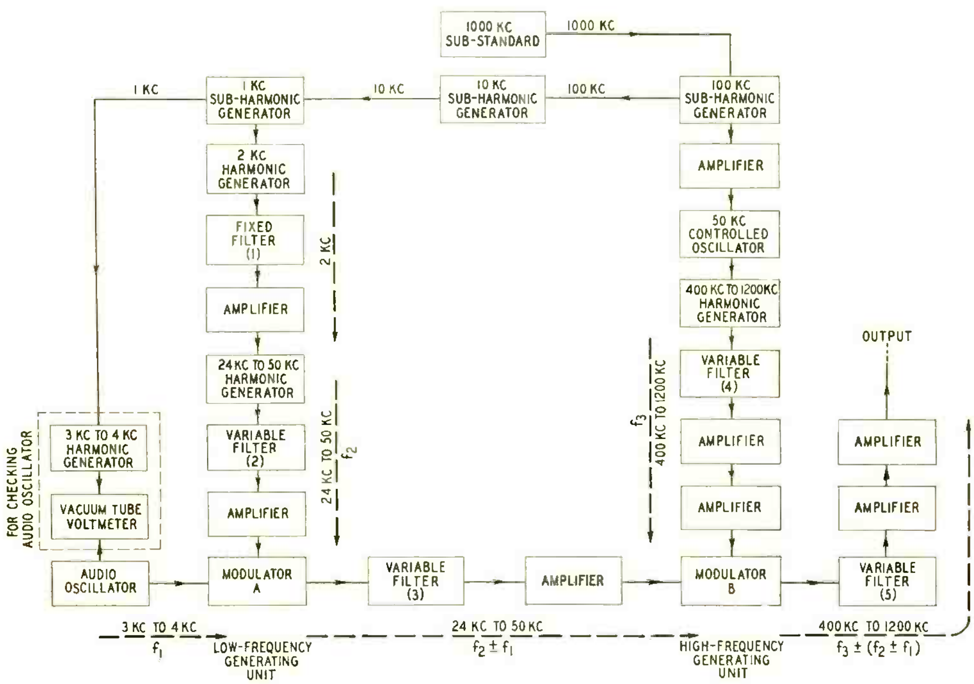



*Fig.* 2—*The complete system of generation*

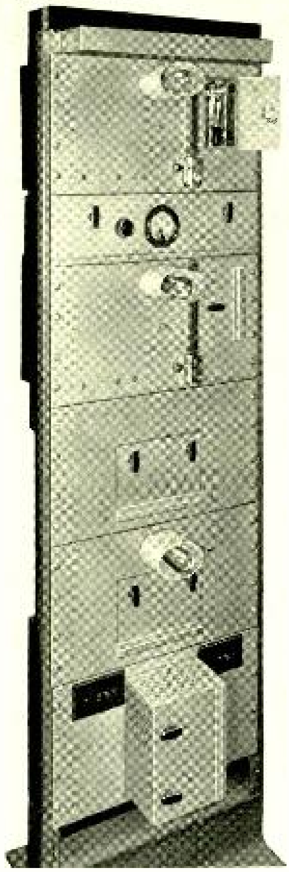


*Fig. 3—The million-cycle frequency source*

ments, and a vacuum-tube voltmeter maintains a continual check between them. Thus any slight variation of one or the other is visible immediately. This frequency source is checked daily against the Bell Telephone Laboratories' 100-kilocycle standard*, by observing the beat between the fundamental of the oscillator and the tenth harmonic of the standard frequency.

The production of 100 kilocycles and one kilocycle from the million-cycle source is accomplished in three steps of 10-to-1 frequency reduction, providing 100, 10 and 1 kilocycles. The sub-harmonic generators are of the "unsymmetrical" type (Figure 4), which may be considered as a two-stage resistance-coupled amplifier, with the output of the last stage feeding into the input of the first. Oscillations are thus produced, the frequency of which is dependent upon the resistance in the grid and plate circuits and the coupling capacities. By making the external plate resistance of one tube much greater than that of the other, one acts as an ordinary amplifier while the other operates over a very wide range of its characteristic and acts as a control tube. The frequency may then be controlled within certain limits by introducing a voltage whose frequency is any multiple of that of the sub-harmonic generator into the common plate lead.

In the low-frequency generator, the one-kilocycle voltage is impressed on the input of a harmonic generator whose output is passed through a single-frequency filter which passes two kilocycles and attenuates all the

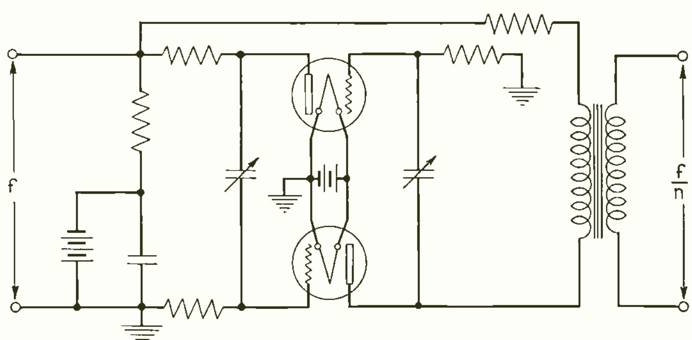



*Fig. 4—When the external plate resistance of the upper tube is made much greater than that of the lower, an input of frequency f will accurately control the output at a sub-multiple frequency f/n whose value is approximately determined by the circuit constants*

*Record, *August*, 1928, *p.* 385.

remaining harmonics 120 db. The two-kilocycle output is first amplified and then applied to the principal low-frequency harmonic generator which supplies all the integral multiples of two kilocycles. Since only one such frequency is wanted at any one time, and only those between twenty-four and fifty kilocycles are ever wanted, a variable band-pass filter, operable in this range, is used to select the desired multiple of two kilocycles and attenuate all others 76 db (Figure 5).

This filter is so built that the impedance and the width of the pass band (500 cycles) are approximately

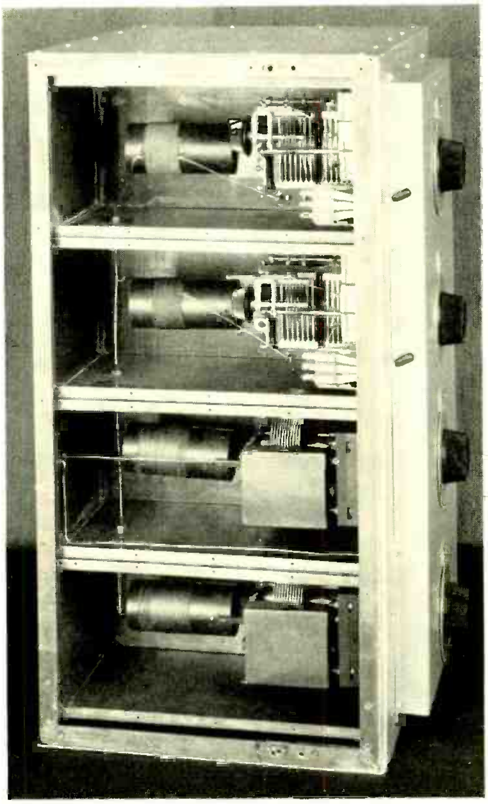


*Fig. 5—Variable-frequency band-pass filter, designed and built by the Transmission Apparatus group for use with the radio-frequency generator*

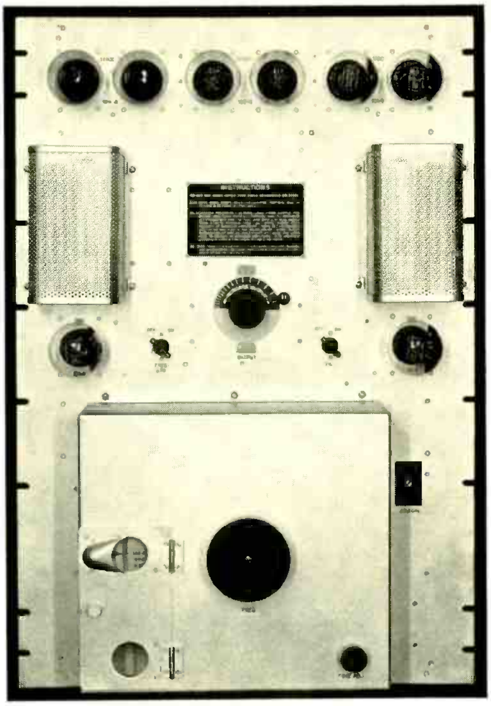


*Fig. 6—The standard Western Electric 13-A Oscillator, shown above, was modified in minor respects for use with the radio-frequency generator*

constant regardless of the position of the band. It consists of two filter sections of a type in which only the condensers need be varied to vary the position of the pass band.

The high-frequency generator is similar to the low in principle. The 100-kilocycle voltage holds in step a 50-kilocycle oscillator whose output feeds into a harmonic generator producing all the integral multiples of 50 kilocycles. As before, a variable band-pass filter is adjusted to select the particular multiple desired between 400 and 1,200 kilocycles and attenuate the others 76 db. Except for its range and the width of its pass band (3,000 cycles), this filter is closely similar to the other.

The audio frequency oscillator is of the Western Electric 13-A type (Figure 6) which has been slightly modified so that, instead of operating between 20 and 9,500 cycles, it operates between three and four kilocycles, and this range is spread out over the whole scale of the variable condenser. To check the frequency of the output, the dial is set to three kilocycles, and the fixed oscillator is adjusted until the three-kilocycle output coincides with 3,000 cycles derived from the million-cycle frequency source as indicated by zero beat on a vacuum-tube voltmeter. The dial is then turned to four kilocycles, and the reading is similarly checked with 4,000 cycles from the frequency source.

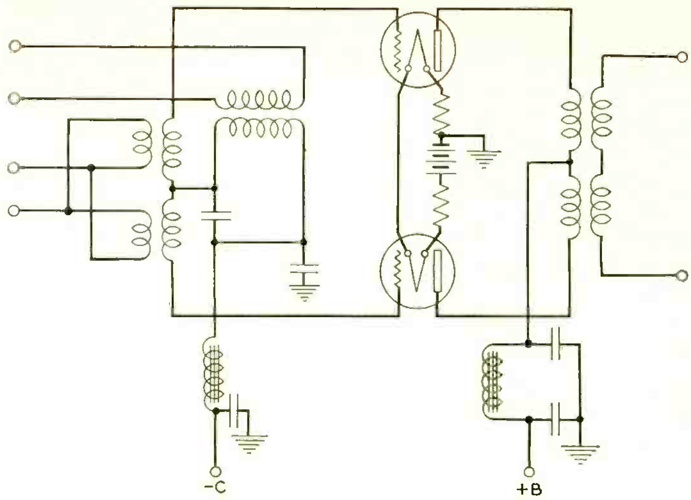



*Fig. 8—The modulators are of the familiar balanced type*

The modified 13-A oscillator consists of two high-frequency oscillating circuits. One circuit generates a frequency of 100 kilocycles and except during preliminary adjustments is held fixed. The other generates a frequency which is variable between 96 and 97 kilocycles.

The outputs of both circuits are impressed on the grid circuit of a

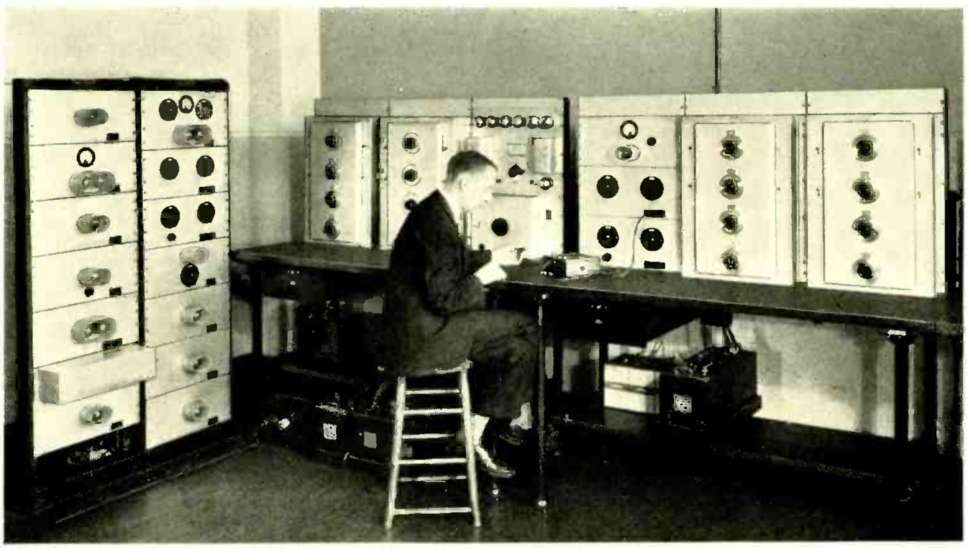


*Fig. 7—The complete radio-frequency generator except for the million-cycle frequency source. The low- and high-frequency generators are on the left and right relay racks. The four variable filters are at the ends of the bench. In the center are the audio-frequency oscillator (left) and the vacuum-tube voltmeter and output amplifiers*

| Apparatus | Harmonic Gen. 24 kc. to 50 kc. | Filter 2 | Audio Ocs. | Filter 3 | Harmonic Gen. 400 kc. to 1,200 kc. | Filter 4 | Filter 5 |
|---|---|---|---|---|---|---|---|
| Settings | 32 kc. | 32 kc. | 3,475 cycles | 35 kc. | 1,100 kc. | 1,100 kc. | 1,140 kc. |

Table 1—Settings for Producing an Output of 1,135,475

balanced modulator in whose plate circuit the modulation products appear. The desired product, whose frequency is the difference between the two oscillator frequencies, is impressed on a two-stage push-pull amplifier. An output transformer, shielded and carefully balanced to ground, reduces the impedance looking backward into the oscillator to between 500 and 600 ohms.

Throughout the 13-A oscillator precautions are embodied to purify the final output. The output of the fixed oscillator passes through a low-pass filter which eliminates harmonics of 100 kilocycles. With these harmonics suppressed, the harmonics in the output of the variable oscillator encounter no frequency in the modulator with which they can combine to produce frequencies less than 100 kilocycles. Acting in conjunction with a shunting condenser, a transformer between modulator and amplifier forms a low-pass filter which efficiently reduces the magnitude of fundamental frequencies of the two oscillators and other high-frequency products of modulation before they reach the amplifier. The balanced, or push-pull, design of the amplifier balances out the second harmonic inherently generated in each amplifier tube, and thus keeps the percentage of

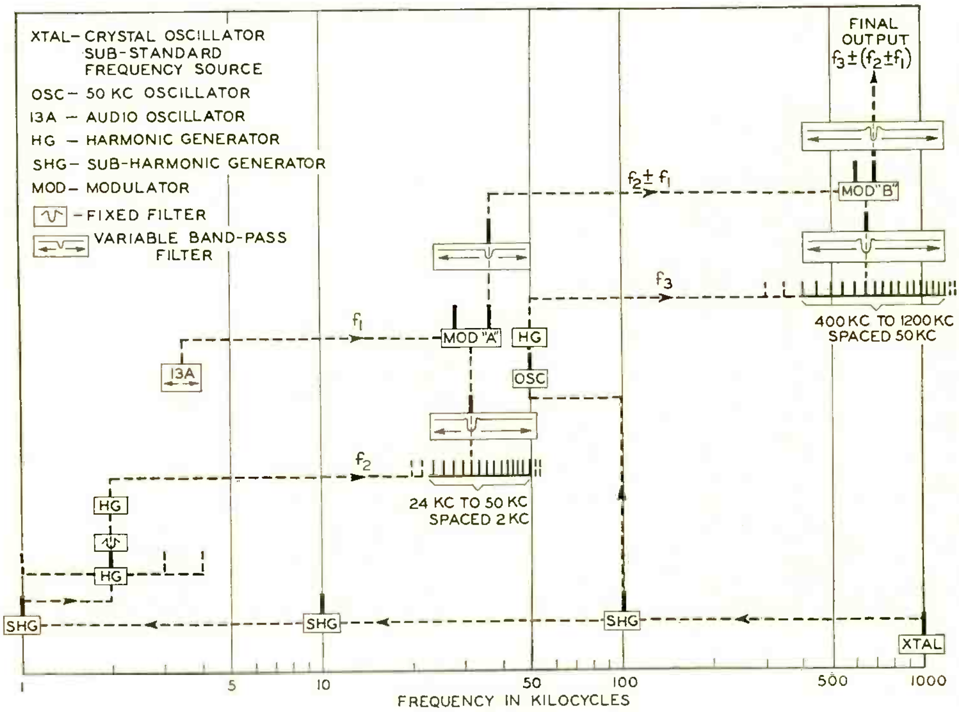



*Fig. 9—The operation, throughout the frequency range, of the component parts of the generator when producing a particular frequency*

harmonics in the output of the oscillator as a whole at a minimum.

The frequency from this oscillator, and the frequency selected by the filter from the low-frequency generator, are applied to the input circuit of modulator A (Figure 8). Since the output contains sum and difference frequencies plus all the other products of modulation, a variable band-pass filter is again employed to select the proper sideband from the modulator. Between 24 and 50 kilocycles, this filter will transmit any 500-cycle band and attenuate by 66 db the unwanted frequencies three kilocycles or more from the edge of the selected band.

The output of this filter is amplified and applied, along with the filtered and amplified output of the high-frequency generator, to the input of modulator B, whose output contains the desired final frequency. To isolate this frequency from the other products of modulation, a variable band-pass filter is used as before. This filter has a band width of ten kilocycles and a range of 400 to 1,200 kilocycles. Frequencies 25 kilocycles or more from the center of the band are attenuated at least 66 db.

The output of this filter is finally amplified through two stages of screen-grid amplification. The low impedance of the final output circuit facilitates transmission of the desired frequency to the place where it is wanted, with minimum attenuation and freedom from extraneous pick-up. The adjustments of the equipment which are required to produce 1,135,475 cycles are shown in Table 1.

This apparatus has been particularly useful in the study of phenomena associated with piezo-electric crystals where a frequency of great stability, variable in very small frequency increments, is required. With its aid the response spectra and temperature coefficients of quartz plates have been determined, the characteristics of quartz-plate filters have been studied, and unknown frequencies have been measured with very high precision.

# A Skin-Effect Phenomenon

By S. A. SCHELKUNOFF
*Mathematical Research*

IN radio work, high frequency currents are often transmitted over a pair of coaxial cylindrical shells, which act as the two conductors in a "go-and-return" circuit (Figure 1-A). The value of these "concentric pipe conductors" for radio purposes is based on the fact that they radiate only a negligible part of the power entrusted to them, and pick up a negligible amount of static and unwanted signals. These virtues have led to their use between antennas and radio receivers in many of the Bell System's radio-telephone links.

At extremely high frequencies, an interesting paradox arises: the resistance of a hollow cylindrical conductor may increase if its thickness is increased. At first glance, this fact seems at variance with known experience and accepted ideas; it seems to be contrary to plain common sense. Yet a very simple argument will reverse the conviction and create the feeling that the paradox is no more than should have been expected.

A steady current flowing in a hollow cylinder is uniformly distributed over its cross-section, and any increase in its thickness lowers the current density, thereby lessening the amount of energy dissipated into heat. Hence the direct-current resistance of the cylinder decreases as its thickness increases. But an alternating current is not uniformly distributed through the conductor: the current tends to concentrate on one or the other of the surfaces. This phenomenon is known as "skin effect." An explanation of "skin effect" will simultaneously resolve our paradox.

Imagine two thin coaxial cylindrical shells carrying current in the same direction, and metallically connected fairly frequently along and around them. Suppose the return path to be another cylindrical shell outside the first two. (Figure 1-B.) A steady current distributes itself in the two connected shells in the inverse ratio of their resistances, but the distribution of alternating current is governed by the ratio of the impedances. The latter ratio is determined not only by the resistances but by the behavior of the alternating magnetic flux produced by the alternating current in

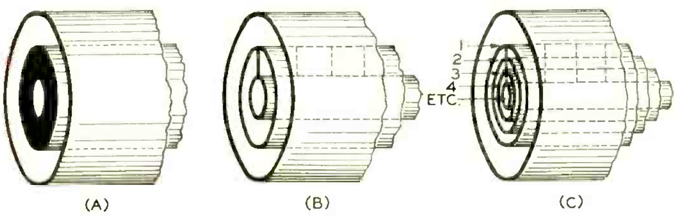



*Fig. 1—A line, consisting of a cylindrical shell and a return path outside it (A), can be regarded as the limiting case of many coaxial shells connected together at frequent intervals, with a return path outside them (C)*

flowing through the two conductors.

This flux can be considered in two parts: the flux outside both the connected shells, and the flux between the inner and outer of these shells. The flux outside both shells affects merely the total current flowing in the shells,

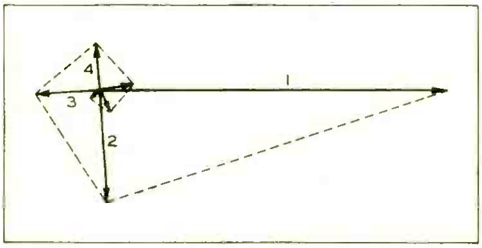



*Fig. 2—At extremely high frequencies, the current in the successive inward shells (Fig. 1-C) shifts in phase by almost 90° and falls off exponentially, more rapidly than can be shown on this scale*

but has no effect on the division of the current between the shells, because in its alternate expansions and contractions it cuts both conductors. Hence in both of these it produces the same back electromotive force of self-induction. The flux between the shells, however, induces a back electromotive force in the inner conductor but not in the outer.

Thus, so far as distribution of current between the coaxial shells is concerned, the outer shell behaves as a pure resistance and the inner shell has a resistance plus an inductive reactance. An inductive reactance increases in direct proportion with frequency. Hence, as the frequency increases, the impedance of the inner shell increases, and a larger proportion of the total current flows in the outer shell. Moreover, since the inductive reactance forms a larger proportion of the total impedance of the inner shell, the current in the inner shell lags increasingly behind that in the outer shell. At extremely high frequencies the current in the inner shell is small and lags behind that in the outer shell by almost ninety degrees.

The argument applies equally well to three or more connected coaxial shells (Figure 1-C). At sufficiently high frequencies the current in each succeeding shell is small compared with that in the preceding and lags behind it by almost ninety degrees. Thus the current in the third shell flows in a direction nearly opposite to that in the outer shell. At intermediate frequencies the phase shift from one conductor to the next varies, according to the frequency, from zero to ninety degrees. The distribution of a current of extremely high frequency in the successive shells is illustrated by the broken spiral in Figure 2, and the distribution of a current of intermediate frequency in Figure 3. The frequency at which the current distribution of Figure 2 is reached depends on the distances between the shells. The greater these distances, the greater the inductances and thus the lower this frequency. Conversely, the greater the frequency, the greater the phase shift from shell to shell, and fewer shells are needed for complete reversal of phase.

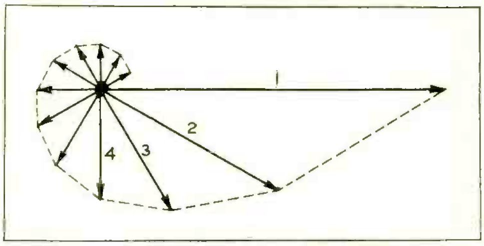



*Fig. 3—At frequencies lower than that assumed in Figure 2, the phase shift and decline of current density in successive inward shells are less rapid*

An ordinary non-laminated hollow

cylindrical conductor (Figure 1-A) can be thought of as the limiting case of an infinite number of separate shells, connected together at increasingly frequent intervals. Hence, the current density diminishes as one recedes from the outer surface of the conductor and its phase changes somewhat as shown in Figure 4. The thicker the conductor, and the higher the frequency, the more rounds the spiral makes.

If any given current of any fixed frequency is sent through such a conductor, then as the thickness is increased (while the outer diameter is kept fixed), the current is at first distributed over a larger area and the resistance naturally decreases. But eventually, that optimum thickness is reached beyond which the current begins to flow in the opposite direction. Since the net current in the initial direction remains the same, there must be an overall increase in absolute current densities, and hence an increase in dissipation of energy, the latter being independent of the direction of flow. Thus the effective resistance is gradually increased until the second reversal of phase occurs.

If plotted against thickness, the

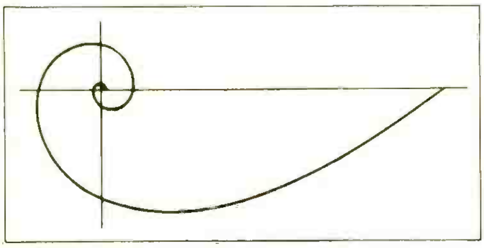


*Fig. 4—The phase shift and decline of current density, as we proceed inward from the outer surface of the inner cylinder of Figure 1-A, follow a logarithmic spiral, as can be seen by regarding the cylinder as made up of an infinite number of infinitely thin shells of the sort supposed in Figure 3*

resistance of a shell at a specified frequency varies somewhat as shown in Figure 5. Since the current density also diminishes quite rapidly, the oscillations of the curve are extremely small except for the first dip, but the optimum resistance may be about nine per cent lower than that of a solid conductor. The lower the frequency, the greater the optimum thickness.

If attention is now directed to the cylinder constituting the return path,

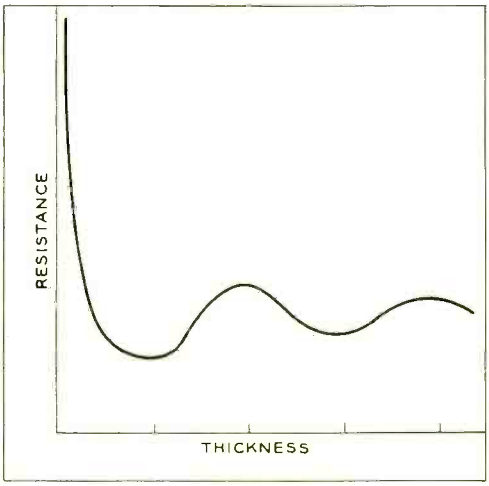



*Fig. 5—At any particular frequency there is an optimum thickness for a cylindrical conductor separated a certain distance from its return path: a thickness at which its resistance is a minimum. The diagram is not drawn to scale, but merely indicates the effect in a general way*

it can be seen that it too can be regarded as the limiting case of increasingly many connected coaxial shells. Here practically the entire flux is inside the outermost of these shells, and it is the inward shells that behave as pure resistances with respect to the adjacent outward shells. Hence the current tends to concentrate toward the inner surface of the conductor: that is, again toward the surface nearest to the other path. Otherwise, the situation is unchanged.

This interesting phenomenon is quite "obvious" if it is admitted (with Maxwell) that energy resides in the dielectric; most of the energy travels parallel to the axis, but some of it diffuses into the imperfect conductors, only to be transformed there into heat. As the frequency is increased and the energy is thus pumped in and out faster, the attenuation and the phase shift in the current density which take place as one recedes from the surface into the conductor, become steadily greater.

## *Radio Effects of Meteor Shower*

*During the Leonid meteor shower which occurred on the night of November* 15-16, *radio pulse measurements were made at the Bell Telephone Laboratories at Deal, N. J. In the opinion of J. P. Schafer and W. M. Goodall, who carried out these tests, the results confirm the theory of A. M. Skellett that meteors cause sufficient ionization in the layers of the upper atmosphere to reflect short wave radio signals.*

*It is a well known fact that there are two ionized regions which reflect short wave radio signals. Coincident with the occurrence of visible meteors overhead, the ionic density of the lower layer was often observed to increase. This ionization was usually found to last from twenty seconds to two minutes and at times much longer. The same investigators had previously made observations during all the more important meteor showers of* 1931 *and* 1932, *but unfavorable weather conditions had prevented a direct correlation between the measured increases in ionization and the passage of meteors overhead. This correlation has now been obtained, although at times during the night clouds obscured portions of the sky.*

# A Frequency Monitoring Unit for Broadcast Stations

By R. E. CORAM
*Radio Development*

THOUGH near in point of time, it is technically a far cry back to the days when broadcast stations were all assigned to the same wavelength of 360 meters and the resulting interference annoyed only the few enthusiasts for distant reception. Today a wide frequency range is carefully apportioned among stations, and regulations against interference increase in stringency. A recent general order of the Federal Radio Commission requires each radio station to insure that its carrier frequency does not deviate more than fifty cycles from the designated value. The order is in reality a promise that conditions of radio reception will be further improved for those enthusiasts, now numbering millions, who live far from metropolitan centers and depend on distant stations for their radio programs.

In order to make frequency adherence a certainty, the Commission has also ordered that all stations provide means independent of the radio transmitter by which the carrier frequency of the station may be checked. It is for this use that the Western Electric No. 1-A Frequency Monitoring Unit has been developed. By it the carrier frequency of a station can be checked against a reference frequency.

As the source of the reference frequency, the new equipment employs the No. 700-A Oscillator*, a highly stable unit whose frequency is

*Record, Dec., 1931, p. 106.

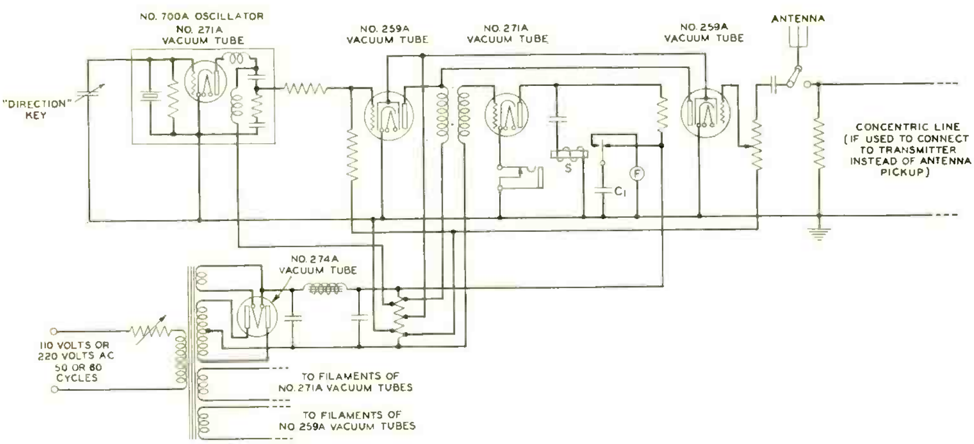



*Fig. 1—The new frequency monitoring unit beats a portion of the station carrier with the output of a 700-A Oscillator and measures the frequency of the beat note*

controlled by a quartz plate. The operating principle of the monitoring unit is to combine in a detector the output voltage from this oscillator together with a portion of the carrier voltage from the radio transmitter. Any difference between these two frequencies appears as a beat note. This note, through the medium of a relay, controls the indication of a meter which is calibrated to read directly in cycles per second the difference in frequency.

The oscillator, identical with that furnished in Western Electric broadcasting transmitters, is a compact unit of two compartments in which the quartz plate and the entire oscillator circuit are assembled. The quartz plate is mounted in a heavy copper casting which approximates a thermally equi-potential shell. The heater resistance is embedded in the bottom of the casting and just above it is located the bulb of a mercury thermostat. After the quartz plate and oscillator circuit are calibrated in these Laboratories in accordance with the carrier frequency assigned by the Commission, the lid of the aluminum container is sealed in place.

In any type of frequency measuring equipment where an unknown frequency is compared with a fixed reference frequency, there must be an accurate means of measuring the difference between them; and for convenience this means should be as simple and as easily manipulated as possible. While there are numerous methods available, the one employed in this case is considered the most logical type for use where simplicity, accuracy, and freedom from trouble are paramount.

The output voltage from the No. 700-A Oscillator is amplified by a screen-grid tube and applied to the grid of a detector tube. A similar amplifier increases the voltage obtained from the unknown source and applies it also to the detector tube. The difference-frequency voltage developed in the plate circuit of the detector is applied to the winding of the polarized relay S (Figure 1). The armature vibrates at the difference frequency and alternately charges the condenser C1 from the detector plate voltage supply and discharges it through the direct current milliammeter F. The circuit constants are so proportioned that the condenser is in effect completely charged and discharged during each cycle of the relay armature. The resulting current through the meter is directly proportional to the number of condenser discharges in a given time, and the meter is therefore calibrated with a uniform scale in cycles per second. If the difference frequency becomes relatively low (5 cycles per second or less), the damp-

*Fig. 2—The amount of departure of the station from its assignment can be read directly on the right-hand meter*

ing of the meter is no longer sufficient to produce a steady deflection, and the meter needle will pulse once for each beat between the two carriers. By this method it is possible to adjust the radio transmitter to zero beat with respect to the reference oscillator after observing the meter swings over a short period of time.

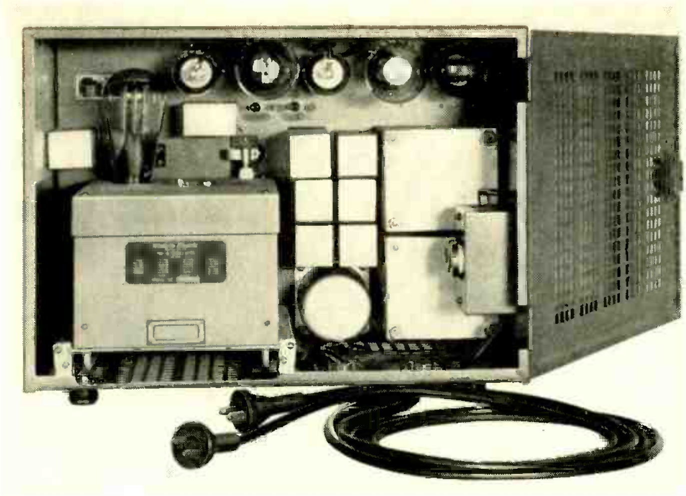


*Fig. 3—In the compact arrangement of the monitoring unit, the 700-A Oscillator is at the left*

To ascertain whether the radio transmitter is low or high with respect to the reference oscillator, the operator presses a push button which adds a small capacity to the reference oscillator circuit and thus lowers its frequency. Instructions on the face of the meter remind the operator that a decrease in the reading when the button is pressed means that the transmitter frequency is low, and vice versa.

In order to make the No. 1-A Frequency Monitoring Unit completely operable from the commercial a-c power source and hence eliminate cumbersome batteries, tubes whose cathodes are indirectly heated are used wherever a-c hum would be detrimental. A full-wave rectifier supplies plate power to the oscillator, detector and amplifier tubes. A voltmeter indicates the oscillator plate voltage, which can be adjusted by means of a rheostat in the primary circuit of the transformer. The unit is equipped with a cord and plug for attachment to a 110 volt, 50 or 60 cycle, a-c circuit. With a slight modification, the unit can be operated from a 220-volt, 50 or 60 cycle circuit.

For temperature control purposes, in addition to the mercury thermostat and heater resistance which are included in the No. 700-A Oscillator, it is necessary to have a sensitive relay through which the opening and closing of the thermostat contacts will control the current supplied to the heater resistance. In this unit a three-element gas-filled tube is employed for the purpose. A transformer supplies filament, grid, and plate voltages for the tube, and the plate current flows through the heater resistance. When the thermal chamber reaches its proper operating temperature, the thermostat contacts close. This applies an out-of-phase potential to the grid of the tube, preventing the flow of plate current. With normal operation this action is repeated at about one minute intervals and is indicated by the flashing of a small lamp connected in the heater circuit.

If a spare oscillator is periodically used in the transmitter, a three-cornered comparison system may be established so that even a slow drift in any oscillator's frequency cannot take place without being noticed.

The use of a relay in the plate circuit of the detector contributes to this monitoring unit a feature unique among equipment of its type. This feature is the ability to measure the carrier frequency whether or not the carrier is modulated. The relay has no "sense of amplitude" but only a "sense of frequency." Thus the unit can be connected wherever its installation is most convenient: at any stage in the transmitter, or even to a small antenna nearby.

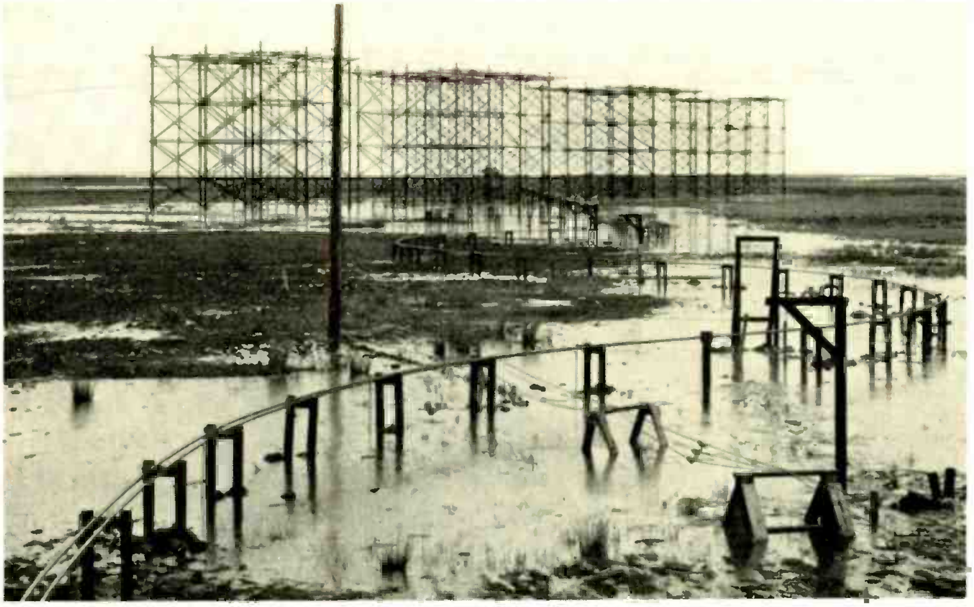
The range of usefulness of this sort of equipment is determined by its adaptability to all the conditions that are likely to be encountered in radio stations. While the unit will ordinarily be coupled to some circuit in the radio transmitter or connected to a small antenna in the operating room, there are station officials who would like to be able to check the transmitter frequency even though the station is several miles away. With this in mind, the input circuit has been designed so that it may be fed not only through a transmission line or from an antenna at the station but also from one of the amplifier stages in a radio receiver. Such a radio receiver can even be used at the same time to monitor the program.

## *Telephone Service to Peru*

*Another South American country was placed within reach of Bell System telephones on October 14 when service was inaugurated between North America and a number of cities in Peru. The service was opened by an exchange of greetings between officials of the United States and Peruvian governments in Washington and Lima.*

*The voice channel thus established links Bell and Bell-connecting telephones in the United States, Canada, Cuba and Mexico with telephones of Lima, Callao and other Peruvian cities, constituting about seventy per cent of all telephones in that country. The charge for a three-minute call between New York and any of these cities is $30.*

*The channel between North America and Peru is formed by a radio circuit between radio stations of the American Telephone and Telegraph Company in New Jersey and of All America Cables, Inc., at Lima. It is operated on wave lengths of approximately 15 meters, corresponding to frequencies of about 19,000 kilocycles.*



# Transmission Lines for Short-Wave Radio Systems

By C. B. FELDMAN
*Radio Research*

RECENT years have seen the growth of radio systems in which it is necessary to place the transmitting and receiving antennas some distance from their associated radio units and from each other, and to connect antenna to unit by a transmission line. Although transmission lines which transfer energy between radio units and antennas are fundamentally no different from power or telephone lines, the high frequencies employed in radio transmission prescribe a technique quite different from that found suitable for power frequencies.

In both, for example, it is important to minimize line losses. In power transmission, where the line is only a fraction of a wavelength long, this can be done by terminating the line in a high impedance and so maintaining a high ratio of voltage to current. In radio transmission, however, the line is many wavelengths long, and the reflections resulting from a high terminating impedance would cause standing waves. These waves appreciably augment transmission losses, and also sometimes affect the operation of the radio unit connected to the line. Furthermore, line irregularities, which in low frequency work can usually be treated as continuous loading, become at radio frequencies reflection points often several wavelengths apart. As before, the resulting reflections produce standing waves.

Radiation and pick-up consequently become increasingly hard to avoid with open-wire lines as line operation approaches radio frequencies. Under certain conditions the stray power radiated by a transmission line associated with a transmitter may be an appreciable fraction of that radiated by the antenna connected to the line. These radiations may completely annul the directional characteristics of an antenna and in addition may cause interference to other radio stations. Similarly, since the sensitivity of radio receiving equipment is high, static and other noise picked up by a poorly designed transmission line may reach a level comparable to that of the desired signal.

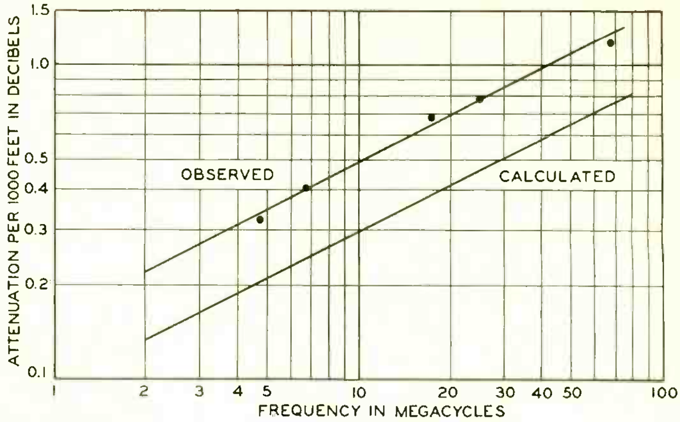



*Fig. 2—In spite of considerable precaution in its construction, an experimental open-wire line had sufficient unbalance to cause attenuation 70 per cent higher at radio frequencies than the attenuation which copper losses alone would produce*

Hence, although the primary purpose of a radio transmission line is to transfer energy between an antenna and a radio unit, the efficiency with which it does this is of no greater importance than the degree to which it is isolated from its associated antenna, from other antennas and lines, and from extraneous sources of signals. Indeed discrimination against undesired signals and static is often of greater importance than the overall gain from antenna to telephone line.

The simplest conceivable connection between radio apparatus and an antenna is a single wire, but single-wire lines are of limited utility because of their marked radiation characteristics. The power radiated by a wire several wavelengths long may even be as much as

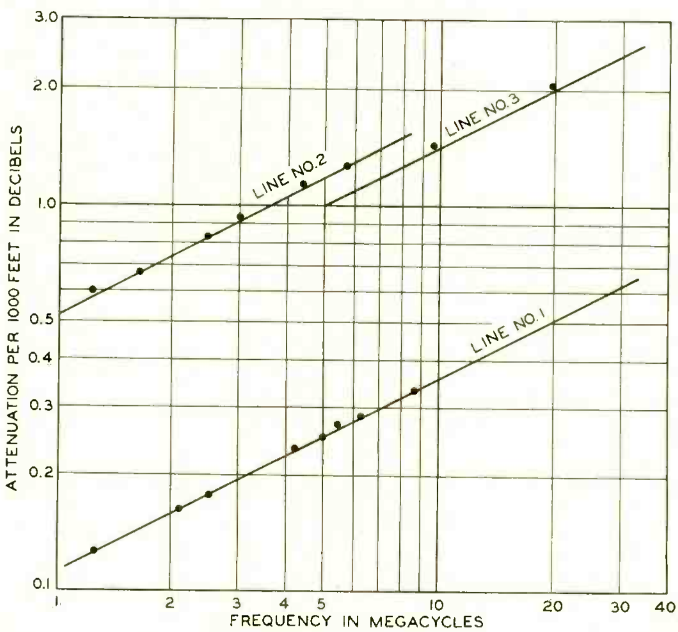


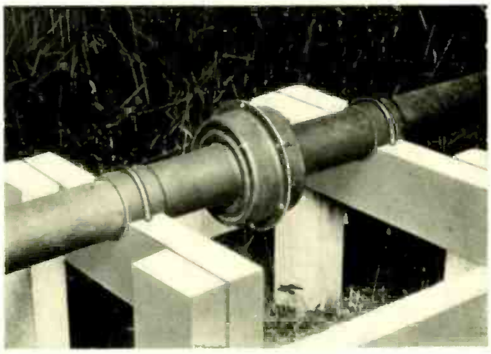

*Fig. 1—In the attenuation of concentric-tube transmission lines at radio frequencies, there is close agreement between theory (curves) and experiment (points)*

that radiated by the antenna to which it is connected. In fact single wire lines, particularly when properly terminated, are desirable radiating elements for certain services, and diamond-shaped arrays of such elements are now employed in some of the radio facilities of the Bell System.*

The power losses and cross-talk due to radiation may be reduced by employing two conductors, separated a small fraction of a wavelength, in a go-and-return circuit. If the two wires do not carry equal currents exactly opposite in phase, however, there will appear current components which employ the two conductors in parallel, and radiation losses of the type ascribed to single-wire conductors will appear. Although these are far less than those of single wire lines, there are many practical cases where the radiation from two-wire lines produces an undesirable amount of cross-talk and loss of signal discrimination.

Multiple-wire lines, comprising several pairs of conductors in go-and-return circuits, may be employed to reduce still further the undesired radiation from transmitters. But again care must be exercised in maintaining the required current amplitudes and phases, or the radiation losses ascribed to single wire lines may impair the utility of the system. When associated with receivers, multiple-wire lines, of course, reduce static and noise interference by their shielding effect.

From the standpoint of isolation, an ideal electrical connection between antennas and radio apparatus is approached only when the circuit is shielded. One way of accomplishing this result is to use one conductor as a shield. A concentric-tube line comprising an outer sheath, within which an inner conductor is supported on insulators, is the common form of this construction. When properly made of copper tubing, the external tube of such a line effectually shields the inner conductor and thus, so to speak, "isolates the ether" within the sheath. The currents flow principally on the outer surface of the inner conductor and on the inner surface of the outer conductor.



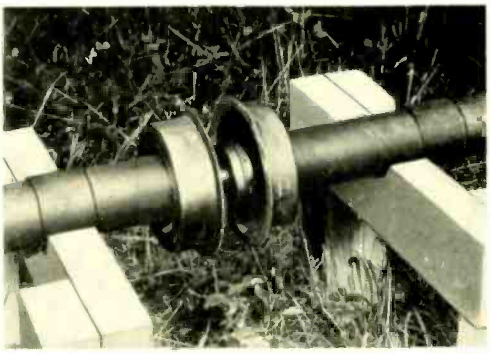


*Fig. 3—By flexing like a diaphragm, this joint accommodates a change in length with temperature of as much as one-half inch*

The high degree of isolation thus afforded can easily be impaired. Pick-up from neighboring antennas or otherwise may cause currents of appreciable magnitude to flow upon the exterior of the sheath. Spurious couplings between the line and the antenna or the radio equipment may

*Record, *April*, 1932, *p.* 291.

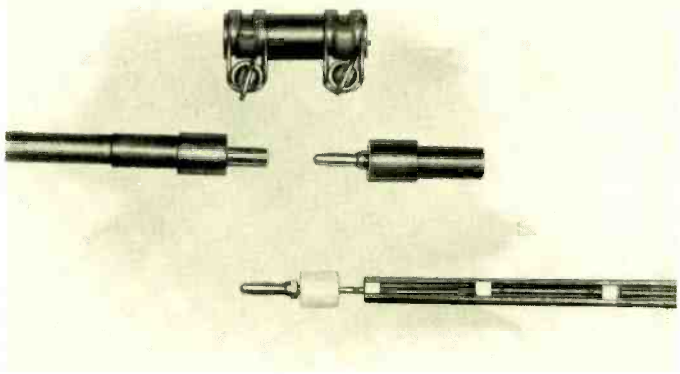


*Fig. 4—Small shielded lines can be used for radio-frequency station wiring, and can be connected by plugs and jacks*

introduce these currents into the shielded circuit.

Grounds placed at frequent intervals are useful in reducing these currents; sometimes indeed the line can be buried in the earth. Additional improvement is obtained by constructing the circuits which transform the antenna impedance to the line impedance so as to minimize capacitive coupling to the sheath.

In the efficiency with which they transmit power, there is little to choose between practicable open-wire lines and concentric tube lines, provided a reasonable degree of current balance is maintained. The balance can be obtained by carefully designing the terminal equipment at the antenna and the radio unit so that currents will not be introduced which employ the two conductors in parallel, and the ground as a return.

Owing to the circular symmetry and to the fact that the electromagnetic fields are confined within the outer conductor, the losses in concentric tube lines are amenable to rather exact mathematical analysis. At radio frequencies the analysis is surprisingly simple, and the agreement between theoretical and experimental results is excellent, as can be seen in Figure 1. In fact, concentric tube lines can serve as standards of impedance at radio frequencies.

Such calculation reveals that, for a given size of the outer conductor, there is an optimum inner conductor diameter for minimum attenuation. In practice it has been found that small departures from this value, or from exact concentricity, have but slight effect on performance. The insulators used to support the inner conductor, unless spaced too closely, also have only a negligible effect.

The losses in open wire lines can not be calculated so simply and certainly, because the electromagnetic field about them is more complex. Except in the ultra-short wave region the

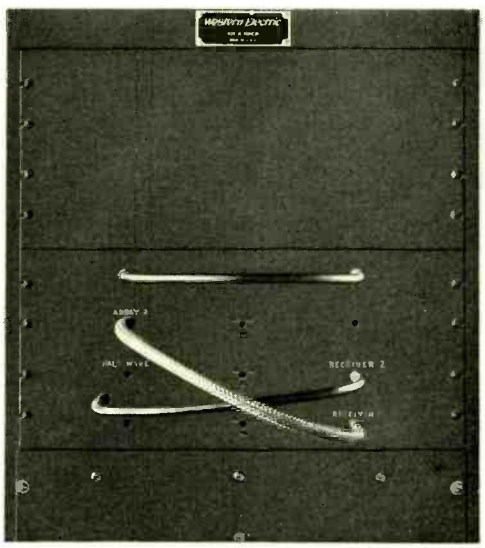


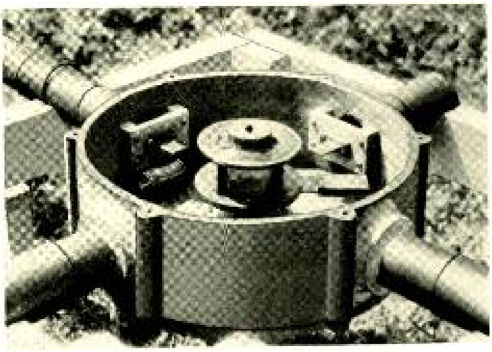
*Fig. 5—At a jack board different receivers can be connected to different antennas by concentric patching cords*

power radiated by balanced two-wire lines is small compared with that transmitted along the line. In fact, the attenuation due to copper losses in balanced two-wire lines is not very different from that in concentric-tube lines of practical sizes. Experience shows, however, that it is difficult in practice to restrict attenuation to that from copper loss. This is exemplified by the discrepancy between the curves plotted in Figure 2. The calculated curve takes account of copper losses only; the balanced radiation loss is negligible. The discrepancy of 70 per cent is attributable mainly to losses in the earth beneath the line, brought about probably by small and practically unavoidable unbalance, giving rise to currents employing the earth as a return path.

The practical use of concentric-tube lines requires the solution of several mechanical problems. Variations in length with temperature, for example, cannot well be accommodated by line sags as in the case of open wire lines. Small shielded lines can be laid sinuously, as at the Bell System's ship-to-shore receiving station shown in the headpiece, but the expansion and contraction of larger lines must be taken up by joints.

Such joints should be weather-proof, non-microphonic, and electrically not too different from the line itself. A joint successfully accommodating a variation of one-half inch has been designed (Figure 3), but six of these joints in a 300-foot line introduce a noticeable irregularity in impedance. Furthermore, in order that each joint may take care of no more than its share of the total expansion of a line, the inner and outer conductors must be locked together and to a substantially braced support at points midway between joints.

Small concentric lines (Figure 4) are useful as radio-frequency wiring in receiving stations, and can be snaked between partitions like armored cable. They are also used outdoors in experimental work at Holmdel. The lines can be terminated at jack boards, and different antennas can be connected



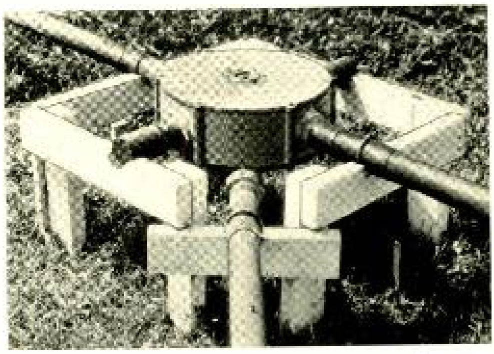


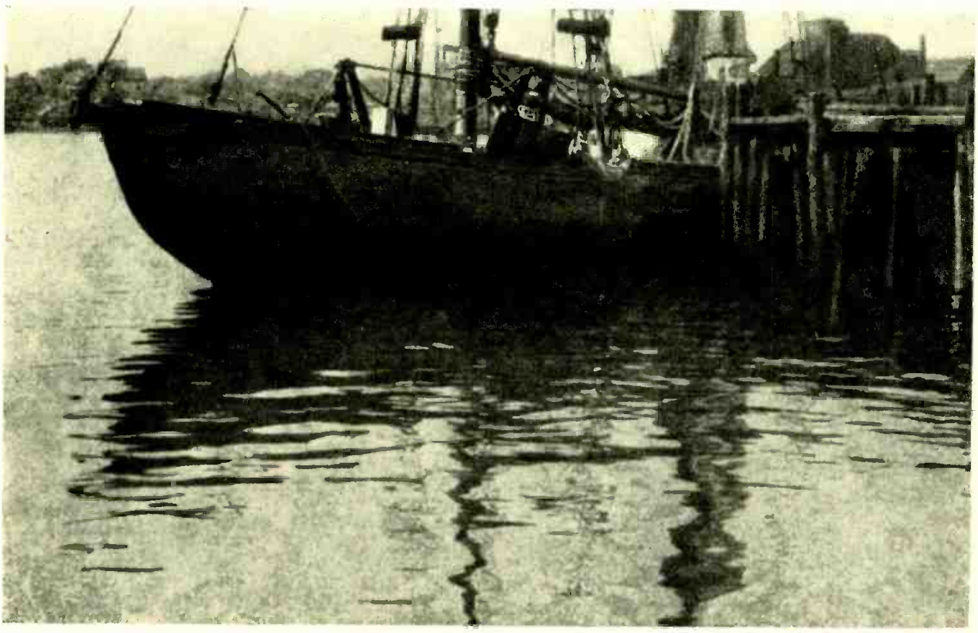
*Fig. 6—In an experimental switch for connecting one of several concentric antenna lines to one transmitter line, a small coil antiresonates the capacitance of the switch for the operating frequency of the transmitter*

to different radio units by patching cords (Figure 5). High-power concentric lines cannot be switched so simply. A switch such as that used experimentally at Deal (Figure 6) for connecting one of several transmitting antennas to a concentric line, is an electrical irregularity in the line which causes reflections if uncorrected. By designing the switch so that its capacitive reactance predominates over its inductive reactance, and anti-resonating this capacitance with a suitable inductance, the irregularity can be minimized.

In general, therefore, choice between an open-wire and a shielded line for a particular service must be based upon balancing the benefits of isolation against the greater cost of the concentric construction. By permitting the compact installation of a number of radio units without incurring cross-talk difficulties, the cost of concentric lines may be more than offset by savings in the cost and maintenance of the station.

Transmitters usually occupy so much space that the lines are necessarily separated enough to avoid serious cross-talk. Static pick-up is unimportant, except for the large lightning surges which can be drained by horn gaps and grounds. Thus at the Bell System's transmitting stations, the high cost of concentric lines has so far appeared unjustifiable, and open-wire lines are employed.

Receiving lines, however, are less costly, and receivers are small enough for compact installation. Furthermore a sacrifice of a few decibels in signal level at a receiver is less detrimental than a loss of discrimination against undesired signals. Small shielded lines with losses as great as two decibels per thousand feet have been found more suitable than open-wire lines, and are now in use at receiving stations in the radio-telephone links of the Bell System's transoceanic and ship-to-shore services.



*One of the winning photographs in the Club's 1932 contest: first prize, junior miscellaneous group, by C. N. Nebel*

# Contributors to This Issue

H. W. ULRICH entered the Bell System as telephone inspector with The Bell Telephone Company of Pennsylvania late in 1902. After eleven years in the operating field, he joined the Technical Staff of Bell Telephone Laboratories—at that time the engineering department of the Western Electric Company. Here, with the circuit laboratory, he has participated in the circuit development of manual central offices, private branch exchanges, and toll circuits. He was also associated with the design and construction of the telephone repeater demonstration for the European engineering department, which resulted in the introduction of telephone repeaters in Europe, with the early development and application of repeaters to commercial service in this country, and with pilot wire regulation for automatic control of transmission with four-wire repeaters. At present he is associated with the manual circuit design group.

R. A. HEISING received the degree of E.E. from the University of North Dakota in 1912, and the M.S. degree from the University of Wisconsin two years later, and then entered the Research Department. He participated in the long-distance radio-telephone experiments of 1915, in wartime radio-communication developments, the early ship-to-shore telephone work, and the trans-atlantic radio circuit development. For the past seven years he has had charge of numerous fundamental investigations in short-wave radio transmission and systems. Most recently his group has been concerned with ultra-short-wave and piezo-electric phenomena.

H. J. SCOTT was graduated from the University of Washington in 1927 with the degree of B.S. in Electrical Engineering, and joined these Laboratories the same year. He has since, with the Radio Research group, been engaged chiefly in the design and development of radio apparatus, including the ship-to-shore equipment for the Leviathan. Most recently he has had a large part in the develop-

*H. W. Ulrich*

*R. A. Heising*

*H. J. Scott*

C. B. Feldman

S. A. Schelkunoff

R. E. Coram

ment of the variable radio-frequency generator which he describes in this issue of the RECORD.

C. B. FELDMAN received from the University of Minnesota the degree of B.S. in 1926, and the degree of M.S. two years later. He came at once to the Laboratories and has been conducting studies of wave propagation, in the course of which he has had a large part in developing coaxial conductors for use as transmission lines between radio receivers and their associated antennas.

SERGEI A. SCHELKUNOFF received the B.A. and M.A. degrees in mathematics from the State College of Washington in 1923, and in the fall of that year joined the Carrier Research group of these Laboratories. Three years later he returned to Washington State as an instructor in mathematics and later became an associate professor. In 1928 he received the Ph.D. degree from Columbia University. The following year he rejoined the Laboratories, entering the Mathematical Research group where he has since been pursuing electromagnetic studies in their relation to communication problems.

AFTER STUDYING mechanical engineering at Massachusetts Institute of Technology, R. E. Coram joined the New England Telephone Company, in whose Plant Department he took part in the early demonstrations of the trans-continental telephone circuit. Seven years later, in 1919, he came to these Laboratories. Here he was associated with the installation of the first commercial, and the development of the type C, carrier telephone systems, and later had charge of the design of the low-power equipment for the long-wave transatlantic radiotelephone transmitters at Rugby, England, and Rocky Point, Long Island, and of the receiver at Houlton, Maine. In recent years he has been in charge of a group developing radio-broadcasting equipment.