BELL LABORATORIES RECORD

DRYNESS IN TELEPHONE CABLES
A. G. HALL

POLICE RADIO SYSTEM
A. B. BAILEY

QUARTZ CRYSTAL FILTERS
W. P. MASON

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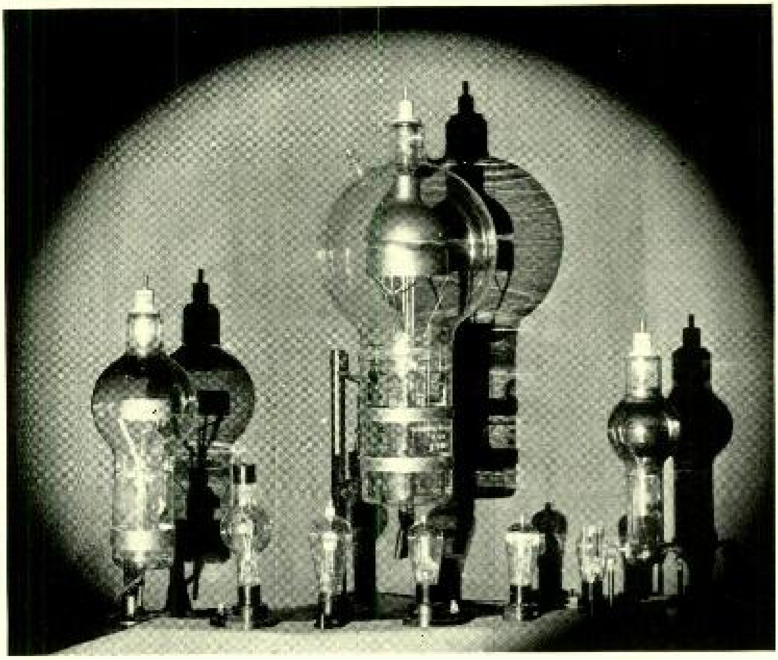

Rectifier tubes designed by Bell Telephone Laboratories for the Western Electric Company

VOLUME THIRTEEN—NUMBER TEN

for

JUNE

1935

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A Police Radio System for Newark

By ARNOLD B. BAILEY
Radio Development

NEWARK is among the first of the larger cities of the country to adopt ultra-high-frequency equipment for its police radio system. By operating in this frequency range a number of definite advantages are obtained. Among them are the relatively high efficiencies that are possible with small antennas, the freedom from natural static, and the diminution of interference from other stations because of the limited range of these high frequencies. The Newark police radio apparatus, which was manufactured by the Western Electric Company, has now been in service for some months, and is proving highly effective in the city's fight against crime.

Newark centralizes its radio dispatching in a large room at Police Headquarters. The general arrangement is shown in Figure 1. Here, in the small room at the left, is the announcer at his desk with a microphone in front of him by which orders are broadcast to thirty-six receivers in police cars and precinct stations. In the center of the room are two tables with large-scale maps of the territory covered. Miniature models of the police cars are placed on these maps in the center of the districts covered so that a glance shows which car is nearest the location of any reported crime. On the right is a small telephone switchboard at which all incoming calls are received. A fire alarm tape recorder is also located here which immediately notifies the radio dispatcher of all fires. Adjacent to the radio room is the police teletype-

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writer room where messages are received in typed form from other police departments. An opening in the wall allows direct communication between the two rooms, and thus facilitates the transference of information between the two systems.

The radio transmitter itself is in a room on the thirty-fourth floor of the National Newark and Essex Bank Building, the highest building in New Jersey. This building was selected by the Hon. Michael P. Duffy, Director of Public Safety, upon recommendation of the engineers of the Department of Public Safety. It was chosen because its extreme height and central location provided a very favorable position for the antenna, height being of paramount importance for short-wave police service. At Newark maximum height, and therefore highest efficiency, was secured by designing the antenna to be mounted on top of a one hundred foot flagpole which itself is six hundred feet above the street.

Fig. 2—Director of Public Safety Michael P. Duffy at his desk at the City Hall. Radio receiver for monitoring police calls at the left

Fig. 1—Radio dispatching room for the Newark police system. Left to right: Lieutenant William Sacher; Samuel Cobb, Dispatcher, in booth, and Robert Schweitzer at the switchboard

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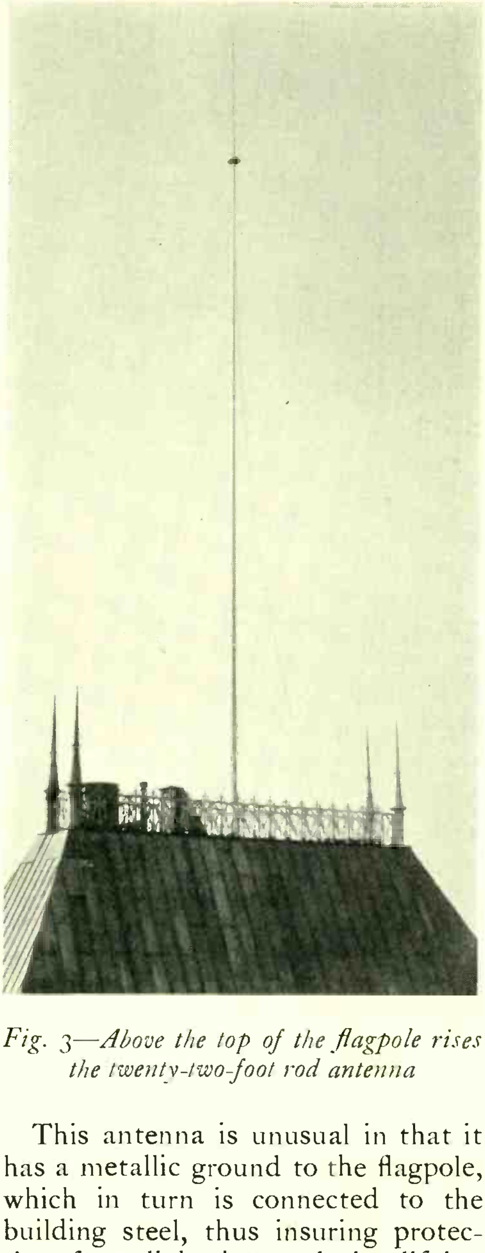

Fig. 3—Above the top of the flagpole rises the twenty-two-foot rod antenna

This antenna is unusual in that it has a metallic ground to the flagpole, which in turn is connected to the building steel, thus insuring protection from lightning and simplifying the erection. The structure consists of a vertical bronze tube three-quarter wavelength or about 7.5 meters long projecting above the flagpole. The circuit arrangement is shown in Figure 4, and its appearance in Figure 3. Effective radiation occurs from the upper half-wave portion of the antenna, the lower quarter-wave portion, together with a parallel wire conductor, acting as an impedance-matching network to couple the high impedance of the antenna to the low-impedance concentric transmission line, which connects the antenna structure with the radio transmitter.

From the base of the antenna, this line runs down through the flagpole to the transmitter. The transmitter consists of two units: one a 50-watt radio transmitter, and the other a 500-watt radio-frequency amplifier. The units are equipped with rectifiers for plate and grid voltage supply. They are tuned from the front by means of controls and indicating meters mounted on the face of the panels. The frequency is stabilized to better than twenty-five thousandths of one per cent by a low-temperature-coefficient quartz plate, which oscillates at one-sixth of the operating frequency. This high degree of stabilization is advantageous in assuring that all police car receivers will always receive the announcements without the need of retuning to compensate for variations in the frequency.

On the operator's desk in the transmitter room there is a high-quality speech amplifier, a microphone, and a monitoring receiver.

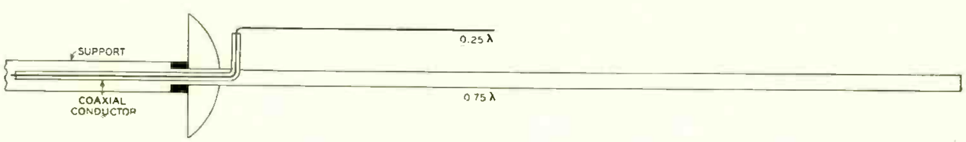

Fig. 4—Simplified cross-section showing arrangement of antenna, coupling section, and concentric transmission line

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Fig. 5—On the wall in front of the dispatcher is a time signal device and on the desk in front of him is the speech amplifier

mitter room and in precinct stations, while the battery set, considerably smaller in size, is used in the police cars. With both types the signals are reproduced by loudspeakers.

From the receiver in the car a shielded antenna cable runs to a screen antenna concealed in the roof of the car. A shielded power cable connects the receiver to a small plate-supply dynamotor in the rear compartment of the coupe. Here also is a heavy-duty storage battery which is charged by the car generator located on the engine block. This generator is designed to deliver about fifty per cent

Since dispatching is normally done from Police Headquarters, the transmitter is designed to be remotely controlled from that point, but it can be operated and announcements sent out from the transmitter room even in the event that connection with Police Headquarters is completely cut off.

The monitoring receiver, shown on the small table at the left of Figure 2, is one of two types developed for ultra-short-wave police work. These are of the super-heterodyne type, very sensitive and in general alike, but one is designed to operate with a battery and dynamotor, while the other obtains its power supply from a 110-volt a-c circuit. The latter type is used in the trans-

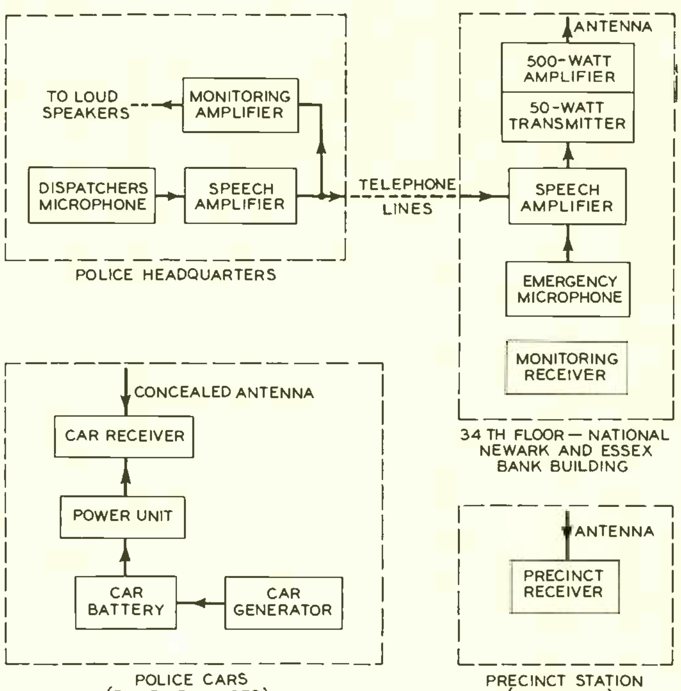

Fig. 6—Block schematic of Newark police radio system

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more current than the standard car generator, and to deliver full output at low speeds so that it will charge the battery during slow-speed cruising.

A block schematic showing the relationship and interconnection of the various pieces of apparatus is shown in Figure 6. The announcer at Police Headquarters, shown at his desk in Figure 5, besides sending out all instructions, announces time every fifteen minutes. A signal given by the device on the wall behind the announcer is a reminder to send out the time announcement. This time announcement furnishes a periodic check on reception even when other announcements are not being made.

Director Duffy is to be congratulated for his part in the pioneer work with this type of transmission recommended by the engineers of the Department of Public Safety. Since the beginning of operation, he has expanded the usual police functions so that all fire alarms are also sent by radio to each police car. During the first thirty days of operation two incipient fires were put out by radio patrol cars before the arrival of the fire apparatus. The value of time saved in such cases is inestimable, and such an important service deserves proper recognition.

The favorable location of the transmitting antenna, the high quality and stability of the transmitter, together with the exceptionally fine automatic volume-control of the receiver assure a substantially constant received signal in all parts of Newark. No dead spots exist. At present the system is operating on a one-way basis only—information being transmitted from Police Headquarters to the police cars and precinct stations. Conversion to a two-way system can easily be made, however, by the addition to each police car of a small radio transmitter and two accessory units.

The battery receiver may be seen face up behind the driver's seat; left to right, John Brinkman, and Harry Foster, driver

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A Recording Transmission Measuring Set

By M. A. LOGAN
Wire Transmission Research

IN improving the characteristics of communication circuits, and in adapting them for particular uses, two types of development have been of incalculable importance. On the one hand, mathematical studies have made it possible to design transmission systems with predictable properties; and on the other, transmission measuring equipment has enabled these properties to be determined in systems actually constructed. Mathematical methods are usually so laborious that they are replaced by measuring methods where practicable. In many cases the cost of mathematical methods is so great that elaborate measuring devices have been constructed to obtain results experimentally. The economies to be had with their help can be seen from the fact that a transmission measuring set recently designed for laboratory use measures and records in four minutes, entirely automatically, the insertion loss at fifty frequencies between one hundred and five thousand cycles.

In principle the new measuring set, like many of its fellows, is a vacuum tube voltmeter which, connected to a source of fixed sending voltage, gives a fixed indication. When an unknown smaller voltage is passed through an amplifier and attenuator into the voltmeter, and attenuation is re-

Fig. 1—The new recording transmission measuring set consists of two bays of equipment, one supplying the testing voltage, and the other measuring the insertion loss of the equipment under test

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moved until the original indication is obtained, the amount of attenuation removed is a measure of the ratio of the received voltage to the fixed voltage. In manually operated sets, however, an operator has to give his full attention to changing the frequency of the sending oscillator, adjusting the attenuation in the receiving equipment, and recording the results of the test. The new set automatically selects the frequencies in succession, adjusts the attenuator, and records the data by a page printer, freeing the operator to prepare other pieces of apparatus for test. Its general appearance is shown in Figure 1.

A set which records at discrete frequencies rather than continuously has the advantage that it can more readily be given an extensive range of transmission losses without sacrifice of accuracy. In those cases where tables would otherwise have to be made from curves, the ability to secure the data directly in tabulated form saves time and tends to eliminate human errors. Assembly of the entire set as a unit makes it possible to use circuit arrangements which would be impracticable if the sending and receiving parts were in different cities, as when measurements are made on long telephone circuits. In particular, accuracy of the set can be insured by designing it so that before each measurement it automatically compensates for any change in sending level or amplifier gain with time and frequency. It has not been designed to measure such quantities as telephone circuit noise or speech volume.

The general arrangement of the set is schematized in Figure 2. The sending voltage is furnished by an oscillator of the Western Electric 13A type, slightly modified in its output circuit and equipped with a motor which, after each measurement is completed, turns the frequency-changing dial to the next setting. The operation of the set is automatically prevented from proceeding until the dial has reached the new setting.

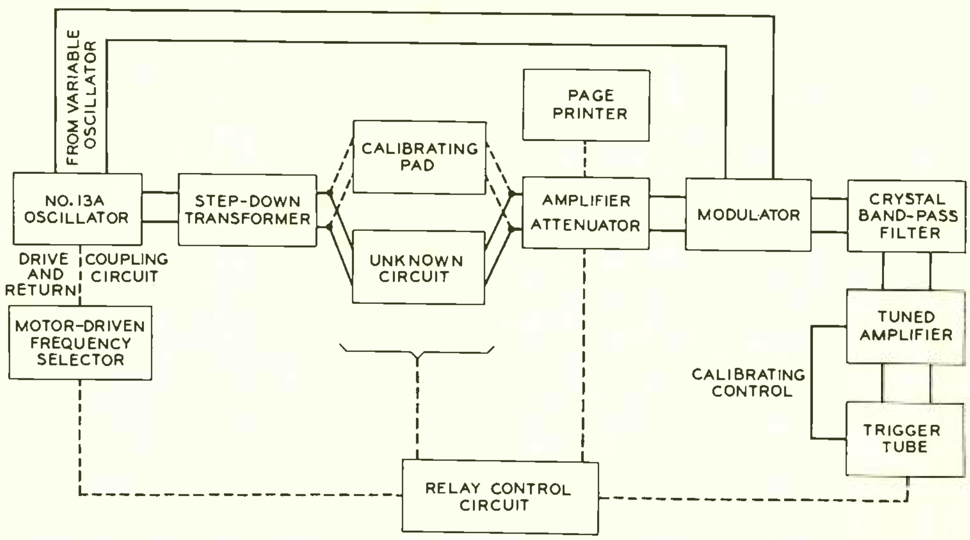

Fig. 2—The transmission measuring set employs a 13A oscillator as a source of sending voltage, and combines its variable high-frequency with the audio frequency output of the circuit under test, to provide a fixed frequency of 100 kilocycles

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The 13A Oscillator, as is fairly well known, consists of two high-frequency oscillating circuits, one generating a fixed frequency of approximately one hundred kilocycles and the other a frequency adjustable between about ninety and one hundred kilocycles. The two oscillations are combined in a balanced modulator, and the difference frequency is filtered from the other modulation products and given two stages of push-pull amplification. The resulting output is adjustable between twenty and nine thousand five hundred cycles, according to the setting of the adjustable high-frequency oscillator.

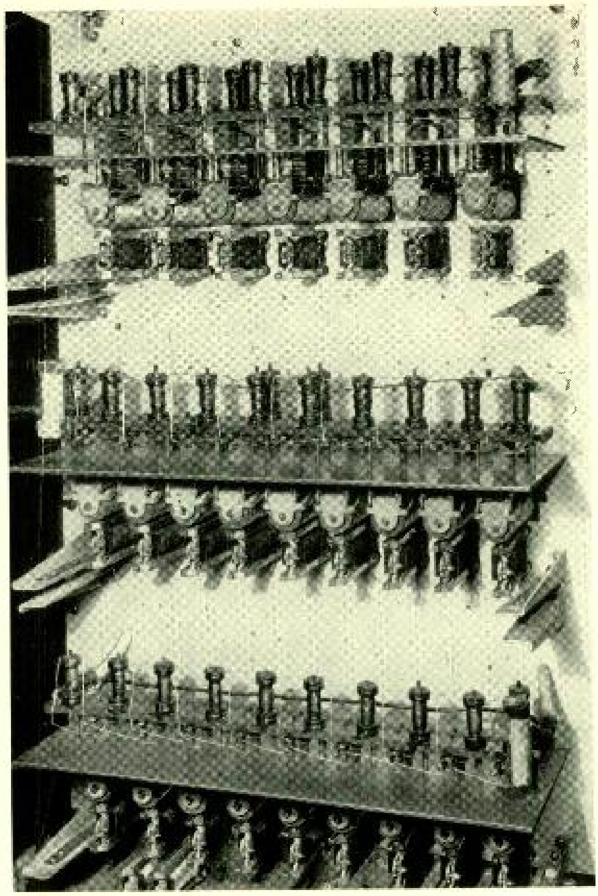

Fig. 3—In the relay-operated attenuator, the attenuation units are carefully shielded from the relays, to minimize the extraneous noise introduced in the measuring circuit

This manner of generating the testing frequency is very helpful in the design of an accurate measuring circuit. When the variable audio frequency is combined in another modulator with the variable high-frequency of the 13A oscillator, and this time the sum-frequency is chosen from the modulation products, that sum-frequency will always be exactly equal to the one hundred kilocycles of the fixed oscillator. This is what is done in the second part of the receiving circuit, and it is therefore possible to perform all the final measurements on a single fixed frequency of one hundred kilocycles, though the measurements apply to the behavior of the tested circuit at fifty different frequencies. Accordingly the measuring set incorporates a filter and a second amplifier, both sharply tuned to one hundred kilocycles, which exclude any modulation products arising from noise and harmonics generated in the circuit under test or in the first amplifier.

As can be seen in Figure 2, the output of the tested circuit is first passed into an amplifier and attenuator variable over a voltage range of ten thousand to one, or eighty db, in steps of one-tenth db. There follows the modulator, whose hundred-kilocycle output is selected by a quartz crystal filter* which passes a band only two or three cycles wide. The fixed frequency is further amplified

*See *page* 305 of this issue of the Record.

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and then rectified; and the resulting dc voltage is applied to the grid of a gas-filled "trigger" tube which serves as the ultimate voltage measuring device. The second stage of amplification is required to insure that a change of one-tenth db in the output of the attenuator will cause a voltage change at the trigger tube which is large compared with any casual change in its breakdown voltage.

The initial amplifier, with which the attenuator is associated, has a high input impedance so that, when bridged across various parts of the usual circuits tested, the measuring circuit introduces an error considerably less than its own accuracy of measurement. The attenuator, shown in Figure 3, is composed of three networks, adjustable in seven steps of ten db, nine steps of one db, and nine steps of one-tenth db, respectively. The three are separated by buffer vacuum tubes so that an adjustment of one will not affect the impedances to which the others are connected, and consequently their voltage ratio.

In operation, the sending voltage is applied to the circuit under test, and attenuation is removed in ten db steps by relays until the trigger tube breaks down. That action operates a relay which replaces the last ten db step, and releases the trigger tube. Attenuation is then removed in one db steps; and, after similar action by the trigger tube, in one-tenth db steps. When the last one-tenth db step is replaced, the setting of the attenuator is recorded by a page printer. Thus, effectively the value recorded is that of the net amplification required to bring the grid voltage of the trigger tube to a point just below its breakdown voltage.

The rectified voltage is applied to the trigger tube in such a direction as to reduce the ninety-volt negative bias permanently applied to the grid. When the net grid voltage reaches a value of about −2.8 volts, the space current, which has been zero, suddenly assumes a finite value determined by the applied plate potential and the resistance in the plate circuit. In actual operation, the plate potential, of +90 volts, is applied just after each step in setting the attenuator and then removed, so that the operation of the switching circuits will not cause any error in the measurements through the noise which they may introduce. After the tube has operated, the plate potential must again be removed to restore the tube to the non-conducting condition.

The overall calibration of the set between each measurement is made by a gain-adjusting circuit forming part of the hundred-kilocycle amplifier. The amplifier employs a tube whose gain depends on the bias of its control grid. A condenser in series with that grid is momentarily charged sufficiently to reduce the gain so that, when the attenuation is all inserted and the output of the testing voltage is applied directly to the receiving set, the trigger tube does not operate. The condenser is then slowly discharged until the tube operates, when the discharge is stopped. The potential across the condenser remains unaltered, and the gain of the amplifier is fixed, during the succeeding measurement. At its conclusion, the frequency is changed, the set is recalibrated, and the next measurement is made.

The set can measure not only losses up to eighty db but gains up to twenty db. The latter is accomplished by inserting twenty db loss in the receiving circuit after the calibration. The fact that twenty db must be subtracted

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from the printed loss measurement is indicated by a quotation mark printed just before the reading, as shown in Figure 4. The set can also measure the voltage at two places in a circuit for each frequency. Thus, for example, measurements made across the receivers of two station sets at each end of a telephone circuit will furnish both the sidetone voltage and the received voltage in parallel columns on one data sheet.

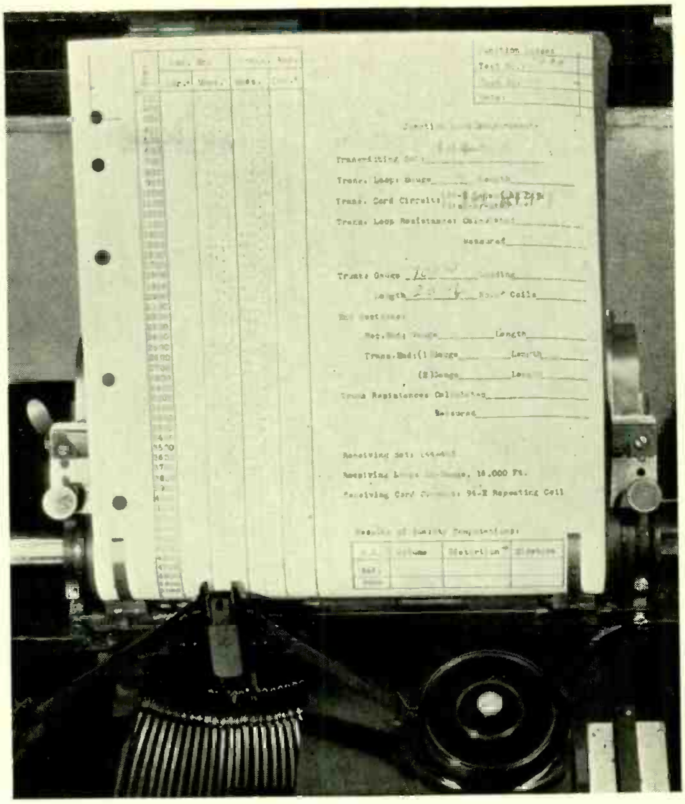

Fig. 4—A teletypewriter records the data on a page-size form

A relay switching circuit controls and performs all these operations with great rapidity in their proper sequence. When the starting button is pressed, measurements are made and recorded at hundred-cycle intervals up to 5000 cycles, at which point the measuring is stopped and the oscillator is automatically returned to the hundred-cycle setting. The ability to make two loss measurements at fifty frequencies in eight minutes without attention to the measuring set has proved extremely valuable.

This measuring set has been designed and constructed primarily to provide data for transmission studies of the circuits used in the local exchange plant. To permit these measurements to be made in the laboratories, artificial lines are used to simulate the trunk and loop conductors. Because of the wide variety of circuit combinations which are found in the local plant and the consequent large number of measurements which must be made in a study of these circuits, it has been particularly desirable to incorporate in this measuring arrangement, the automatic means which have been described for making the measurements on any one circuit in a short time. While this measuring set has been used largely for this purpose, it can be used also to make similar measurements on electrical networks such as filters and equalizers.

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A Marine Radio Compass

By W. L. WEBB
Radio Development

RADIO direction finding has been used by the Navy and many large merchant vessels for some time, and has proved to be of immense value under a variety of situations. Existing apparatus, however, is expensive and has not been employed to an appreciable extent by smaller vessels. With the development of the Western Electric radio telephone, and its installation in fishing vessels sailing from New England ports, it became apparent that the addition of an easily operated radio compass would greatly increase the value of the radio equipment. With this in view Bell Laboratories developed a marine radio compass to be used as an adjunct to the radio telephone. It is not only very simple to operate but of moderate cost. It utilizes the same power supplies as the radio telephone, and the design adopted avoids some of the uncertainties of direction occasionally existing with previous types of radio compasses.

Radio direction finders utilize the directional properties of a loop antenna, shown in the diagram of Figure 1. This characteristic shows that the loop will receive maximum signal when its plane is pointed toward a transmitting station, and little or no signal when its plane is perpendicular to the direction of the station. It is

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evident that the position of zero signal can be determined with greater accuracy than the position of maximum signal because the rate of change of signal strength is greatest where the response of the loop is zero. This position of minimum signal is therefore used to determine the direction of the transmitting station. Since there are two positions of minimum signal, however, the loop when used alone will determine only the line of direction but not the direction proper, or as it is commonly called the "sense" of the direction. To determine the "sense" of the direction, a non-directional antenna is employed in conjunction with the loop. In the usual radio direction finder this "sense" determination requires an extra operation on the part of the operator and its determination may be rather uncertain.

In using a direction finder of the conventional type, the position of minimum or zero signal is usually determined by listening to the receiver output with head telephones, and considerable skill is often required since there are effects tending to obscure this "null" position. Because of circuit unbalance or the effect of metallic objects on board the vessel, there is usually some signal received

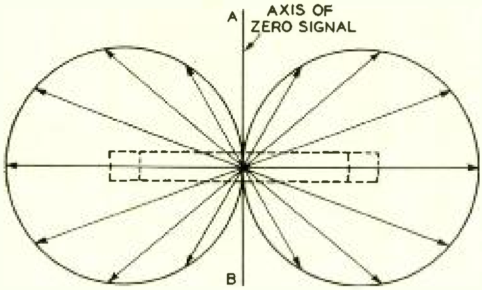

Fig. 1—A loop antenna, indicated by dashed line, has a figure-eight sensitivity characteristic as shown by the vectors

in all positions of the loop, and it is necessary for the operator to balance out this extraneous signal with an additional control known as the "balance" adjustment. With a weak signal, the operator must frequently interpolate between two signal amplitudes of equal value—one on each side of the null position—and in this way determine the null position as that half-way between two positions of approximately equal signal. From these rather complicated operations that must be carried out to obtain an accurate bearing, it is evident that skillful operation is usually required to secure dependable results.

In the development of the new Western Electric radio compass, the objective has been to secure a device that could be readily operated by any of the officers, and that would give accurate results in which they would have the utmost confidence. The new compass gives a positive visual indication of direction, rather than depending on a difficult aural balance, and the usual operations for "sense" determination and "balance" have been eliminated. A typical installation of the radio compass is shown in the photograph at the head of this article, and the apparatus is shown in greater detail in Figures 2, 3, and 4. The loop is secured to the roof of the wheel house directly above the steering compass, and is operated by a handwheel on the lower end of the loop shaft, which is located in the wheel house directly above the steering compass.

In taking a bearing, the receiver—Figure 4—is tuned by rotating the signal tuning knob, which sets the dial, marked in kilocycles, to the desired frequency. A right or left deflection of the indicating meter, shown in Figure 3, is at once noted, and the

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hand wheel is turned in a direction opposite to the direction of deflection of the meter until the meter pointer comes to zero. The bearing of the radio beacon with respect to the vessel's heading is then read directly from the azimuth scale shown just above the hand wheel in Figure 3. The direction of the ship's heading at the time is determined from the steering compass, and by combining the two, the bearing of the radio beacon is determined.

Fig. 2—The loop is mounted in a water-tight aluminum casting, which is supported by an aluminum pedestal fastened to the deck above the wheel house

A loudspeaker is provided for identification of the station and to facilitate tuning. It would not ordinarily be needed for taking the bearing except as a check to identify the station, but under conditions of severe static it is possible to eliminate a good deal of the effect of the static on the indicating meter by neglecting deflections that coincide with crashes heard in the loudspeaker. In this way it is often possible to obtain a good bearing under unfavorable conditions. Provision is also made for plugging in a headset to aid in installation adjustments, although normal service does not contemplate its use.

Besides the on-off switch there are only two major controls on the front panel: a tuning control and a sensitivity control. There is a volume control for adjusting the volume from the loudspeaker, but this will usually be adjusted to a given setting to suit the operator and left there. The sensitivity control is used to set the receiver gain at the proper value to obtain the required sensitivity at any given location. The small rectangular plates along the bottom of the receiver provide access to the required installation adjustments and the telephone jack.

The receiver may be removed from its cabinet by turning the two knobs on the ends of the front panel and withdrawing it with the two handles.

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External connections are made through a plug at the rear of the chassis which disengages when the receiver is removed. Variable condensers and vacuum tubes are mounted on the upper side of the chassis, while the wiring, resistances, and fixed condensers are on the under side. This arrangement, the design of which is due to G. Matejka and C. E. Cerveny, brings all parts into full view for servicing and maintenance tests. A chart is provided on the front panel for recording any data needed concerning the marine radio beacons which are to be used in obtaining bearings.

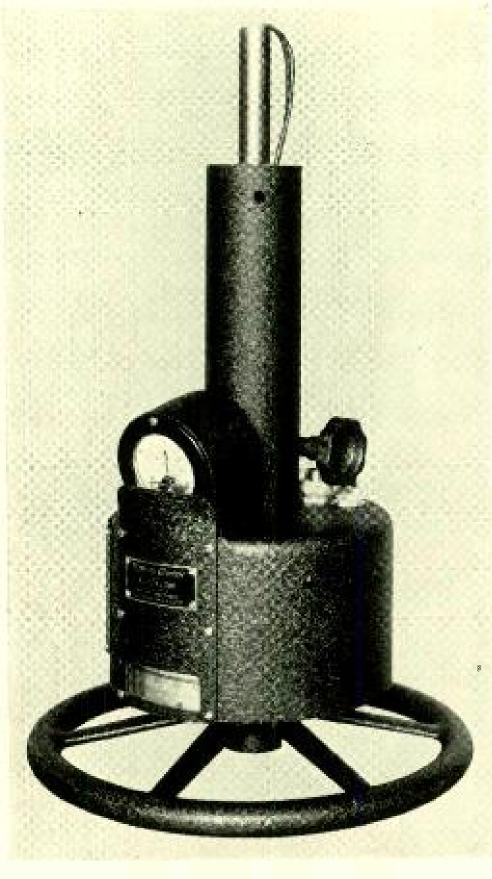

Fig. 3—Lower section of loop mounting, which is in the wheel house above the compass. The bearing is read from the lower scale when the pointer of the meter is at zero

The receiver is of the superheterodyne type, especially designed for use as a radio compass, and covers the frequency range from 242 to 515 kilocycles in one continuous range. This band includes all of the marine radio beacons, most of the airway beacons, as well as all of the ship telegraph frequencies.

It has adequate selectivity to receive radio beacons separated by only from two to four kilocycles, since the attenuation four kilocycles off tune is over fifty decibels. The sensitivity is sufficient to obtain full scale deflection of the indicating meter with a signal strength of five microvolts per meter when the loop is rotated twenty degrees from the position of zero signal. Bearings accurate to one degree can be obtained even at distances of 200 miles, and at greater distances under favorable conditions.

The loop assembly, shown in Figure 2, consists of a statically shielded loop winding, a supporting pedestal with shaft, and the lower assembly shown in Figure 3. This latter assembly contains the compensator, slip rings and brushes, and the necessary terminals. The compensator functions to apply a predetermined correction to the scale pointer automatically and thus to compensate for the deviation of the direction of the radio waves due to the influence of conducting parts of the ship's structure.

The method by which the positive visual indication is obtained can be understood by reference to the simplified schematic in Figure 5. The side frequencies produced from the loop output by the balanced modulator are compared as to their relative phase and intensity with the output of the non-directional antenna. The phase and intensity of the antenna output for a given signal are fixed, but the

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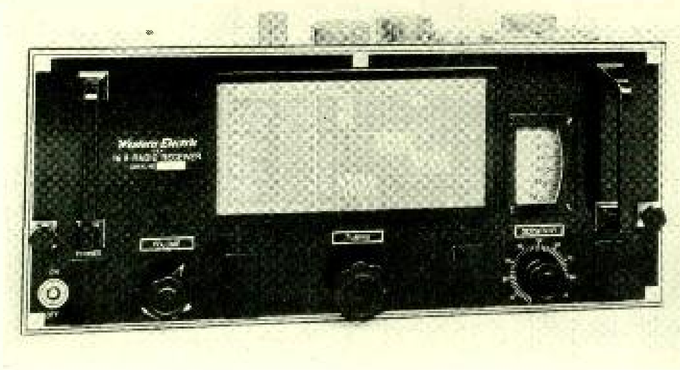

Fig. 4—Front view of direction-finding receiver

phase and intensity of the modulator output depend upon the position of the loop with respect to the direction of arrival of the signal. As the loop is rotated to the right of either of the positions of zero signal, its output will increase, and when rotated to the left, its output will increase also but it will be 180 degrees out of phase from the voltage produced by the right hand rotation. The output of the balanced modulator thus reverses its phase as the loop is rotated through either zero position of the signal.

By energizing the two windings of the dynamometer type meter separately from the detected output of the receiver and the audio frequency oscillator, it is possible to reverse the direction of deflection of the meter by reversing the phase of the receiver output. This makes it possible to obtain the positive visual indication by means of the meter, whose deflection directly follows the position of the loop with respect to the direction of the received signal. By connecting the loop so that for the correct bearing a right hand rotation of the loop deflects the meter to the right and a left hand rotation causes a left hand deflection, the correct bearing can immediately be obtained by following the rule previously mentioned; namely, "rotate the loop in a direction opposite the direction of meter deflection until its pointer is at zero."

Anyone operating a radio compass of this type is greatly impressed with the simplicity of its operation. The ease with which bearings may be obtained and the ruggedness of design of the new radio compass make it very suitable for use on any seagoing vessel.

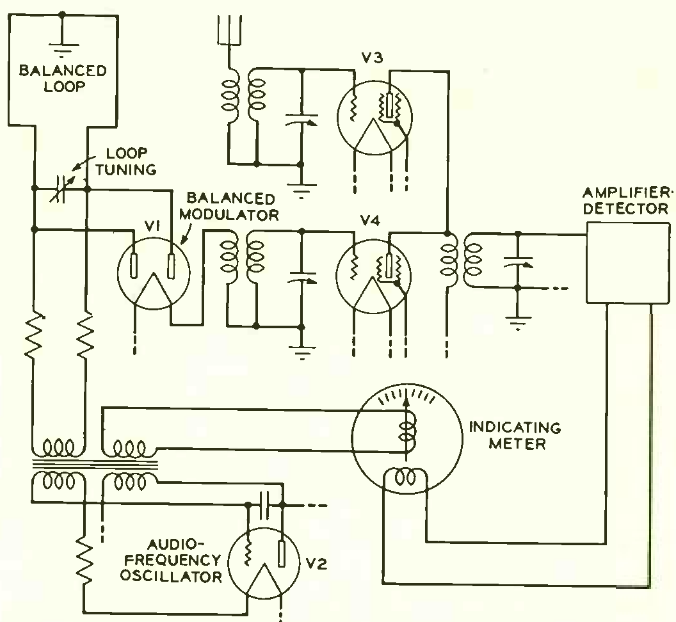

Fig. 5—Simplified schematic of receiver circuit

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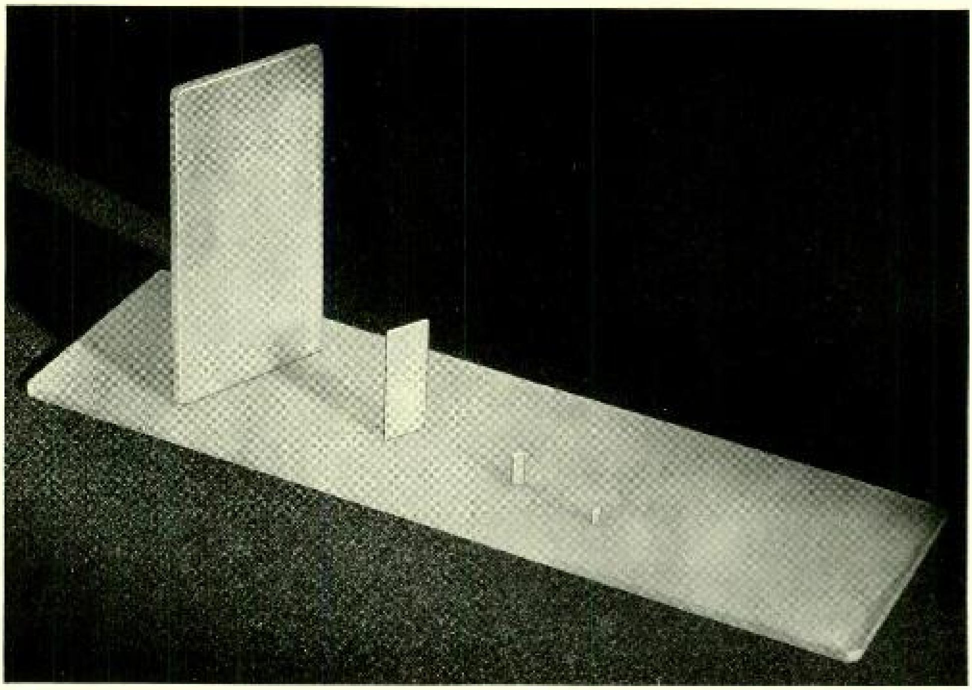

Quartz Crystal Filters

By W. P. MASON
Wire Transmission Research

FILTERS for communication systems must pass frequencies between certain limits without appreciable distortion, and must greatly attenuate frequencies beyond these limits. A certain range of frequencies is required for the transition from zero or very low attenuation to the high attenuation desired beyond the passed band, but it is desirable to have this transition region as narrow as possible. This is particularly important for band-pass filters used for carrier telephone and telegraph, and broadcasting. The number of channels which can be used in a given frequency range depends on the width of the passed band plus the transition band on each side of it, and obviously the more rapidly the transition is attained, the greater is the number of channels that can be used over the available frequency range. This situation is shown graphically in Figure 1.

The steepness of the attenuation characteristic of a filter—that is the steepness of the lines in Figure 1 running from the edges of the pass bands up to the desired attenuation outside the bands—is a function of the ratios of reactance to resistance of the coils and condensers used in the filter. This ratio of reactance to resistance of a coil is generally referred to as its Q. The steepness or slope of the attenuation characteristic is measured by $A/(f_2-f_1)$ as is evident from Figure 1. This slope however is equal to a function of Q divided by the frequency f_1. Since $A/(f_2-f_1) = f(Q)/f_1$, it

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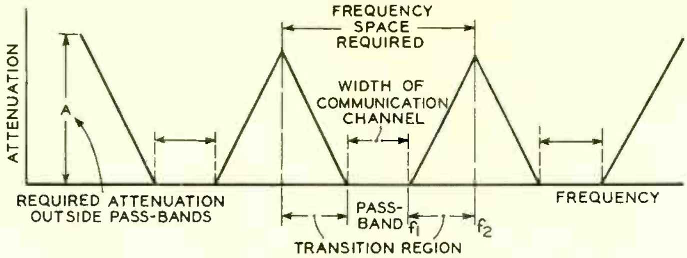

Fig. 1—The efficiency of a band-pass filter in its use of frequency space might be considered as the width of the pass band divided by the frequency separation between the attenuation peaks on each side of the passed band

In an electrical circuit such as a filter, a crystal presents an electrical impedance, which can be represented as shown on the upper part of Figure 2. Here the inductance represents the mass reaction of the crystal against motion; the resistance represents the dissipation of energy; C_0, the natural capacitance of the crystal when no motion occurs; and C_1, a capacitance determined by the storage of mechanical energy in the system. The ratio of C_0 to C_1 is a constant for any given crystal material—for quartz it is 125 to 1. The ratio of L, the reactance of the coil, to R, its resistance, is, of course, its Q, which for quartz crystals is of the order of 20,000 or more.

The reactance characteristics of such a crystal are shown in the lower part of Figure 2. There is one resonant frequency f_R and one anti-resonant frequency f_A. Because of the fixed ratio

is obvious that $(f_2\text{-}f_1)$ is equal to $Af_1/f(Q)$, and since the unused portion of the frequency space is proportional to $(f_2\text{-}f_1)$, it is evident that this unused space in turn is proportional to the frequency at the edge of the passed band, and inversely proportional to the function of Q.

With ordinary coils Q rarely exceeds 400, but this value is high enough to give good efficiency of separation for the lower frequency ranges—say up through the ordinary carrier telephone range. For the higher carrier frequencies, however, and particularly for radio channels, filter elements of much higher Q's are desirable. Such high-Q elements are generally obtainable only in mechanically vibrating systems. Of such systems probably the most easily used is the piezo-electric crystal because it possesses a natural driving mechanism in the piezo-electric effect. Although many substances exhibit the piezo-electric effect, the most satisfactory for general communication purposes is crystalline quartz because of its high degree of permanency and low dissipation. The characteristics and methods of mounting such crystals have already been described in previous issues of the RECORD*.

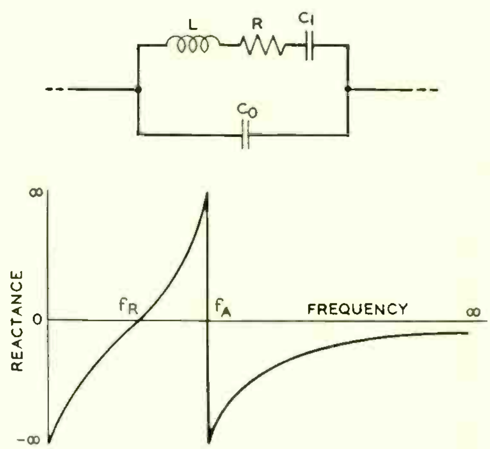

Fig. 2—A quartz crystal acts when associated with a suitable electric circuit as the network shown above. The reactance characteristic of this circuit is shown below

*RECORD, *Sept.*, 1928, *p.* 24; *Feb.*, 1932, *p.* 194; *and March*, 1933, *p.* 200.

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of C_0 to C_1, anti-resonance always occurs at a frequency 0.4 per cent higher than resonance, and thus the general form of the reactance characteristic is fixed. Its position on the frequency scale can be varied, however, by changing the length of the crystal, and its height can be varied by changing the ratio of area of the crystal to thickness.

If an auxiliary condenser be placed in parallel with the crystal, the effective capacity of C_0 is increased, and as a result the anti-resonance frequency can be made less than 0.4 per cent above resonance frequency. This can be done without detracting from the favorable characteristics of the crystal because the Q of condensers

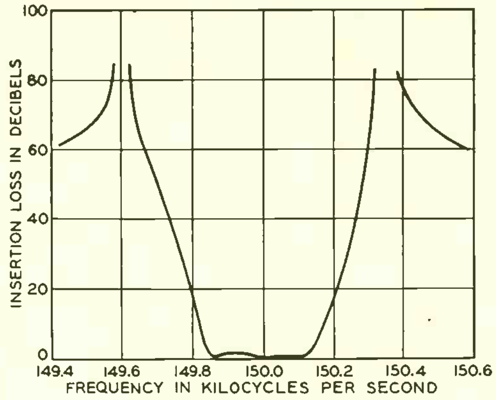

Fig. 4—Measure of attenuation characteristics of ladder type crystal filter

can be made to compare favorably with the Q of the crystals by taking proper precautions.

The simplest form of filter circuit is the ladder type network, and if crystals are placed in each arm, the network shown in the upper part of Figure 3 results. Condensers are shown in parallel with the crystals to permit control of the band width. The performance of such a filter can be analyzed by drawing the impedance curves for the series and shunt arms as shown in the center of the illustration. To have a single pass band, the resonance of the series arm must coincide with the anti-resonance of the shunt arm. Points of maximum attenuation occur at the resonance of the shunt arm and at anti-resonance of the series arms, because the minimum shunt impedance and the maximum series impedance occur at these points. The pass band of the filter must thus lie between these two frequencies, the exact position being determined by the ratio of the series to the shunt impedance. The resulting attenuation characteristics are shown in the lower part of the illustration. Because of the limitation of the ratio of the frequency of anti-resonance to that of resonance,

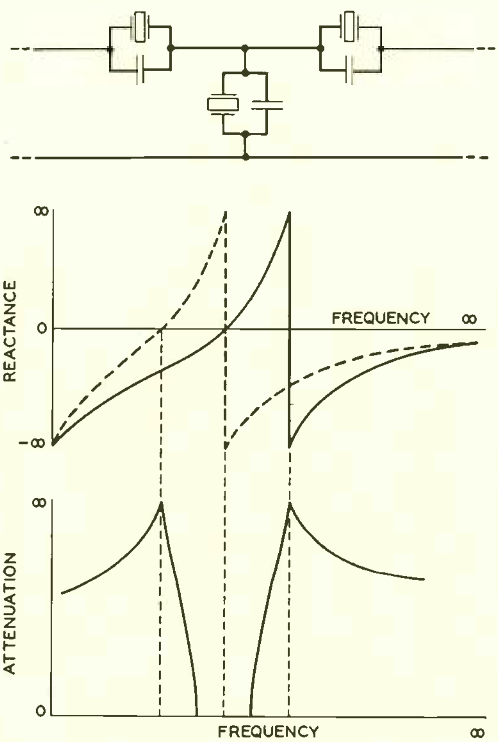

Fig. 3—Ladder type filter network employing only crystals and condensers, above; reactance characteristic, center (solid curve is series branch and dotted curve is shunt branch), attenuation characteristic, below

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already mentioned, the peaks of attenuation cannot be separated by more than 0.8 per cent on the frequency scale, but with the shunting condenser may be less than this amount. The pass band, of course, is always less than the 0.8 per cent. The measured characteristics of a filter of this type are shown on Figure 4. In spite of the narrow pass band—less than 0.2 per cent—the insertion loss in the transmitting band is quite small.

A more general type of filter characteristic may be obtained with a lattice type network, shown with

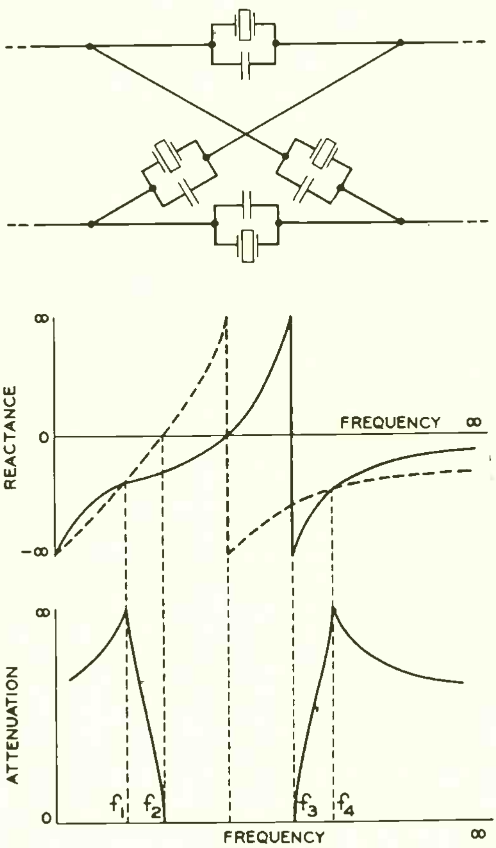

Fig. 5—Schematic diagram of lattice type crystal filter, above; reactance characteristics, center (solid curve is series branch and dotted curve is shunt branch); and attenuation characteristic, below

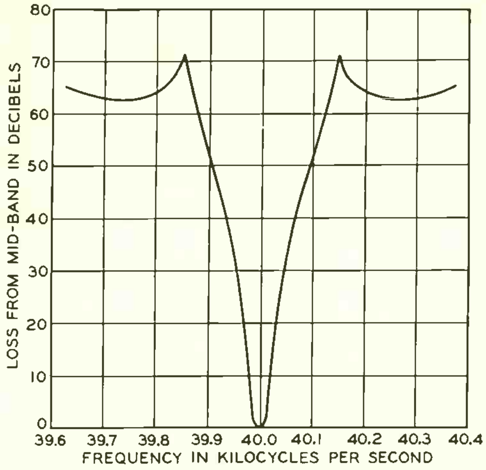

Fig. 6—Attenuation characteristic of lattice type crystal filter with a .05% pass band

crystals and condensers in parallel in Figure 5. The elements of the two series arms are alike as are those of the two parallel arms, but the series and parallel arms differ from each other. The lattice network has a pass band when the reactances of the two arms are of opposite sign, and an attenuation band when they are of the same sign. Since a lattice network is equivalent to a Wheatstone bridge, no current will flow in the output when the bridge is balanced, which occurs when the impedances of the two arms are equal. This locates the position of the attenuation peaks. The reactance characteristics of the two arms are shown in the middle of the illustration, and the resulting filter characteristics, below them. With this arrangement the band width may be the full 0.8 per cent, and the attenuation peaks can be placed in any position by varying the ratio of the impedance of one set of crystals to that of the other. A measured characteristic for a filter of this type is shown in Figure 6. This is the narrow band filter employed with the noise analyzer already described in the

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RECORD*. It has a separation of 0.75 per cent between the attenuation peaks, and a pass band of only a little over 0.05 per cent, or 22 cycles.

For many purposes it is desirable to have filters whose band widths are greater than 0.8 per cent, but they can be obtained only by employing inductance coils or transformers to widen the separation of resonances. Such coils, however, have a low Q as already pointed out, and they will be satisfactory only if they can be used in such a manner that the dissipation they introduce will not overcome the beneficial effect of the low dissipation of the crystals. The place where a resistance will be least objectionable is at the ends of the filter, because here it can be incorporated with the terminal resistance, where it produces the same loss at all frequencies. Loss of this type is easily annulled by vacuum tube amplifiers. The loss of the coil will not affect the slope of the loss-frequency curve, which can be made as steep as that obtainable with crystals alone.

It has been shown by the writer that an impedance in series with each arm of a balanced lattice network can be placed in series with each side, and similarly that an impedance in parallel with each arm can be placed in parallel with each side; put graphically, the circuits at the left of Figure 7 are the equivalents of those at the right. Thus it is possible to employ a coil in series with a crystal and condenser in each arm of a lattice network without detriment to the resulting characteristics of the filter, since the dissipation introduced by the coil will be effectively in series with the network. Also, a coil could be employed in parallel with the crystal and the condenser.

*RECORD, *May*, 1935, *p.* 267.

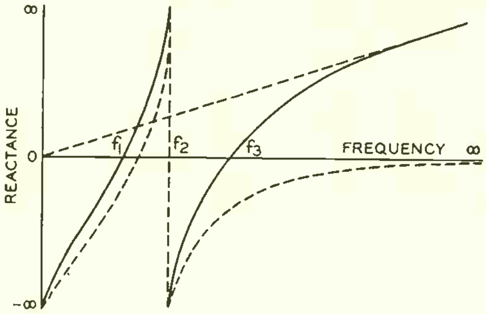

Fig. 8—Impedance characteristic of coil and crystal in series—solid curve. Dotted curve shows individual characteristic

When a coil is placed in series with a crystal, the impedance characteristics of the combination are as shown in Figure 8. Here the dotted curves represent the characteristics of the two elements separately—that of the crystal being similar to the curve of Figure 2, and that for the coil being a sloping straight line—and the solid curve represents their combination. The effect of the coil on the

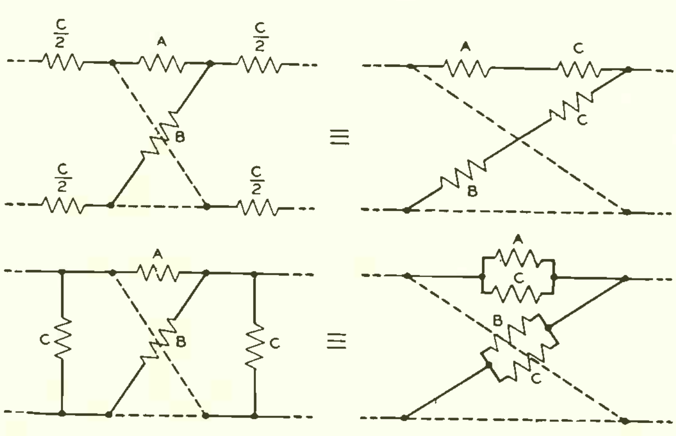

Fig. 7—It can be shown that the circuits at the right are the equivalents of those at the left

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resultant curve is to produce two points of zero reactance, that is, two resonances, instead of one. When the anti-resonance is halfway between the two resonances, the ratio of the higher resonance frequency to the lower is 1.09, so that the resonances are separated by 9 per cent.

By constructing a lattice network with elements of this type, shown in the upper part of Figure 9, the characteristics shown in the middle of the illustration are obtained. The double resonance results in each curve crossing the axis of zero reactance three times. As a result the series and parallel arms are of opposite sign, and thus

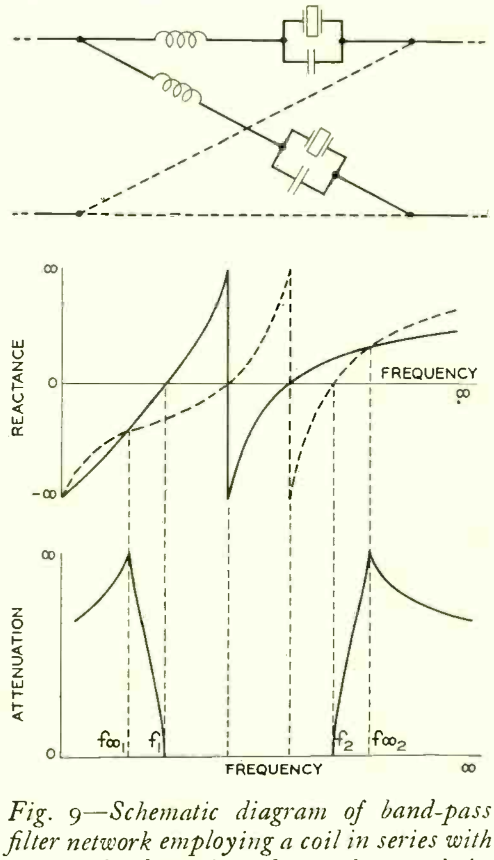

Fig. 9—Schematic diagram of band-pass filter network employing a coil in series with a crystal, above; impedance characteristic, center (solid curve is series branch, and dotted curve is shunt branch), and attenuation characteristic, below

result in a pass band, from the lowest resonance of the series arm to the second resonance of the shunt arm—giving a maximum width of 13.5 per cent. By varying the size of the

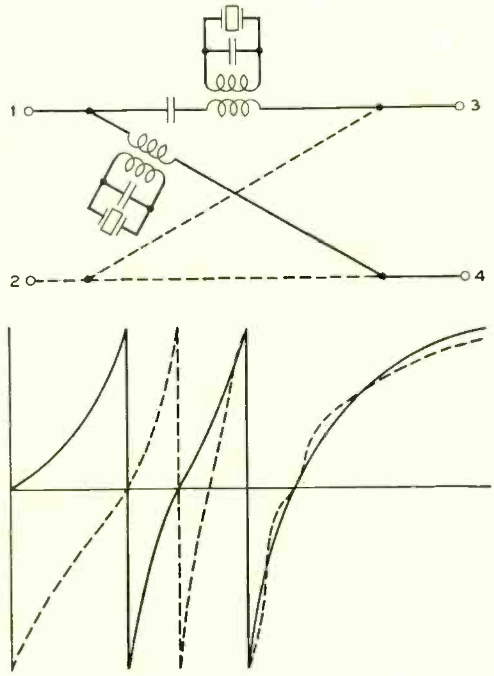

Fig. 10—A low pass characteristic may be obtained by employing transformers in conjunction with crystals, as shown above. Impedance characteristics are given below

condensers in parallel with the crystal, the pass band may be made any width less than 13.5 per cent, although the loss caused by the series resistance becomes fairly large for widths of less than 0.5 per cent. The attenuation peaks, as before, occur where the impedances of the two arms are equal, and the resulting filter characteristic is shown in the lower part of the illustration.

The ability to obtain bands up to 13.5 per cent with this type of network element makes it possible to obtain filters with sharp cut-off of practically any width. Above 13.5 per cent width, the ordinary coil and condenser filter is entirely satisfactory, and below 0.5 per cent width, where the losses of the coil and crystal filter become serious, the all-crystal filter may be used. The iterative impedance of the filter with the coil in series with the crystal is comparatively low—usually under 600 ohms—but by placing the coil in parallel with the crystal, the iterative impedance may be made as high as 400,000 ohms for the narrower band widths. Such filters are suitable for connecting high-impedance screen-grid tubes without the use of transformers. Otherwise the limitations of this parallel type of network are similar to those of the series type.

Elements of this type may also be employed to provide high-pass and low-pass filters by employing transformers for separating the resonant frequencies. An arrangement of this type for a low-pass filter is shown in Figure 10, and other arrangements and modifications are possible. All of the various types have found wide application in high-frequency carrier systems and in the radio field.

Vail Medal Awards for 1934

In the report of the National Committee of Award of Theodore N. Vail Medals for the year 1934 announcement is made of the award of three silver medals, each accompanied by $250, to employees of the Associated Companies of the Bell System for noteworthy public service. In this year's report silver medals are awarded:

To Emma Gatti, Supervisor of the New Jersey Bell Telephone Company at Hackensack, New Jersey, "for initiative and unusual resourcefulness in directing effective first-aid treatment for a child who had been seriously injured" by falling downstairs and crashing her hand through a window, thereby severing not only an artery but the tendons of the palm of the hand.

To Leona Smith, Contract Manager of The Mountain States Telephone and Telegraph Company at Morrison, Colorado, "for initiative, courage and effective use of telephone facilities in warning inhabitants of an impending flood" caused by a cloudburst in Bear Creek Canyon above Morrison.

To Charles Leroy Tubby, Combinationman of the Indiana Bell Telephone Company at Linton, Indiana, "for initiative, resourcefulness and effective action in establishing and maintaining telephone communication in an emergency" which involved the rescue of five men from a fire-trapped mine.

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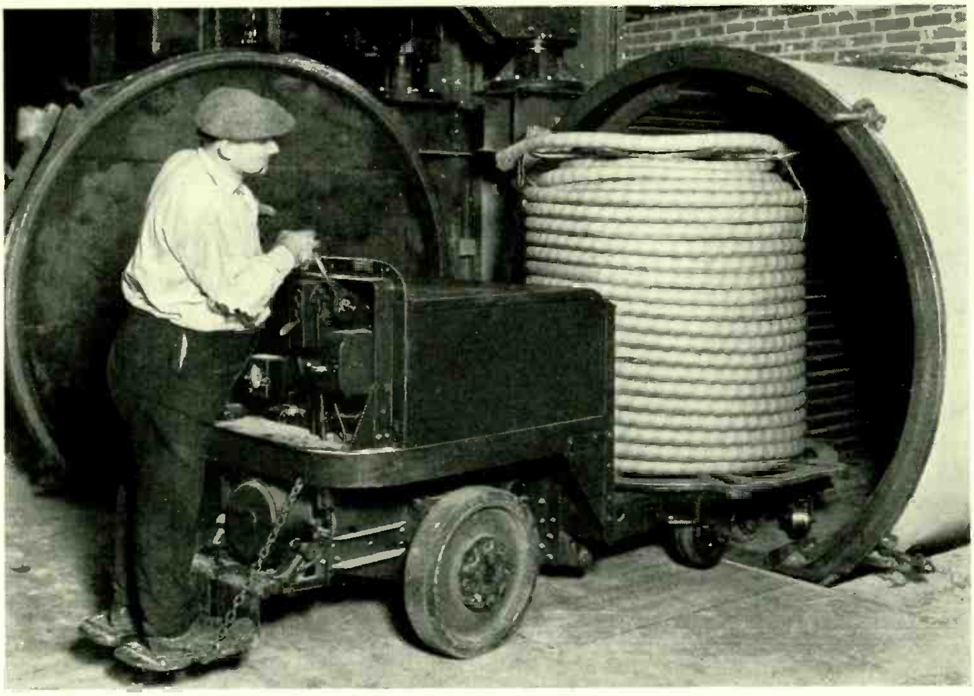

Dryness in Telephone Cables

By A. G. HALL
Cable Development

PAPER, when in a relatively dry condition, is very efficient as insulation, but when damp is very poor. That used for telephone cables, therefore, must be fairly free of moisture. The effect of moisture in a cable is to lower the insulation resistance and increase the a-c conductance and, to a less extent, the capacitance. When a cable core is sufficiently damp, the wires are virtually all shorted together rendering the cable inoperable. Some drying is invariably required to secure values of insulation resistance and conductance that will result in a satisfactory cable. Paper so readily absorbs moisture from the air, however, that in the manufacture of telephone cables no attempt is made to dry it until just before the cable core is covered with a lead sheath. After this the lead sheath protects the paper from further exposure to the moisture in the air.

The amount of moisture paper contains depends primarily on the relative humidity of the air or other gas in the surrounding space. In any method of drying, therefore, the cable core is put into a partially or totally enclosed space and the relative humidity within the space is decreased by raising the temperature, by reducing the absolute pressure of the air or gas, by replacing the air or gas at suitable intervals by gas which has had part of its moisture removed, or by some combination of these methods. Time

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is required to bring about an equilibrium between the relative humidity, or the vapor tension of the air or gas, and the moisture in the paper. At first the drying is rapid, but the rate of drying tapers off so that at some time before complete equilibrium is attained, a condition is reached beyond which further drying results in only slight improvement in the electrical characteristics.

A comparatively moderate amount of drying generally suffices to raise the d-c insulation resistance to a satisfactory value. Drying beyond this point is usually for the purpose of improving transmission by reducing the a-c conductance. The transmission, however, may also be improved by other means than drying. A decrease in conductor resistance or in the mutual capacitance of the circuit, or an increase in the inductance of the loading will also improve the transmission, and which method is used is largely a matter of economics. If additional drying is warranted, it is because it gives an improvement in transmission at a lower cost than could be obtained by other methods.

Whether it is more economical to effect an improvement in transmission by reducing the conductance or by some other means depends to a certain extent on the relative importance of the series losses—which are proportional to the conductor resistance—and the shunt losses—which are proportional to the conductance. For a unit length of loaded line the attenuation constant, α, is given approximately by the expression $\alpha = (R/2L + G/2C)\sqrt{LC}$ where R, L, G, and C are the total resistance, inductance, conductance, and capacitance per unit length including the loading coils. This shows the constant as a function of series losses $(R\sqrt{C})/(2\sqrt{L})$, and shunt losses, $(G\sqrt{L})/(2\sqrt{C})$. An increase in inductance such as is occasioned by loading, obviously decreases the series losses and increases the shunt losses. Since it is the shunt losses that drying decreases, drying is of much greater importance for the larger gauge loaded cables, such as are used for toll circuits, than for exchange area cables, where loading is less frequently employed.

When lead covered cable first came into use, nearly all of it was for exchange area service. The drying this cable received was only that required to meet values of insulation resistance which would permit satisfactory maintenance of the circuits. It left an appreciable amount of moisture still in the paper. Although the requirements that this type of cable has to meet today are practically unchanged in severity, improvements in drying

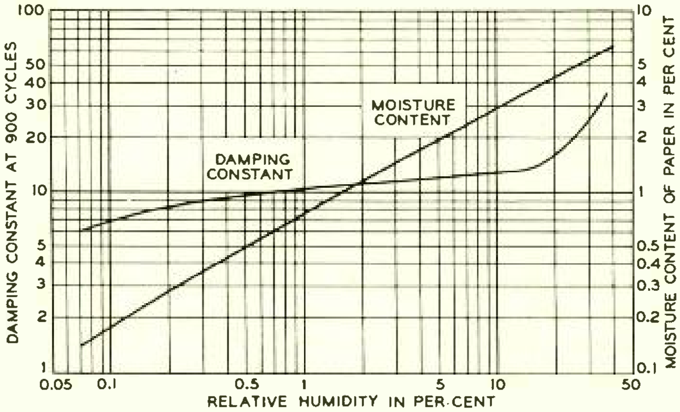

Fig. 1—Approximate relationship for one type of cable between relative humidity of atmosphere, moisture content of paper in equilibrium with atmospheric conditions, and the damping constant at 900 cycles. Temperature 75°F.

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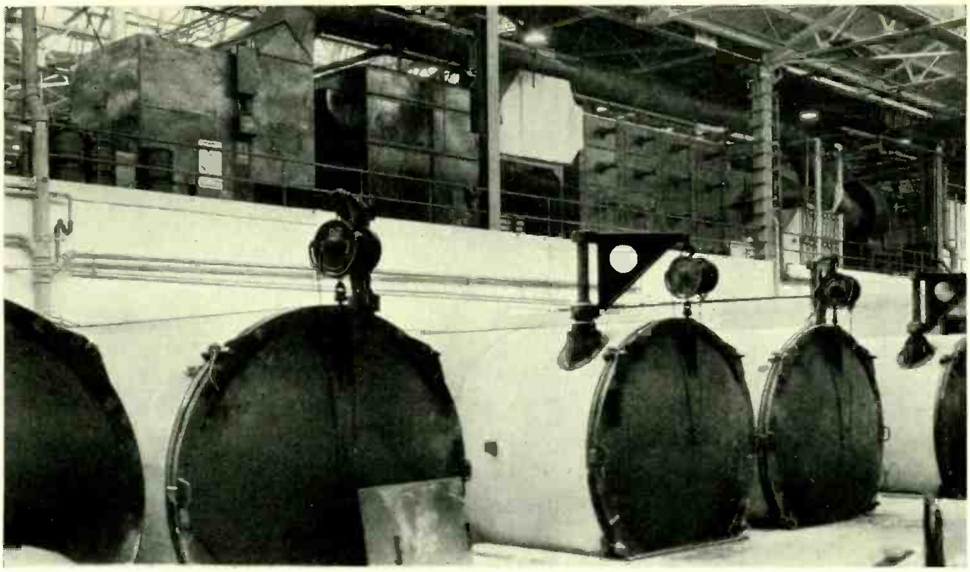

A row of vacuum drying tanks at Point Breeze with air conditioning equipment above for the storage room. The cable cores are put into the tanks from this end, as shown in the photograph at the head of this article, and taken out at the other end directly into the storage room

methods since that time have resulted in much higher insulation resistance at less cost.

The original drying equipment of the Western Electric Company consisted of ovens maintained at or slightly below a temperature of 270 degrees Fahrenheit, through which air at atmospheric pressure was circulated. Cable cores were kept in the ovens for twenty-four hours or longer, depending on size and length, and were then placed in holding ovens held at about 180 degrees. Just before being sheathed, they were moved to ovens which were maintained at 120-180 degrees, directly behind the presses.

Late in 1909 it was decided to proceed with the manufacture of a toll cable between Boston, New York, and Washington. This project was the forerunner of a broad system of loaded toll circuits in lead covered cables throughout the country. Since there was no commercially satisfactory type of telephone repeater available at the time, No. 10 A.W.G. and No. 13 A.W.G. conductors were required to assure satisfactory service between Boston and Washington and intermediate points. Results from experimental cables indicated that with the conductance obtainable with the existing drying equipment, the shunt losses would be approximately 20% of the total for the 10 gauge and 14% for the 13 gauge loaded circuits. These losses were sufficiently large to warrant an attempt to reduce them by further drying.

From the expression for the attenuation constant given above, it is noted that the shunt loss is proportional to G/2C, which has been called the damping constant. The approximate relationships between damping constant, relative humidity of air in cable, and per cent moisture content of paper are shown by the curves of Figure 1, the data for which were com-

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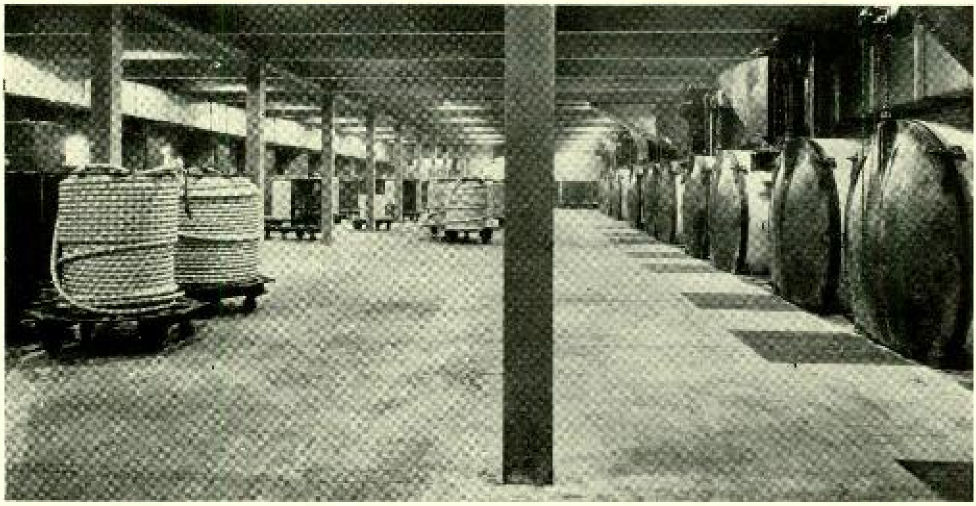
piled by A. C. Walker of these Laboratories. These curves show that under conditions represented by a temperature of 24 degrees Centigrade and a relative humidity of 40 per cent, which occur in the paper storeroom at certain seasons of the year, paper will contain about 6 per cent moisture and the damping constant of a cable with such paper would be about 40. After the oven drying then in use, the damping constant would be reduced to about 11.5—corresponding to a moisture content in the paper of about 1.4 per cent. At this stage, therefore, about 22 per cent of the moisture would still remain in the paper, so that there was opportunity of still further reduction of the damping constant by additional drying.

From a consideration of possible methods, it was concluded that the additional drying could best be obtained after the cable core had been lead sheathed. The plan finally adopted was to give the cable core the usual oven drying before lead covering, and then to place the lead covered cable in an oven operated at about 270 degrees Fahrenheit with a connection to a vacuum pump at one end of the cable and to a dry-air supply at the other. Dry air was obtained by bringing compressed air at a temperature of 75 degrees into intimate contact with calcium chloride, which reduced its relative humidity to between 1 and 2 per cent, and then heating it to 270 degrees, which further reduced its relative humidity a hundred fold. Twenty-four hours was found to be an efficient period of drying. By such a drying period the damping constant is reduced from 11.5 to 7.5, and the resulting attenuation constant is decreased about 7.5 per cent for the 10-gauge and 4.5 per cent for the 13-gauge loaded circuits.

Extensions of the toll circuits in cable during the next few years required a smaller proportion of No. 10 A.W.G. circuits, and most of the cables contained No. 13 and No. 16 A.W.G. circuits. With the No. 16 A.W.G. loaded circuits the average reduction in transmission losses due to the calcium chloride dried air treatment was only about 2.3 per cent.



The storage room at Point Breeze showing the ends of the vacuum tanks used for unloading

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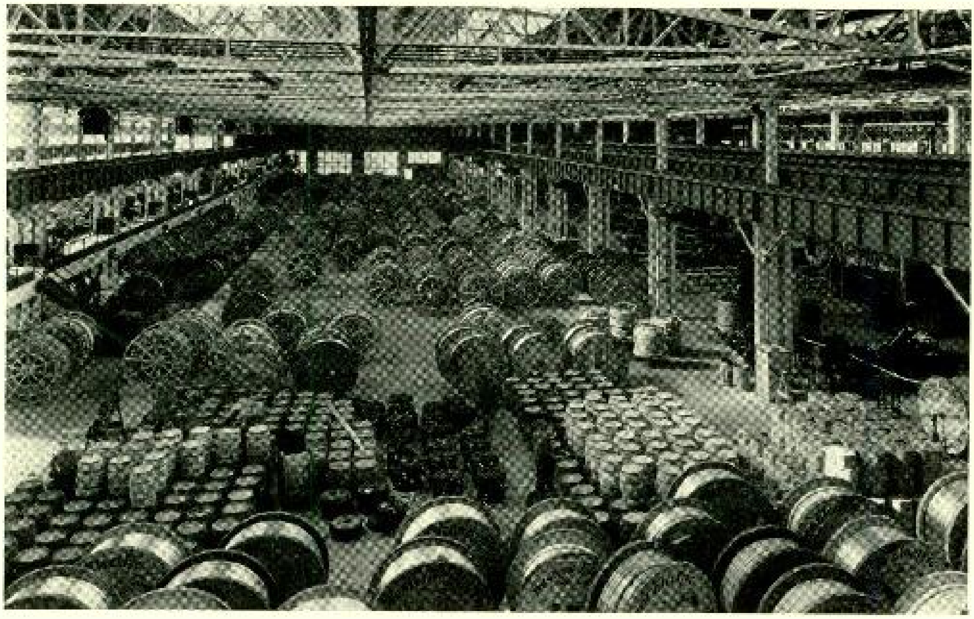

After being sheathed the cable is allowed to cool before being inspected and then crated for shipment

Moreover by 1916, the vacuum tube repeater had reached a stage of development that permitted 19-gauge circuits with repeaters to be considered for the longer toll cables. With the general introduction of 19-gauge circuits, the improvement in transmission resulting from the added drying after lead covering was no longer economical for a large part of the output.

Moreover, equipment for an improved method of drying cable was installed by Western Electric, in which drying of cable cores in vacuum replaced drying at atmospheric pressures. The vacuum tanks are operated at a temperature of 270 degrees Fahrenheit. There is a preliminary period of heating at atmospheric pressure but for the remainder of the period a vacuum corresponding to a residual pressure of about one inch of mercury is maintained. If the vacuum were applied immediately, the heat would reach the cable core at a lower rate, and the temperature would be made still lower by the cooling effect of rapid vaporization of moisture at the reduced pressure. To speed up the process, therefore, the cable core is given a preliminary heating at atmospheric pressure. During this period the core is heated throughout, and a considerable amount of moisture is driven from it, with the result that the overall drying time is materially decreased.

An investigation of the effectiveness of the drying by vacuum tanks indicated that cable cores received an equivalent drying in about one-third of the time previously required. If toll cables were given a 24-hour drying in the vacuum tanks and were then lead covered immediately, the damping constant was between 7.5 or 8.0, nearly as low as that obtained by the added drying after lead covering. If on the other hand the cores stood in the storage ovens eight or ten hours before being lead covered,

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the damping constant rose to about 11.

In these storage ovens, the only drying of the air was that caused by raising its temperature. Between 1924 and 1930, however, cable storage ovens supplied with dried air were installed at the three cable factories of the Western Electric Company. Each of these installations differed from the others in major points, and each at the time was a pioneer installation of the particular method used to obtain very low relative humidities in such large spaces.

Later the three installations were changed to employ Silica Gel for drying, making the three installations more nearly alike. The air is first cooled, which reduces its moisture content somewhat, and is then passed through Silica Gel to be further dried. The air is then heated to 110 degrees Fahrenheit, which further reduces its relative humidity. At Kearny where this system was first installed, it was found that the relative humidity which could be maintained was limited by the leakage of moisture through the thick concrete walls and floors. This condition was corrected at Hawthorne by the application of a waterproof coating. At Point Breeze, the storage oven was protected by an aluminum foil placed in the center of the floors and walls and on the inside of the ceiling.

This improved drying in the vacuum tanks and the greater dryness maintained in the storage room, in conjunction with the use of smaller conductors which made the gain from drying of less importance, led in 1926 to the Western Electric Company's discontinuing the additional drying of toll cable after lead covering, thereby saving a large fraction of the cost of the drying operation with no substantial impairment of electrical values. The application of these improved facilities to the drying of subscriber cables not only reduced the cost of drying but resulted in much higher values of insulation resistance than had previously been obtained.

Telephone Statistics of the World

Statistics of world telephones taken from a compilation recently completed by the American Telephone and Telegraph Company show that there were 32,495,855 telephones in the entire world on January 1, 1934. Of these, over fifty-one per cent were in the United States, thirty-five per cent in Europe and three and one-half per cent in Canada.

Distribution of World Telephones by Continents

Continents	*Number of Telephones*	*Per Cent*
North and Central America	18,107,350	55.72
Europe including U. S. S. R.	11,306,955	34.79
Asia excluding U. S. S. R.	1,420,539	4.37
Oceania	737,466	2.27
South America	651,919	2.01
Africa	271,626	.84
Total	32,495,855	100.00

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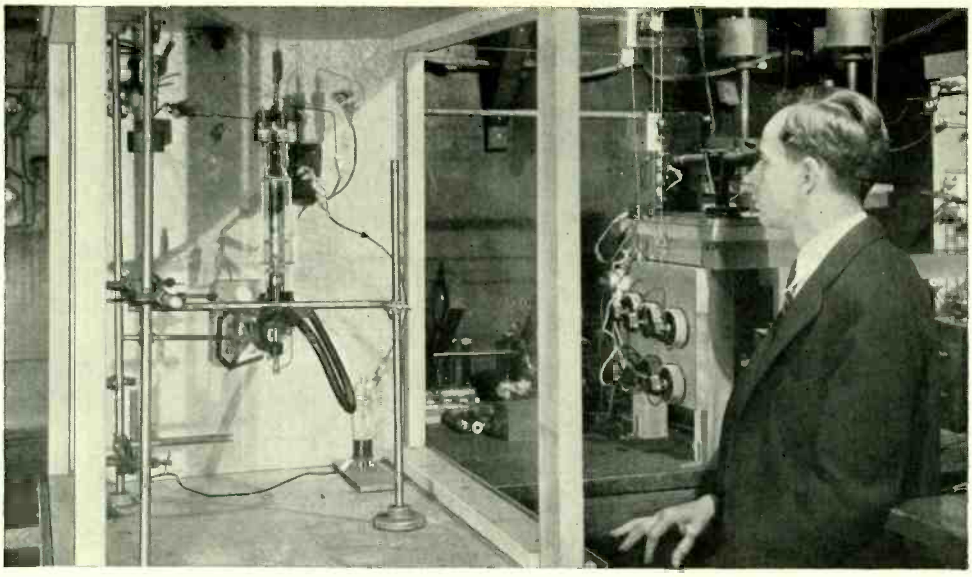

Measuring the Photosensitivity of Crystals

The electrical conductivity of many substances increases to a greater or less extent when light falls on them. Among these selenium is probably the best known because it was in this material that the property was first recognized. The diamond also is photosensitive to a limited extent. Some of these substances show the effect in their initial state while others acquire their light sensitive characteristics through special treatment.

Red mercuric iodide crystals normally display photosensitivity when first precipitated but lose this property on aging. F. C. Nix has discovered that such crystals can be resensitized by applying a difference of potential to them for a few minutes. This is done with the apparatus shown in the photograph. The crystal is placed between two metal plates near the bottom of a vacuum flask especially constructed for the purpose and a potential difference of from 1000 to 2000 volts is applied across the plates. Liquid air or other refrigerants are used to cool the crystal since the effect increases with decrease of temperature. The changes in conductivity of the crystal with changes of incident light are determined by measuring the current through the crystal with the string electrometer shown at the right of the photograph which R. Rulison is observing.

These photosensitive substances are not only of theoretical interest but have found practical application in a variety of problems involving photometric measurements and the control of processes where changes of light intensity are involved.

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Contributors to This Issue

Arthur G. Hall joined the Western Electric Company in 1909 after spending two years at the Lewis Institute and graduating two years later from the University of Michigan. After five months in the Student Course at Hawthorne, he transferred to West Street where he entered the Physical Laboratory. About this time work on the development of phantom cables suitable for loading was started at Hawthorne and, early in 1910, Mr. Hall transferred there to aid in this work. With the exception of a short absence in 1912, he continued this work until late in 1913 when he was placed in charge of a group engaged on cable development work at Hawthorne. In 1921 he was loaned to the International Western Electric Company and for a little over two years spent his time in cable factories in Switzerland, Holland and Italy and returned to Hawthorne in 1923. Since then he has been continuously engaged on cable development problems. In 1928 he was detailed to the Kearny plant, to take charge of a group working on cable development.


A. G. Hall

Following his graduation from the California Institute of Technology in 1927 with the degree of B.S. in Physics and Engineering, Mason A. Logan entered the Laboratories as a member of the Transmission Research Department. In 1933 he received the degree of M.A. in Physics from Columbia University. He has also acted as instructor in the out-of-hour course in transmission circuits. Mr. Logan is the point of contact in his department for inquiries from Local Systems Development engineers as to the transmission qualities of proposed new circuits, including such fundamental problems as losses, cross-talk and circuit noise. While associated with a comprehensive investigation of the


M. A. Logan


A. B. Bailey


W. P. Mason

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transmission performance of circuits at various frequencies, Mr. Logan made a number of contributions to the design of the measuring circuit he describes.

W. P. Mason received a B.S. degree in Electrical Engineering from the University of Kansas in 1921 and immediately joined the Technical Staff of the Laboratories. While here he took postgraduate work at Columbia University and received an M.A. degree in 1924 and a Ph.D. degree in 1928. The first four years of his work with the Company were spent in investigations of carrier transmission systems. Since then he has been occupied in the development of wave transmission networks, both electrical and mechanical.

Arnold B. Bailey received a B.S. degree in Engineering Administration from Massachusetts Institute of Technology in 1925 and then became a member of the instructing staff of the Department of Economics of the Institute. In 1926 he joined the Radio Development Department of the Laboratories and specialized in the design and installation of radiotelephone and broadcast transmitters. He aided in the development of a universal radio beacon for aircraft and later made a series of technical studies on the location and selection of radio sites for broadcast stations, including Stations WABC, WSB and WHN. For the last two years Mr. Bailey has been engaged in the design and development of two-way mobile radio communication systems.

W. L. Webb graduated from the State College of Washington in 1929, with the degree of B.S. in Electrical Engineering. After short periods with the Great Northern Railway and the General Electric he joined the Technical Staff of these Laboratories in the spring of 1930, and was associated with the Radio Development Department. At the time his article in this issue of the Record was written, he was a member of the group developing radio receivers.

Inspecting the recently installed Western Electric 5000-watt transmitter for Station WTCN of the St. Paul "Pioneer Press" and "Minneapolis Tribune." Left to right, A. L. Lennon, Chief Engineer of the station, F. H. McIntosh, Bell Telephone Laboratories and J. M. Sherman, Federal Communications Commission

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