The GENERAL RADIO
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ELECTRICAL COMMUNICATIONS TECHNIQUE AND ITS APPLICATIONS IN ALLIED FIELDS

A BRIDGE-TYPE FREQUENCY METER

INSTRUMENTS for the measurement of audio frequencies are usually based on one of the numerous bridge circuits in which frequency enters explicitly. The familiar tuned-circuit wavemeter has not made a satisfactory audio-frequency meter because of the large amount of power lost in it when the usual current indicator is used. The resonance bridge makes use of a similar tuned circuit in one arm, the other arms being pure resistance. For any reasonable values of inductance the capacitance required to tune to the lower audio frequencies is so large that an air condenser cannot be used. The capacitance then is fixed and the inductance made variable in order to have continuous adjustment. Different ranges are obtained by changing the capacitance. The bridges of Campbell and of Kennelly and Velander make use of a variable mutual inductor and a number of fixed condensers.

Bridges using inductance, either self or mutual, have two serious defects. The shape of the frequency scale depends upon the characteristics of the variable inductor used and cannot be appreciably altered. The magnetic field of the inductor is such that it cannot be satisfactorily shielded from the source of frequency being measured.

The Wien bridge circuit has been chosen for the Type 434-B Audio-Frequency Meter because it eliminates both of these objections. Since it uses only resistance and capacitance, it has no external magnetic field. The two variable resistors may be so constructed that the frequency scale has the most desirable shape. A schematic diagram is shown in Figure 1. The conditions for balance of this bridge are:

$$f = \frac{1}{2\pi\sqrt{PQC_PC_Q}}$$

and

$$\frac{C_Q}{C_P} = \frac{A}{B} - \frac{P}{Q}. \qquad (1)$$

In order to provide a single control, upon which the frequency scale may be mounted and to maintain the second balance condition, the two resistors P and Q and the two condensers C_P and C_Q are made equal, and the two ratio arms are made two to one:

$$\frac{P}{Q} = \frac{C_Q}{C_P} = 1 \text{ and } \frac{A}{B} = 2. \qquad (2)$$

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THERMOCOUPLES

IN the practical system of electrical units, there are two fundamental quantities, namely: the unit of electrical charge (the coulomb) and the unit of resistance (the ohm). All other units are defined in terms of these two. The measurement of all electrical quantities, and hence the calibration of electrical meters, must, therefore, be referred back ultimately to the coulombmeter.

The coulombmeter can measure only the preponderance of charge-motion, or current, in one direction. Its use is, therefore, restricted to the uni-directional motion of electrical charge.

In order to measure alternating movements of electrical charge, we are obliged to utilize some manifestation of charge-motion which is independent of the direction of motion. This may be done most satisfactorily by converting the energy of charge-motion into heat energy in the electrocalorimeter. If a charge Q is moved through a resistance R in a time T the amount of the heat energy (measured in joules) produced is given by multiplying the resistance (ohms) by the square of the ratio of the charge (coulombs) to the time (seconds). Thus the electrocalorimeter for alternating currents plays an analogous role to the coulombmeter for uni-directional currents.

If we assume a state of thermal equilibrium in the resistance, the temperature of the resistance will be a function of the square of the derivative of Q with respect to T, that is, a function of the square of the instantaneous value of the current. A convenient method of measuring the temperature of this resistance is to associate with it a thermocouple junction, the operation of which depends upon the Peltier effect, which may be described briefly as follows: If a circuit is made up of two materials, A and B, there must be two points, M and N, where A meets B. If the junctions M and N are of different temperature, there will exist in the circuit an electromotive force (Peltier voltage) whose magnitude depends upon the nature of the materials A and B and upon the temperature difference between the junctions M and N, and whose polarity is determined by the

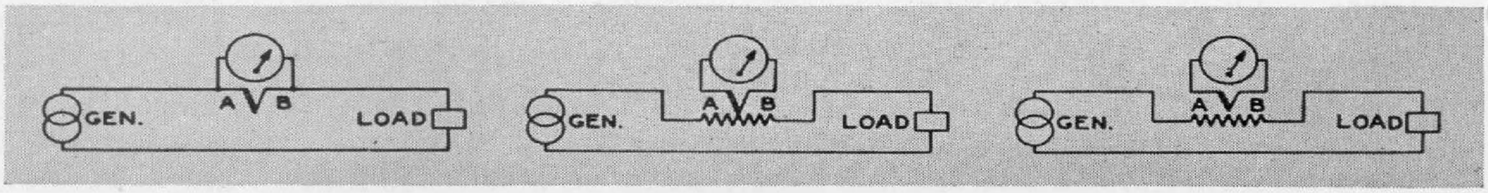


FIGURE 1. Typical thermocouples. *Left:* Mutual type. *Center:* Contact type *Right:* Separate heater type

relative temperatures of *M* and *N*. From the foregoing it will be evident that, if one of these junctions is brought into association with a resistance which is carrying a current and which is in thermal equilibrium, the open circuit voltage developed will be accurately a function of the root-mean-square value of the current in the resistance.

Such an instrument is called a thermocouple and, indicating as it does exact root-mean-square values of any varying current, it may well serve as the primary reference instrument for all alternating-current measurements. The thermocouple may, of course, be calibrated in terms of direct current by reference to the coulombmeter or to a d'Arsonval ammeter which, in turn, has been calibrated with reference to the coulombmeter.

Thermocouples may be classified into three separate types: the mutual type, the contact type, and the separate heater type (see Figure 1). In the mutual type, the elements of the junction constitute a resistance which is common to the circuit carrying the current to be measured and to the galvanometer circuit used to measure this current in terms of the thermoelectric current produced by the heated junction. In the contact type of couple there is no mutual impedance between the two circuits, the junction being in electrical contact with the heater resistance at one point only, while in the separate heater type the junction and the heater resistance, although they may be physically joined, have no conducting path between them.

The mutual type, which is the simplest to manufacture, possesses some serious disadvantages due to the mutual impedance. Since the current from the generator divides between the galvanometer and load, a *shunting error* is introduced which, being a function of the frequency, makes it somewhat difficult to calibrate this type of thermocouple in terms of direct current. Furthermore, unless a condenser intervenes, a part of the thermoelectric power is dissipated through the generator and load which, of course, reduces the sensitivity. The mutual couple has also a *reversal error* which makes the calibration in terms of direct current a function of the direction of the current. This reversal error may be eliminated by taking the trouble to find the mean of two reversed direct-current readings for each point observed in calibrating the device. If, however, the alternating-current wave from the generator is not symmetrical with respect to the zero axis, the reversal error may introduce an appreciable discrepancy in the readings.

Using a mutual type junction, if we wish to alter the current sensitivity by changing the value of the mutual resistance of the junction, we are obliged to change the resistance of the galvanometer to match if we are to obtain maximum over-all efficiency.

These objections are very much minimized in the contact type of couple. Here the shunting error is negligible and the reversal error may be made very small (less than 1%) so that an accurate direct-current calibration may be obtained by taking the mean of reversed direct-current readings. The frequency error is nil except at very high frequencies where the heater resistance becomes modified due to skin effect and the presence of an appreciable amount of leakage reactance due to the distributed capacitance of the heater or capacitance to ground.

The separate heater type, of course, can have no reversal error. In the earliest types, the junction was usually inserted within a helical heater. However, in order to obtain a maximum sensitivity equivalent to that of the contact type, the junction and heater are generally bound in physical contact by means of a bead of insulating material. The thermal capacity of this bead renders the separate heater type of couple somewhat more sluggish in response to heater-current changes than the contact type. The separate heater type, which was first introduced in 1919 by the General Radio Company, is often very useful in certain high-frequency measurements where the capacitance of the galvanometer system to ground would introduce very appreciable errors should the contact type of couple be employed.

In the separate heater and contact junctions the resistances of heater and couple are independent, permitting a single couple resistance to be combined with various heaters giving couples which may be used interchangeably with a single meter.

The temperature of a given heater resistance passing a given current and, hence, the sensitivity of a thermocouple, can be increased considerably by placing the couple in an evacuated container, thereby minimizing greatly the cooling action due to convection currents.

The General Radio Company has provided a series of vacuum thermocouples of both the contact and the separate heater types. These couples are mounted in a convenient moulded bakelite housing which is provided with four pin plugs, giving an assembly designated as the Type 493 Thermocouples. The name plate indicates the heater and couple terminals, as well as the heater and couple resistance and the rated current. This assembly contains also an eccentric alignment pin which prevents interchange of the terminals when the assembly is inserted into suitable switch jacks. The Type 274-RJ Mounting Base and the Type 298-B Meter Mounting are both convenient for use with these interchangeable thermocouples.

For use with such thermocouples, the General Radio Company has provided the Type 588-AM Direct-Current-Meter. This meter has a resistance of 10 ohms, requires 500 microamperes (5 millivolts) for full-scale deflection, and has a uniform 50-division scale graduated from 0 to 50 which is very convenient for making and using thermocouple calibrations. This meter is supplied mounted in the Type 298-B Meter Mounting.

A list of the thermocouples carried in stock, together with descriptive data, appears in Catalog F, Part 3, pages 221 and 222. — Horatio W. Lamson

A STABLE LABORATORY AMPLIFIER

THE recent development of oxide-rectifier instruments has produced a high impedance alternating-current voltmeter useful over the entire audible frequency range. In this device, advantage is taken of the high sensitivity and high resistance of direct-current instruments, using them in conjunction with a copper-oxide rectifier.

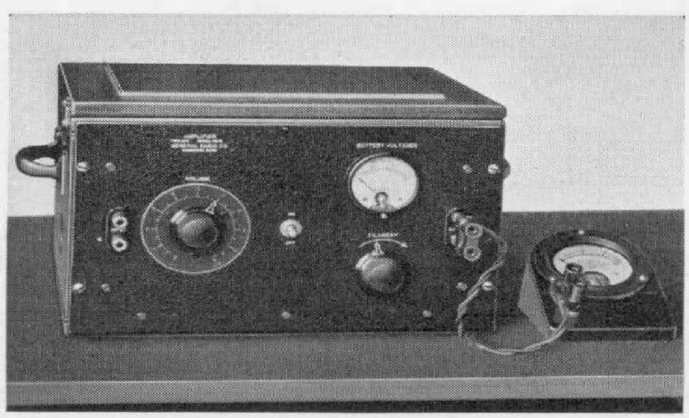
The characteristics of the oxide rectifier and associated meter limit the best voltage sensitivity which may be obtained to approximately two or three volts full scale. In applying such instruments to circuits requiring a more sensitive indicator, such as the detector of a bridge circuit, greater sensitivity is required. This amplification of sensitivity can readily be obtained by means of a vacuum-tube amplifier.

An amplifier for this purpose should have a wide band of transmitted frequencies and a high gain. The power output is of secondary consideration, since comparatively little power is required to operate the indicating instrument.

The General Radio Company has recently developed an amplifier for this and similar applications. This amplifier (Type 514-A) has a gain of about 250 and a transmission range of approximately 20 to 100,000 cps. The power output is about 7 milliwatts.

If an amplifier of these general characteristics is employed as a detector in a bridge circuit using a 20,000-ohm meter as an indicator, substantially the same sensitivity of bridge balance can be obtained at all frequencies within the range of the amplifier as is possible with telephones applied directly to the bridge at 1000 cps. The advantage of the visual indicator even at 1000 cps. is very great, particularly where a large number of observations are to be made. The amplifier and meter extend the range well beyond that possible with telephones or alternating-current galvanometers of any commercial type.

If used with a common indicating device which will respond at super-audible frequencies, the amplifier offers a null detector for bridge circuits operating at frequencies as high as 100 kc. Throughout a good deal of the audible range, the sensitivity is equivalent to that possible with standard telephones applied directly to the bridge, since telephone and ear sensitivity fall very rapidly as the frequency departs from 1000 cps. The sensitivity when using the oxide meter and amplifier is somewhat less than that obtained with the best direct-current wall galvanometers, but is comparable to that obtained with the less expensive direct-current galvanometers. The high input impedance of the amplifier is a distinct advantage in high-impedance bridges. If, instead of a meter, telephones are used on the output of the amplifier, a far greater bridge sensitivity is available at 1000 cps. than can be obtained



Type 514-A Amplifier and a Type 588-DM Alternating-Current Voltmeter with any commercial galvanometer at direct current or at natural period for vibration galvanometers.

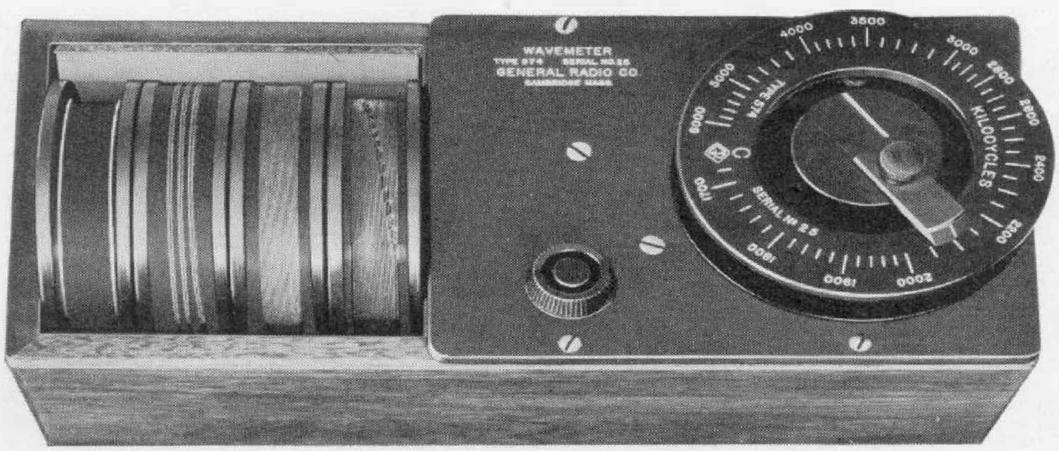
Where very great sensitivity is required, it is possible to cascade two of the Type 514-A Amplifiers. Where this is done, some protection of the first unit from acoustic vibration is essential. With two of the amplifiers in cascade, a greater sensitivity is obtained than is possible with any commercial type of galvanometer.

The Type 514-A Amplifier is, of course, not limited in its application to bridge circuits. It can be used as a voltage multiplier in general measurement work and when so used, can be calibrated. Other applications include photo-cell work. An interesting feature of the amplifier is a terminal plug which permits use of the amplifier batteries for external circuits. This feature is of particular advantage when using the amplifier in photo-cell circuits.

The Type 514-A Amplifier has a flat frequency characteristic from 20 to 100,000 cycles. The amplification is approximately 250 to 1 over this range. The input impedance is one megohm and the optimum load impedance, 20,000 ohms. Twelve volts will be maintained across this load with a 230-type tube in the output. For lower impedance loads, a 231-type tube is recommended. With this tube in the output, 15 volts will be maintained across an external load of 50,000 ohms and the voltage amplification will be in excess of 50 to 1. A potentiometer is provided for control of amplification.

The Type 514-A Amplifier can be provided either for cabinet or rack mounting. The price of the cabinet type is $70.00. — Charles T. Burke

A GENERAL-PURPOSE WAVEMETER



Type 574 Wavemeter

Many uses may be found for a simple direct-reading wavemeter covering a wide range of frequency. The new Type 574 Wavemeter, which is calibrated in terms of frequency and which has a nominal precision of 1%, is valuable as a general-purpose instrument and also for obtaining rapid supplemental readings in conjunction with high-precision equipment.

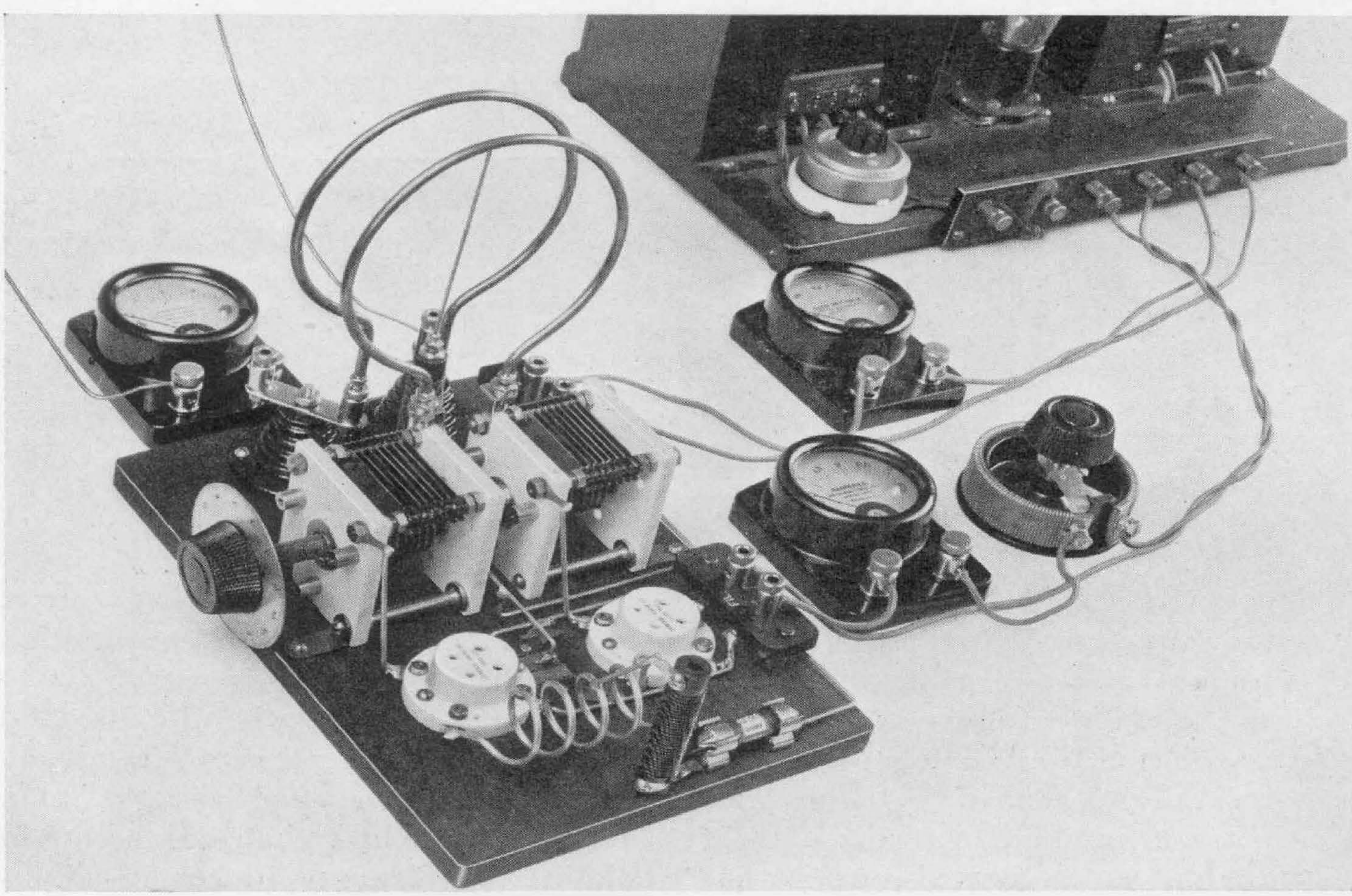
The scales, which are hand-calibrated in terms of our primary frequency standard, are engraved directly upon each of the five interchangeable plug-in bakelite coil forms (4 inches in diameter and 1 inch long) which are used to cover a continuous range from 166 kilocycles per second to 70 megacycles per second (1800 to 4.3 meters). The vernier-driven condenser is mounted on a bakelite panel attached to a polished walnut case which contains storage space for the four coils not in use. Measuring 11 inches long by 5 inches square and weighing but 4½ pounds, this meter is easily handled and may be placed in any position for use. Intended to be used in reaction observations, no resonance indicator is included. The Type 574 Wavemeter is priced at $50.00, and the code word is CARRY.

A FIVE-METER TRANSMITTER

R. L. Tedesco (W 1CAC) and his brother, Albert (W 1BMB), have designed a successful five-meter transmitter which we are pleased to bring to the attention of Experimenter *readers*

A FIVE-METER phone transmitter built with General Radio parts has worked out very successfully. The oscillator, modulated by the constant-current or Heising method proved to be a good method of voice transmission over short distances. The most desirable thing about it is the absence of the interference encountered on the other bands. It is also possible to radiate directively by the use of reflectors in the antenna system.

The push-pull Armstrong or TNT circuit was used, a practical description of which was given by J. J. Lamb in the July, 1931, issue of *QST*.

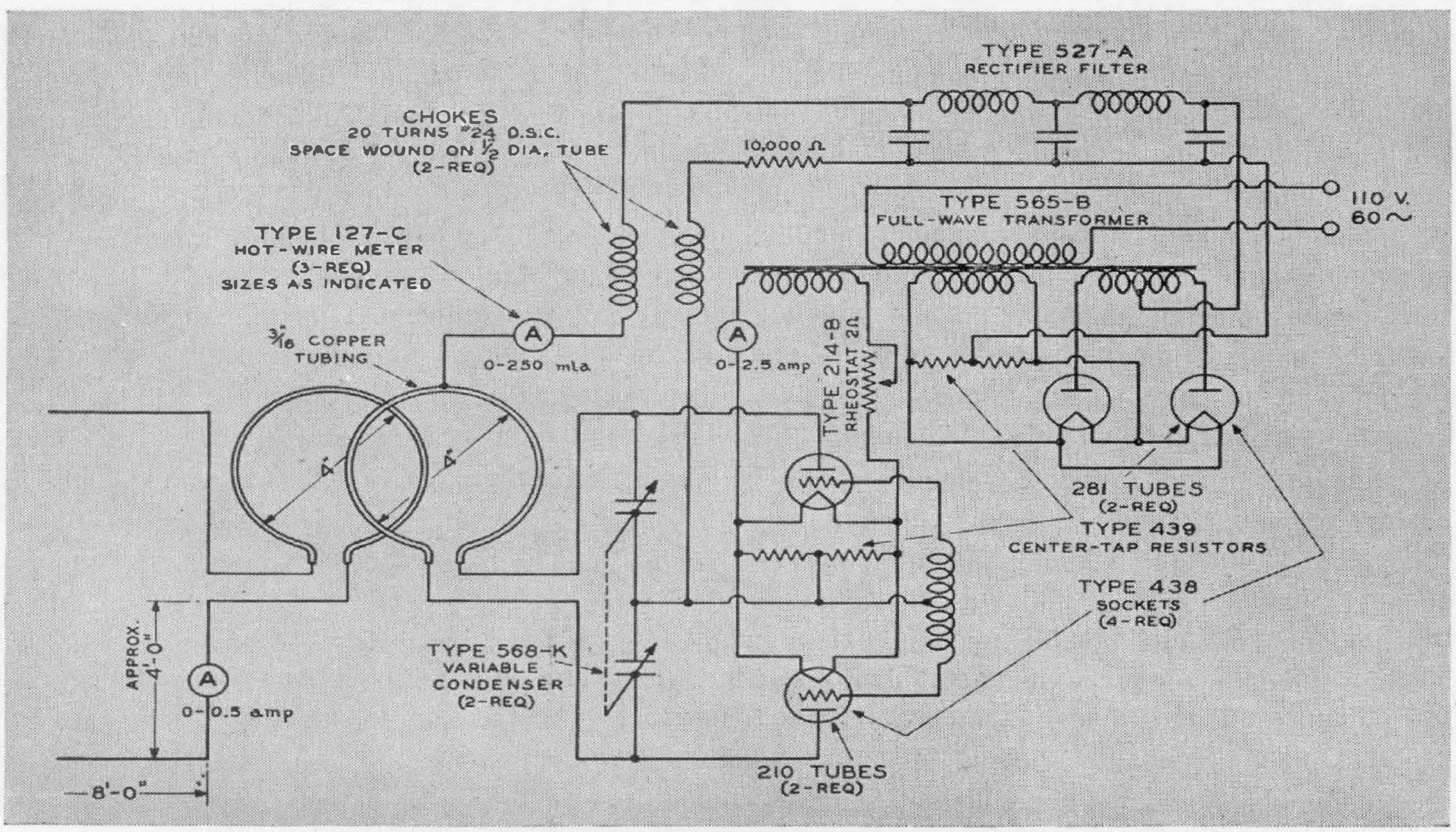


The 5-meter transmitter described in the accompanying article

The condensers are mounted in tandem with a common shaft, giving a common rotor and split stator condenser. The stators carry the plate-coil sockets which are General Radio Type 274-J Jacks mounted in a right-angle bracket as shown. These are held in place by the nuts of the stator plate rods. The plate coil is a 4-inch turn of 3/16-inch copper tubing or heavy wire with two Type 274-P Plugs soldered or threaded to the ends. A plate-voltage feed wire, which is soldered to the exact center of this loop, also carries a plug-in pin at the opposite end.

Nearby are mounted two Type 657 Sockets, separated so as to allow the proper spacing for wiring and other units. These carry the grid coil which is made of 4 one-inch turns of No. 10 copper wire and soldered to the grid terminals of the sockets. A fair amount of spacing should be allowed between coil and baseboard. A tap made at the exact center of this coil goes directly to the radio-frequency choke made up of 20 turns of No. 24 D.S.C. wire, double-space wound on a ½-inch wooden or hard rubber dowel 2″ long. A Type 437 Center-Tap Resistor is mounted between the sockets, by soldering directly onto the filament-supply wires. Note that the condenser rotors are at ground potential.

Two Type 274-K Binding-Post Assemblies mounted on the baseboard with spacers allow means for making connections to the power supply, both for filament and plate voltages. Power may be derived from a rectified and filtered alternating-current supply of 550 volts for the plates of two 210-type tubes. 7.5 volts are necessary to light the filaments. Such a unit consists of a full-wave transformer (Type 565-B) and a Type 527-A Rectifier Filter



Circuit diagram for 5-meter transmitter

with 281-type tubes as rectifiers. The filament posts connect to the 7.5-volt secondary on the transformer with a 2-ohm rheostat and a 2.5-ampere ammeter in series with the tubes. A plate milliammeter is also desirable because it not only indicates the amount of current the plates are drawing but also shows when the tubes are oscillating. It also indicates when circuit is tuned to resonance.

The antenna coupling coil is mounted on a pair of TYPE 260 Wall Insulators which have a strap of 1/16-inch brass, 1/2-inch wide fastened at the center, with 2 TYPE 138-V Binding Posts at each end of the strap. One pair of binding posts support the antenna coil and the other pair make connections to the antenna feeder system. The distance between the plate coil and antenna coil (same construction as the plate coil) is approximately 1 1/2 inches.

The proper length of the antenna and feeder is very important. For five-meter operation 8 feet of horizontal wire in each leg is necessary and the distance from binding post to the flat top should be either 4 or 8 feet as is most convenient. An antenna current meter should be inserted in one of the legs of the doublet antenna to indicate the resonance peak and amount of current. It is important to tune the antenna to the oscillator if the maximum amount of power is to be radiated from the antenna. The antenna wires should be properly insulated also, a very convenient form of insulator being the General Radio TYPE 280 Strain Insulator which may also be used as a feeder separator.

After all units are assembled on the baseboard, a power supply unit is on hand, and a final inspection of all wiring made, apply the power from the power supply and proceed to adjust the apparatus.

When tubes are oscillating properly a plate current drain of about 80-90 milliamperes should be indicated by the plate-current meter. Adjust the tuning condenser until maximum current is read on the antenna-current meter, an indication that the maximum amount of power is being transferred into the antenna system. It is possible to further increase the transfer of energy into the antenna by reducing the coupling but that tends to cause instability in the oscillator. No tuning of the antenna system is necessary if the specified directions for the feeders and antenna are observed. When using a pair of 210-type tubes as oscillators with 550 volts on the plates a current of about 500 milliamperes should be indicated by the antenna current meter.

This oscillator can be used either for C W or phone. Keying for C W can be accomplished by inserting a key in the grid-return; modulation, by inserting a modulation tube at the same point.

— R. L. TEDESCO

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