Part Three

RESONANT CIRCUITS

In performing experiments on resonant circuits, it is necessary to have a source of radio-frequency voltage. For this purpose a combination crystal and self-controlled oscillator is used. This in turn must have a source of power for the heater and plate of the tube. The units shown in the photographs differ only in a few details from similar equipment to be found in practically every amateur station, and if an oscillator and power supply already are available there is nothing to prevent their being adapted to the purpose.

Ordinary voltmeters and milliammeters cannot be used for radio-frequency measurements, so it becomes necessary to devise an instrument which will be suitable. A vacuum-tube voltmeter, useful for r.f. voltage measurements, is relatively simple to build. One which is adequate for the purposes of these experiments can be constructed from a few resistors and condensers, in addition to a small receiving triode. Power for the voltmeter can be taken from the oscillator supply.

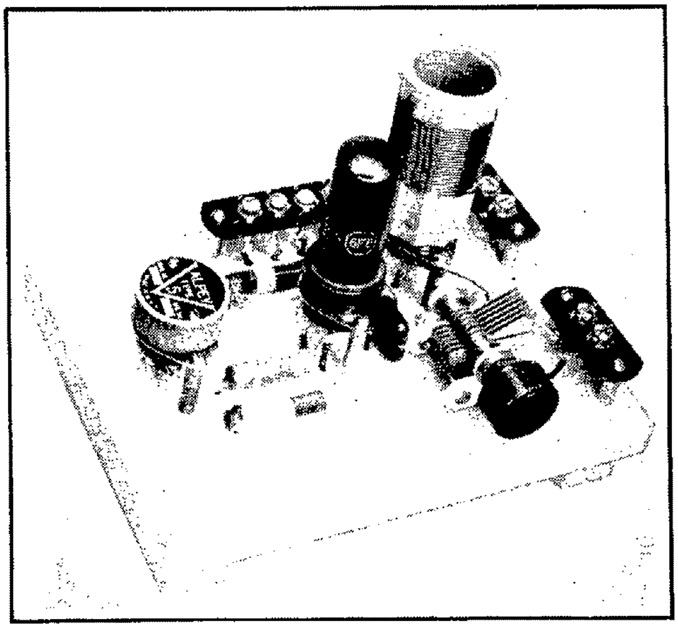


Fig. 1 — Oscillator for generating r.f. signal used in measurements on resonant circuits. It may be used either with crystal or TNT grid coil, so that either fixed or variable frequency may be obtained. The socket at the left, occupied by the crystal in this photograph, also is used for the grid coil. The breadboard measures 6 × 8½ inches. Power supply connections are brought out to the rear terminal strip. The terminals on the strip in the lower right-hand corner are connected to the ends of the plate tank circuit; the other two-terminal strip is for link output.

Oscillator

The oscillator shown in the photograph, Fig. 1, is a conventional pentode circuit when crystal is used, and is converted to a TNT by plugging in a grid coil and grid condenser in place of the crystal. The plate tuned circuit of the oscillator is parallel fed, which is advantageous in that no d.c. voltage appears on either the coil or condenser. The plate coil specified in Fig. 2 should be about the right size for most of the experimental work, but in one or two cases shunt capacity of leads may reduce the tuning range to the point where a slightly smaller coil would be desirable. It is therefore suggested that the coil be tapped about 5 turns from one end and provision made for shorting out the 5 turns when required. Alternatively, a separate coil having 25 turns spaced to make the length 1¼ inches may be used. A pair of output terminals is connected directly across the tank for set-ups which require a fairly high r.f. voltage. Provision also is made for link output.

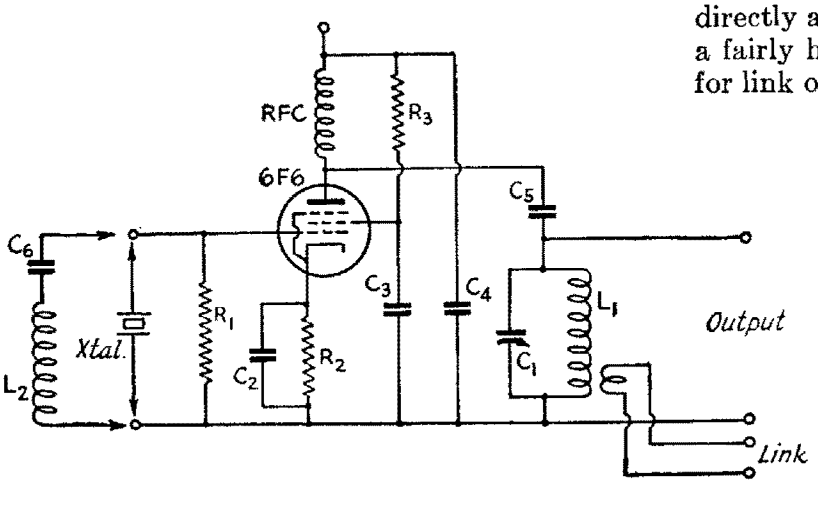


***Fig.* 2 — Oscillator circuit.**
C_1 — 100-μμfd. variable.
C_2, C_3, C_4 — 0.01-μfd. paper.
C_5 — 0.002-μfd. mica.
C_6 — 500-μμfd. mica.
R_1 — 0.1 megohm, 1 watt.
R_2 — 400 ohms, 1 watt.
R_3 — 10,000 ohms, 10 watts.
L_1 — 30 turns No. 20 enameled, close-wound on 1½-inch diameter form.
L_2 — 45 turns No. 30 enameled, close-wound on 1½-inch diameter form.
RFC — 2.5-mh.r.f. choke.

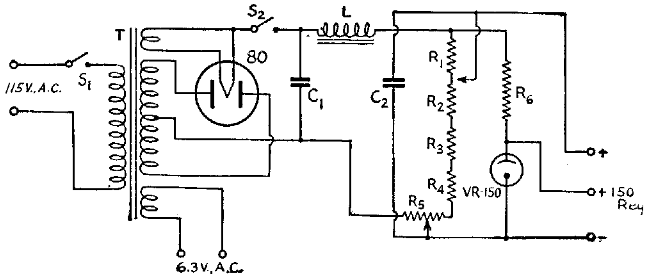


Fig. 3 — Power supply circuit.
C_1, C_2 — 16-μfd. electrolytic, 450 volts.
R_1, R_2, R_3, R_4 — 5000 ohms, 10 watts.
R_5 — 5000-ohm wire-wound potentiometer.
R_6 — 10,000 ohms, 10 watts.
L — 10 to 15 henrys, 100 ma.
T — Replacement or similar transformer to deliver 250 to 300 volts d.c. from filter at 100 ma. (350 volts a.c. each side center tap); with 5-volt and 6.3-volt filament windings.
S_1, S_2 — S.p.s.t. toggle.

For crystal control, any crystal in the 3.5-4-Mc. band can be used. For tuned-circuit frequency control, the "untuned" grid coil, which has a grid blocking condenser incorporated in the coil form, replaces the crystal. The number of turns on this coil should be adjusted so that the oscillator output voltage is substantially uniform (without load) over as much of the 3.5-4-Mc. band as possible. Other wire sizes may be used provided this requirement is met.

Power Supply

The power supply, Figs. 3 and 4, uses an ordinary replacement transformer with an 80 rectifier and condenser-input filter. Any supply which delivers about 250 to 300 volts at 75 to 100 milliamperes will do. The voltage divider incorporated in this supply enables continuous adjustment of the output voltage from zero to the maximum voltage of which the supply is capable. The output filter condenser is connected to the output terminals rather than to the voltage divider so that the condenser can act as a by-pass when the supply is used for audio work. A similar divider can be added to any existing supply, of course. A regulated tap, using a VR-150-30, and delivering 150 volts under loads varying from zero to about 20 milliamperes, is included. A switch is provided in the rectifier output so that the d.c. voltage can be shut off when adjustments are made, while keeping filaments hot.

V.T. Voltmeter

The vacuum-tube voltmeter need not be accurately calibrated, since absolute values of voltage need not be known. However, it is essential to know *relative* voltage values, and a preliminary voltage calibration therefore is necessary. It is desirable to have a voltmeter with a scale as nearly linear as possible, and also one which has high input impedance since the accuracy of measurement of voltages in resonant circuits will be impaired if the voltmeter takes appreciable energy. For these reasons a feedback-type triode voltmeter is used. Selection of the proper cathode resistor sets the voltage range; in the present case approximate ranges of 10, 30 and 100 volts are provided when the plate-circuit milliammeter has a full-scale range of 1 milliampere. The universal test instrument can be used for measuring the plate current.

The circuit of the v.t. voltmeter is shown in Fig. 6. It is simply a tube biased nearly to cutoff so that the positive cycle of an a.c. voltage applied to the input circuit will cause the plate current to increase. Under ideal conditions the increase in plate current will be proportional to the applied voltage, and in practice this linear relationship is very nearly achieved. Some initial fixed bias is applied to the grid by means of the voltage divider consisting of R_5 in series with R_6; R_6 is in the cathode circuit and the drop across it biases the grid negatively. Additional bias is provided by the cathode resistors R_2, R_3 and R_4. The lower the resistance used here the greater the sensitivity — that is, the higher the plate current reading for a given voltage applied to the grid. The higher the resistance, the greater the input

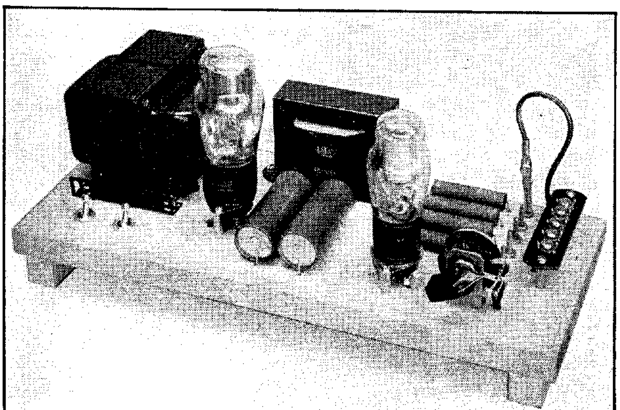


Fig. 4 — The power supply unit. Mounting of parts closely follows the circuit diagram of Fig. 3. The baseboard is 6 × 14 inches. Voltage divider taps are machine screws projecting through the baseboard just to the left of the terminal strip. The variable section of the divider is mounted on a metal bracket at the right front.

voltage range which can be handled; the linearity also is improved with high resistance.

The voltmeter should be calibrated against a d.c. source. The transformerless supply described in Part 2 is quite suitable for this purpose. Connect its negative output terminal to the ground terminal of the v.t. voltmeter input and the positive terminal to the grid side, then vary the output voltage over a suitable range and take readings of the voltmeter tube plate current for each applied voltage. The test instrument can be used to measure both current and voltage by switching it back and forth from the plate of the voltmeter tube (when it should be used as a 0-1 milliammeter) to the input terminals of the v.t. voltmeter (when it should be used as a d.c. voltmeter of appropriate range). When enough data have been taken, plot curves showing plate current against grid voltage for all three values of cathode resistance. A typical chart is shown in Fig. 7. The calibration is linear on the two higher ranges except near the low end of the scale, where there is a small departure from a straight line.

The value of the bias resistor R_6 may require some modification for tubes of slightly different characteristics. Its resistance should be high enough to bring the plate current almost, but not quite, to zero when no voltage is applied to the input terminals. Should the plate current be zero at first trial, R_6 should be reduced in resistance until the plate milliammeter shows a small indication — between zero and a few hundredths of a milliampere.

Changing the plate voltage has the effect of shifting the curve up or down on the graph, but if the *increase* — not the actual value — in current with applied input voltage is considered, the calibration is not changed appreciably. However, with higher plate voltage the plate milliammeter may go off scale near the upper end of the range, while lower plate voltage will cut down the maximum grid input voltage which it is possible to handle without overloading. The regulated tap on the power supply of Fig. 4 provides a constant voltage of suitable value.

Condensers C_1 and C_2 are r.f. by-passes and tend to build up the plate current to a value which indicates the peak voltage of an applied

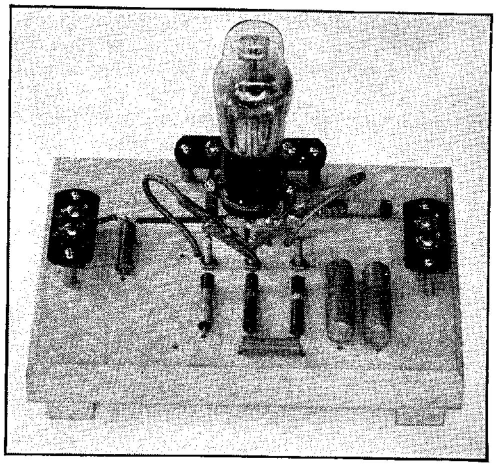


Fig. 5 — Vacuum-tube voltmeter for r.f. measurements. It has three ranges, 10, 30 and 100 volts. Input terminals are at the left, power supply terminals at the rear, and meter terminals at the right. The three cathode resistors are in the front center, with machine-screw terminals projecting through the board to serve as connection posts. The flexible wire at the left connects to the 1-μfd. by-pass condenser (one of the old flat metal-can type) which is mounted underneath the baseboard. The right hand flexible lead connects to the tube cathode. When making r.f. measurements the 1-μfd. condenser is disconnected.

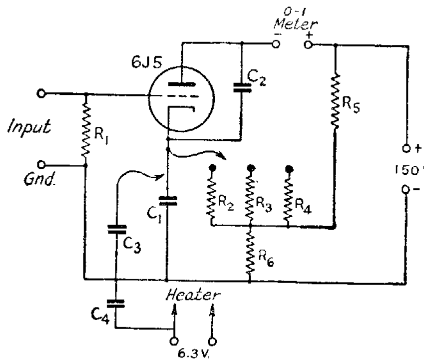


Fig. 6 — V.t. voltmeter circuit.

C_1, C_2 — 0.1-μfd. paper.
C_3 — 1-μfd. paper.
C_4 — 0.01-μfd. paper.
R_1 — 5 megohms.
R_2 — 3000 ohms, 1 watt (10-volt scale).
R_3 — 25,000 ohms, 1 watt (30-volt scale).
R_4 — 0.1 megohm, 1 watt (100-volt scale).
R_5 — 50,000 ohms, 2 watts.
R_6 — 3000 ohms, 1 watt.

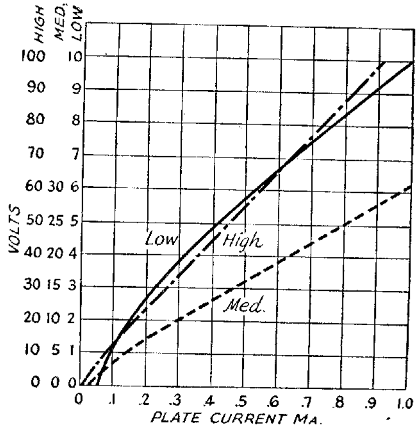


Fig. 7 — Typical d.c. calibration curves for the vacuum-tube voltmeter of Fig. 5.

r.f. wave. C_3 is a similar by-pass for audio frequencies across the cathode circuit. Whether or not the instrument reads peak voltage is not important in the present application, since relative voltages are of chief interest. In making r.f. measurements it will be sufficient to assign the measured voltage a value equal to the d.c. voltage which gives the same plate current reading. C_4 is an r.f. by-pass on the heater circuit.

Circuit Board

It is convenient, although not wholly necessary, to have a "circuit board" arranged somewhat as shown in Fig. 8. Variable condensers can be fastened solidly to it, as can also one coil. The other coil is left free for varying coupling when both are used. In the unit shown in the photograph, the coils are wound on ordinary mailing tubes and are mounted on small pieces of Presdwood or thin wood (so the free coil will sit still and not topple over) by miniature stand-off insulators. The variable condensers should have a maximum capacity of 250 μμfd. or more to give ample experimental range; old broadcast condensers will do quite nicely. The small condenser at the left is for capacity coupling when needed.

A half-dozen or so 6- to 8-inch lengths of flexible wire with alligator clips at each end will be convenient for changing circuits. There is no permanent wiring on the circuit board shown; all connections are made by means of such clips.

Calibrated Receiver

Relatively few tests can be made on r.f. circuits without measurement of frequency. It is assumed that every amateur will have a receiver with 80-meter bandspread and that he has calibrated or can calibrate it to reasonable accuracy. Calibration methods are described in the *Handbook.* Once a half-dozen or so calibration points are obtained a smooth curve can be drawn through them to give accurate-enough indications for experimental purposes. It will be sufficient to read to 10-kc. intervals.

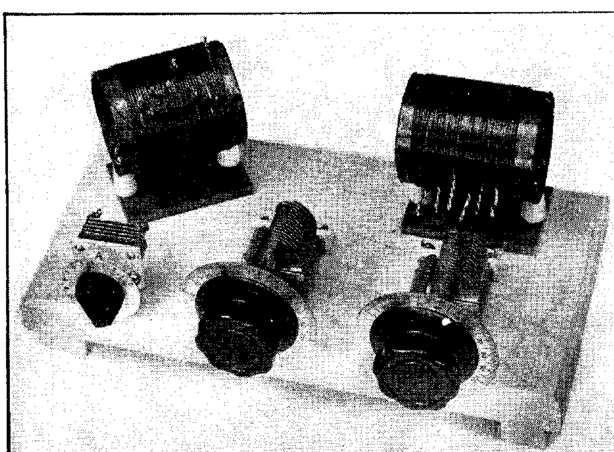


Fig. 8 — A circuit board such as this is convenient for making up various types of resonant circuits. The tuning condensers are 250-μμfd. units; any condensers having this or higher capacity will be satisfactory. The coils, wound on mailing tubes of 2¼-inch outside diameter, have 35 turns each, tapped every 5 turns, with turns spaced to occupy a total length of 2 inches. The wire is No. 18. The small condenser at the left is for coupling purposes and may have a maximum capacity from 25 to 50 μμfd.

ASSIGNMENT 8

Study *Handbook* Section 2–10. Perform Exp. 15.

Questions

1) What is "skin effect"?

2) If a current of one ampere flows through a series-resonant circuit having a resistance of 10 ohms and inductive and capacitive reactances of 500 ohms each, what is the applied voltage? What voltage appears across the terminals of the inductance? Across the terminals of the condenser?

3) When is an ordinary radio circuit resonant?

4) Describe the operating characteristics of a series-resonant circuit; of a parallel-resonant circuit.

5) Define the quantity Q.

6) An inductance of 10 microhenrys is used in a parallel-resonant circuit tuned to 7 megacycles. If the coil has a resistance of 3.5 ohms at this frequency, what is the Q of the circuit? Losses in the condenser may be neglected. What is the parallel-resonant impedance of the circuit?

7) A resistance of 5000 ohms is connected across the circuit of Question 6. What is the new value of circuit Q? What is the equivalent resistance introduced in *series* with the coil by the shunt resistor?

8) How may the Q of an unloaded circuit (one in which all the energy supplied to the circuit is consumed in the circuit itself) be increased? If the circuit is parallel-resonant and is shunted by a fixed value of resistance, how may the circuit Q be increased?

9) In the circuit of Questions 6 and 7, what values should the inductance and capacity have, to give a circuit Q of 25 when the circuit is loaded by the shunt 5000-ohm resistance?

10) Plot a curve showing the values of inductance required to tune to 3.5 megacycles with any value of capacity between 50 and 250 μμfd.

11) Neglecting coil resistance, plot a curve showing the variation in Q of the circuit in Question 10 as the L/C ratio is varied, when a resistance of 10,000 ohms is connected

across the circuit. Plot in terms of the capacity in use. Plot a similar curve for a resistance of 5000 ohms.

12) What is the resonant frequency of a circuit consisting of a coil of 30 microhenrys and a capacity of 60 $\mu\mu$fd.?

13) A resonant circuit is formed by a 50-$\mu\mu$fd. condenser and a coil of 10 microhenrys. The latter has a resistance of 2 ohms at resonance.

a) What is the resonant frequency of the circuit?
b) What is the Q of the circuit?
c) What is the parallel-resonant impedance of the circuit?
d) If one volt at the resonant frequency is applied in series with the circuit, what voltage will appear across either the coil or condenser?
e) If 250 volts at the resonant frequency is applied in parallel with the circuit, what is the equivalent series voltage, corresponding to the series voltage in (d), acting in the circuit? What then is the current circulating in the parallel-resonant circuit? What is the line current (see Exp. 14)? What is the ratio of circulating current to line current, and what circuit quantity does it equal?
f) A resistance of 8000 ohms is connected across the parallel-resonant circuit. Find the new value of circuit impedance. (Use the ordinary formula for resistances in parallel, since the impedance of the tuned circuit alone is a resistance at the resonant frequency.) If the impedance of the tuned circuit alone were neglected in determining the new impedance, would the error be appreciable? What would be the per cent error caused by neglecting the impedance of the tuned circuit alone if the inductance and capacity had the same values but the coil resistance was 40 ohms?
g) If 250 volts at the resonant frequency is applied across the circuit with the 8000-ohm resistor in shunt (assuming the original coil resistance of 2 ohms) what is the circulating current in the circuit? What is the line current? What is the new value of circuit Q?

14) A resonant circuit to operate at 14,200 kilocycles is to be loaded so that the effective parallel impedance will be 4000 ohms. Assuming that the coil resistance will be negligible (that is, nearly all the energy will be dissipated in the load, not in the coil itself) what inductance and capacity should be used to give a Q of 15?

15) If a voltage of lower frequency than the parallel-resonant frequency of a circuit is applied, what type of reactance does the circuit exhibit? Which branch of the circuit carries the greater current, the inductance or capacity? What are the conditions when the applied frequency is higher than the resonant frequency? Compare with a series circuit.

16) What is the piezoelectric effect?

17) What is meant by the term "loaded circuit"?

18) Two coils, one having an inductance of 15 microhenrys and a resistance of 5 ohms, and the other an inductance of 9 microhenrys and a resistance of 3 ohms, are available for use in a circuit to operate at 7500 kc. Which will give the greater selectivity?

19) If the Q of a coil having an inductance of 100 microhenrys is found to be 125 at a frequency of 2000 kc., what is the effective r.f. resistance of the coil?

20) What capacity is necessary to tune the coil of Question 19 to 2000 kc., and what will be the parallel impedance of the circuit?

ASSIGNMENT 9

Study *Handbook* Section 2–11. Perform Exps. 16–20, inclusive.

Questions

1) Name six ways in which radio-frequency energy may be transferred from one resonant circuit to another.

2) What is meant by "critical coupling"?

3) What happens to the effective series resistance of the primary circuit when the coupling to the secondary circuit is increased? What is the effect of increasing coupling on the parallel impedance of the primary circuit? On the overall selectivity of the two circuits?

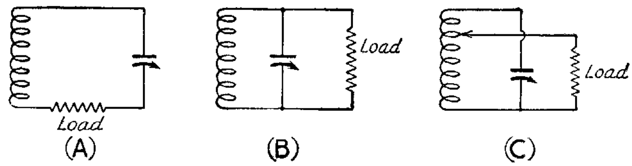
4) What is mutual inductance?

5) On increasing the coupling between two circuits it is found that the primary is thrown off tune. What is the cause?

6) Define coefficient of coupling.

7) A 600-ohm load is connected to a resonant circuit which in turn is coupled to the tuned plate circuit of a transmitter operating at 7100 kc. If the secondary circuit must have a Q of 10 to obtain sufficient energy transfer, what values of inductance and capacity must be used (assuming negligible losses in the coil itself) in the secondary circuit if the inductance, capacity and load are connected in series? Would these values be practicable at this frequency? If the secondary circuit is parallel-resonant and is shunted by the 600-ohm load, what values of inductance and capacity should be used to obtain the required Q? Suppose a condenser of only half this capacity was available; what could be done to obtain sufficient coupling?

8) Assuming that a variable condenser having a maximum capacity of 300 $\mu\mu$fd. and a minimum capacity of 30 $\mu\mu$fd. is available to tune the secondary or load circuit, indicate which of the circuits, A, B, or C in the diagram (page 32) should be used to couple to the primary (at 7100 k.c.) if the secondary circuit must have a Q of 10 for adequate energy transfer, when the load resist-



ance has the following values: 10, 20, 70, 150, 600, 2000, 5000 ohms. Find the value of capacity which should be used in each case, and also the value of inductance necessary to tune to resonance in each case.

9) What is a low-pass filter? How may such a filter be constructed?

10) What are the distinguishing characteristics of a high-pass filter?

11) What is the purpose of shielding? What type of shield eliminates or reduces electrostatic coupling?

12) What materials are satisfactory for magnetic shielding at audio frequencies? At radio frequencies?

13) What happens to the inductance of a coil when it is enclosed in a shield? What is the effect on the Q of the coil? What determines the magnitude of these effects?

14) What is a band-pass filter? Describe a simple form of band-pass filter.

15) Describe the principle of operation of the bridge circuit.

16) How would you arrange two coils to obtain the highest possible mutual inductance?

ASSIGNMENT 10

Study *Handbook* Sections 2–12 and 2–13.

Questions

1) What is meant by the term "standing wave"?

2) What is the wavelength in meters corresponding to a frequency of 3500 kilocycles? What is the wavelength in feet?

3) What is the shortest length of wire in free space which will be resonant at a given frequency?

4) Describe the construction of a concentric line.

5) How is the current distributed along a wire a half wavelength long at the frequency at which it is excited? What is the current distribution if the wire is one wavelength long?

6) Describe the impedance characteristics of a folded quarter-wavelength line.

7) Why can a concentric line be built to have higher Q than a tuned circuit which operates at the same frequency?

8) What is radiation resistance?

9) What beat frequencies are produced when currents having frequencies of 2000 kilocycles and 2450 kilocycles are mixed in a circuit suitable for the production of beats? What beats are produced if the two frequencies to be mixed are 3900 kilocycles and 1500 cycles? 7150 kilocycles and 7149 kilocycles?

10) What is meant by ground potential?

11) When are by-pass condensers necessary?

12) What requirement must a by-pass condenser meet to function properly?

13) What is the purpose of a choke coil, and what requirements must it meet with respect to the characteristics of the circuit in which it is used?

14) A by-pass condenser is to be used to shunt r.f. current at a frequency of 14.15 megacycles around a circuit having an impedance of 6000 ohms. What value of capacity would be suitable?

15) A 500-ohm resistor is to be effectively bypassed for 100-cycle alternating current. What value of capacity is required?

16) Direct current is to be fed to a radio-frequency circuit which has an impedance of 2500 ohms at 3600 kilocycles. What inductance should the choke coil have? (In actual practice, the impedance of the choke coil would be affected by the distributed capacity of the coil, but this need not be considered in the problem.)

17) A 15-henry inductance is being used as a choke coil through which direct current is being fed to an a.c. circuit which has an impedance of 4000 ohms at 500 cycles. Is this value of inductance adequate? Would it be adequate if the frequency were 60 cycles?

EXPERIMENT 15

Resonant Circuits

Apparatus: The oscillator, power supply, vacuum-tube voltmeter, test instrument, circuit board and the calibrated receiver are needed for this experiment, together with two 1-watt resistors, 50,000 and 100,000 ohms. Use the full output voltage of the supply (250 to 300 volts) on the oscillator, which is operated with the coil in the grid circuit to give variable frequency.

Procedure: Connect a condenser and coil on the circuit board in parallel, and connect the input terminals of the v.t. voltmeter across the parallel circuit. Set the oscillator frequency to about 3700 kilocycles as determined by the receiver calibration (keep the gain low so that the signal is weak enough to give a good zero-beat indication) and bring the oscillator and tuned circuit near enough to each other to get a good v.t. voltmeter indication when the circuit is tuned through resonance. A reading of nearly full scale (on either the 30- or 100-volt scale) should be obtained when the circuit is resonant at the oscillator frequency. Once the relative positions of oscillator and circuit to give such a reading have been determined, do not move either unit. Should one or the other be accidentally moved, recheck to obtain the same maximum reading at resonance before going ahead.

Using all the turns in the coil, set the condenser to resonance. Then vary the oscillator frequency in steps of about 20 kc., taking readings on the v.t.v.m. each time, until the frequency is sufficiently far from resonance to bring the v.t.v.m. reading down to the low end of the scale. Do not touch the tuned circuit in the meantime. Take readings on both the low- and high-frequency sides of resonance. Then connect the 100,000-ohm resistor across the tuned circuit and repeat the measurements over the same frequency range. Finally, follow the same procedure with the 50,000-ohm resistor across the circuit. When the run is complete, convert the plate-current readings to volts by means of the v.t.v.m. calibration curve and then plot a curve showing the voltage across the circuit against frequency.

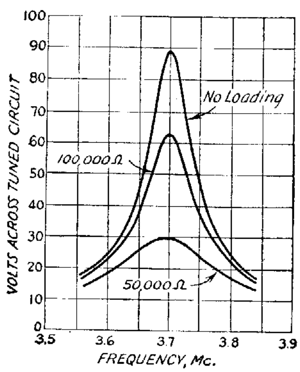


Fig. 9

Typical results of such measurements are shown in Fig. 9. The voltage is highest at resonance, dropping off with frequency on either side at a rate determined by the losses in the circuit. These losses are highest with the lower values of parallel resistance, hence the resonance curves of the loaded circuit become progressively less sharp as the loading is increased (parallel resistance lowered). Since the coupling to the oscillator is not changed during the run the voltage induced in the circuit remains unchanged, but the voltage rise at resonance decreases with loading, indicating that the Q of the circuit is decreasing.

Using a smaller number of turns on the coil, repeat the experiment, plot the data, and compare the curves to those obtained with the whole coil. Take a series of such data with different values of inductance. When the inductance is changed, change the position of the coil, if necessary, to get the same maximum value of voltage at resonance without load, or else convert the new readings to the original scale by multiplying each value by the ratio of the original maximum voltage to the new maximum voltage.

If some low-resistance 1-watt units are available (50 to 200 ohms) the experiment can be varied by taking readings similar to those described above, but with the low-resistance units connected in series with the coil and condenser instead of in parallel. In such case connect the v.t.v.m. across the condenser. When plotted, these readings can be compared to the curves obtained with the parallel resistors, in which case it will be observed that the higher values of series resistance give curves comparable to those obtained with the lower values of parallel resistance. If the losses in the circuit itself are small compared to the loss in the connected resistor, the relationship between parallel resistance and equivalent series resistance can be found from the formula

$$Z = \frac{X^2}{R}$$

where Z is the resistance actually connected in parallel and R is the equivalent series resistance. Conversely the impedance of the circuit can be found when the series resistance R is known. Calculate the values from the experimental data obtained.

EXPERIMENT 16

Inductively-Coupled Circuits

Apparatus: Same as for Exp. 15, with the addition of 25,000- and 10,000-ohm 1-watt resistors.

Procedure: Set up the oscillator for crystal operation, but remove the plate coil and connect the free coil on the circuit board in its place, using flexible leads. Set the plate voltage tap on the power supply for about half voltage (between R_2 and R_3, Fig. 4). Connect the fixed coil on the circuit board in parallel with the nearest variable condenser, using all the turns on the coil. Connect the v.t. voltmeter across this circuit. The general arrangement is shown in Fig. 10.

This experiment involves varying the coupling between the two coils, so it is convenient to make a scale to indicate the degree of coupling. The simplest way to do this is to rule a line on the board to serve as a guide for the movable coil so that its axis always will coincide with that of the fixed coil, and then mark off half-inch intervals along the guide line. Zero spacing will simply be the closest possible spacing between the coil bases on the board, and need have no reference to the actual separation between the turns.

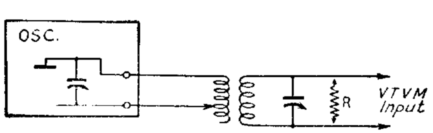


Fig. 10

This method of measuring coupling is purely arbitrary, but will serve the purpose satisfactorily. At the very close spacings, quarter-inch intervals on the guide line will be desirable.