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Receiver Tuned Circuits

By the Engineering Department, Aerovox Corporation

TUNING, as performed in radio reception, consists essentially in setting certain circuits to admit signal voltages of one frequency while excluding those of all other frequencies. *Selectivity* is a measure of the extent to which this action is achieved. A circuit is said to be selective when it enables the complete rejection of unwanted frequencies, even those which lie quite close to the desired signal. All receiver tuned circuits should provide selectivity.

The important tuned circuits of a receiver are identical with the basic arrangement shown in Figure 1, consisting of a capacitance connected in parallel with an inductance, or are elaborations of this same arrangement. In order that the circuit may be adjusted, the property of one of its elements is made variable; although it would be entirely possible, though difficult of manipulation, to have both variable. The majority of systems, for numerous reasons of electrical and mechanical practicability, employ a variable condenser, rather than an adjustable inductance.

The tuned circuits of a receiver may be operated as series tuned circuit or parallel tuned circuit. The characteristics of the series tuned circuit are essentially the same as those of the parallel tuned circuit, except that the series tuned circuit depends on a line current increase for its operation while the parallel tuned circuit depends upon a line current decrease for its operation. Therefore, the selectivity of the series tuned circuit depends primarily on a low line resistance, while the selectivity of a parallel tuned circuit depends primarily on a source of high series resistance.

From a study of the antenna or coupling transformer of a radio frequency or intermediate frequency stage, it will be noted that the grid circuit is a tuned series circuit as the voltage is induced in the coil, and therefore can be considered acting in series with the coil and the condenser. The plate circuit, however, of an i.f. transformer is a parallel tuned circuit in series with the plate impedance of the tube. Since this plate impedance is fairly high, the parallel circuit gives the maximum voltage gain and selectivity possible.

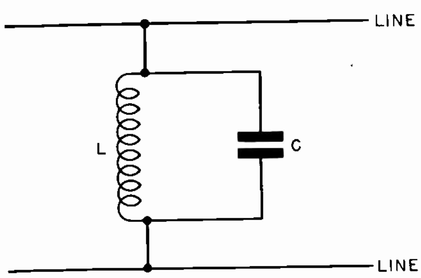


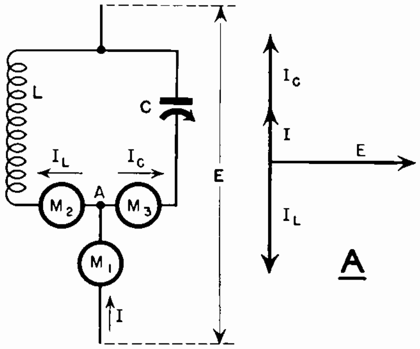
Fig. 1

The property of *parallel resonance* which is associated with circuits of the type in Figure 1 is the underlying *modus operandi* of the tuned circuit, and an understanding of the principles governing the parallel resonant circuit is essential to a full comprehension of tuned circuit operation and design.

THE PARALLEL RESONANT CIRCUIT

An alternating current views the parallel resonant circuit of Figure 1 as an inductive reactance in shunt with a capacitive reactance. And in flowing down through this combination, the current will encounter separate impeding effects in the two legs, the two reactances acting upon it by different amounts depending upon the frequency of the current alternations and the values of the coil and condenser components.

At some one critical frequency, for any given inductance and capacitance values, the inductive reactance and capacitive reactance will be equal. Because of the nature of the two kinds of reactance, the impeding action of the circuit will be almost entirely due to the capacitive element at frequencies below this critical frequency and largely to the inductive at frequencies higher. At this critical frequency of *resonance*, the two reactances, being equal and of opposite algebraic sign,



Figs. 2 and 2A

will neutralize each other, leaving the coil resistance (which is generally negligible in comparison with the coil reactance) as the sole circuit property remaining to impede the passage of current.

Consider three suitable a.c. ammeters; M_1, M_2, and M_3, connected in the parallel resonant circuit in the manner illustrated in Figure 2. When an alternating current, I, is caused to flow into the circuit by action of an impressed e.m.f., its intensity will be indicated by the meter M_1. This current, termed the *line current*, will divide at the junction point, A; a portion (I_c, the condenser current) flowing through the capacitive leg of the circuit will actuate M_3. And the other (I_L, the coil current) flowing through the inductive leg will actuate M_2. The readings of M_2 and M_3 will be unequal and that of M_1 *may be less than either of the former.*

If then the capacitance of the condenser C is adjusted throughout its range, I_c and I_L will gradually tend to become equal, while at the same time the line current, I, will be growing steadily smaller. Assuming that the capacitance range of C is appropriate, there will be one setting of this condenser at which C and L will have the proper relation to render the circuit resonant at the frequency of the applied voltage. *I* will fall to a very low value, approaching zero, at resonance, while the large magnitude and near equality of I_c and I_L at that point indicate that the reactive properties of the circuit have very nearly disappeared. Because of the high current in the circuit, the voltage developed across LC will be at its peak.

Beyond resonance, I_c and I_L will again become unequal as the capacitance of the condenser is varied further, the condenser current continuing to move upward; the coil current downward.

Thus, it may be seen that the proper adjustment of L and C at any frequency will result in the appearance of a maximum voltage (the resonant voltage) across the combination and minimum current (line current) in the external circuit. And when the circuit is connected to a voltage-operated device, such as to the grid-cathode input of a vacuum tube, voltages of desired frequencies may be selected and applied to the device by *resonating* the circuit. This is the basic function of the receiver tuned circuit.

The resonant frequency, f may be determined from the equation:

(1) $$f = \frac{1}{2\pi\sqrt{LC}}$$

From which:

(2) $$L = \frac{1}{4\pi^2 f^2 C}$$

And

(3) $$C = \frac{1}{4\pi^2 f^2 L}$$

f is in cycles per second,
C in farads, and L in henries.
f in each case is taken to be the resonant frequency.

The above equations hold for both series and parallel circuits.

In the case of pure capacitance in parallel with pure inductance, the simple vector relations of Figure 2A would apply. Here, I_c is leading the applied voltage, E by 90 degrees, while E leads I_L by 90 degrees. I, the line current, leads E by 90 degrees when I_c is greater than I_L and lags E by 90 degrees when I_L is greater than I_c. When $I_c = I_L$ (parallel resonance), I is zero.

Inductive reactance equals ωL and capacitive reactance equals $1/\omega C$. Actually the coil possesses some resistance which appears as a resistance in series with L (see Figure 3) and while:

(4) $$I_c = -X_c E = -\omega CE = -2\pi fCE,$$

(5) $$I_L = E/\sqrt{R^2+X_L^2} = E/\sqrt{R^2+(\omega L)^2} = E/\sqrt{R^2+(2\pi fL)^2}$$

Condenser loss encountered in practice (which appears as a resistance associated with C) has not been considered here.

With respect to phase, the line current I (the vector sum of I_c and I_L) is:

(6) $$I = E\sqrt{\left(\omega C - \frac{X_L}{R^2+X_L^2}\right)^2 + \left(\frac{R}{R^2+X_L^2}\right)^2}$$

The vector relations of Figure 3B apply. At resonance, the line current I is at its minimum value (I_R), is in phase with E, and is equal to $ER/R^2 + (X_L)^2$.

The vector diagram of the series circuit is shown in Figure 3C. It should be noted that this diagram is similar to the diagram for the parallel circuit, except that the voltages replace the currents.

THE NATURE OF C

In Figures 1, 2 and 3, capacitance associated with the coil in parallel resonant circuits is represented by the condenser component C. Actually, however, C represents not just the capacitance of the condenser but the *total* capacitances acting in shunt with the coil. And these include (1) the actual condenser capacitance, (2) the distributed capacitance of the coil, and (3) stray shunt capacitance due to wiring and to coil and condenser terminals, all of which act in parallel to resonate the circuit. Wherever C appears in the foregoing formulas it has the inclusive meaning:

(7) $$C = C_c + C_d + C_s$$

Where:
C = total capacitance resonating the circuit,
C_c = condenser capacitance,
C_d = distributed capacitance of the coil, and
C_s = all stray capacitance due to wiring, etc.

For these reasons, the coil L may be discovered to possess a natural resonant frequency, even with no condenser as such connected across it, because the small distributed, and stray capacitances form with it a parallel resonant circuit. It is highly important that these extra capacitances be kept as low as possible if consequential losses are to be avoided in receiver tuned circuits and full advantage is to be taken of the variable

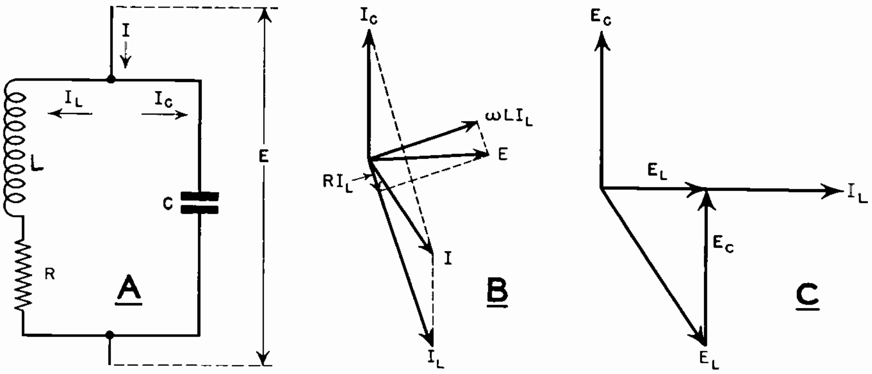


Fig. 3

condenser range. Hence, increased turn spacing or lattice winding is resorted to in efficient circuits to reduce distributed coil capacitance.

TUNING RANGE

From equation (1) it is seen that in any variable condenser-fixed coil parallel resonant circuit the maximum and minimum frequencies at which the circuit may be resonated will be determined by the maximum and minimum capacitances in shunt with the coil. Neglecting distributed and stray properties, these limiting capacitances may be taken as those of the tuning condenser. The wider the capacitance range of the latter, the wider will be the frequency band over which the circuit may be resonated.

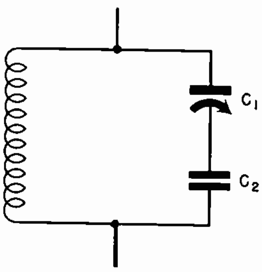


Fig. 4

Often in practice, the maximum resonant frequency of a tuned circuit is chosen as some multiple of the minimum frequency; the ratio of 2:1 being quite common in some applications, although a slightly higher ratio (nearly 3 to 1) is encountered in broadcast tuners. In the case of amateur band-spreading, the band of frequencies covered by the tuned circuits is only a few kilocycles wide, representing a ratio of less than 1.5:1 in some cases.

If it is desired to multiply or divide the resonant frequency of any parallel resonant circuit by any factor, and the fixed inductance value, original frequency, and original capacitance are known, the capacitance of the condenser at the new frequency will be equal to the capacitance at the original frequency divided by the square of the factor:

$$C_2 = \frac{C_1}{n^2} \tag{8}$$

$$f_2 = nf_1 \tag{9}$$

Where:

C_1 = capacitance at original frequency,
C_2 = capacitance at new frequency,
f_1 = original frequency,
f_2 = new frequency,
n = factor by which the original frequency is to be multiplied.

Thus, to double the resonant frequency (or to provide a tuning range of 2 to 1) the capacitance must be quartered—the tuning condenser must have a capacitance range of 4:1. Or to halve f, C must be quadrupled. Within practical limits, any desired frequency range may be achieved by employing the condenser which gives the proper amount of capacitance variation in conjunction with the inductance capable of resonating at the band-limit frequencies.

RANGE EXTENSION — TRIMMER AND PADDER

It is obvious from the foregoing that the range of capacitance variation in the condenser will decide the frequency range of the tuned circuit, and that any extension of the capacitance limits above and/or below their normal positions will correspondingly widen or narrow the band of response.

In order to bring about such changes in the limiting values of C, mechanical alterations would be possible, although hardly practicable, in the tuning condenser by addition or removal of plates. However, such a procedure would involve much labor and would affect both maximum and minimum values very nearly to the same degree, and this is not always desirable when setting a frequency range.

The same results may be accomplished electrically by interposing auxiliary condensers in series or parallel with the main tuning capacitance to operate upon the latter's maximum and minimum capacitances according to the following relations for the parallel connection:

$$C_{min} = C_{min_c} + C_a \qquad C_{max} = C_{max_c} + C_a \tag{10}$$

For the series connection:

$$C_{min} = \frac{1}{\frac{1}{C_{min_c}} + \frac{1}{C_a}} \qquad C_{max} = \frac{1}{\frac{1}{C_{max_c}} + \frac{1}{C_a}} \tag{11}$$

Where:

C = resultant minimum or maximum capacitance,
C_c = condenser capacitance at maximum or minimum as indicated,
C_a = auxiliary capacitance.

From (10) a variable condenser having a maximum and minimum capacitance rating of 100 and 10 mmfd. would have its range altered to cover 35 to 125 mmfd. by connecting a 25 mmfd. auxiliary condenser in parallel. And if the auxiliary capacitance is made 100 mmfd., the resultant capacitance range would become 110 to 200 mmfd. If the auxiliary (trimmer) condenser were variable between these values of 25 and 100 mmfd., then any number of maximum and minimum values (and corresponding widths of bandspreads) could be obtained by properly setting it. By application of relations (1) and (8) various frequency coverages could be determined. It must be remembered, of course, that where C appears in those equations and formulas it is taken to be the complex term appearing on the right-hand side in (10).

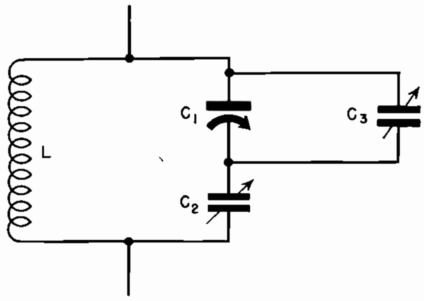


Fig. 5

It may be desirable, however, to restrict the maximum capacitance of C without greatly affecting the minimum, in order to achieve a desired frequency range, and in such a case an auxiliary capacitance (padder) is connected in series with C (see Figure 4) and the relations of (11) apply.

In this series combination, if the tuning condenser C_1 has a range of 10-100 mmfd. and the padder C_2 a fixed value of 100 mmfd., then the capacitance range of C_1 is transformed to 9-50 mmfd. (equation 11). Note that the tuning condenser maximum has been altered considerably more than its minimum. If the value of C_2 is reduced to 50 mmfd., the range becomes 8.3-33.3 mmfd., and if it is reduced further to 25 mmfd., the range becomes 7.1-20 mmfd. Note also that as C_2 is reduced in capacitance it has less reducing effect upon the maximum value of C_1, while at the same time not altering the C_1 mimimum tremendously.

The conventional receiver tuned circuit employs the arrangement shown in Figure 5 with both trimmer (C_3) and padder (C_2) made variable to achieve any desired amount of bandspread or band compression. The relations of (10) and (11) are combined to explain the circuit.

In Figure 5 the total working capacitance in parallel with L, neglecting distributed and stray properties, is

$$C = \frac{1}{\frac{1}{C_2} + \frac{1}{C_1 + C_3}} \tag{12}$$

and equation (1) becomes:

$$f = \frac{1}{2\pi\sqrt{L \frac{1}{\frac{1}{C_2} + \frac{1}{C_1+C_3}}}} \tag{13}$$