



SECTION 2

ADVANCED
PRACTICAL
RADIO ENGINEERING

TECHNICAL ASSIGNMENT
PRACTICAL APPLICATIONS OF
SERIES AND PARALLEL CIRCUITS

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PRACTICAL APPLICATIONS OF SERIES AND PARALLEL CIRCUITS

FOREWORD

Many students up to this point have conscientiously studied the necessary mathematics, magnetic circuits, inductance and capacity, and a.c. circuit theory, but with the thought in the back of their minds, "I wonder when we are going to get to Radio?" The answer at this point is "now".

The preceding work has been extremely important and essential. The engineer cannot study and apply circuit theory without the necessary mathematics; he cannot study circuit applications without a sound foundation of circuit theory upon which the applications are based. Having acquired that foundation, the next step is to build up a general background of specific applications.

In this assignment you will study tuned antenna circuits and typical circuits by means of which antennas are coupled to receivers and transmitters. Such circuits are generally applicable to all branches of radio and television. You will learn the importance of developing, by means of tuned circuits, voltage gain *ahead* of the first receiver tube. You will study a typical circuit used to suppress harmonics developed in a transmitter before they can reach the antenna and be radiated; also are described methods of eliminating strong interfering signals of nearby transmitters from a sensitive receiver.

You will learn the functions of the tuned "tank" circuit in a transmitter r.f. power amplifier and some of the design factors. You will see how such a circuit may be designed for very high frequency operation (as in FM broadcasting and television) and what variations are necessary for "push-pull" operation.

Then you will study typical band pass filter circuits, their operating characteristics and their appli-

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cations particularly to receiver i.f. amplifiers, including those for television. You will also study the low pass filter, particularly as used in high voltage d.c. power supply circuits.

All of these circuits will be taken up in greater detail from the design point of view in later assignments. At this point you should acquire a general picture of the more important applications of tuned r.f. circuits in radio transmitters and receivers. Of course, in practice there are many modifications of the circuits discussed here to meet specific requirements. Also a type of circuit shown in a transmitter application may be just as applicable in a receiver, and vice-versa.

It is suggested that in conjunction with your study of this assignment, you get any transmitter and receiver instruction books which may be available and see how many of these circuits you can find in use in your own equipment. Trace out the various tuned circuits in the transmitter or receiver diagrams and note that although at first glance they may appear complex, they all may be resolved into some modification or combination of simple basic circuits.

From here on you will find your assignments becoming more and more interesting and highly practical.

E. H. Rietzke,
President.

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PRACTICAL APPLICATIONS OF SERIES AND PARALLEL CIRCUITS

INTRODUCTION.—It is first necessary to know the theory and basic mathematics of ICR circuits—that is, how they operate. In the final analysis, however, the engineer is primarily interested in the uses to which the series and parallel circuits, and combinations of such circuits, may be put. It is the purpose of this assignment to discuss a number of practical uses for the circuits which have been studied in great detail in earlier assignments.

Tuned radio-frequency circuits are used for several basic purposes; often a circuit is expected to perform simultaneously several functions. The principal functions are:

1. To accept or pass a single frequency, rejecting all frequencies both higher and lower than the specified frequency.
2. To reject a single frequency, passing all frequencies both higher and lower than the specified frequency.
3. To accept or pass a specified band of frequencies, rejecting all frequencies both higher and lower than those within the band.
4. To excite the control grid of a vacuum tube, a voltage drop across a part of the resonant circuit being used for this purpose. The resonant voltage rise due to the circuit Q ordinarily is taken advantage of in the performance of this function.
5. To transfer power between a generating device and a load circuit, an example being in the circuits used to couple a comparatively high resistance transmitting vacuum

tube to a comparatively low resistance antenna.

Low frequency tuned circuits—resonant to audio and power frequencies—are also encountered in radio apparatus. Two examples are: The low pass filter used to remove the ripple components from the output of a power supply rectifier. The tuned audio frequency circuits used to provide a desired high frequency cut-off or a desired frequency compensation effect in an audio amplifier. Although the values of L and C used in such circuits are entirely dissimilar from those used in resonant radio frequency circuits, the principles of operation are identical.

In the following discussion of practical circuits, typical circuits will be selected, each will be given a number for later reference, and the operation of each will be taken up in considerable detail.

Circuit 1. Tuned Antenna Circuit. This circuit is shown in Fig. 1, (a) and (b). In 1(a) the receiving antenna circuit consists of the antenna itself (A) which contains distributed capacity, inductance and resistance, together with lumped inductance L and variable capacity C . This is a simple series circuit containing L , C and R , all the components of all the circuit elements being in series. When the circuit is tuned to resonance with the incoming signal by means of C , the impedance of the circuit is reduced to simple resistance and maximum current flows in the antenna circuit and through L , thus inducing the greatest voltage across the

tuned grid circuit. The tuned antenna circuit is not very extensively used in modern receivers be-

other r-f tuned circuits. By properly designing the loop circuit to have very low radio frequency re-

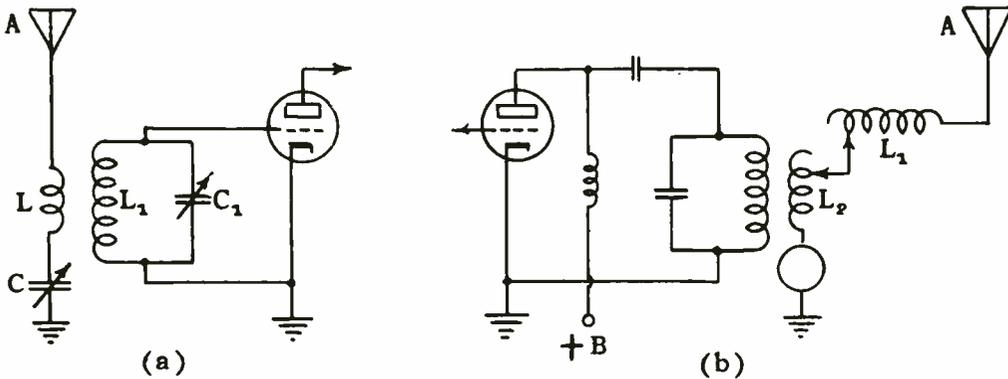


Fig. 1.—Antenna circuit for a receiver and transmitter.

cause it adds another control, and because with modern high gain tubes and multistage amplifiers, the added sensitivity is seldom required.

A notable exception to this statement is in loop-pickup receivers such as those used in radio direction finders. In a receiver designed for use with unknown antenna constants—as in the case of a commercial broadcast receiver—an additional tuning control would be required for the antenna because without knowing accurately during receiver design the exact constants of the antenna to be used, there would be no way to design the antenna tuning condenser so that it would "track" with the gang condensers used to tune the other r-f circuits. Where a loop of known constants is to be used in place of the antenna for signal pickup, the section of the gang tuning condenser used to tune the loop circuit and the capacity of the connecting cable, are designed to "track" with the

sistance, it is possible, by the use of a loop consisting of only a few turns of less than one foot in diameter, to deliver a signal voltage to the grid of the first r-f amplifier that does not compare too unfavorably with that obtained from the conventional untuned antenna of average length.

A typical loop employed in a modern aircraft automatic radio direction finder consists of 16 turns of 48 strands No. 38 Litz wire on a 7.5 inch form, the rotatable loop being enclosed within a weather-proof streamlined plastic housing. By means of suitable tuning capacity, this loop can be used for the radio range frequencies—200 to 400 KC/s—and the broadcast frequencies—550 to 1650 KC/s. A typical marine type r.d.f. may employ a loop 10 or 12 inches in diameter having correspondingly fewer turns. The most important factor in loop design is low r-f resistance.

In some modern receivers

a semi-tuned antenna is used in which C is replaced with a small variometer, (variable inductance), and this is used to approach a resonant condition and thus increase the receiver sensitivity after a station is tuned in.

The tuned antenna circuit of 1(b) is used in a transmitter. The transmitting antenna is always tuned to resonance because in order to develop the maximum antenna power it is necessary to operate at unity power factor. In the circuit shown, tuning is accomplished entirely by means of variable inductance. L_2 consists of a few turns coupled to the tank circuit inductance by means of which power is delivered to the antenna, and the impedance of the antenna is matched with that of the tube. L_1 is the tuning or loading inductance. The capacity of the circuit is only the distributed capacity between antenna and ground. The total inductance of the circuit consists of L_1 plus L_2 plus the distributed antenna inductance. The resistance is distributed throughout the circuit.

Capacity tuning of a transmitting antenna is almost never used as series tuning capacity would decrease the effective circuit capacity and require an excessive amount of inductance to compensate for the decreased capacity. This in turn could be compensated for by the use of a larger antenna but that would be a very uneconomical arrangement. A transmitting antenna ordinarily is required to operate at only one frequency. In such event it is designed to have a fundamental frequency slightly higher (probably about 15 to 20 per cent higher) than the operating frequency, which permits the use of

the necessary inductance for coupling and tuning.

Where it is necessary for the transmitter to operate with a single antenna over a band of frequencies, as in most Naval ship installations, most aircraft installations, and in some other situations, in order that the antenna may be large enough to operate efficiently at the lower frequencies, its capacity may be too great to tune to the higher frequencies. In such case series capacity is inserted near the ground connection and the antenna circuit is then tuned by means of L_1 and L_2 as explained above.

As in any series resonant circuit, the selectivity of the antenna circuit is increased by the use of large L and small C . (The reason for this was explained in detail in an earlier assignment). However, the primary function of an antenna is to collect or radiate the maximum amount of energy, this being accomplished by making the antenna length (or height in the case of a vertical antenna) as great as possible consistent with the ability, when properly coupled, to resonate at the operating frequency. A large antenna of course means large capacity to ground, with the corresponding requirement of small inductance. Thus for efficient operation the antenna circuit should not be depended upon as a means of obtaining great r-f selectivity. (It may be remarked at this point that the subject of antennas, both transmitting and receiving, will be discussed in considerable detail in later assignments.)

Circuit 2. The tuned grid circuit. Such a circuit is shown in Fig. 1(a) as L_1C_1 inductively coupled to the antenna. L_1C_1 is a

simple series circuit in which, except at ultra-high frequencies, almost all of the circuit resistance is in the coil with very little loss in the capacitor. On first thought it may appear that the circuit L_1C_1 connecting between grid and filament of the r-f amplifier tube is a parallel tuned circuit. However, it is only incidental that the grid and filament connections are such as to cause this assumption. Actually L_1C_1 form a simple low-loss series circuit which is tuned to resonance for maximum current. In Fig. 1(a) the desired voltage which is used to drive the grid of the amplifier tube is taken from across C_1 , the actual grid excitation voltage being, $E_g = IX_{C_1}$. Actually in some similar series resonant circuit applications E_g is taken by means of a tap from a portion of the turns of L_1 . In Fig. 2 a tapped circuit is used; this circuit consists of LC_1C_2 in series, the grid driving voltage being taken from across only C_1 .

Another factor in determining the mode of operation of L_1C_1 is the manner in which the voltage is applied. The voltage is induced in L_1 by virtue of its inductive relation to L and hence is applied in series with L_1C_1 . For the circuit to operate as a parallel resonant circuit it would be necessary to apply the driving voltage directly between the upper terminal of L_1C_1 and ground instead of inductively injecting the energy into the circuit. In that event there would be no resonant voltage gain at the grid because the original voltage would be applied directly between grid and cathode.

This circuit has two important functions—selectivity and gain.

The factor of selectivity is important because, for the minimum of interference in the receiver output, it is essential that interfering signal voltage reaching the grid of the first tube be reduced to a minimum. Thus from the point of view of selectivity it is desirable that L be fairly large and C not too large for the band of frequencies which must be covered.

One of the most objectionable types of interference in broadcast reception is "cross talk" which consists of modulation of the desired signal carrier by an interfering signal. Such modulation usually occurs at the grid of the first tube and of course cannot be removed by later circuit selectivity as it has become an actual frequency component of the amplified signal voltage. While the use of a variable- μ tube is a very important factor in decreasing cross-talk because it permits automatic reduction of the tube amplification factor when a strong signal carrier is tuned in with consequent reduction of gain for the undesired signal, the fundamental factor is selective frequency discrimination ahead of the first tube. Thus instead of the simple circuit L_1C_1 of Fig. 1(a) quite complex circuits are sometimes used. Such circuits will be discussed later in this assignment.

The second important function of L_1C_1 is voltage gain, or the resonant rise of voltage in the tuned circuit. To appreciate this factor it is necessary to know something of the factors which produce noise in a radio receiver. The degree of voltage gain that it is practical to use in a receiver is limited by the noise developed in the receiver itself. This does not

include static and other noises picked up by the receiver which may be serious or negligible depending upon the locality and the conditions under which the receiver is operated. The gain-limiting noise developed in a receiver is due to two principal causes, tube noise and thermal agitation noise. The former can be reduced to a low value by proper tube design. The latter is developed in the circuit itself and is the most serious source of inherent receiver noise at broadcast frequencies.

There must be some type of circuit, tuned or untuned, connected between the grid and filament of the first tube, [See Fig. 1(a)]. The circuit inductance consists of copper wire and in this copper wire there are an almost infinite number of atoms and electrons continually in a state of agitation, moving back and forth in all directions, *the degree of agitation being a function of temperature*. Each electron movement constitutes a current flow and normally, with no applied voltage, these movements practically cancel each other reducing the normal circuit current due to this source to a very small value. There are, however, intermittent surges in which, for the instant, more electrons happen to be moving in one direction than in another. These haphazard currents, while small, set up small haphazard voltages across the circuit between grid and filament, *the voltage for a given current being a direct function of the circuit impedance*. While very small, in a high gain receiver these voltages are not negligible. At the broadcast frequencies thermal-agitation voltages will average about 3 microvolts, while at 6000 KC/s the average will

be about 1 μ V.

It should be emphasized that these intermittent voltage surges are present in the grid circuit *whether it is connected to the tube or not*; the voltage amplitudes are functions of the circuit impedance and the temperature. The frequencies of these noise voltages are in the audio range and hence are *not* affected by the circuit tuning. They are of lesser amplitude at the higher frequencies than in the broadcast band simply because smaller coils having lower impedance are used at the higher frequencies.

The signal from a distant broadcast transmitter may reach the receiver input with an amplitude of 3 or 4 μ V. If this is applied directly to the grid of the first tube it has an amplitude only in the order of that of the thermal-agitation voltage which of course also modulates the weak signal carrier, possibly to a greater extent than does the speech or music modulation. The carrier with its two modulation components (speech and noise) is amplified through the receiver and the result is an output consisting of an unintelligible mixture of noise and speech. Thus with the receiver input voltage applied directly to the grid, even with a quite large antenna, it is not practical to design a receiver for sensitivity of anywhere near 3 μ V.

This is even more apparent when it is remembered that if a tuned circuit is not used between grid and filament of the first r-f tube, it will be necessary to substitute a grid leak to provide a d-c path between grid and filament. The grid leak resistance may be .25 megohm to .5 megohm, this being far greater than the impedance of the tuned

circuit coil at the audio noise frequencies. Thus the thermal-agitation voltages developed in the resistor may considerably exceed the figures stated above although the thermal currents in the high resistance of course are much smaller. Some types of resistors develop much greater noise of this type than do others.

Consider the conditions when using the circuit of Fig. 1(a). Assume that $L_1 C_1$ is a circuit having quite high Q . In an earlier assignment it was shown that a resonant rise of voltage across C_1 of twenty or more times the antenna voltage is easily obtainable. Thermal-agitation noise is still in the order of $3 \mu\text{v}$, but $3 \mu\text{v}$ of r-f voltage at the receiver input now represents $60 \mu\text{v}$ or more across C_1 , so that the signal voltage applied to the tube is much greater than the noise voltage developed at the tube input, and in the receiver output the intelligibility will be high and high receiver gain and sensitivity becomes entirely practical.

The relative effects under the two conditions may be expressed in terms of modulation percentage. If the average amplitude of the thermal-agitation voltage is $2 \mu\text{v}$ and the signal carrier voltage applied to the grid of the first r-f tube is $4 \mu\text{v}$, then the noise modulation of the carrier is 50 percent. In ordinary speech the average modulation percentage may be in the order of 25 per cent. Under this condition the average noise at the receiver output will have amplitude twice as great as that of the desired speech output. On the other hand, if by the use of a tuned circuit the speech-modulated carrier voltage can be increased to $80 \mu\text{v}$ at the

grid of the first tube, the noise voltage remaining at $2 \mu\text{v}$, the percentage of modulation due to the noise component is reduced to 2.5 per cent; since the speech modulation is still 25 per cent, the desired signal-to-noise ratio at the receiver output has been increased to 10 from the former ratio of .5, a gain of 20 times.

There is of course thermal-agitation in the grid circuit of each tube, but practically the effect may be neglected in all but the first tube, because when the signal reaches the later tubes it has been amplified and is many times greater than the noise voltage developed at those tubes. Thus it will be seen that from the view points of both selectivity and high gain, the tuned grid circuit of the first r-f tube is a very important circuit. Careful design of this circuit can contribute greatly to the overall usefulness of a receiver.

Since both the selectivity and voltage gain of the tuned grid circuit are factors of the circuit Q , it is apparent that every effort must be made to keep Q high. Assuming that a well-designed capacitor is used, the reduction in circuit resistance is accomplished primarily by low-loss design of the coil. Factors in coil design involve the shape and dimensions of the winding, the size of wire, and the type of core (iron or air). A well-designed iron core coil can be made to have considerably lower r-f resistance than one having an air core, as explained in a later assignment.

An equally important, but often neglected factor in the effective Q of the grid circuit is the manner in which the tube itself is operated. Normally the grid of the r-f ampli-

fier should be operated slightly negative (usually about 1 to 3 volts) with respect to the cathode. Under such condition the grid-cathode resistance, which is connected directly across the tuning condenser, is in the order of megohms and hence has negligible effect of the effective circuit resistance and Q . However, if the grid is not biased negatively and is permitted to swing positive with strong signals, grid current flows and the grid-cathode resistance may drop to a quite low value. This low value of shunt resistance across C_1 is the equivalent of series resistance inserted in the tuned circuit, with the consequent reduction of Q . This decreases both the selectivity and resonant voltage gain of the grid circuit and may seriously affect its usefulness. The small negative grid bias is usually obtained by a cathode resistor but a bias cell or a fixed bias from the power supply may be employed.

Circuit 3. This circuit as shown in Fig. 2 allows a more con-

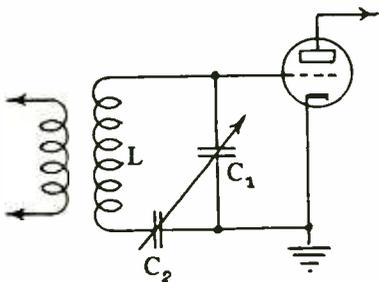


Fig. 2.—Tuned r-f circuit.

stant voltage to be applied to the grid of the tube over the frequency band to which the circuit tunes. Consider first the circuit of Fig. 1(a). Assume that varying C_1 over

its extreme range causes a circuit capacity variation of from 50 to 450 $\mu\mu\text{F}$. This is a capacity change of 9 : 1. Since

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

with fixed L the frequency varies inversely as \sqrt{C} . Thus capacity variation of 9 : 1 results in a frequency variation of 3 : 1. If the low frequency to which the circuit will tune is 550 KC/s, the high frequency will be 1650 KC/s. $X_c = 1/2\pi fC$; at 1650 KC/s with C decreased to 1/9th the 550 KC/s value and f only 3 times as great, X_c is three times as great at 1650 KC/s. If the current in the circuit is substantially constant over the frequency range, the voltage between grid and filament varies 300 per cent as the circuit is tuned from one end of the band to the other. If this circuit happens to be used as the tuned grid circuit of an oscillator, as in a superheterodyne receiver, the oscillator output will not be even approximately constant over the tuning range.

This may be corrected considerably by the use of a circuit as shown in Fig. 2. Assume that the circuit is to have a tuning frequency range of 3 : 1. C_1 is a large variable capacitor whose capacity varies between 500 and 1500 $\mu\mu\text{F}$. C_2 is a smaller capacitor with a capacity range such that the total series capacity of the circuit is 50 to 450 $\mu\mu\text{F}$. Since the smaller capacity exercises the predominating effect in the total capacity of a series circuit, C_1 has little effect on the circuit tuning; the frequency range is 3 : 1. However, the voltage applied to the tube between grid and filament is the voltage across

C_1 . As compared with the circuit conditions at 550 KC/s, at 1650 KC/s the capacity of C_1 is one-third as great and the frequency is three times as great, so that X_c is the same at both ends of the frequency range. If substantially constant circuit current may be assumed, the voltage applied between grid and filament will be quite uniform over the tuning range of the circuit. Thus E_{c_1} becomes a direct function of the resonant circuit current which can, by proper design of plate-grid coupling in an oscillator, be held quite uniform over the desired tuning range.

With inductive coupling, the effective coupling increases with frequency as does the circuit resistance so that the change in one tends to counteract the change in the other. By careful design in which the above principles are applied, an oscillator can be made to have quite constant output voltage over its tuning range. This type of circuit is frequently used in heterodyne frequency meters. Its disadvantages are the cost and dimensions of a high capacity variable condenser and the gang tuning arrangement. This generally limits its use to higher priced precision apparatus.

Circuit 4. It is often necessary to bypass a single frequency from a radio frequency circuit. An example of this is shown in the circuit of Fig. 3. This circuit consists of the final power amplifier tank circuit of a transmitter which delivers power to a transmission line as shown. The transmission line is coupled to the tank circuit by means of the r-f voltage drop across the capacity combination C_1 . In modern transmitters, broadcast

and others, the r-f amplifiers, in order to obtain efficient operation are operated either Class B or Class C, that is, biased to or beyond cut-off. This results in the introduction of harmonic frequencies in the plate current which are not present in the grid excitation voltage. As will be shown, the greater proportion of the harmonic frequency components can be quite effectively suppressed by proper tank circuit design. However, in the case of a high power transmitter, a harmonic component of the power output which is small in proportion to the fundamental may still contain enough energy, that radiated from the antenna, may cause r-f interference over considerable distances. In such event it becomes necessary to employ special harmonic suppression circuits or filters.

Two harmonic filters are shown in Fig. 3, one between each transmission line wire and ground. The principle of operation is quite simple. Consider the case of a transmitter operating on 1150 KC/s with a troublesome second harmonic which must be suppressed. The frequency of the second harmonic is 2300 KC/s. With the two filters disconnected the transmitter and radiating system are adjusted to proper operation at 1150 KC/s. Each of the two filters is then carefully adjusted to resonate at 2300 KC/s. Being resonant series circuits at 2300 KC/s, the frequency of the troublesome second harmonic, the only opposition between the transmission line wires and ground at that frequency will be the actual resistance of the filter circuits which, by the use of low-loss capacitors and coils, can be made very small. Thus the second harmonic

component of transmitter output is short-circuited to ground. At the same time, since the filters are not

channel. In such a situation it may be extremely difficult to adequately clean up the broadcast station out-

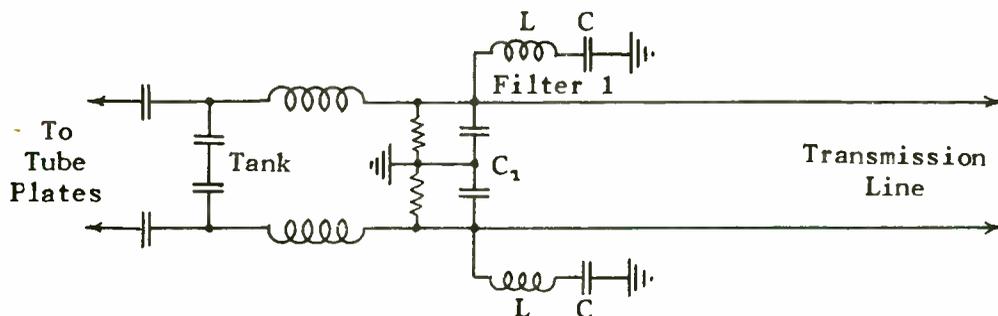


Fig. 3.—Transmission line harmonic filters.

resonant at the fundamental frequency of 1150 KC/s, very little loss is introduced at this frequency because of the high filter reactance. To obtain efficient harmonic suppression, it is essential that the effective resistance of the filter circuits be kept to a minimum and that they be very carefully adjusted.

Of course should the third harmonic predominate and be the most troublesome, the filters should be tuned to the third harmonic frequency. In some cases it will be found that, due to special circumstances, several harmonic frequencies—particularly higher order harmonics are troublesome. Such a situation might be where a broadcast station is located within a few miles of a military receiving center where many receivers operate over wide frequency bands. One or more of the broadcast station harmonics may fall within an important high frequency

put and a number of filters at different locations in the circuit tuned to the troublesome frequencies may be required.

A similar series circuit has been used to eliminate interference from a high power nearby transmitter in a system in which a number of receivers operate from a single antenna. The fundamentals of such a system are shown in Fig. 4. R is a large value of resistance, sufficiently large to make the antenna completely aperiodic. (Probably in the order of 50,000 to 100,000 ohms. An antenna, or any circuit, is said to be "aperiodic" when it is so damped by resistance that it has no resonant effect or natural period. Thus an antenna, though possessing L and C , can be made aperiodic by inserting enough resistance to make negligible the effects of L and C .) With the antenna untuned, signal currents of all frequencies will flow in R and the individual re-

receivers will select the desired frequencies from the voltage drops across R. In order to prevent

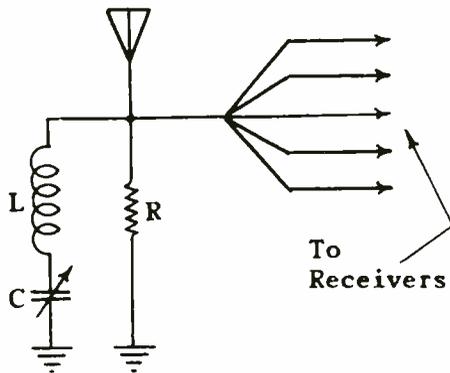


Fig. 4.—Series filter for a receiver input.

reaction between receivers, each receiver should be coupled to R through a vacuum tube coupling circuit. This may consist simply of a screengrid tube excited from the antenna and feeding into an untuned or very broadly tuned plate circuit.

To minimize the effect of the signal voltage from the nearby interfering transmitter, the tuned series circuit LC is connected between the high potential side of R and ground, and carefully tuned to the frequency of the interference. This provides practically a short-circuit to ground at that frequency, the effectiveness of the circuit being an inverse function of the resistance of the circuit. Since the filter is not perfect, the signal at the interference frequency should still be adequate if it is desired to pick up the nearby station on one of the receivers. The engineer probably will find a number

of similar cases where the series filter can be used to advantage to eliminate some single frequency.

In the design of a series resonant circuit for a particular purpose, two primary points must be kept in mind: First, the selectivity of the circuit is mostly a function of the L/C ratio. That is, unless the coil is of poor design so that its resistance is excessive, maximum selectivity will be obtained by the use of large L and small C. Second, how low is it necessary to make the impedance at resonance? For example, in Circuits 3 and 4 where it is desired to drain off a single frequency, the greatest selectivity will be obtained by the use of large L and correspondingly small C. This brings up the question, however, as to how great the selectivity need be.

In the case of the harmonic suppressor of Fig. 3, the frequency to be drained off is 2300 KC/s and the frequency to be passed along the transmission line is 1150 KC/s, a large difference in frequency. In that case a high degree of selectivity is of secondary importance as compared with low resistance at resonance. Everything else being equal, a coil of fewer turns will have less resistance than one having a greater number of similar turns. Thus for this purpose a quite low L/C ratio should give better harmonic suppression.

One important limitation, however, must be observed: *the values of reactance, X_L and X_C , must not be reduced to the point where the reactance at the fundamental frequency is too low.* The reactance of the harmonic filter at the fundamental frequency ($X_C - X_L$) must not be less than 10 times the characteristic

(surge) impedance of the line across which the filter is connected. For example, if the impedance of the transmission line is 600 ohms, the fundamental frequency 1150 KC/s, and the filter is to resonate at the second harmonic, 2300 KC/s, $X_C - X_L$ at 1150 KC/s must not be less than 6000 ohms. If a 70 ohm line is used with the same frequencies specified $X_C - X_L$ at 1150 KC/s should not be less than 700 ohms. Thus the harmonic filter must be designed with the line impedance as a very important factor; its L and C values must be a compromise between maximum harmonic attenuation and minimum attenuation at the fundamental frequency the line is required to pass.

In the circuit of Fig. 4 conditions are quite different. In this case it is presumed that the maximum receiver effectiveness is desired at all frequencies, the only object in using the filter being to make it possible to operate the receivers as closely as possible to the interfering frequency. The degree of suppression of the interfering signal when the receiver is tuned directly to that frequency is immaterial as that can be taken care of by the receiver gain control. The important feature desired in this filter is a high degree of selectivity. (It is assumed of course that good low-loss construction is to be employed). Thus in this circuit the best results should be obtained by the use of a comparatively large low-loss inductance and a small variable capacitor.

From the above, it will be seen that although the principle of operation is identical in the circuits of Figs. 3 and 4, the conditions under which the circuits operate are quite different and call

for entirely different design. Such differences of circuit operating conditions are found throughout the field of radio and it is therefore impossible to state definite rules which will apply in all cases. When a circuit is to be designed for a particular purpose, the design engineer must give full consideration to each factor involved.

Circuit 5. This circuit, as shown in Fig. 5, is also designed to suppress a single frequency but in a different manner than in Circuit 4. In this case it is desired that all frequencies except the one to which circuit IC is tuned pass freely along the antenna circuit and through the antenna coil of the receiver. Circuit IC is carefully tuned to resonance at the interfering frequency, and, being a parallel circuit, offers maximum opposition at that frequency.

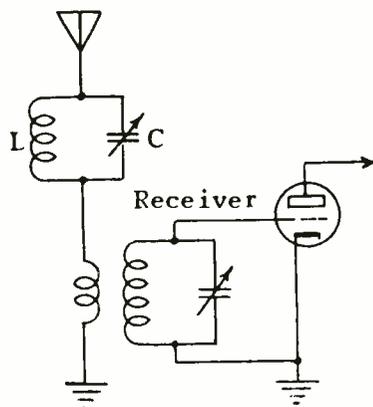


Fig. 5.—Parallel rejector filter for a receiver input.

Since it is desired to suppress a single frequency and pass all other frequencies a highly selective circuit is desired. This may be ob-

tained by using a high Q circuit, or in other words, a small inductance with as small a resistance as is practical.

Thus for best results "L" should be small, "C" large, and "R" small. The steeper the slope of the total reactance curve at the resonant frequency the sharper will be the resonant curve and therefore the more selective will be the circuit. This is shown from the formula

$$f_2 - f_1 = \frac{R}{2\pi L}$$

Where:

f_2 is the frequency above resonance where $X = R$ and the power dissipated is equal to one half the power at resonance.

f_1 is the frequency below resonance where $X = R$ and the power dissipated is equal to one half the power at resonance.

It can be seen from this formula that the smaller the difference is between f_2 and f_1 (called half power points), the sharper will be the resonant curve and therefore the larger will be the Q of the circuit.

$$\frac{f_2 - f_1}{f_0} = \frac{R}{2\pi f_0 L} = \frac{1}{Q} \text{ so therefore}$$

the larger Q is made the smaller will be the change in frequencies.

It occasionally becomes necessary to eliminate interference from two nearby transmitters. This may be done in a simple manner as shown in Fig. 6. Two parallel trap or rejector circuits are used, LC and L_1C_1 , each tuned to one of the interfering frequencies. With such an arrangement, it is particularly important that the parallel selecti-

ivity be adequate in order that signals are not lost from the receiver too far on each side of the interfering frequencies. It is also important that the parallel circuits be of low loss design in order that the losses introduced into the antenna circuit may be as small as possible. This is less important if the antenna circuit is untuned because the normal impedance of an untuned antenna is high and a small resistance increase may be negligible. However, if the antenna circuit is operated at series resonance as in Fig. 1(a), a small increase in r-f resistance may

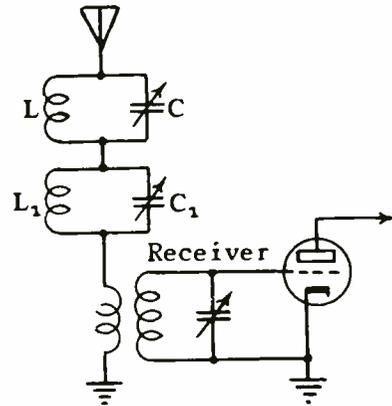


Fig. 6.—Double rejector circuit.

result in a substantial decrease in the antenna signal current and hence in the signal voltage at the grid of the r-f amplifier.

It should be remarked at this point that shielding of individual circuits or at least shielding of the coils, is desirable in all circuits discussed in this assignment, in order to minimize coupling between coils which tends to decrease the effect of filters, and introduce

undesirable reaction between tuned circuits .

Circuit 6. This is the parallel "tank" circuit used to furnish load impedance for a transmitting amplifier tube. There are several important factors to be considered in the design of such a circuit. Some of these factors will only be mentioned briefly at this point, the detailed discussion and mathematical calculations being considered in a later assignment. The circuit is as shown in Fig. 7.

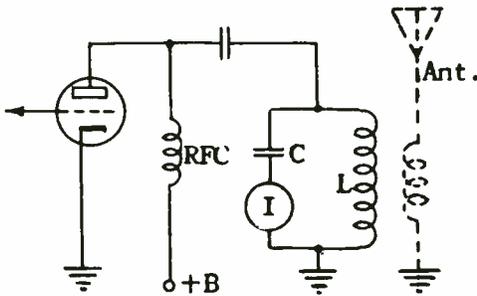


Fig. 7.—Typical "tank" circuit for a transmitter output stage.

This circuit performs several functions: First, it is adjusted as a parallel resonant circuit consisting of L , C and R until its impedance, which is approximately equal to L/CR , matches the impedance of the tube so that the tube will deliver maximum power output. In that connection, the most important component of the effective circuit resistance is that resistance which is reflected into the tank circuit from the antenna. Since the antenna is actually the load in which the

tube output power is to be expected, the circuit design and adjustment are only correct when the tube is operating into the proper load impedance *at the time the antenna coupling is correct*. A reference to the earlier assignment on coupled circuits will make clear how varying the coupling between the tank and the antenna inductance effectively varies the tank circuit resistance, this in turn varying the effective L/CR impedance into which the tube operates. Since the tube delivers maximum power output into an impedance which matches R_p , the internal plate-filament impedance of the tube, proper tank circuit design and proper coupling to the antenna are both essential.

The second function of the tank circuit is to minimize the harmonic component in the amplifier output. Assume that the amplifier is to be operated Class B, that is biased to just about plate current cut-off. The grid excitation then causes pulses of plate current to occur on every other alternation, no plate current flowing during the negative grid excitation alternation. (This is shown in Fig. 8.) The plate current flowing through the tube and load impedance builds up an effective a-c component of voltage across the tank circuit LC . Also, due to the intermittent nature of the plate current pulses and the curvature of the lower extreme of the $E_g I_p$ curve, the plate current contains very large harmonic distortion components. In fact, in such a circuit the amplitude of the second harmonic component in the plate current may be as great as 70 per cent of the fundamental. An output containing such r-f harmonic distortion could not be coupled directly to an anten-

na because the radiation of harmonic energy would be excessive.

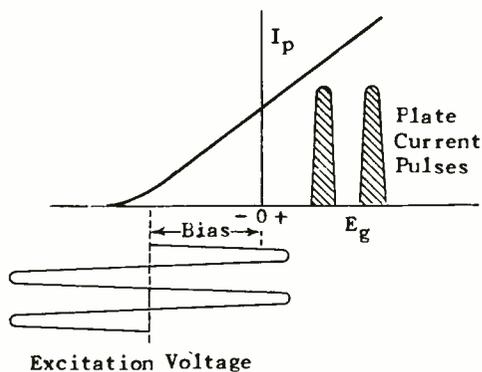


Fig. 8.—Class B operation.

Consider some simple figures. Assume that the effective a-c component of plate current flowing through the tube and through the parallel tank impedance L/CR is 1 ampere. Assume that the effective parallel tank impedance is 3000 ohms. Then the effective a-c voltage built up across the tank circuit LC will be $IZ = 1 \times 3000 = 3000$ volts. Since the tank circuit LC is tuned to resonance, $X_L = X_C$. Assume X_L and X_C each equals 150 ohms. The voltage across the parallel combination is 3000 volts; the current in each branch, L and C , is $E/X = 3000/150 = 20$ amperes. Thus there will be an effective a-c component of current of 1 ampere in the external circuit and 20 amperes flowing in the tank circuit. This is in accordance with the principles previously studied for parallel resonance.

An interesting relation between the adjustment of the load resistance and the average plate current and power output, as indicated by the d-c plate ammeter, can be shown at this point. Consider the case of a simple Class B amplifier shown in Fig. 8 and assume for simplicity that the d-c component of plate current flows through the inductance of the tank circuit. With no excitation the plate current as indicated by the d-c meter will be very small because of the near-cut-off negative grid bias voltage. When excitation voltage is applied to the grid, plate current pulses normally will occur as shown in Fig. 8. Several load conditions can occur, as determined by the design and adjustment of the load circuit. The load circuit consists of the parallel tuned plate tank circuit and any circuit coupled to it, usually an antenna.

First, if the tank circuit is tuned far from resonance, either X_L or X_C will be so small compared with the tube R_p that for all practical purposes it will form zero load impedance. The plate current will be large, all the power developed by $E I_p$ will be dissipated at the plate of the tube, and if the excitation voltage amplitude is large the plate will heat excessively.

Second, assume that the tank LC circuit is *tuned exactly to resonance* and that the *circuit resistance is zero*. (An impossible condition of course but one which can be approached by extreme circuit design). As shown in an earlier assignment, this would result in infinite tank circuit load impedance Z_L and zero a-c component of plate current. The plate current indica-

tion by the d-c ammeter would be very small.

Third, assume that to the circuit of condition 2, an antenna circuit or some other power dissipating circuit is coupled inductively. This will cause resistance to be reflected into the tuned tank circuit; L/CR will assume some practical value and the plate current, as indicated by the d-c ammeter will increase. The plate current will be a function of the load resistance as will the ratio of the power dissipation between the plate and the load circuit. As the coupling between the dissipative circuit (antenna) and the low-loss tank circuit is increased, the resistance reflected into the tank circuit is increased, $Z_L = L/CR$ is decreased, the resonant plate current increases, and the power output from the tube increases.

As the coupling is further increased, the trends as described above continue until the coupling is such that the reflected R causes the tank $Z_L = L/CR$ to equal the plate resistance of the tube, at which point maximum power output is delivered by the tube for the available grid excitation which is assumed to be constant for all operating conditions described. It should be understood that while the plate current has been increased by the increase of load resistance due to tighter coupling, the plate current at tank circuit resonance is still considerably less than the off-resonance plate current because the parallel load impedance Z_L is considerably greater than the reactance offered by the detuned off-resonance circuit. In all of the variations of coupling described above, it is necessary to retune the tank circuit

to resonance each time the coupling is changed because varying the mutual inductance between the two circuits changes the effective inductance of both.

The final condition is approached as the coupling between the dissipative load and the tank circuit is tightened beyond the point where $Z_L = R_p$. Z_L now becomes less than R_p , the plate current increases and the difference between the tuned and untuned plate current decreases, the power output from the tube decreases, the operating efficiency decreases, the power dissipated at the tube plate increases and the plate tends to heat.

Fig. 9 illustrates the type of tuned tank circuit and coupling to the transmission line used in one type of 75 MC/s v.h.f. airways beacon transmitter. The tank circuit consists of $L_1 C_1 C_2$ and the coupling unit which feeds the transmission line to the antenna is $L_2 C_4 C_5$. Plate voltage is fed to the tube at the center of L_1 through the filter consisting of choke r.f.c. and C_3 .

Fig. 10 shows the details of L_1 and L_2 . L_1 is made of .25 inch copper tubing slightly over a foot long and mounted horizontally. L_2 is similar in construction and dimensions but is hinged so that it can be varied in relation to L_1 as shown to vary the loading of the power amplifier. In position 1, L_2 is 90° from L_1 and the coupling between the two is practically zero. In positions 2 and 3 the coupling is progressively increased and a d-c plate current ammeter connected below the r-f choke (Fig. 9) would indicate increased plate current as the angle to L_1 is decreased. This is an extremely simple but highly practical arrangement. The angle

of L_p is varied until the plate current at resonance indicates that the tube is properly loaded. The

amplifiers are designed to operate either Class B or Class C, so far as the bias and excitation voltages

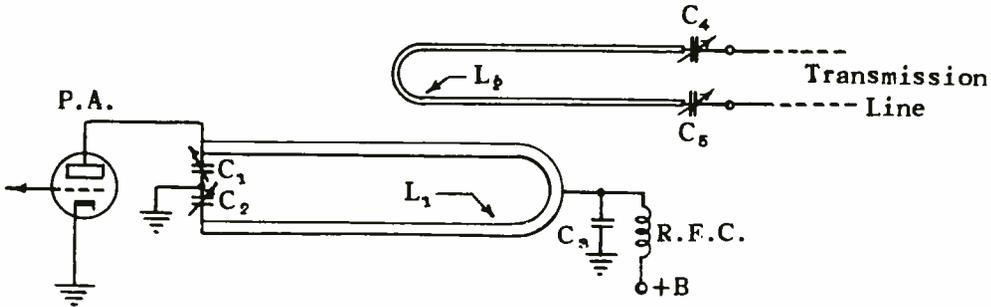


Fig. 9.—A tuned tank circuit for u. h. f. operation.

tank circuit is retuned by means of $C_1 C_2$ for minimum plate current each time the coupling is changed.

Another ratio which is very important in tank circuit design is the KVA/KW ratio. KVA is "kilovolt amperes" and KW is "kilowatts".

The tank circuit is operated at parallel resonance. This is necessary in order to obtain the necessary load impedance at zero phase angle into which the tube must operate, without the use of dissipative resistance of the same magnitude. In other words, if it is desired to operate the tube into a zero phase angle impedance of 3000 ohms, this can be accomplished with a low-loss parallel tuned LC circuit to which is coupled the desired comparatively low resistance load, usually an antenna.

A second, and most important, reason for using the resonant parallel tank circuit is for the suppression of harmonics. Modern r-f power

are concerned. This means that the a-c component of plate current is composed of the fundamental fre-

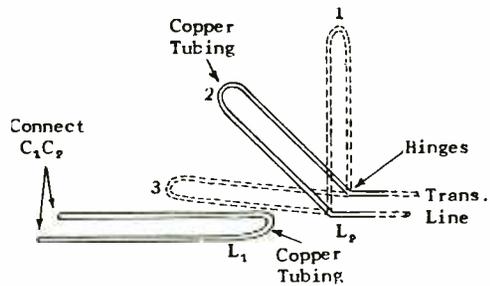


Fig. 10.—Method of varying coupling.

frequency and large amplitude harmonic components. It is essential that these harmonic components be suppressed before transfer of power to the antenna.

This is done by selecting, by means of a circuit resonant only to the fundamental frequency, the

fundamental component from the composite. The r-f voltage at the tube plate is developed only if an appropriate impedance is connected into the circuit at the point between plate and ground. The current then flowing in the tank circuit—which represents to the tube the load impedance—is a function of the plate r-f voltage and the reactance (X_L and X_C) of the L and C branches. Since the circuit is operated at resonance $X_L = X_C$ and $I_L = I_C$.

Assume that at the resonant frequency the loading of the tank circuit is such that with normal grid excitation the r.m.s. plate voltage is 5000 volts developed across Z_L . Assume that at this frequency X_L and X_C each equals 250 ohms, that $Z_L = 3000$ ohms, and that the power output of the fundamental frequency component is 5 KW. At this frequency the tank current r-f ammeter will indicate E/X_L (or E/X_C) = $5000/250 = 20$ amperes. Thus the apparent power expressed in volt-amperes in $EI = 5000 \times 20 = 100,000$ VA = 100 KVA (kilovolt-amperes). It has been stated above, however, that the actual power output at this frequency is only 5 KW.

Thus there is a great difference between the apparent power (expressed in kilovolt-amperes) and the real power (expressed in kilowatts). From the basic theory of parallel circuit operation in which a theoretically zero-loss circuit may be assumed, it will be seen that the apparent power can be very large in a resonant LC circuit where X_L and X_C are made small, while at the same time the real power, if zero losses could be assumed, could be zero.

The relation between the apparent power and the real power can

be expressed as a ratio, KVA/KW. Under the conditions assumed above $KVA/KW = 100/5 = 20$.

It will be seen that this ratio is made large by making the parallel reactive values, X_L and X_C , small while reducing the reflected resistance in the L branch to make the load impedance Z_L have the desired value. Thus a large KVA/KW ratio is attained by the use of small L and correspondingly large C.

As X_L and X_C are decreased, the off-resonance impedance of the circuit is decreased and the parallel selectivity increases. With X_L and X_C very small compared with the impedance at resonance, the impedance offered by the load circuit at the harmonic frequencies is very small. It will be shown in later assignments that as the load impedance in the plate circuit of a vacuum tube is decreased below $Z_L = R_p$, the power output of the tube falls off very rapidly. Where the impedance is made very small compared with R_p , as explained above, the power output will be correspondingly very small. Thus while the harmonic components of plate current may be quite large in relation to the fundamental component, the load circuit is so ineffective at the harmonic frequencies that the harmonic components of tank current can be made extremely small compared with the fundamental, and the larger the KVA/KW ratio is made, the greater will be the harmonic suppression, and of course the less the harmonic energy that enters the antenna circuit.

It would seem that for purposes of r-f harmonic suppression the KVA/KW ratio should be made as large as possible, and in fact for c.w. transmission this ratio can be made

quite large. When the transmitter is to be modulated, however, the circuit selectivity must be taken into consideration. It is desired that the tube operating characteristics be uniform over the frequency range of the carrier + and - the sideband frequencies. If the transmitter is to be modulated over a range of frequencies of 0 to 10,000 cycles/second as in broadcast transmitters, the frequency range of uniform operation must be 20 KC/s, or 10 KC/s on each side of the carrier. The KVA/KW ratio must not be so great that the tank circuit discriminates against any frequencies within this range. On the other hand, if the modulation frequencies are restricted to 0 to 3000 cycles/second as in many radio telephone transmitters, the band to be passed extends only 3000 cycles to each side of the carrier and increased tank circuit selectivity—increased KVA/KW ratio—may be used. Also the KVA/KW ratio, for a given range of modulation frequencies, can be made greater as the carrier frequency is increased, because at the higher carrier frequency the modulation frequency is a smaller percentage of the carrier and a greater degree of selectivity becomes permissible.

A practical analysis of all of these factors will be undertaken in a later assignment which is devoted entirely to the design of tank circuits and their coupling to the antenna. At that time the practical limits of the various factors and calculations for the actual degree of harmonic suppression will be discussed.

Fig. 11 shows a parallel tank circuit in which the principle of operation is the same as in Fig. 7

except that in Fig. 11 two tubes are operated in push-pull. The actual

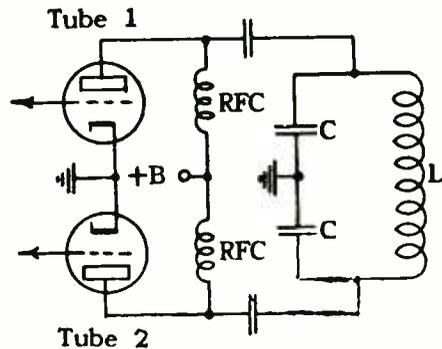


Fig. 11.—A parallel tank circuit.

calculations for this circuit are made exactly as for the single tube circuit except that only one-half the total power output is used and only one-half the circuit is used in the calculation. Thus for the total circuit, L is twice as great as in the single tube circuit, and each value of C is equal to the C for a single tube circuit, so that since the two capacities are in series the total capacity is $C/2$. With L doubled and C reduced by one-half, the resonant frequency of the tank circuit as calculated will be the same for the single tube circuit and the push-pull circuit. The KVA/KW ratios will be the same in both cases.

Circuit 7. The band pass filter: This circuit, as shown in several of its forms in Figs. 12, 13, and 14, is used extensively as interstage coupling in intermediate frequency amplifiers, particularly in broadcast and television receivers. One of the difficult prob-

lems in receiver design is to make the receiver sufficiently selective to eliminate strong local signals when tuning to a distant station on an adjacent channel, while at the same time keeping the frequency range of equal voltage gain sufficiently wide to accommodate a carrier and the upper and lower side-band frequencies.

In an earlier assignment on coupled circuits it was shown that when two resonant circuits, tuned to the same frequency, are coupled together, there is a tendency for the circuit current, and consequently the voltage across the output terminals, to take the form of double peaks as the frequency is varied through resonance from a lower to a higher frequency or vice versa. One peak will be below, the other above, the common resonant frequency. The frequency separation between peaks will be a function of the degree of coupling, the tighter the coupling the more widely separated the peaks. This is shown in Fig. 15, (a), (b) and (c).

The curve of Fig. 15(a) is the result of very weak coupling, that is, small mutual inductance M . Fig. 15(b) represents a quite good frequency response curve—essentially flat on top so that the voltage gain will be uniform over the desired band width, and sharp cut-off on each side of the band to be passed. Fig. 15(c) is the result of excessive coupling. The band passed is wide and the cut-off on each side is sharp, but there is a pronounced dip at the resonant frequency which would decrease the response of the low frequency side-bands.

The circuits of Figs. 12, 13 and 14 are identical in operation and all are used to a considerable

extent. In Fig. 12 M is varied by varying the physical relation be-

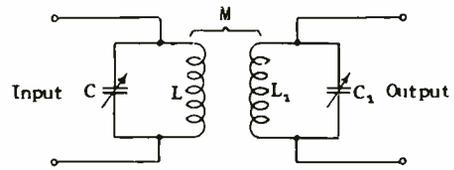


Fig. 12.

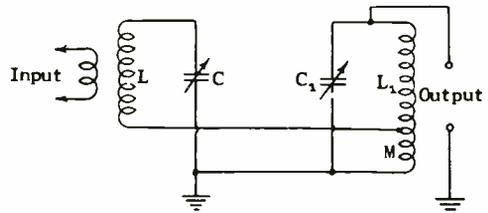


Fig. 13.

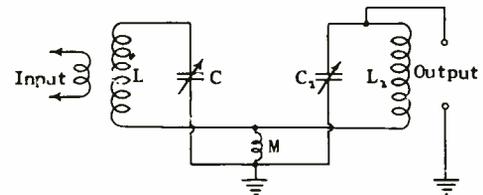


Fig. 14.

Several circuit variations for band-pass coupling.

tween the two coils, usually by moving one closer to or farther from the other. With this arrangement both coils will be mounted within the same shield can and the coupling varied by means of a screw adjustment from outside the shield.

In Fig. 13 the two coils are individually shielded or placed at right angles within a common shield and a small amount of inductance M in one coil is made common to both tuned circuits. This circuit does not lend itself readily to variable coupling.

In Fig. 14 the two coils L and

L_1 are identical and are separately shielded or mounted at right angles for minimum coupling. The small Coil M is common to both circuits and is separately shielded from both of the main coils. This circuit lends itself very readily to variable

between each pair of i-f amplifier tubes) and since each contributes to the selectivity of the receiver, each will be adjusted to pass a somewhat wider band than is desired and the combination will bring the overall response to the required

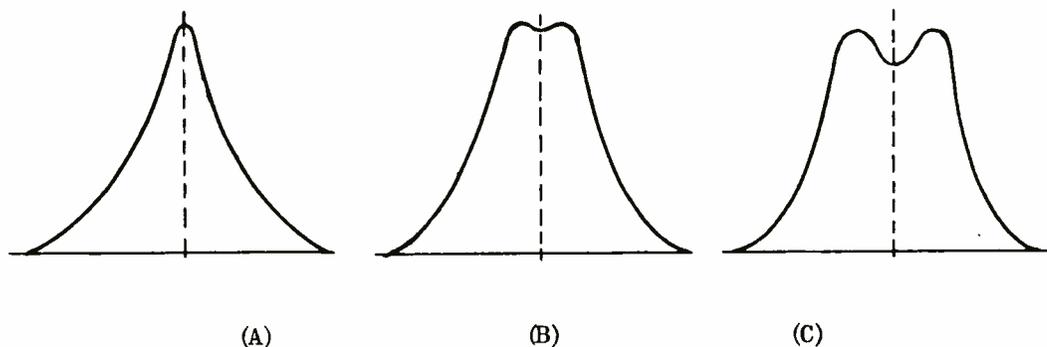


Fig. 15.—Selectivity curves for various amounts of coupling.

coupling. M may be in the form of a small variometer with an external screw adjustment; or it may take more modern form of an iron core coil with a movable iron core which allows the inductance of M to be varied by changing the effective permeability of the core. The larger M is made, the tighter the coupling between the two circuits and of course the broader the frequency response curve.

The circuits of Figs. 12 and 14 are used extensively to couple the intermediate frequency amplifier stages of superheterodyne receivers. Many modern high-quality receivers are designed for variable band width so that the band of frequencies passed can be widened for high fidelity reception or narrowed to permit reception through bad interference. Since several band pass circuits ordinarily will be used in a multistage i-f amplifier (such a circuit will be used as coupling

width and shape as indicated by measurement with an oscilloscope and a signal generator. As a rule in such an array of amplifiers and filter circuits, only one will be arranged for manual adjustment by the operator, M in the others being fixed. The calculations for the required amount of M are taken up elsewhere. By proper adjustment of each circuit, the overall response curve can be made to have almost any desired form.

Occasionally a very selective band pass r-f circuit is required ahead of the first tube to eliminate cross-talk interference from nearby transmitters. A double band pass filter as shown in Fig. 16 may be used. IC into which the antenna is coupled forms the first tuned circuit which is inductively coupled to L_1C_1 which in turn is coupled by means of M to L_2C_2 which in turn is coupled to L_3C_3 . This circuit is not so complex as it may seem. By

properly proportioning the four coils and providing proper trimmer

rier frequency employed 25.75 MC/s); second, because of the wide fre-

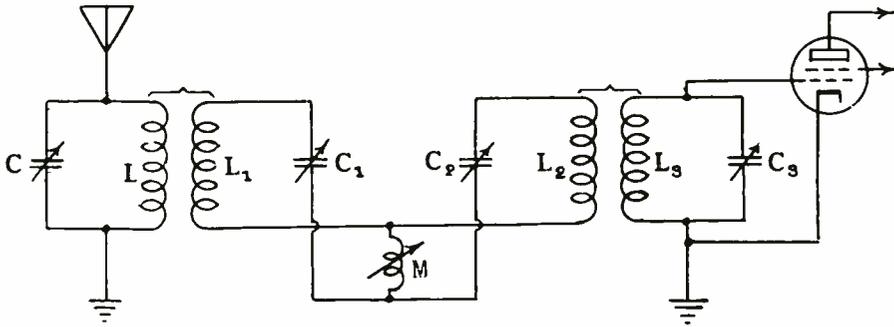


Fig. 16.—A double band-pass filter.

capacitors for C , C_1 , C_2 , and C_3 , the circuit may be tuned by a single dial. M is made adjustable so that the total selectivity of the circuit may be adjusted within limits, the coupling between L_1 and L_2 , also having equal effect on the selectivity. By proper design such a preselector circuit can be made to have excellent frequency response characteristics and to reduce cross-talk to a very low level even from strong local transmitters.

While not shown in any of the above circuits, capacity coupling may be used in place of inductive coupling in the band pass circuit. However, inductive coupling is much more extensively used for that purpose in radio receivers.

Fig. 17 illustrates a type of band pass filter frequently used as interstage coupling in the picture channel intermediate frequency amplifier of a television receiver. Fig. 18 represents the "equivalent circuit" of Fig. 17.

This circuit has several interesting features, first because of the high video intermediate car-

rier frequency which must be passed (approximately 6 MC/s for a good picture); third, because of the necessity for suppressing sound intermediate carrier frequency of

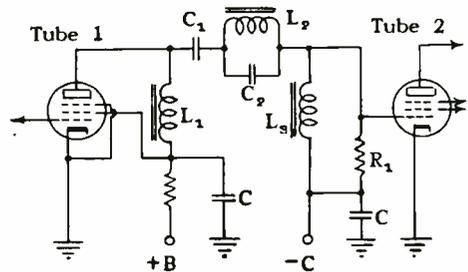


Fig. 17.—An i-f television band-pass filter.

the adjacent channel which is 1.5 MC/s above the desired picture intermediate carrier frequency, or 27.25 MC/s.

The overall response curve of a typical multistage television i-f picture amplifier is shown in Fig. 19. First, note that the band of practically uniform gain is very wide (approximately 3 MC/s) in

proportion to the center frequency; this indicates that the coupling

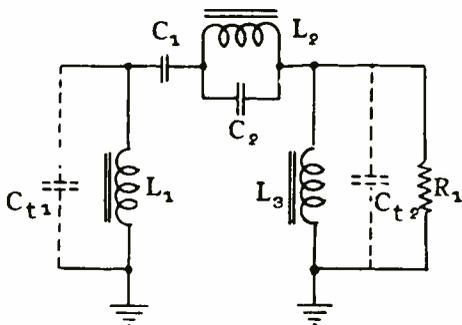


Fig. 18.—Equivalent circuit of Fig. 17.

between stages is quite tight. Second, note that the resonant frequency of the filter is *not* at the picture carrier frequency; the latter is placed on the higher frequency *slope* of the curve to permit the use of single sideband transmission and reception. Third, note that the sound carrier of the *adjacent* television channel is only 1.5 MC/s removed from the desired picture carrier as compared with 4.5 MC/s separation of the accompanying sound channel, so that in localities where several television stations are operating the *adjacent* channel sound interference is the one requiring maximum suppression.

Consider Fig. 17 and the equivalent circuit of Fig. 18, Neglecting L_2C_2 temporarily, consider the two circuits of Fig. 18, L_1C_{t1} and L_3C_{t2} coupled quite tightly by C_1 . R_1 is, in a typical case, a 2200 ohm load resistor to provide a filter output load equal to the characteristic impedance of the filter. L_1 and L_3 are small permeability tuned coils by means of which the tuned circuits are resonated at approximately 24 MC/s as

indicated in Fig. 19. Because of the high resonant frequency the fixed capacities C_{t1} and C_{t2} , appearing in Fig. 18, can be quite small. Actually, as shown in Fig. 17, C_{t1} is the plate-cathode capacity of Tube 1 and C_{t2} is the grid-cathode capacity of Tube 2. The capacities designated by C in Fig. 17 are simply bypass capacitors to permit series feed of the plate and bias voltages.

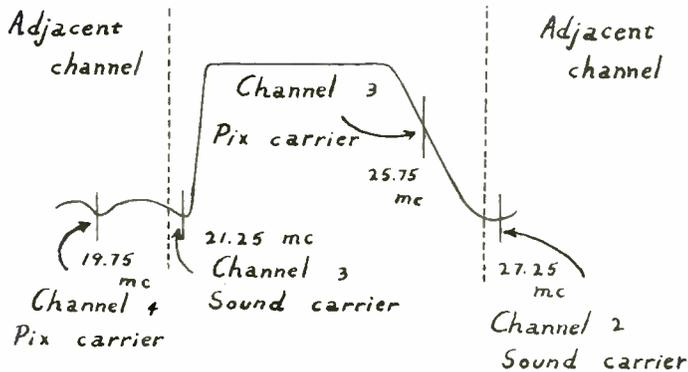
The parallel circuit L_2C_2 is a rejector circuit tuned to the frequency of the adjacent sound carrier. As such it accentuates the sharp cut-off characteristic desired at upper frequency side of the picture band and assists in the rejection of the adjacent channel sound carrier which would cause interference in the picture if its audio modulation components got into the second detector and video amplifier.

In practice usually two or more amplifier stages employing band pass coupled circuits similar in principle to that shown in Fig. 17 are used in conjunction with a stage coupled by means of a simple tuned circuit which is broadly peaked to fill in the "dip" in the response curve caused by the excessive coupling of the band pass filters. [See Fig. 15(c)]. The entire combination of amplifier coupling circuits and reject circuits is tuned (usually by permeability tuned coils and fixed capacitors), using a cathode ray oscilloscope and signal generator, until the overall response curve has the desired shape over the required frequency band. The curve of Fig. 19 represents the overall response of such an amplifier.

A more complete treatment of picture i-f amplifiers, their design

adjustment, and reasons for the type of response curve shown, will be

a given value. In radio apparatus such circuits ordinarily are used



Intermediate Frequency in MC/s

Fig. 19.—Response curve of a typical television i-f picture amplifier.

given in the assignments on television receivers. At this point it is desired only to point out one of the many examples of the uses for the simple resonant circuit in the more complex combinations. Very often circuits designed to perform special functions appear quite complex and usually the complete mathematical expression for such a circuit is complex. As a rule, however, by careful thought the complex circuit can be broken down into its simple series and parallel components and its functions traced without too much difficulty, as is done above.

Circuit 8. The low pass filter. This circuit is used wherever it is desired to pass direct current or low frequency current, but to block all frequency components above

at audio and power frequencies. For example, assume that an audio oscillator is designed to deliver a test voltage at a frequency of 400 cycles/second and that it is desired to have the voltage at the output terminals quite free of harmonic frequencies, 800, 1200, 1600, 2000, etc., cycles/second. This can be done by passing the 400 cycle output through a low pass filter designed to have a cut-off at around 600 cycles per second. Such a filter properly designed will pass the 400 cycle voltage with little attenuation but will attenuate all frequencies higher than 600 cycles, in this case the harmonic components. The degree of high frequency suppression can be made almost any desired amount by the use of an

adequate number of filter sections. Two arrangements of the low pass filter are shown in Figs. 20 and 21. In Fig. 20 the circuit consists simply of an inductance in series

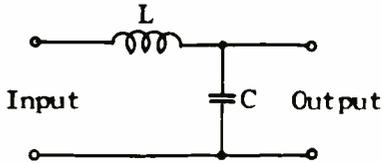


Fig. 20.—An "L" type filter.

with the line and a capacity across the line in an L arrangement. The circuit of Fig. 21 contains the same elements but the inductance

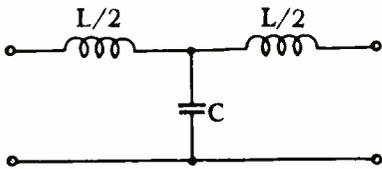


Fig. 21.—A "T" type filter.

is divided into two sections and a T arrangement is used. The equation of the low-pass filter is simple:

$$f_c = \frac{1}{\pi\sqrt{LC}}$$

where f_c = cut-off frequency

$$\pi = 3.1416$$

L and C in Henries and Farads respectively.

This equation should not be confused with the somewhat similar equation for the resonant frequency. The latter is,

$$f_r = \frac{1}{2\pi\sqrt{LC}}$$

For a given combination of L and C the cut-off frequency f_c is just twice as great as the resonant frequency f_r , because in the latter the denominator is multiplied by 2. The ordinary LC tables give the value of f_r , not f_c .

In the design of a filter for a given f_c , either L or C may be arbitrarily chosen on the basis of other known factors and the equation solved for the unknown member. Factors entering into the initial selection of L or C will be discussed in later assignments when the circuit will be studied mathematically in greater detail. Fig. 22 consists of two sections of the circuit of Fig. 20 in series. Fig. 23 shows two sections of the circuit of Fig. 21 in chain or cascade. The greater the number of chain or cascade sections, the greater will be the attenuation of frequencies about the cut-off frequency. The lower the resistance losses in the filter, the sharper and more defined will be the cut-off point, and the less the attenuation, due to the resistance

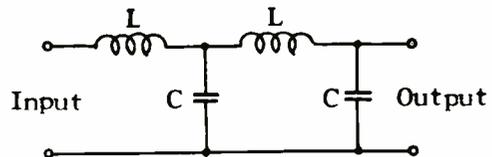


Fig. 22.—A "π" type filter.

losses, of the lower frequency voltages that are to be passed.

The most extensive use of the low pass filter in radio is to remove the ripple frequency components

from the d-c output of a rectifier. A half-wave single-phase rectifier

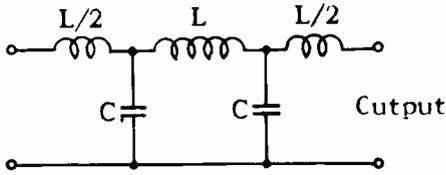


Fig. 23.—A double "T" type filter.

operating from a 60 cycle power supply will supply direct current with a-c components at 60, 120, 180, 240, etc., cycles per second. To supply a steady source of direct current without the a-c component, the rectifier output is passed through a low pass filter, designed in this case to have cut-off at 30

or 40 cycles/second. A full-wave single-phase rectifier will have its principle and lowest ripple component at 120 cycles with all the attendant harmonic frequencies; a 90 cycle cut-off frequency will be satisfactory.

Iron core inductances will of course be used at the audio and power frequencies. For 60 cycle rectifier power supply filters, the inductance ordinarily will be in the order of several henries and the capacity in the order of several microfarads.

Occasion may of course arise to use the low pass filter at radio frequency. If so, its L and C values are calculated just as at the lower frequencies, the only difference being in the magnitudes of L and C.

PRACTICAL APPLICATIONS OF SERIES AND PARALLEL CIRCUITS

EXAMINATION

1. (A) State the advantages of the use of a high Q tuned circuit between the antenna and the first r.f. tube of a broadcast receiver.

(B) Explain IN DETAIL how the advantages mentioned in Question 1(A) are obtained.

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EXAMINATION, Page 2.

2. (A) You wish to minimize the transfer of harmonic energy along a transmission line so that there will be a minimum of harmonic radiation from the antenna. Explain by the use of a diagram how this can be accomplished by means of simple series resonant circuits.

(B) A transmission line having a surge impedance of 80 ohms is being used to transfer energy at 1,000 kc/s from a 5 kw transmitter to an antenna. Which of the following LC combinations is most suitable for suppression of the third harmonic and why? $L = 28.2 \mu\text{h}$, $C = 100 \mu\mu\text{f}$; $L = 126.6 \mu\text{h}$, $C = 200 \mu\mu\text{f}$; $L = 5.6 \mu\text{h}$, $C = 500 \mu\mu\text{f}$.

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EXAMINATION, Page 3.

3. (A) What is the advantage of a high kva/kw ratio in the tank circuit of a transmitter linear amplifier?

(B) How can this ratio be increased? Decreased? Explain.

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EXAMINATION, Page 4.

(C) A television tank circuit is required to pass a band of 9 mc. Should the kva/kw ratio be high or low? For 200 MC/s what ratio would be used?

4. (A) What is the advantage of band pass coupling between stages of intermediate frequency amplification in a television receiver?

(B) Explain how the width of the band passed may be adjusted by a change of circuit values.

PRACTICAL APPLICATIONS OF SERIES AND PARALLEL CIRCUITS

EXAMINATION, Page 5.

4. (B) (Continued)

5. (A) Why is a transmitting antenna always tuned to resonance?

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EXAMINATION, Page 7.

6. (Continued)

7. You wish to use an arrangement as shown in Fig. 6 to block interfering frequencies of 740 kc/s and 590 kc/s. You have two variable capacitors available. Each capacitor has a range of 40 μf to 350 μf . You wish to use identical coils for the two circuits. What inductance would you use? Design for high selectivity.

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EXAMINATION, Page 8.

8. The tuned antenna circuit of Fig. 1(A) has the following constants: Antenna capacity $.0012 \mu\text{f}$, antenna distributed inductance $22 \mu\text{h}$, $L = 18 \mu\text{h}$, C has a range of $100 \mu\mu\text{f}$ to $1,000 \mu\mu\text{f}$. What is the frequency range over which this circuit will resonate? Antenna capacity is to be considered in series with C .

9. The tank circuit of Fig. 11 consists of an inductance of $35.2 \mu\text{h}$ and a total capacity of $.002 \mu\text{f}$. The effective resistance of the circuit *without* reflected resistance from the antenna circuit is 4 ohms.
- (A) How much additional resistance must be reflected into this circuit from the antenna (in series with the 4 ohm value) to make the effective resonant impedance of the tank

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EXAMINATION, Page 9.

9. (A) (Continued)

circuit LC equal to 2,500 ohms? (Review Inductive and Parallel Circuits if necessary).

(B) Neglecting the mutual inductance between L and the antenna coil, to what frequency is LC resonant?

10. (A) What is the particular advantage of the circuit of Fig. 2 of the assignment for use in an oscillator? Explain fully how this advantage is obtained.

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EXAMINATION, Page 10.

10. (A) (Continued)

(B) With reference to the circuit diagram below, indicate whether the following LC circuits operate as series or as parallel tuned circuits: L_1C_1 , L_2C_2 , L_3C_3 , L_4C_4 , L_5C_5 , and L_6C_6 .

