RADIO COILS AND CIRCUIT APPLICATIONS

RADIO COILS

Radio coils are frequently thought of in the light of being essentially radio components, and as a part of the more general classification "Inductance." In order to understand the performance of coils in radio receivers, it is first necessary to understand the fundamental ideas about inductance and about resonant circuits.

Inductance is of two general types, "Self-Inductance" and "Mutual-Inductance," both of which are important in a radio receiver and both of which are described below.

SELF INDUCTANCE

Self inductance is, by definition, that magnetic property of a circuit that opposes any change in current. When a current flows in a wire, a magnetic flux is set up around that wire. If the current increases, the flux increases and, as it increases, the flux generates a voltage that tends to oppose the increase in current.

If the conductor is wound into a coil, the flux from many turns is concentrated so that each turn in the coil encloses not only its own flux, but also that from many other turns, thereby greatly increasing the effectiveness of each turn. Where the turns are large in diameter but bunched very closely together, the inductance increases practically in proportion to the square of the number of turns in the coil.

The practical unit of inductance is the "Henry" which is that value of inductance in which one volt is generated when the current is changing at the rate of one ampere per second. This unit of inductance is of quite convenient size when dealing with problems in power filter design, but is much too large for convenience when dealing with problems in intermediate frequencies or in high frequencies. For intermediate frequency work a one-thousandth part of a Henry, called a millihenry, is the most convenient unit of inductance, and for higher frequencies the microhenry, a one-millionth part of a Henry, is more convenient.

When an inductance is connected in an alternating current circuit, the current that flows is a function of the voltage across the inductance, the frequency of the current, and the magnitude of the inductance. The impedance to the flow of current is expressed:

$X_L = 2\pi FL$ or $X_L = \omega L$ where
$\omega = 2\pi$ times Frequency (cycles per second),
$F =$ frequency (cycles per second),
$L =$ inductance in Henrys.

Impedance in an alternating current circuit is very similar to resistance in a direct current circuit except that the magnitude of the impedance changes with frequency. If it were not for this fortunate effect, radio receivers and any other devices employing resonant circuits would be unknown.

MUTUAL INDUCTANCE

In the section on Self-Inductance, above, the definition of "Self-Inductance," and the properties thereof were briefly explained. If, in the example of the bunched winding, half of the turns formed one circuit and the remaining half formed another circuit, a change in magnetic flux occasioned by a change in current in one winding, would induce two voltages, one in its own winding opposing the change in current, and the other in the second coil. This phenomenon of a voltage induced in the turns of one coil by a change in current in another coil is known as "Mutual Inductance."

The unit of Mutual Inductance is the "henry" defined as that value of mutual inductance in which one volt is generated across the terminals of one coil when the current in the other coil is changing at the rate of one ampere per second.

The practical units for Mutual Inductance are the same as those for self inductance, namely the Henry, Millihenry and Microhenry.

A very convenient property of mutual inductance is that the mutual inductance existing between two dissimilar coils is the same, whether the current change is in the large coil and the voltage is measured in the small one or vice versa, regardless of how dissimilar the coils may be.

This phenomenon called mutual inductance makes the formulae for inductances in series or in parallel much different from the formulae for resistances. In the latter case, the equivalent resistance of two resistances in series is the sum of the individual resistances; but in the case of two inductances in series, there may be a mutual inductance between the coils that may seriously disturb that simple relationship. If the two coils are placed so that the wires of one coil and those of the other coil occupy practically the same space, as in the case of winding the second coil as a single layer directly over the first single layer coil, or between the turns of the first coil, the overall inductance of two equal coils wound as above, will be twice the sum of the inductances of the two individual coils, if the coils are connected "Aiding" and will be practically zero if connected "Opposing." This is a special case which seldom occurs, but shows one of the extremes of mutual inductance which can influence the equivalent inductance of two coils connected in series.

The general expression for any case involving only two coils in series is: overall inductance equals the sum of the individual inductances plus or minus twice the mutual inductance. The reason for this relationship is given in the following explanation.

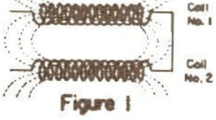

Figure 1

A current change in coil No. 1 induces in itself a voltage proportional to its inductance, and similarly in coil No. 2 a voltage proportional to the inductance of coil No. 2. The current change in coil No. 1 induces a voltage in coil No. 2 proportional to the mutual inductance between the two coils, and similarly the current change in coil No. 2 induces a voltage in coil No. 1 of the same magnitude because the mutual inductance is the same whether measured from the first to the second coil, or in the reverse direction. The overall inductance is proportional to the total voltage induced, and is consequently equal to the sum of the individual inductances plus or minus twice the mutual inductance. The "plus or minus" provision is made because the voltage induced in one coil by a current change in the other does not necessarily aid the self-induced voltage in the coil. Inductances themselves are positive, there being no negative inductances; nor, strictly speaking, are there any negative mutual inductances; but a mutual inductance may be connected into a circuit so that its effect may oppose some other effect and can be considered as a negative mutual inductance *when so connected.*

The maximum value of mutual inductance that can exist between two coils is equal to the square-root of the product of the two individual inductances. In practice it is very difficult to obtain sufficiently close coupling to produce this limiting value unless the two coils are wound together, the wires from both circuits being wound on the coil simultaneously.

COUPLING COEFFICIENT

When two coils are arranged so that some definite mutual inductance exists, the coils are said to be magnetically coupled.

In many calculations, it is frequently convenient to express the amount of coupling as a percentage of the maximum that could possibly exist, rather than a numerical value of mutual inductance. In such a case, the term applied to this percentage is "coupling coefficient" which, for inductance, is defined as the quotient resulting from dividing the existing mutual inductance by the maximum possible mutual inductance (square-root of the product of the two separate inductances).

DESIGN OF RADIO COILS

Since almost all radio-frequency coils operate in resonant circuits, the coils must be designed for three important characteristics — inductance, distributed capacity, and losses.

For simple geometric forms such as the solenoids, formulae are available in many text books for calculating the above mentioned characteristics, but for universal wound coils no satisfactory formulae exist for any one of the three quantities. Within limits, the inductance and distributed capacity are practically constant with frequency, but the losses change with frequency, requiring different designs for minimum losses in coils of the same inductance but operating at different frequencies. This is the reason for the great amount of design work required on radio-frequency coils.

The losses in a coil may be divided into the following classes:

1 — Ohmic or D.C. losses in the wire
2 — Eddy-current losses in the conductor
3 — Eddy-current losses in the shield

4 — Eddy-current losses in the core material
5 — Skin effect
6 — Dielectric loss in the wire insulation
7 — Dielectric loss in the terminal strip

None of these items is independent of the others, and a change to improve one usually changes one or more of the remaining factors.

Considering the sources of loss in the order named above, the D.C. or ohmic resistance of a coil can be reduced by increasing wire size, in which case the coil becomes larger, and, in the case of shielded coils, brings the coil closer to the shield, which consequently increases the shield losses. In addition, because the copper cross section increases, permitting higher eddy-voltages to be generated, the eddy-current losses in the conductor increase.

The eddy-current losses in the conductor are minimized by subdividing the conductor as finely as is economical, insulating each of the subdivided parts from all other parts. Commercially, this is done by the use of so-called Litz (Litzendraht) wire, which consists of many strands of fine wire, each strand individually insulated with enamel, and the group of wires covered with some insulation, usually silk, nylon, celanese, or cotton is used over the group.

Eddy-current losses in the shield are minimized by using a shield as large as possible, or large enough so that further increase in diameter produces no improvement, and by the choice of shield material of the lowest economical specific resistance. The shield materials in common use are copper, aluminum and zinc, named in the order of their merit. Magnetic alloys, such as sheet iron or silicon steel, are very high in R F losses.

A peculiar phenomenon with regard to composite shields is that whenever a shield is made of two closely bonded materials, the characteristics of the shield approach the characteristics of the poorer material. For example, a copper plated steel shield is almost as bad as an all steel shield of equal dimensions even though the plating is commercially heavy.

Iron cores are frequently used in coils to increase the effectiveness of the turns of wire, thereby permitting a given inductance to be obtained with fewer turns, and consequently with lower D.C. resistance. The core itself introduces some eddy-current losses which partially offset the improvement made by reducing the number of turns.

Eddy-current losses in the conductor have dictated the use of Litz wire wherever economically possible, but "Skin Effect" goes a step farther and requires that the conductor not only be subdivided into a multiplicity of individually insulated strands but that these strands be arranged in a special manner. In an attempt to have each individual strand occupy a place on the surface of the conductor an equal percent of the time, so that the current would divide equally among the many strands and thereby give the lowest effective R.F. resistance, the original braided Litzendraht wire was developed. Because of price, however, modern "Litz" wire as used in radio receivers, is merely twisted, which brings different strands to the surface at different points giving a result approaching that of braided Litz, but at far less expense. Where Litz wire is made without twisting, that is, with parallel strands, the results are inferior to twisted Litz on two counts: (1) the losses are consistently higher than for twisted Litz, (2) coils made with it exhibit greater variations in resistance than coils made from twisted Litz. (All Meissner Litz wire is twisted.)

A very important and frequently unsuspected contributor to coil losses is the insulation of the wire. Analyzing a coil, it will readily be apparent that the fabric insulation on the wire is the dielectric of the distributed capacity of the coil. The losses in the insulation influence the coil just as surely as would an external condenser of the same capacity connected across the coil, having the same fabric for a dielectric. With this in mind, many coil designs have been improved by increasing the thickness of fabric insulation, thereby reducing the distributed capacity and consequently its detrimental effect. In many cases, this effect was so important that increasing the insulation thickness resulted in improvement in the coil even though smaller wire was used to give space for the insulation!

In considering the distributed capacity of a coil it must be remembered that, in many instances, the terminals on the coil contribute an important part to the distributed capacity, and that the losses in the terminal strip should not be neglected. On some coils of high quality, hard rubber terminal strips are used to minimize the losses occasioned by the terminal strip.

Since all of the losses in a coil taken together make up the radio frequency resistance of the coil, a single number can be used to express this quantity, but the resistance alone does not give sufficient information to judge the electrical excellence of the coil. Resistance is usually the undesired quantity in a coil, and practically all coil designs attempt to make it as low as possible. Reactance is the desired characteristic of the coil and is the product of frequency, inductance and the usual multiplier, 2π. A special term has been given to the ratio of the desired to the undesired characteristic of the coil. This term is "Q" which is defined as the reactance divided by the resistance.

From the foregoing discussion of the factors influencing the performance of radio coils it is obvious that when Meissner lists high "Q" coils the products offered are the results of many hours of work on each individual design backed by the experience of years on the same type of problem.

SHIELDING

Having considered, in the paragraphs last preceding this section, the effect of high insulation loss in a radio coil or its associated terminal strip, it immediately follows that the losses in any associated wiring should also have an effect on the efficiency of the circuit. Probably the most serious offender in this category is a shield on any high potential R F hookup wire.

The common type of shielded wire, consisting of two wax impregnated cotton braids over the conductor, covered with a woven copper shield is particularly bad when used on high- "Q" resonant circuits. Such shielding frequently has a capacity of 50-to 100-mmfd. per foot which means that if more than a few inches are used, so much capacity may be added to the circuits that they may not be tunable with the trimmer condenser provided. In addition, the capacity added has high losses even when dry. It is characteristic of this type of wire that as it becomes damp its losses increase tremendously, thereby greatly reducing the efficiency of high-"Q" circuits, and, in addition, the capacity increases, detuning the circuits. This loss in efficiency is bad enough, but when detuning is added, the cumulative results may prevent operation of a receiver having an appreciable amount of shielding on grid or plate leads. Because of these humidity effects, the safe rule to follow is never to use a close fitting shield on any R.F. or I.F. circuit. If, however, it is necessary to use shielding, some form of large diameter shielding should be used. A piece of spiral spring, whose inside diameter is considerably larger than the outside diameter of the insulation on the wire passing through it, makes a good flexible shield. In this case, a great deal of the dielectric between the conductor and the shield is air. This partially reduces the dielectric loss, but even this should be avoided if possible.

The electrically ideal type of shielding is the partition type which separates one tube and its associated wiring from another tube and its wiring. Since it is not always possible to employ partition shielding, the next best thing to use is either rigid bare wire in a rigid shield tube, or a small wire in a large diameter shield such as is frequently employed on automobile antenna lead-ins.

If a close-fitting shield must be used, the best economical commercial insulation obtainable such as polyethylene or some of the newer plastics should be used.

RESONANT CIRCUITS

The fundamentals of resonant circuits are covered so thoroughly and completely in many standard text books on radio, that no attempt will be made here, in limited space, to cover the same territory. Only a very few important ideas and relationships will be brought to your attention.

Inductance and capacity, when measured in an alternating current circuit are found to possess "Reactance" measurable in ohms. The reactances, although both measured in ohms, have the peculiar property of adding to resistive ohms as if the resistance were the base of a right angle triangle, the reactance were the altitude of the triangle, and the overall impedance the hypotenuse of the triangle. This relationship is expressed as the square of the hypotenuse being equal to the sum of the squares on the other two sides.

The reactances of a condenser and of an inductance are of opposite sign, however, so that if an inductance and a capacity are connected in series, the overall reactance will be the *algebraic* sum, or in this case, the numerical difference between the two reactances.

From the above statement it follows that for any given value of inductive reactance, a value of capacity can be chosen whose reactance will exactly equal the inductive reactance. A special name, "Resonance" has been given to this condition. The circuit is referred to as being "In Resonance." Under this condition the current is limited only by the resistance in the circuit.

When circuits are resonant, some very astonishing things can happen. Consider the circuit shown in Fig. 2.

This is a theoretical case because it is impossible to obtain both inductance and capacitance without resistance, although, of the two, a perfect condenser can be approached closer than a perfect inductance. If all of the resistance is considered to reside in the inductance, E_1 ceases to exist as a separate voltage that can be measured with a meter, but it still limits the current flow at resonance. The voltages that then could be measured are $E_2 = 100$ and $E_3 = 100.005$ volts.

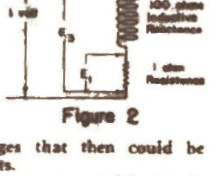

Figure 2

If an inductive and a capacitive reactance are connected in parallel the total reactance is higher than the highest reactance instead of being lower than the lowest, which is the case existing when reactances of the same type are connected in parallel.

The reason why the effective impedance of two similar impedances connected in parallel is lower than the impedance of either separate circuit branch is immediately obvious. The second circuit offers a second path for current, raising the total current, and, since it is known that with constant voltage supplied, increased currents indicate lower impedances. The reason why the impedance rises when dissimilar reactances are connected in parallel is explained as follows:

When an inductive reactance is connected across a supply of alternating voltage a current flows 90 electrical degrees or ¼ of a cycle behind the voltage. When a capacitive reactance is connected across a similar supply, a current flows 90 electrical degrees or ¼ cycle ahead of the voltage. From this it is obvious that when both types of reactance are connected to the same voltage source, the currents will be exactly ½ cycle apart, meaning that the moment the current is at its positive peak on the alternating current wave in the condenser, the current in the inductance is at its negative peak, or that the total current in the two circuits will be the arithmetic difference between the two individual currents. It is obvious then that since connecting two dissimilar reactances (one capacitive and one inductive) in parallel reduces the total current drawn from the line, the impedance must increase. If the condenser and inductance both have zero losses, the same current would flow in the inductance as if the condenser were absent, and the same current would flow in the condenser as if the inductance were absent, but no current would be drawn from the line. The impedance of the combination must therefore be infinite.

Since radio coils do not come within 10% of being as good as high grade condensers, and since condensers themselves are not perfectly loss free, it follows that the infinite impedance circuit discussed is theoretical and that it is highly desirable to have a convenient method of calculating the impedance of actual circuits.

Starting with the formula for the impedance of an inductance of practical design in parallel with a condenser simple algebraic manipulation produces the very workable formula

Resonant Impedance $= Q \omega L$

where Q is the "Q" of the coil (by definition, its reactance divided by its resistance) $\omega = 2\pi$ times frequency in cycles per second, and L is the inductance in henrys.

ANTENNA COILS

The basic types of antenna coils have high-impedance inductive, high-impedance capacitive, low-impedance inductive and low-impedance capacitive couplings. Typical values of capacity, self inductance and mutual inductance for these four types of broadcast coils are shown in Fig. 3.

HIGH-IMPEDANCE PRIMARY

High-impedance magnetic coupling, usually spoken of as "High-Impedance Primary" is the most universal type of coupling on the broadcast range of household receivers. It has good image ratio, reasonable gain, and, when properly designed, almost negligible misaligning of the first tuned circuit as the size of antennas is changed. With the usual design of coil, this type of coupling results in higher gain at the low-frequency than at the high-frequency end of the tuning range. Sometimes, to compensate for this deficiency at the high frequency end, a small amount of high-impedance capacity coupling is used. This capacity is connected from the antenna to the grid terminals of the coil. Its size is from 3 to 10 MMF.

It is to be noted that capacity coupling can reduce as well as raise the gain of a high-impedance magnetically coupled transformer, depending upon the polarity of the windings. **If capacity coupling is to aid the magnetic coupling, a current entering the antenna terminal of the primary and the grid terminal of the secondary must go around the coil form in opposite directions, and the coupling capacity must be connected between these two points.**

LOW-IMPEDANCE PRIMARY

Antenna coils with low-impedance primaries, although cheaper to manufacture than high-impedance primaries, are rare on the broadcast band of modern home radio receivers.

This type of coupling, when used with any of the conventional household antennas, gives a great deal more gain at the high-frequency end than at the low-frequency end of the tuning range. This gives rise to very poor image-ratio when used in a superheterodyne receiver.

The closely coupled low-impedance primary reflects the antenna capacity across the tuned circuit in an amount depending upon its inductance and coupling coefficient. Without attempting to derive an expression for the actual magnitude of this effect, suffice it to say that if the primary is large enough to give reasonable gain at the low-frequency end of the frequency range, the reflected antenna capacity will be so high that the secondary tuning condenser will not be able to tune to the high-frequency end of the band, and every different antenna capacity would change the amount of mistracking. Because of this sensitivity to changes in antenna capacity, and because of poor image ratio, the low-impedance primary is seldom used on broadcast-band antenna coils.

On short-wave coils, the low-impedance primary is used almost exclusively because the antenna gain is usually higher than with a high-impedance primary, and the antenna is usually resonant in or below the broadcast band. For this reason, the image-ratio does not suffer nearly as much as in the case of using low-impedance broadcast coils in place of coils with high-impedance primaries.

HIGH-IMPEDANCE CAPACITY COUPLING

The high-impedance capacity coupling scheme consists essentially of connecting the antenna directly to the grid end of the first tuned circuit through a capacity, usually from 1 to 10 mmf. This method of coupling has been popularly used on amateur receivers of simple design, where simplicity of coil construction was imperative, but is not used in broadcast receivers by recognized manufacturers because of the very poor image-ratio that results.

Practically speaking, the only use for high-impedance capacity coupling in a broadcast receiver is as reinforcement to a high-impedance primary, as discussed in the paragraph on "High-Impedance Primaries."

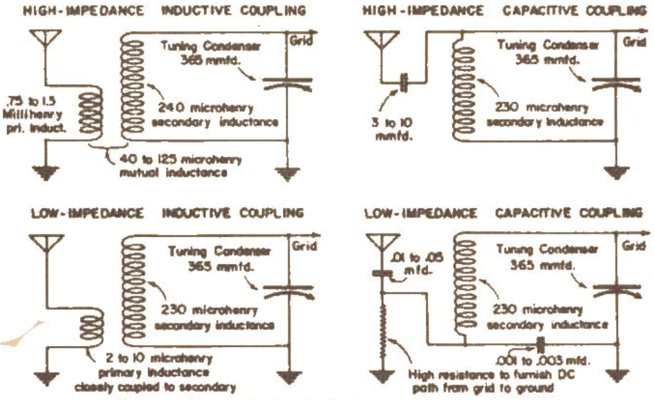

Figure 3 Typical Antenna Coils

LOW-IMPEDANCE CAPACITY COUPLING

Low-impedance capacity coupling, familiarly known among radio engineers as the Hazeltine coupling system, consists of coupling the antenna directly to the junction of the low side of the tuning inductance with the high side of a high-capacity coupling condenser which is connected to ground. (See Fig. 3.) The voltage across this coupling condenser is multiplied by the resonance phenomena of the tuned circuit to give appreciable voltage at the grid.

This circuit is particularly adapted to receivers that must use a high-capacity shielded lead-in such as an automobile radio receiver. In such a circuit, the shielded lead-in is made part of the coupling capacity because of the circuit arrangement and, practically speaking, causes no loss in voltage as would be occasioned if this capacity would be connected across a high-impedance primary. For this statement to be strictly true, it is necessary that the shielded lead-in have a good power factor or else the losses in the lead will slightly reduce the effective circuit "Q," thereby bringing down the gain in the antenna coil by a corresponding amount.

This type of coil has high gain and excellent image-ratio. The drawbacks to its use are that the R.F. amplifier circuit, if used, must have a value of capacity included in its tuned circuit equal to the antenna coupling capacity in order that proper tracking may result.

An alternative is to use a tuning condenser whose antenna section is different than its R.F. section, but this can only be done where a heavy production schedule justifies the additional tool cost.

When this coupling scheme is used in household radio receivers, precautions must be taken to prevent 60-cycle hum modulation from being introduced into the first tuned circuit by low-frequency voltages picked up on the antenna circuit. In the best of receivers employing this circuit, an R.F. choke is connected from antenna to ground to provide a low impedance path for power frequencies in order to keep hum modulation off of the grid of the first tube.

R. F. COILS

R.F. coils may be divided essentially into four types: high-impedance magnetic, low-impedance magnetic, high-impedance magnetic with high-impedance capacity coupling, and choke-coupled circuits.

The high-impedance magnetically coupled R.F. coil has characteristics very similar to the high-impedance antenna coil and therefore needs little discussion.

The low-impedance magnetically coupled R.F. coil has the same deficiency as the similar antenna coil and is consequently seldom used in the broadcast range of a superheterodyne receiver. Like the antenna coil, it has possibilities for higher gain than the high-impedance type, but usually the selectivity is enough worse to rule out this type of coupling on modern receivers.

In the shortwave range, this is the most popular type of circuit, because it is the one giving the highest gain and since, with a fixed capacity of gang condenser, it becomes increasingly more difficult to obtain high gain as the frequency is increased, this circuit with its high gain is the almost universal choice in spite of its deficiencies in image-ratio.

The R.F. coil employing a high-impedance primary in combination with high-impedance capacity coupling is the most flexible design, and is popularly used for that reason. By shifting the primary resonant frequency and by changing the amount of capacity coupling together with changes in "Q" of the secondary circuit, the overall gain of an amplifier stage can be made to have almost any desired shape with respect to frequency; that is, it may give high gain in the middle, at the high-frequency end, at the low-frequency end, or almost any shape desired, to compensate for the frequency characteristics of the other stages employed in the receiver.

The choke-coupled R.F. circuit is very similar to the high-impedance primary with high-impedance capacity coupling, except that, in choke coupling, the magnetic coupling has been made zero, but design still requires that the choke have as much inductance as a primary would have, in order that the resonance of the primary circuit may fall outside of the tuning range of the secondary.

OSCILLATOR COILS

Oscillator coils in modern receivers exhibit less variation in types than any other R.F. component. They either do or do not have a "tickler."

Those oscillators that do not have a tickler coil, oscillate by virtue of the feedback across the padding condenser. A typical circuit of such an oscillator is shown in Fig. 4. Using a 456 KC IF system requiring relatively small padding condensers makes this type of operation possible. The only bands that have padding condensers small enough to sustain oscillation are the long wave and broadcast bands. In some high frequency oscillators a similar circuit is used with only the tube interelectrode capacities providing the voltage dividing feed back network and with the tuning condensor connected across the entire circuit. A typical tickler circuit is shown in Fig. 5.

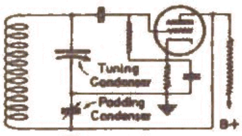

Figure 4

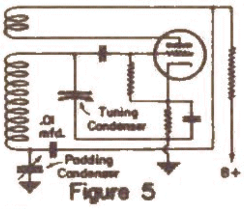

Figure 5

IF TRANSFORMERS

Intermediate-frequency transformers used in radio receivers have taken a variety of forms and have operated at many different frequencies. They may be divided into several classes according to the number of selective circuits: untuned or self-tuned, single-tuned, double-tuned, and triple-tuned. Receivers have employed IF transformers with more than three tuned circuits per transformer but such cases are very rare.

The untuned IF transformer usually added practically no selectivity to a receiver. Its principal purpose was to give a high amplification at very little cost. It was always used in conjunction with one or more tuned IF transformers which supplied the required selectivity.

SINGLE-TUNED IF TRANSFORMERS

The single-tuned IF transformer has taken two important forms, the bi-filar coil and the double coil types.

In the former case, the two wires constituting primary and secondary are wound simultaneously, forming a coil that is a single physical unit yet having two independent circuits. The start of the primary was usually the plus "B" connection and the start of the secondary was ground. The outside of the primary was the plate connection and the outside of the secondary was the grid connection. These transformers were characterized by very high gain and comparatively little selectivity. They were used on receivers that had no A.V.C. and the secondary low-potential end usually connected directly to chassis. Such a transformer could not be used satisfactorily in a receiver employing the conventional diode type A.V.C. circuit for the reason that on damp days there is enough leakage between primary and secondary to produce a decidedly positive bias on the grids of the automatically controlled tubes.

In addition, such a structure possesses such a high capacity between windings that the ripple in the "B" supply would be transferred to the diode load resistance which would produce a bad audio hum in the output of the receiver. A third reason why this type of transformer would not now be acceptable, even if there were no diode load resistance to pick up hum or to be incorrectly biased, is the frequent failure of windings due to electrolytic corrosion. Where two conductors are run so intimately parallel for so many turns, with opposite D.C. potentials applied to the two wires, ideal conditions are set up for rapid failure due to electrolytic corrosion in the presence of moisture.

With this transformer redesigned to have two physically separate coils wound side by side, the objectionable features of leakage, corrosion and hum transfer are reduced to a very small per cent of their original importance, and transformers acceptable in today's critical market can be produced. The largest remaining objection to the single-tuned transformer is selectivity. In a low-frequency amplifier operating at 125 KC or 175 KC, the transformers are too sharp for good audio fidelity, and at the higher intermediate frequencies such as 456 KC, the transformers do not add sufficient adjacent-channel selectivity.

Single-tuned transformers may be divided into two classes according to the circuit tuned; some have their primaries tuned while the remainder have their secondaries tuned. As far as secondary voltage is concerned, there is not a great deal of difference regardless of which winding is tuned, but if there is a question of single-stage oscillation in the tube driving the single-tuned transformer, greater stability is had by tuning the secondary than by tuning the primary.

DOUBLE-TUNED IF TRANSFORMERS

The double-tuned IF transformer is, by far, the most popular type. It is simple in construction, has negligible leakage, no measurable hum transfer into diode circuits and can have its selectivity curve made as sharp as two single-tuned transformers in cascade, or can be considerably broader at the "Nose" of the selectivity curve than two cascaded single-tuned transformers, yet on the broader part of the selectivity curves maintain practically the same width as the cascaded single-tuned transformers.

If the coupling on a double-tuned transformer is made sufficiently loose, the transformer is quite selective and has a resonance curve of the same general shape as a single circuit, except sharper. As the coupling is increased, the gain will go up until the point of "critical coupling" is approached where the gain of the transformer is practically constant but the selectivity curve is changing, particularly at the "nose" of the curve. As the coupling continues to increase, first there is a decided flattening on the nose of the selectivity curve, after which continued increase in coupling produces an actual hollow in the nose of the curve. Still greater increase in coupling can spread the two "humps" and deepen the "hollow" in the nose of the response curve until a station can be tuned in at two places on the dial very close together.

Variations in magnetic coupling cause variations in the gain and selectivity of IF transformers as described above, but this is not the only source of variation. Variations in capacity coupling can be equally important in transformers operating above 400 KC. This variation is so important that it is discussed separately in the section "Capacity Coupling in IF Transformers."

The complete selectivity characteristics of any circuit can be shown only by a curve from which it is possible to determine the performance at any point, but nearly as much useful information can be given in a few figures where the selectivity of IF transformers is concerned.

The Meissner catalog lists the "Band Width" of each transformer at two points on the selectivity curve. These two points are labeled 2X, and 10X meaning respectively, two times, and ten times. These terms designate the place on the selectivity curve at which the gain at resonance is two, or ten times the gain at the point specified. The width of the response curve has been measured at these points and has been tabulated so that the comparative selectivity of transformers may be judged.

TRIPLE-TUNED IF TRANSFORMERS

Triple-tuned IF transformers have been used for two general purposes: greater adjacent-channel selectivity without increasing the number of tubes and transformers, or a better shape on the nose of the selectivity curve to produce better audio fidelity than is produced by double-tuned transformers. Capacity coupling on such transformers is of even greater importance than in double-tuned transformers, especially where both plate and diode hook-up wires come out at one end of the transformer shield, as is the usual case with output IF transformers.

CAPACITY-COUPLING IN IF TRANSFORMERS

The ordinary circuit diagram of a double-tuned IF transformer is as shown in Fig. 6, but actually the circuit in Fig. 7 is more representative of true conditions.

The capacity coupling, shown in dotted lines, is a very important part of the coupling in practically all transformers operating at frequencies above 400 KC. This statement applies with even greater emphasis as the frequency, or the "Q," of the coils is raised.

The capacity that is effective in the above mentioned "capacity coupling" is that which exists between any part of the plate end of the primary circuit and any part of the grid end of the secondary circuit; to be more specific, the capacity between the plate and grid sides of the trimmer condensers, the plate and grid ends of the coils, the plate and grid leads, the grid lead and the plate end of

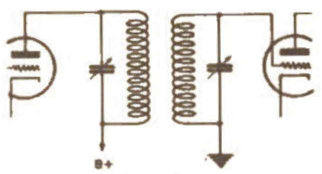

Figure 6

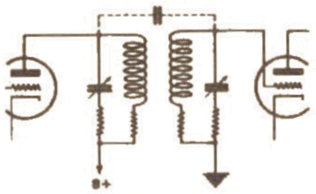

Figure 7

the primary coil, and between the plate lead and the grid end of the secondary coil.

Figure 8

The capacity between the two high-potential plates of a trimmer condenser such as the Meissner unit shown in Fig. 8 is 0.35 mmfd. if both trimmers have an even number of plates and the bottom plate of each trimmer (on the same base) is a high-potential (either grid or plate) electrode. If an odd number of plates is used on both trimmers, the capacity drops to 0.07 MMF The difference between these two coupling capacities, amounting to only 0.28 MMF. is sufficient to make quite a difference in the gain of transformers operating above 400 KC.

Double-tuned IF transformers may be built with the magnetic coupling either aiding or opposing the capacity coupling. For reasons of production economy, both coils on one dowel are usually wound simultaneously, which means they must be wound in the same direction. For reasons of production uniformity, the insides of both windings are usually chosen as the high-potential ends of the coil so that the outside (low-potential) ends of the coils will automatically act as spacers to keep the high-potential hook-up wires from approaching the high-potential ends of the coils.

If transformers are designed so that the circuits are considerably under "Critical Coupling," variations in capacity coupling are equally important whether the magnetic coupling aids or opposes the capacity coupling. In the former case, an increase in capacity coupling will raise the gain of the transformer while in the latter case an increase in capacity coupling will reduce the gain of the transformer (except in the very rare cases where capacity coupling predominates).

If the transformer is at "critical coupling" and the magnetic and capacity couplings are "aiding," an increase in capacity coupling will merely decrease the selectivity, while if the couplings are "opposing," an increase in capacity coupling will increase the selectivity and reduce the gain.

In all of the above cases, the effect of increasing capacity coupling is described because transformers are ordinarily built with a certain irreducible minimum capacity and any changes must necessarily be additions.

Whether capacity coupling aids or opposes the magnetic coupling in a given transformer may be determined by inspection. If the coils are wound in the same direction, which is the usual case, the magnetic coupling opposes the capacity coupling if both grid and plate are connected to the same ends of their respective coils. Ordinarily both grid and plate are connected to the inside ends of the coils in order to keep the high-potential ends of the coils away from the hook-up leads passing the coil.

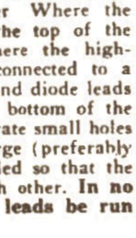

Figure 9

Special precautions and constructions are employed in building Meissner IF transformers in order to keep the capacity coupling uniform, so that transformers of uniform gain and selectivity characteristics may be provided. Fig. 9 shows fiber spacers used to hold flexible hook-up wires in a pre-determined place with respect to the coils, and Fig. 10 shows the "Perm-a-strut" construction employing rigid leads for maximum uniformity of capacity coupling.

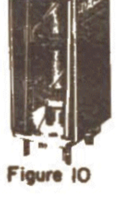

Figure 10

In order to take advantage of the uniformity built into IF transformers by means of rigid leads, or leads held in place by means of spacers, it is essential that the grid and plate leads remain everywhere well spaced from each other Where the grid lead is brought out through the top of the shield, this is no problem, but where the high-potential end of the secondary is connected to a diode it is customary for both plate and diode leads to be brought out through the open bottom of the shield. In such cases, either two separate small holes in the chassis, well spaced, or one large (preferably 1" or larger) hole should be provided so that the leads may be well spaced from each other. **In no case should both grid and plate leads be run through one small hole together.**

Triple-tuned IF transformers, particularly output transformers where diode and plate leads both pass through the open end of the shield can, are particularly subject to gain and selectivity variations as a function of variation in capacity coupling.

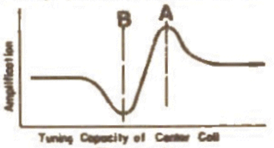

Figure II

As an example, in a particular triple-tuned output transformer where the plate and diode leads ran close together, it was found that in attempting to align the transformer, the middle circuit was effective as long as either the input circuit or the output circuit was out of tune, but as soon as both input and output circuits were aligned, the center circuit had a very peculiar action. If the gain of the transformer is plotted against the capacity of the middle circuit, a curve similar to Fig. 11 was obtained. From this it is seen that there is one adjustment (A) that produces an increase in the overall amplification of the transformer. At this point the center circuit is contributing to the selectivity of the transformer. At another point (B) the amplification through the center circuit opposes the capacity coupling from the input to the output winding and results in a considerable decrease in amplification. At all other settings of its tuning condenser, the center circuit is so far out of resonance that it has no effect upon the gain of the transformer, which for all practical considerations, may be assumed to be a double-tuned capacity-coupled transformer. When the capacity between the high-potential input and output leads was reduced to a very low value by keeping the leads in opposite corners of the shield can, the transformer behaved as a triple-tuned transformer should, with all three circuits effective.

TRACKING

Early models of radio receivers usually used only one tuned circuit per receiver, but as the number of circuits was increased to provide better selectivity, tuning a radio set became a problem beyond the grasp of the average citizen, and confined the sale of receivers to the "DX" hunter who spent innumerable midnight hours listening for new stations.

To make the receivers commercially more acceptable, simplifications in tuning were imperative. To this end, designs were produced that had a nominal single-dial control with an "antenna compensator" to produce maximum results. Such receivers were essentially single-dial control over a limited frequency range, but required an adjustment of the antenna compensator when passing from one end of the tuning range to the other. This simplification in tuning permitted general merchandising of radio receivers to the average citizen.

In order to make such receivers possible, it was necessary for the condenser manufacturer to produce tuning condensers with several individual condenser-sections on one shaft, in which, at any point in its rotation, the several sections of the condenser were practically identical in capacity, and the radio manufacturer was required to produce coils that had practically identical characteristics.

Given identical condenser sections and identical coils, it is obvious that the resonant frequencies of the several identical combinations of coils and condensers would be the same. In other words, such circuits would be self-adjusted to the same station and it would no longer be necessary to tune each circuit separately. In the language of the radio man, the circuits are said to "Track." These conditions made the single-dial control receivers possible.

As long as low-impedance magnetically coupled antenna circuits were employed, it was not possible to eliminate the "Antenna Compensator" since the size of antenna had considerable effect upon the tracking of the first circuit, but when high-impedance primaries were adopted on the antenna coil, true single-dial control with all circuits tracking became possible.

It is not to be understood from this that a high-impedance primary on the antenna coil automatically makes the coils track properly, for there are designs of high-impedance antenna coils that mistrack seriously. Neither is it to be inferred that a properly designed high-impedance antenna coil gave perfect tracking independent of antenna constants. A properly designed high-impedance antenna coil gives reasonable gain and tracks well enough that when trimmed to accurate tracking, the increase in sensitivity in the receiver is not greater than 30%.

In setting up the conditions for perfect tracking, the first requirement is identical circuits, the second is simplicity of circuit, the third is identical circuit inductance and capacity.

It is much simpler to track two RF stages of similar circuits and constants than it is to track an antenna and RF stage, and it is simpler to track two high-impedance circuits than it is one high-impedance and one low-impedance circuit.

The circuits which track most easily are those having the smallest number of circuit elements. The simplest possible circuit of an RF amplifier is shown in Fig. 12-A, which, for purposes of track-

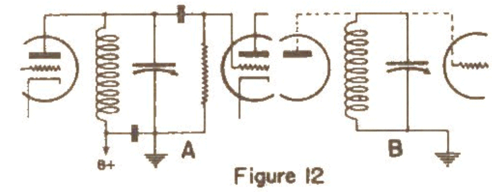

Figure 12

ing, is equivalent to Fig. 12-B. In this circuit there is one inductance tuned by one variable condenser, which condenser is assumed to include the grid and plate capacities. This circuit, in the broadcast band with the conventional capacity gang condenser, has entirely too much amplification, too much gain variation from one end of the tuning range to the other, and too little selectivity. Where the lack of selectivity and lack of uniform gain is not a serious problem, the gain of the amplifier can be reduced by tapping the coil to connect the plate somewhere near the middle of the

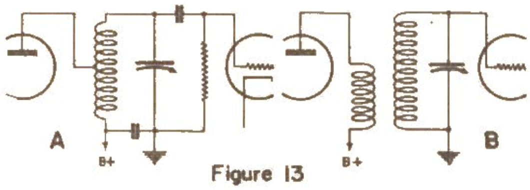

Figure 13

coil as in Fig. 13-A. In order not to have the plate voltage on the tuned circuit, a primary is usually wound on the coil, spaced between or exactly over the secondary turns, so that for all RF purposes, the plate is a tap on the secondary, but for DC is isolated. The RF coil now has a secondary tuned by the tuning condenser and is tightly coupled to the primary which has a very small capacity (plate and wiring capacity) across it. This arrangement permits the simple circuit of 13-B to be used. Such a circuit has two resonant frequencies, but for practical purposes the second resonant frequency is so high that it seldom causes any trouble, except in the case of certain high-frequency coils where the inductance of leads is comparable to the coil inductance.

The high-impedance primary type of RF coil has an inductance in the plate circuit many times higher than the inductance of the tuning coil. Such a circuit has two resonant frequencies, both of which are important. One is the frequency determined almost entirely by the secondary inductance and tuning capacity, and the other by the plate inductance and the plate capacity.

In Superheterodyne receivers, which almost universally employ an intermediate frequency lower than the broadcast frequencies, it is important to see that the primary-circuit resonance does not occur at the intermediate frequency, or the RF amplifier circuits will pass unwanted signals of intermediate frequency directly into the intermediate amplifier, even though the grid circuit of the RF amplifier is tuned to a frequency far removed from the intermediate frequency. This is particularly true of receivers employing an intermediate frequency just below the broadcast band, such as the 456 KC now so popular. On such receivers, the primary resonance should be placed either midway between the IF and the low end of the broadcast band, which gives high gain but leads to considerable production difficulties, or the primary resonance should be placed well below the intermediate frequency. The latter arrangement is highly recommended over the former because it is more uniform, causes less trouble from oscillation, and produces better tracking.

The presence of the primary circuit resonant below the low end of the tuning band has the effect of lowering the secondary inductance as the low end of the tuning range is approached. Fig. 14 shows the tuning curve for a high-impedance and a low-impedance RF circuit adjusted to have the same low-frequency inductance and the same maximum frequency. The low-impedance circuit is seen to follow the frequency curve calculated from the secondary inductance and total tuning capacity, but the high-impedance circuit does not follow this curve, departing from the calculated values at the low-frequency end. This point is brought out to show that two circuits may track perfectly over part of their tuning range and yet badly mis-track over another part due to resonances from some circuit not a part of the tuned circuit. From this it is easy to see that similarity of circuit is an aid in tracking.

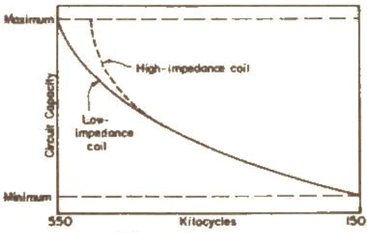

Figure 14

The amount the actual tuning curve of a high-impedance stage departs from the ideal curve depends upon two factors: the proximity of the primary resonance to the low end of the secondary tuning range, and the degree of coupling between primary and secondary. In the design of high-impedance coils, a reasonable limit on both of these factors may be assumed as follows: first, primary resonant frequency less than 80% of the lowest tuning frequency, but must not occur at the frequency of the IF amplifier in a superheterodyne receiver; second, magnetic coupling between primary and secondary should not exceed 15% coupling coefficient.

If the two circuits whose tuning curves are shown in Fig. 14 are to be tracked together, a series of compromises must be made. The tuning curves shown may be accepted as satisfactory, or a compromise may be made in the gain of the stage by moving the primary resonance farther away, with consequent reduction in gain, but resulting in a straighter tuning curve, or the inductance may be changed to make the low end mis-track less and the previously perfect tracking of the remainder of the tuning curve be less perfect. Such tuning curves are shown in Fig. 15.

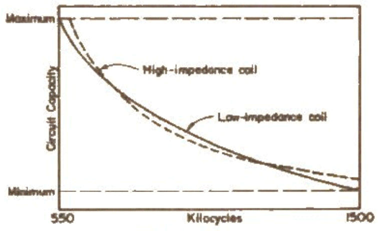

Figure 15

With the advent of superheterodyne reception, the problem of tracking became more complicated. The problem then became one of tracking one or more circuits to cover a given frequency range while another circuit (the oscillator) of different arrangement must maintain not the same frequency but a constant *frequency difference* in Kilocycles. Since the oscillator frequency is almost always above the signal frequency, and since the oscillator must cover the same number of Kilocycles from maximum to minimum, but cover them at a higher frequency than the antenna circuit, it is obvious that the oscillator covers a smaller frequency ratio than the antenna circuit.

In order to accomplish a restricted oscillator frequency-range compared to antenna frequency-range if no other restrictions were imposed, two methods are available; (1) Connect a fixed condenser across the oscillator. This reduces the capacity ratio by adding to the minimum capacity a much greater percentage than it adds to the maximum; (2) Connect a fixed condenser in series with the tuning condenser to reduce its maximum capacity without materially changing its minimum capacity. In actual receiver design, a combination of both types of compression is used, producing better average tracking than could be accomplished by either method alone. Formulas have been developed for calculating the values of inductance, padding and aligning capacities to be used to track an oscillator coil with a given antenna or RF coil, but unless there is access to a considerable amount of complicated test equipment, oscillator tracking must be accomplished experimentally with simple equipment.

TRACKING REPLACEMENT COILS

Radio servicemen are frequently called upon to replace Antenna, RF or Oscillator coils that have failed either through corrosion, or because of the failure of some other component in the receiver, or because damaged by some outside agency such as lightning.

Usually the damage is confined to the primary of the coil, in which case very frequently a new primary can be installed in place of the old one.

If the primary is replaceable, the winding direction of the old primary should be noted before removing it so that the new one may be installed with its winding direction the same.

If the damaged coil is beyond salvaging by installing a new primary, or if the secondary has been damaged, it will be necessary to install a new coil and check its tracking with the remainder of the tuning circuits.

In order to permit replacement coils to be tracked rapidly and to eliminate the possibility of having removed too much inductance and thereby ruined the replacement coil, to say nothing of the hours of labor installing, checking, removing and altering the coil, etc., Meissner has developed "Universal Adjustable" replacement antenna, RF and oscillator coils which are provided with a screw-driver adjustment of inductance by means of a movable core of finest quality powdered iron. By means of this adjustment, it is as easy to add inductance as to remove it, and to quickly obtain the optimum value of inductance. A coil of this type is shown in Fig. 16.

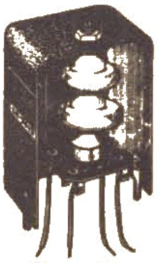

Figure 16

When a replacement antenna or RF coil is installed in a TRF receiver, the process of aligning is very simple. The dial is set to 600 KC, a dummy antenna of 200 mmfd. connected between the high side of the service oscillator and the antenna connection of the receiver, an output indicator of some type is connected to the output of the receiver, the service oscillator tuned to the receiver and the screw adjustor in the top of the can rotated until maximum sensitivity is obtained. The receiver and signal generator are next tuned to 1400 KC and the circuits aligned in the usual manner by adjusting the trimmers on the gang condenser. The process should then be repeated in order to obtain the best possible alignment at both checking points. It is best to seal the inductance adjustment on the coil by the application of a satisfactory cement, such as Duco Household Cement or equivalent.

When replacing an antenna or RF coil on a superheterodyne, essentially the same practice is followed as above with the exception that, since the oscillator determines the dial calibration, if the adjustments thereon have been disturbed, it is necessary to readjust the oscillator circuit to agree with the dial calibration at the checking points before adjusting the inductance of the new coil or aligning it.

If a new oscillator coil is being installed, the greatest aid to rapid adjustment of the new coil to proper inductance is an *undisturbed padding condenser adjustment*. There are innumerable combinations of oscillator inductance, padding capacity, and trimmer capacity that will track an oscillator circuit at two places in the broadcast band, but these various combinations give varying degrees of mis-tracking throughout the remainder of the band. If the padding condenser has not been disturbed, one of these variables is eliminated, and, with only inductance to adjust for proper alignment at the low-frequency end of the band, and capacity to adjust at the high-frequency end of the band, the adjustment is practically as easy and rapid as installing and adjusting an antenna or RF coil.

If the oscillator padding condenser has been disturbed, it will be necessary to track the oscillator with the remainder of the receiver in the same experimental manner as used in the determination of the original design values. To arrive at a satisfactory alignment, the following experiment should be conducted systematically, *writing down* the answers obtained, so that the data does not become confused in your mind.

1. Align the IF amplifier at the frequency specified by the manufacturer.
2. Adjust the padding condenser to some value known to be much *lower* in capacity than its normal adjustment.
3. Set the dial and signal generator (of known accuracy) to 600 KC and adjust the oscillator inductance by means of the screw in the top of the can until a signal is heard. If no signal is heard within the range of the oscillator inductance adjustment, screw the adjustment as far in as possible and increase the padding capacity until a signal is heard.
4. Attempt to align the oscillator trimmer condenser to agree with the dial at 1400 KC. If the adjustment cannot be made, again increase the capacity of the padding condenser and reduce the inductance (by turning the screw out) of the oscillator coil to obtain a new setting at 600 KC. This process should continue until both 600 and 1400 KC are correctly indicated.
5. When both 600 and 1400 KC are correctly indicated, tune the receiver to the generator set at 1000 KC and make a *sensitivity measurement* which should be recorded.
6. Now increase the padding condenser capacity *slightly*, decrease the inductance to give a 600 KC signal, align at 1400 KC and again measure sensitivity at 1000 KC. If the sensitivity at that point is better than it was before, repeat this operation until the sensitivity measurements show greatest sensitivity and then start falling off again. If the steps in the process have been written down, recording the number of revolutions and fractions thereof on the adjusting screw of the inductance, it should be easy to return to the adjustment giving maximum 1000 KC sensitivity. When this adjustment is set, seal it with some satisfactory cement such as Duco Household Cement or equivalent and then give the receiver a complete alignment.

ALIGNMENT OF RECEIVERS

Modern radio receivers employ from two up to eight, ten or even more circuits to achieve the selectivity desired. These circuits, however, are of little benefit unless all of them are working at their proper frequencies simultaneously. Only someone acquainted with the alignment of receivers in a radio production department, or someone engaged in radio service work who has adjusted a receiver on which someone has tightened all of the adjusting screws, can realize how dead a receiver can sound when all of its tuned circuits are out of adjustment any considerable amount.

The purpose of "Aligning" a radio receiver is two-fold — to adjust it for maximum performance, and to make the dial indicate within two or three percent the frequency of the station being received.

Since a trimmer adjustment is more sensitive when the circuit capacity is low, the trimmer adjustment is usually made near the high-frequency end of the tuning range. If the adjustment is made at the very end of the range, the maximum mis-tracking over the adjacent portion of the band will be greater than if an alignment point is chosen some small distance from the extreme high-frequency end of the tuning range. In the broadcast band, 1400 KC is the usual choice and is the frequency recommended as standard by the Institute of Radio Engineers. On shortwave bands on the same receiver, it is a good practice to align them at the same position of the gang condenser.

On a TRF receiver, all tuned circuits operate simultaneously at one frequency. When aligning a factory-built receiver, or a kit receiver having a dial calibrated to match the coils and condenser used, the dial is set to indicate the frequency of some signal of known frequency and the individual circuits adjusted to maximum performance on that signal at that setting of the condenser.

On a Superheterodyne receiver, circuits must operate at three different frequencies, properly related if satisfactory performance is to be obtained. Beginning with the circuits closest to the output tubes, the intermediate-frequency circuits must all operate at the same frequency in order to give satisfactory amplification. Actually they will work over a wide frequency range, but if they are operated very far from the intermediate frequency specified for the given dial, coils and tuning condenser, the dial indications will be in error more than the customary few percent and, in the case of receivers employing specially cut tracking plates in the oscillator condenser, serious mistracking of the oscillator with other tuned circuits will result, producing a loss in sensitivity and reduction in image-ratio.

The first adjustment on a superheterodyne receiver is therefore to align the intermediate-frequency amplifier at the correct frequency. Fortunately for satisfactory receiver operation, but unfortunately for the home set builder, there are no steady signals on the air at intermediate frequenceis to be used for aligning IF transformers. The IF transformers furnished by Meissner are aligned in the factory to the frequency specified in the catalog. If no equipment is available to furnish the proper aligning frequency, the transformers will be closely enough in alignment to pass a signal from a local broadcasting station when the complete receiver is operating. The transformers should be adjusted to give the strongest signal by adjusting, in turn, each of the adjustments on all of the IF transformers. As the adjusting screw is turned continuously in one direction, the output of the receiver will continue to increase up to a certain point beyond which the signal begins to fall again. By reversing the direction of rotation of the adjusting screws, each can be set for maximum signal output. As alignment proceeds, and the receiver becomes progressively more sensitive, the input should be reduced by retarding the setting of the sensitivity control, if the receiver has one, or by using progressively shorter antennas or merely short lengths of wire, or by tuning in weaker stations. The last expedient is not recommended unless all others fail, because in tuning in a new station the receiver may not be accurately tuned and it may be necessary to slightly retune all IF circuits.

When the alignment of the IF amplifier is completed, alignment of the RF and oscillator circuits should be made. If there is a signal generator or service oscillator available, it should be used as the frequency standard for alignment only if it is known to have an accurate frequency calibration. A manufacturer's statement of accuracy should not be assumed to hold for long periods of time especially if tubes have been changed in the oscillator. The accuracy can be quickly checked by beating the signal from the service oscillator against stations of known frequency using an ordinary radio set to receive both signals.

If the generator has an accurate frequency calibration, set the frequency to an appropriate frequency for the band to be aligned (all aligning frequencies are specified in Meissner Kit instruction sheets) which is usually about 80% of the maximum frequency tunable on that band, set the receiver dial to the corresponding frequency, connect an appropriate "Dummy Antenna" (see following section, "Dummy Antenna") between the high side of the signal generator output and the antenna connection of the receiver, turn the volume and sensitivity controls of the receiver full on, turn the generator up to high output and adjust the *Oscillator* trimmer until a signal is heard. Reduce the signal from the service oscillator as alignment proceeds always using as little signal input as possible because weak signals permit a more accurate alignment than strong signals.

Next align the RF amplifier circuit. On the bands below 6 MC the frequency of the RF amplifier circuit has very little effect upon the oscillator frequency, but at higher frequencies the adjustment of the RF circuit has a slight effect upon the frequency of the oscillator, and consequently it is necessary, when aligning a high-frequency RF amplifier, to rock the gang condenser very slightly as the alignment proceeds to be sure that a shift in oscillator frequency has not shifted the heterodyned signal out of the range of the IF amplifier. The antenna circuit is then aligned in the conventional manner.

Shifting the tuning dial to a point about 10% up from its low-frequency end, the oscillator circuit should be "padded" for best tracking with the antenna and RF circuits. If the radio set is sufficiently sensitive to produce a readily discernable hiss in the speaker, probably the easiest way to pad the oscillator circuit is to adjust the padding condenser for maximum hiss or maximum noise. If the receiver is not sufficiently sensitive to align by the noise method, a signal of constant amplitude should be tuned in, and then as the padding condenser is turned continuously but very slowly *in one direction*, the gang condenser should be rocked back and forth to keep the signal tuned in. If the sound output is plotted against time, Fig. 17 shows the result of the above described operation. The padding condenser should be set as it was at point A, giving best sensitivity.

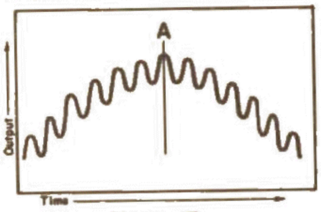

Figure 17

When this point is padded, it is well to return to the high-frequency end and realign that part of the band.

On coils operating in the frequency range 150 to 400 KC with an IF amplifier of 456 KC, the padding capacity is so important in the oscillator tuning scheme that the oscillator should be padded before the high-frequency alignment, and then the circuit aligned and padded at least twice.

Simple receivers can be aligned without instruments by tuning in stations of relatively constant volume, but it is a difficult problem to obtain optimum alignment on any kind of a signal except a constant tone. If the receiver to be aligned is complicated and no equipment is at hand for alignment, it would be well to take the receiver to a serviceman possessing adequate equipment and have him align the receiver.

DUMMY ANTENNA

Receivers are aligned on signals furnished by a "Service Oscillator" or "Signal Generator" because that is the only method of obtaining truly satisfactory signals of constant tone, of adjustable strength, and of the desired frequencies.

In order to make allowance for the effect that the outside antenna will have on the alignment of the receiver, a substitute for the antenna called a "Dummy Antenna" representing the *average* antenna is used to connect the service oscillator to the antenna connection of the receiver.

On frequency ranges up to 1700 KC the average antenna is essentially a capacity of 200 MMF if used on a high-impedance primary. It has an inductance of a few microhenrys but this small inductance can be neglected except in the case of aligning receivers having a low-impedance primary or a Hazeltine low-impedance ccapacity coupling.

On frequencies above 1700 KC, the average antenna can be represented by a 400-ohm carbon resistor.

SPURIOUS RESPONSES IN RECEIVERS

In the dawn of Radio Broadcasting, stations were few in number and limited in power. Receiving sets were likewise extremely simple, employing, as a rule, only one tuned circuit. As the power of transmitters was raised, receivers were no longer able to separate the undesired signal from those desired. Consequently, receivers of progressively greater selectivity were developed, adding tuned circuits for greater selectivity until high quality TRF receivers used as many as six tuned circuits, all ganged together and operating from one knob. The superheterodyne method of reception was then popularized, making possible a degree of selectivity never approached in the best of TRF receivers. Throughout the entire development, spurious responses were, and still are, an important design and service problem.

In TRF receivers, these unwanted responses might be divided into the following classes: cross modulation, adjacent-channel interference, and intercarrier 10 KC whistle.

With the advent of the Superheterodyne method of reception the following additional classes of spurious responses became evident: "tweets" at IF harmonic frequencies, simultaneous reception of two stations separated by a frequency difference equal to the IF frequency, reception of a station located above the dial-indicated frequency by a frequency equal to twice the IF frequency; reception of stations on or close to the intermediate frequency.

With the exception of "tweets" on stations which operate on a frequency corresponding to harmonics of the intermediate frequency, all of the remainder will respond to simple treatment to reduce or eliminate the trouble.

SPURIOUS RESPONSES — CROSS MODULATION

"Cross modulation" in a TRF receiver is, by accepted definition, the modulation of any desired program by some undesired program several or more channels away. This can occur in spite of extreme overall selectivity because it is a function of the selectivity *preceding* the first tube.

In superheterodyne receivers, the term "Cross Modulation" is confined to those modulations which occur at some frequency **not related** to the desired signal **by some simple frequency relation involving the intermediate frequency,** such as, frequency of interfering signal being above the desired signal by a frequency equal to the intermediate frequency or twice the intermediate frequency. These special frequencies are classed as "Image frequencies," and are treated under a separate heading.

"Cross Modulation" is accentuated by the following design features in receivers: (1) A sharp cut-off tube such as a type 24 tube as the first tube in the receiver, (2) lack of selectivity ahead of the first tube, (3) an antenna circuit with a primary resonant near the frequency of a local station when connected to an antenna of proper constants, (4) antenna circuits with extremely close coupling, (5) antenna circuits of very high gain. All of these troubles are caused by having too large a signal of undesired frequency present on the first grid simultaneously with the desired signal. The actual modulation occurs in the first tube after which no amount of selectivity can remove the interfering modulation.

The cure for such trouble is either to use a first tube which has less tendency to cross modulate, such as a variable Mu remote cutoff tube, or to reduce the amount of interfering signal by any one of the following means: (1) Install an appropriate wave trap such as shown in Fig. 18 over A, tuned to the frequency of the interfering station. (2) If the primary circuit is reasonant near the frequency of the interfering stations, change the resonant frequency by a 100- to 200-mmfd. condenser connected either in series with the antenna or connected between the antenna and ground posts of the receiver (3) Shorten the antenna, if long. (4) If a low-impedance antenna coil is used and the interfering station is at the high-frequency end of the dial, install a new antenna coil with high-impedance primary. (5) Connect a resistance across the antenna and ground terminals of the receiver using a value satisfactory for reducing the effect, usually 1000 to 3000 ohms.

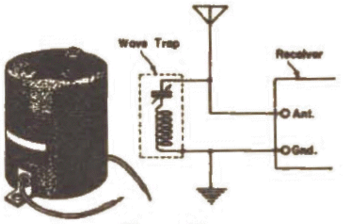

Figure 18

SPURIOUS RESPONSES — ADJACENT-CHANNEL INTERFERENCE

"Adjacent-Channel Interference" is closely related to the adjacent-channel selectivity of a receiver. If insufficient for certain locations and selections of stations, selectivity may be improved by the use of better coils, but in TRF receivers the effort probably does not justify the expense of obtaining new coils of higher "Q" that track properly. In superheterodyne receivers, the adjacent-channel selectivity can easily be improved by installing new IF transformers having greater selectivity than those previously in use. Here no tracking problem is present and standard stock IF transformers may be used. If the original transformers had only fair selectivity, it is recommended that iron-core transformers similar to that shown in Fig. 9 be installed. If the original transformers have good selectivity but still higher selectivity is desired, install triple-tuned IF transformers similar to that shown in Fig. 19. In the latter case, the additional tuned circuits will add selectivity faster, and with better audio quality, than will iron-core IF transformers.

Figure 19

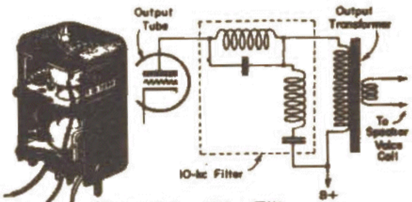

Figure 20 10kc Filter

SPURIOUS RESPONSES — INTER-CARRIER 10 KC WHISTLE

Inter-carrier 10 KC whistles can be suppressed either by increasing the selectivity of the receiver or by filtering out the objectionable 10 KC note. By far the most convenient and economical method is to install a 10 KC filter such as shown in Fig. 20. It will be immediately apparent upon inspection of the circuit diagram, that this filter consists of two tuned circuits, one resonant and one anti-resonant, giving unusual attenuation of the 10 KC interfering note. The constants of the filter have been chosen to permit the audio response to carry out flat very close to 10 KC before the filter begins to attenuate seriously. When the filter does begin to attenuate, however, the output drops very rapidly as 10 KC is approached.

SPURIOUS RESPONSES — IMAGE AND HARMONIC INTERFERENCE

A few superheterodyne receivers have complaints on Cross Modulation, but usually complaints of interference on such receivers are closely tied up to the heterodyne operation and the interferences occur between stations separated by a frequency equal to the intermediate frequency, twice the intermediate frequency or some fractional multiple of that frequency.

Where two local stations, separated by a frequency equal to the intermediate frequency, are observed to ride in on almost any weak program, or to come through simultaneously when the oscillator is blocked, one is acting as the heterodyne for the other to produce the intermediate frequency. The remedy for such trouble is to install a wave trap tuned to the stronger of the two stations; a second method, but one which disturbs tracking and dial calibration, is to re-peak the IF transformers on a new frequency, far enough from the frequency difference between the two local stations to avoid the trouble. Depending upon conditions, the shift may vary from 10 to 25 KC either above or below the original frequency. Receivers having oscillator padding condensers should be repadded and re-aligned. This treatment is not recommended where receivers have specially cut oscillator plates on the gang condenser for purposes of tracking.

"Image interference," which is by far the most important type of superheterodyne interference, is that interference which is produced by a station located above the desired station by a frequency difference equal to twice the intermediate frequency.

The cause of image interference is that the heterodyne principle works on a frequency difference, irrespective of whether the desired signal is below or above the oscillator frequency. The first detector tube cannot recognize and differentiate between signals above and below oscillator frequency. If the frequency difference is correct, the first detector produces an IF signal. The selection of the signal frequency (usually below the oscillator frequency) and the rejection of the image frequency (usually above the oscillator frequency) is the function of the tuned circuits ahead of the first detector. The ordinary types of receivers have only one tuned circuit ahead of the detector with consequently poor image ratio. Commercially good receivers have two tuned circuits, producing much higher image ratios. A few very high class receivers have three tuned circuits producing a *measured* image ratio far better than most such receivers are capable of producing when operating on a broadcast signal rather than operating from a signal generator because of inadequate shielding.

In general, the image rejection is a direct function of the "Q" of the antenna and RF circuits and of the number thereof, but there are a few receivers employing special schemes to improve image response at certain points in the band.

Generally, image ratio is a built-in function of the receiver that it is not economical to change by the addition of tuned circuits or improvement in coil design.

Where "Image" interference is experienced from only one local station, a wave trap can be connected to remove that interference. If, as is sometimes the case, the desired station is an important out-of-town station and the interfering image station is a powerful local transmitter, it may be necessary to employ a double wave trap such as shown in Fig. 21 which gives extreme attenuation to a narrow band of frequencies.

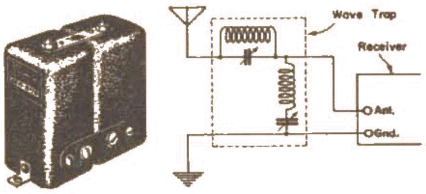

Figure 21 Dual Wave Trap

In some cases, where it is permissible to alter the calibration of the receiver slightly, image trouble between a definite pair of stations can be eliminated by shifting the intermediate frequency, but such treatment merely shifts the image interference to another station.

SPURIOUS RESPONSES — IF HARMONIC "TWEETS"

"Tweets" on harmonics of the intermediate frequency can best be eliminated by shifting the intermediate frequency. Admittedly, this treatment merely moves the interference from one to another station but, in general, the problem of attenuating IF tweets is so complex that the work of eliminating them is not justified unless the results can be applied to a large number of similar receivers. Usually, moving the intermediate frequency to shift the tweets to another station is the only economical correction to apply.

SPURIOUS RESPONSES — IF INTERFERENCE

Reception of undesired stations on or near the intermediate frequency is caused by inadequate attenuation to IF ahead of the first detector. Usually, two-gang superheterodynes only are troubled with this type of interference, but occasionally even three-gang receivers will exhibit this type of trouble when close to such interfering stations. The usual remedy is the use of a wave trap of the type shown in Fig. 18 which may be adjusted to the intermediate frequency of the receiver if the interference is weak, or the use of a two section trap similar to the two section image trap illustrated in Fig. 21 if the interference is bad.

REGENERATION AND OSCILLATION

In the design and construction of radio receivers, employing either a limited number of amplifier stages with very high gain per stage, in an attempt to obtain the greatest possible sensitivity and selectivity from a given investment in parts, or in the design of a super-sensitive receiver having a multiplicity of conservatively designed stages, one of the limiting factors in the direction of extreme sensitivity is regeneration, which, when extreme, results in oscillation.

Regeneration is the process of building up a voltage by re-amplifying a voltage that has already passed through an amplifier. It is caused by feeding back a voltage from one point in an amplifier to some preceding point **working at the same frequency.**

Regeneration is usually present in some degree in all receivers, sometimes by design and sometimes by accident. When limited to a relatively small amount, it is useful and can be handled in quantity production of receivers with a fair degree of uniformity, but when employed in large amounts, the production variations between receivers is apt to be quite large, because regeneration tends to exaggerate relatively small differences in individual set components. In addition, receivers employing large amounts of regeneration will usually exhibit far greater changes in sensitivity, as a function of humidity variations, than will sets with little regeneration.

Normally, in domestic broadcast receivers, whatever regeneration there is has been limited by design constants to a value that will not cause trouble, and therefore no control is provided to be set by the user. In amateur receivers, controlled regeneration is employed to accomplish amazing results in the hands of an experienced operator attempting to obtain the maximum possible performance from the minimum of equipment. Usually in such cases the regeneration control is second in importance to the tuning control, requiring re-adjustment as soon as the receiver dial is moved an appreciable amount.

From the above it is not to be concluded that regeneration, of itself, is undesirable, because it can, if judiciously used, add a great deal to the performance of a receiver. What is to be concluded, however, is that in the design of a receiver, the amount of regeneration present under the best and worst operating conditions should be determined, and the regeneration limited to an amount that is safe for the type of service for which the receiver is intended.

In receivers which have not been properly checked for regeneration, conditions sometimes exist that permit the receiver to regenerate until sustained oscillations result under certain weather, tuning, or antenna conditions, or when receiving signals below certain strengths.

Regeneration may be broken down into two general classifications even though fundamentally the cause is the same. These two classes are single-stage regeneration and over-all regeneration.

SINGLE-STAGE REGENERATION

Single-stage regeneration in amplifiers is usually the least understood type of regeneration trouble and frequently has baffled many service men and radio experimenters. It is peculiar in that no amount of isolation and filtering applied to screen, cathode, plus "B" or grid return seems to make any improvement.

The feedback actually occurs inside of the tube in the stage that is giving trouble. The coupling exists between grid and plate through the inter-electrode capacity of the tube or any additional stray capacity between these two points. To some, this may seem unreasonable when the inter-electrode capacity is as low as .01 mmfd. or less, but it is an actual fact that is easily proven.

When single-stage oscillation is suspected, raising the grid bias will stop the regeneration, but so will this change stop over-all regeneration. The true test for this phenomena is to connect a milliammeter (properly bypassed) in the plate circuit of the suspected tube as shown in Fig. 22. Remove the preceding and following tubes, and then place an intermittent short-circuit on either the grid or plate circuit of the suspected stage while watching for changes in the plate current in that tube as an indication of the starting and stopping of oscillation. The tube and associated tuned

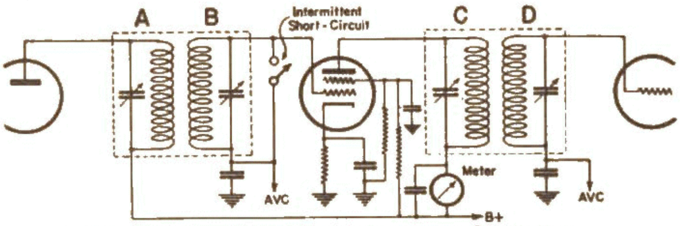

Figure 22 Test for Single-stage Oscillation

circuits form a tuned-grid-tuned-plate oscillator similar to a transmitting circuit that was very popular in the early days of vacuum tube transmitters.

The standard cures for this trouble are:

(1) Use a tube with lower inter-electrode capacity.

(2) Neutralize the inter-electrode capacity.

(3) Reduce the gain of the circuit by raising the tube bias.

(4) Reduce the value of the resonant impedance in either grid or plate circuits, or possibly both. This may be done by using coils of lower Q, or coils of the same Q but lower inductance, or by tapping one or both of the tuned circuits so that only a portion of the resonant impedance is introduced into the grid or plate circuit.

This type of oscillation is not confined to intermediate-frequency amplifiers but is encountered in RF amplifiers as well, if the primary is closely coupled to the secondary (as most shortwave RF primaries are) and has too many turns in an attempt to obtain high RF stage gain. In such cases it is necessary to reduce the number of primary turns until single-stage oscillation stops.

A peculiar effect may have been observed by some experimenters that they have never been able to explain, which can be understood when considered in the light of single-stage regeneration. This phenomenon is that a given amplifier stage may be stable when lined up properly, but will be unstable and oscillate when one or two of the associated circuits are misaligned. This phenomenon may have been observed accidentally and has not been reproduceable because the reasons were not understood. Referring to Fig. 22 it will be seen that the resonant circuits are lettered for easy identification. Consider that the middle tube is the offender, but with all circuits aligned it refuses to oscillate or give any other evidence of misbehavior. If circuit A is progressively misaligned in one direction and circuit D progressively misaligned in the opposite direction, single-stage oscillation will soon result. The same results can be accomplished on variable coupling IF circuits, that are mechanically variable, if the coupling is progressively reduced. The explanation is the same in both cases, but is accomplished by a different agency. In both cases the impedance of circuits C and D rises until single-stage oscillation occurs through the inter-electrode capacity of the tube. The explanation for this statement is given here below.

When a single circuit is resonant it presents a definite resonant impedance that is a direct function of its "Q" and its reactance. If another similar circuit, similarly resonant to the same frequency, is coupled to the first circuit, and set near "Critical Coupling" the resonant impedance of the combination approaches half the impedance of either circuit separately. It is this loading effect that keeps the impedance down when all circuits are aligned, and the absence of which, when circuits A and D are detuned, that permits the impedance of circuits B and C to climb high enough to cause single-stage oscillation.

OVER-ALL REGENERATION

Over-all oscillation is a familiar complaint on multi-stage TRF receivers even of good design, and on IF amplifiers of high gain. On experimental receivers in the process of development it may be produced by any one of a number of causes. Only by experiment can the offending source of coupling be discovered and removed. It may be of two general types, high-impedance or low-impedance, or might be considered voltage feedback and current feedback although all feedback phenomena in radio receivers are, strictly speaking, voltage feedback phenomena.

Coupling between antenna and grid or plate leads, and couplings between grid leads or plate leads, etc., all of which are relatively high voltages impressed on the very small capacities existing between the points just mentioned are classed as high-impedance feedbacks. Appropriate partition type shielding quickly stops this type of feedback.

Under the heading of low-impedance feedbacks are placed all oscillation troubles resulting from the use of common cathode, screen or plate bypass condensers, common leads in high-frequency circuits, couplings resulting from the common shaft of a gang condenser, etc. Eliminating oscillation from these sources requires a study of the receiver and many experiments, isolating the various circuits that are suspected of causing the feedback, until finally the real offender is discovered.

Sometimes feedbacks are degenerative instead of regenerative and the disconcerting fact may be discovered in some cases that isolation of certain circuits increases rather than decreases oscillation troubles.

On manufactured receivers made by a reputable company which attempts to keep uniform quality, over-all oscillation after some time in service can usually be quickly traced to some circuit element that changes characteristics with age. For example, if no paper condenser is used across the electrolytic filter condenser to insure a permanent low-impedance RF path to ground, over-all IF oscillation can occur when the RF resistance of the electrolytic filter condenser increases with age.

In TRF receivers, frequently high-resistance contacts between the gang condenser shaft and the wipers causes over-all oscillation which can be eliminated by a thorough cleaning of the contacting surfaces. Common bypass condensers also should be suspected as the cause of feedback. When they are, they are usually found very easily by connecting a known good condenser across each bypass condenser successively until the defective unit is found.

INTER-ELECTRODE CAPACITY

It has been pointed out, in the section on Single-Stage Oscillation, that the coupling medium for such oscillation is the inter-electrode capacity of the tube.

The method of measuring such small capacities in the presence of much larger capacities in a network that cannot be opened to measure the desired capacity directly may be of interest.

Fig. 23 represents the capacity network that exists in the tube as far as feedback capacities are concerned.

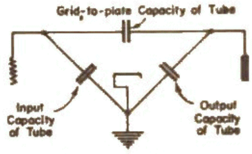

Figure 23

The method of measurement is to have a similar network, Fig. 24, in operation, supplying a voltage to some measuring device and fed by a source with the proper characteristics. The output capacity of the tube is connected across the measuring circuit and a reading obtained on the output meter; then, when the grid of the tube is connected to the source of voltage, there will be an increased reading on the meter. The calibrated condenser is then reduced in capacity until the meter reads as before. The inter-electrode capacity of the tube is the difference in the capacity of the calibrated condenser at its two settings.

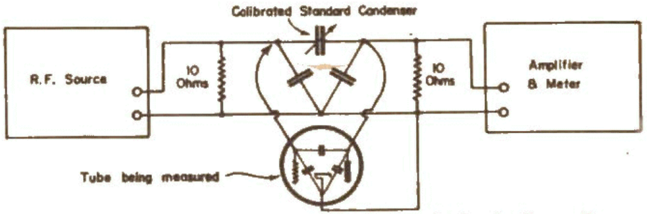

Figure 24 Measurement of Inter-electrode Capacity

The calibrated condenser for the above measurement is an elaborate device not available to the experimenter or service man, therefore the above method of checking inter-electrode capacity cannot be attempted, but a very similar method can be used to check the uniformity of inter-electrode capacity in the manner shown in Fig. 25. Here a signal generator or service oscillator is used to furnish a signal to a low-impedance load so that the input-impedance of a tube may be connected across it with negligible change in voltage. The inter-electrode capacity feeds the signal into the radio receiver across whose input a low-impedance load has been connected so that variations in the output capacity of the tube will be swamped out. An output meter on the receiver will serve to indicate the relation between tubes of differing inter-electrode capacity.

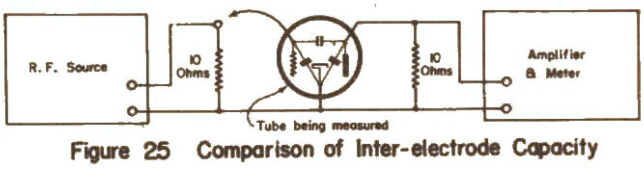

Figure 25 Comparison of Inter-electrode Capacity

The above system for comparing inter-electrode capacities has been successfully used in a number of laboratories desiring checks on inter-electrode capacity but which were unable to purchase complete equipment for making these measurements. It probably is not a measurement that any service man will have occasion to use, but some advanced experimenters, attempting to obtain the maximum possible performance from circuits, may desire to check their tubes for this parameter.

FIDELITY vs. SELECTIVITY

One of the most frequent requests from experimenters working on high-fidelity receivers is for IF components that will permit high-fidelity reception, yet have good adjacent-channel selectivity.

The following considerations will show that it is impossible to meet both specifications simultaneously. In order to transmit a single audio frequency by the double sideband transmission method which is standard on all types of broadcast and shortwave entertainment transmissions, a carrier and two additional frequencies are required. These additional frequencies are located one above and one below the carrier frequency by an amount exactly equal to the audio frequency. For example, if it is desired to transmit a 10 KC note on a 1000 KC carrier, the upper sideband will be 1010 KC and the lower sideband will be 990 KC. It can be shown mathematically and it can actually be demonstrated that in the above case three separate signals exist, if a sufficiently selective receiver is used for the demonstration. Since it is the American practice to assign broadcasting frequencies at 10 KC intervals, it is obvious that the 10 KC transmission of the 1000 KC station above mentioned will fall exactly on the carriers of the two adjacent channels and will produce heterodynes that will give rise to spurious audio responses in any receiver having a selectivity curve wide enough to pass both sidebands on a 10 KC modulation.

Since it is reasonable to assume that there will be modulation on both adjacent channels it will be obvious that the transmissions of the two adjacent channels will encroach upon the territory that the 1000 KC station is using if it modulates up to 10 KC. Now if all three stations are producing a signal of equal intensity and are all modulating up to 10 KC the receiver will not be able to separate these three programs. If, however, the pass-band of the receiver is narrowed down until it accepts a band of frequencies only 4 KC above and below its mid-frequency, it will accept from the adjacent channels only those frequencies above 6000 cycles which frequencies carry a comparatively small part of the energy of speech or music and consequently will not interfere with the desired program to as great an extent.

If the ratio of desired signal strength to adjacent-channel strength is now changed so that the desired signal is many times stronger than the adjacent channel signal strength, the pass-band of the receiver can be increased considerably without introducing appreciable interference.

From the above it can be seen that "High-Fidelity" reception can be used only where the ratio of desired signal to adjacent-channel signal is very great, say 1000 times or more, and that, unless the receiver is confined to the reception of local stations, it must be able to sharpen its selectivity curve when it is desired to select one station whose signal strength is near or below the signal strength of the adjacent channels. In order to accomplish this economically, IF transformers, whose physical and electrical features are shown in Fig. 26, are available. In these transformers, the pass-band is varied by changing the coupling between primary and secondary, by means of a tapped coil in series with one winding closely coupled to the other. By this arrangement a very high percentage change in coupling can be accomplished with practically no change in the self-resonant frequency of the tuned circuit which has been switched. This arrangement permits one receiver to be adjusted for either wide or narrow pass-band instead of requiring two independent receivers of the desired characteristics.

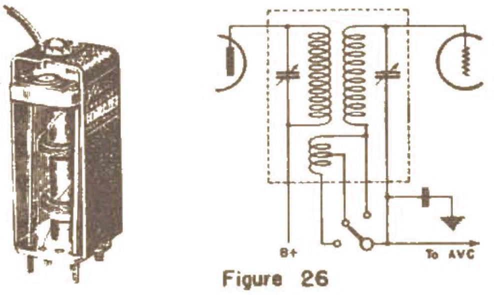

Figure 26

DISTORTION IN DIODE DRIVER STAGES

When a diode detector must work at reasonably high levels, as in the case of feeding a low-gain audio system such as a type-55, -85 or -6R7 tube working a push-pull stage through a transformer, considerable energy is required by the diode and its load resistance.

If the gain of the diode driver tube is varied by means of the conventional AVC circuit wherein full AVC voltage is applied to all controlled tubes, it may be found that very serious distortion is produced at high signal levels. If such distortion occurs, it is probable that the last IF tube is not able to furnish the power output required to properly drive the diode circuit when this IF tube has a relatively high bias. The quick test for this trouble is to remove the AVC voltage from the last IF tube and hold its bias constant at its nominal minimum value while the receiver is again checked for distortion. If the above test eliminates the distortion, that tube may be left without AVC or may have applied to it only a fraction, usually ¼ to ½ of the voltage that is applied to the remaining tubes.

MICROPHONICS

In the original design of receivers one of the most exasperating and illusive problems confronting the radio engineer is that of preventing "Microphonic Howls." First-class radio manufacturers usually do everything economically practical to minimize this trouble but, even in spite of these efforts, this trouble still produces many service calls.

The cause of the trouble is easily understood, but finding the offending item is usually a difficult job with many apparently correct answers proven wrong before the real offender is found. Often when one source of trouble is eliminated another shows up.

The most powerful tool for the solution of such a problem is the combination of audio oscillator, audio amplifier, output meter and unmodulated signal generator. Fig. 27 shows the arrangement of parts for the test.

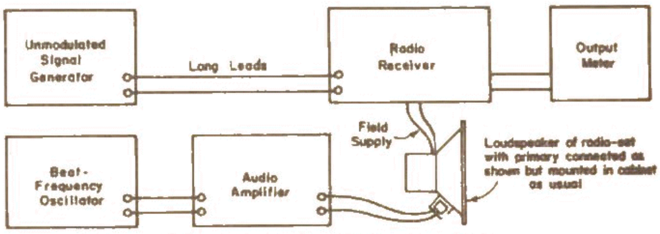

Figure 27 Mechanical Vibration Test

The receiver is tuned to the signal generator using modulation on the generator, if necessary, to properly tune the receiver. The modulation is removed without disturbing the tuning of either generator or receiver and the beat frequency oscillator is started, putting into the speaker an output approximately equal to the full output of the receiver. As the beat frequency oscillator is run over the audio range from 60 to 5000 cycles slowly, various sharp peaks will be noticed on the output meter. This audio output from the receiver is caused by the mechanical vibration of some part of the receiver modulating the CW carrier supplied by the generator. The actual means of modulation may be the vibration of a condenser changing capacity in time with the vibration to produce capacity modulation of a tuned circuit, or vibration of a coil or coil lead may give inductive modulation of the tuned circuit, or vibration of the elements in the tube itself may give direct modulation of the electron stream. Whatever may be the modulating element, the best chance of locating it quickly is provided by the above setup. The beat frequency oscillator is set to the frequency giving the greatest reading on the output meter and a search is made for the element producing this modulation. If the source is found, some means usually can be found to eliminate or reduce the trouble.

As the frequency to which the receiver is tuned increases, the percentage change in frequency necessary to produce howling becomes increasingly smaller. In the shortwave range the stability required to eliminate howling is so great that it is practically impossible to eliminate all howling on high volume. In many cases, shortwave receivers with the speaker in the same cabinet with the radio set cannot be operated at full volume. Receivers have even had their oscillator coil and oscillator tuning condenser poured full of wax to prevent vibration and still could not be kept from howling at high volume on shortwaves! Service problems of eliminating microphonic howls should be undertaken with due consideration of the difficulties involved and of the impossibility of producing a 100% permanent cure if the receiver has a shortwave range and has its speaker in the same cabinet with the receiver.