HOW BROADCAST, ALL-WAVE, AND TELEVISION SUPERHETERODYNE RECEIVERS WORK

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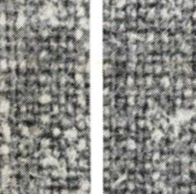

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STUDY SCHEDULE NO. 23

This textbook is crammed with practical facts, practical circuits and practical servicing hints for superheterodyne receivers, most of these being based upon radio theories presented in previous lessons. This means that, if any subject in this lesson gives a bit of difficulty, you can clear up things by reviewing the previous lesson which covers the theory of that subject. Thus, if the operation of the local oscillator in a superheterodyne is not quite clear to you, review the lesson on oscillators.

☐ 1. The Superiority of the Superheterodyne ....Pages 1-5

A brief comparison of the superheterodyne and the t.r.f. receiver. A review of the parts of the superheterodyne. Answer Lesson Questions 1 and 2.

☐ 2. The Importance of the Preselector ....Pages 6-13

By presuming that there is no preselector, we show the number of undesirable interference conditions which can exist. There are a number of service hints in this section, so study it carefully. Answer Lesson Questions 3, 4, 5 and 6.

☐ 3. The Local Oscillator ....Pages 14-17

There are a number of requirements placed on the local oscillator. It has to supply a voltage at the proper frequency, without frequency drift, and without fluctuations in amount. Typical circuits are shown.

☐ 4. The Mixer-First Detector ....Pages 18-24

This is the stage where the frequency change takes place. Today, combination oscillator and detector stages are the most common, so be sure to study these circuits carefully. Answer Lesson Question 7.

☐ 5. Oscillator-Preselector Tracking ....Pages 25-30

To the serviceman, this is a very important section. Alignment of receivers to obtain the proper tracking is a frequent service step, so read this section a number of times. Answer Lesson Questions 8 and 9.

☐ 6. The Intermediate Frequency Amplifier ....Pages 31-34

The importance of the choice of the i.f. value; typical circuits; requirements for high fidelity; variable selectivity. Answer Lesson Question 10.

☐ No. 7 The Television Superheterodyne ....Pages 35-36

This short section shows how television sets use standard circuits, with certain modifications, for video signal amplification. This is a preview of this branch of radio.

☐ 8. Mail Your Answers for this Lesson to N.R.I. for Grading.

☐ 9. Start Studying the Next Lesson.

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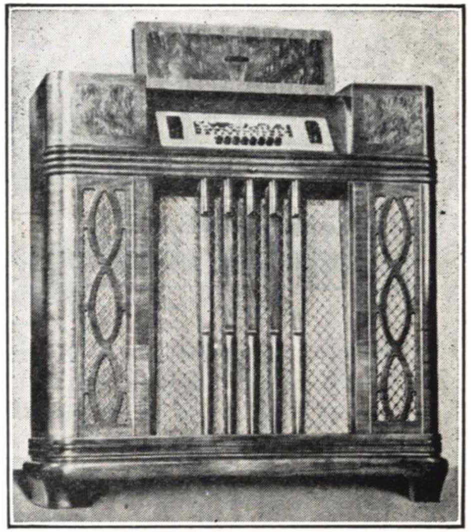
HOW BROADCAST, ALL-WAVE, AND TELEVISION SUPERHETERODYNE RECEIVERS WORK

The Superiority of the Superheterodyne

THE superheterodyne receiver is by far the most common type of radio set in use today, so it is well worth further study. You have learned, in previous lessons, how almost all the components of a "superhet" function and have been given a preview of this circuit. Now we will collect this information and show you in more detail how the various components act when they are combined. If you find you are a little hazy on the operation of some individual circuit component, by all means make a quick review of the lesson in which it was discussed. Doing so will make it much easier for you to grasp all the details of the operation of the superheterodyne.

Basically, the superheterodyne principle of r.f. amplification involves the conversion of each incoming signal within the receiver tuning range to one definite fixed radio frequency which is known as the intermediate frequency or the i.f. value.* It is much easier to get optimum (best) results from an r.f. amplifier which always works at the same frequency, as in the i.f. amplifier in a superheterodyne receiver, than from an amplifier which is tuned through a wide range of radio frequencies, as in t.r.f. receivers.

► This is true for frequency modulation receivers as well as for amplitude modulation receivers. Incidentally, both use the same *sections*—the important differences are that an FM receiver has a slightly different i.f. design, uses a limiter stage, and has a different demodulator or second detector. (FM receivers are described fully in another lesson.) This lesson covers AM receivers; however, you will need all this information to gain a complete understanding of FM receivers.



Courtesy Philco

This large console radio uses the superheterodyne circuit.

Review of R.F. Amplifier Operation. If you will review in your mind the action of an r.f. amplifier, you will recall that the gain and selectivity of

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*When a signal demodulator (second detector), audio amplifier, loudspeaker, and power pack are added to a superheterodyne r.f.-i.f. amplifier, the result is a complete superheterodyne receiver. The above-mentioned sections of the receiver are of conventional design and are all covered thoroughly elsewhere in the Course.

any stage are dependent upon the resonant resistance of the plate load; this resonant resistance depends upon L/C (the ratio of coil inductance to condenser capacity), and upon the losses in the tank circuit. In tuning to different frequencies, we vary the condenser capacity and thus vary the L/C ratio. For this reason, and because tank circuit losses are different at each frequency, uniform amplification at all frequencies is not obtained readily. Thus the amplification and the selectivity of a t.r.f. receiver are different at each setting of the tuning dial.

► In the superheterodyne receiver, on the other hand, practically all of the gain and selectivity are produced at one fixed i.f. value, regardless of the frequency of the incoming signal; selectivity and sensitivity are therefore uniform at all tuning dial settings.

A comparison of the performance curves of a superheterodyne receiver with those of a t.r.f. receiver having approximately the same number of tubes will show very clearly the superiority of the superheterodyne. Such curves are given at *A*, *B*, *C* and *D* in Fig. *1*. In these, sensitivity is measured in terms of microvolts of signal input required to get a 50-milliwatt output; thus, a lower input value means a more sensitive receiver. The sensitivity curve for the superheterodyne (Fig. *1A*) is practically constant for all frequencies in the tuning band, while the same curve for the t.r.f. set (Fig. *1B*) varies considerably and represents much lower sensitivity. The selectivity curves in Figs. *1C* and *1D* give, for various frequency values off resonance, the ratio of signal input at resonance to the signal input required to give the same output at the off-resonance frequency: the steeper the curve, the more selective the receiver. The curve in Fig. *1C* (for the super) thus represents very good selectivity which is uniform at all frequencies in the band, while the curves in *1D* (for the t.r.f. receiver) show poor selectivity at 600 kc., and show increasingly poorer selectivity at higher frequencies in the band.

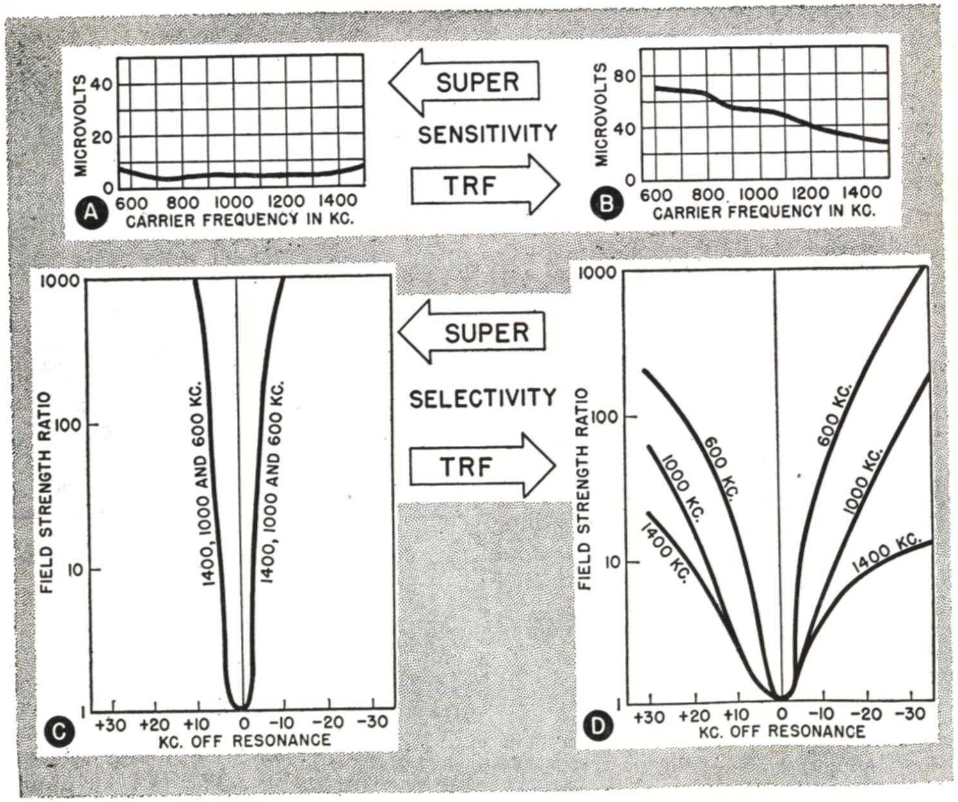


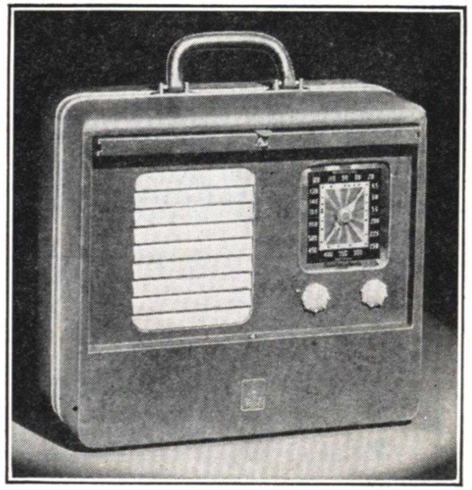
FIG. 1. These sensitivity and selectivity curves for a superheterodyne receiver and for a t.r.f. receiver show clearly the superiority of the superheterodyne.

► If a t.r.f. receiver were designed for all-wave reception, it would be necessary to change every coil in the set each time the band* was changed. In a superheterodyne receiver, however, only the coils in the preselector and oscillator sections need be changed. Because of this, every practical all-wave receiver is a superheterodyne. In addition, the public demand for high-fidelity reception, which entails amplification of wide side bands over the entire range of carrier frequencies, is easier to meet with the fixed i.f. amplifiers used in supers. It is no wonder that the superheterodyne is the most widely used system today; only a few of the compact and inexpensive midget receivers are manufactured now with t.r.f. circuits.

PREVIEW OF SUPERHETERODYNE PRINCIPLES

Before the i.f. amplifier can do its job, the incoming signal with its picture or sound modulation must be converted to the intermediate frequency selected. This is done by combining the *incoming modulated r.f. carrier* with a *local r.f. oscillator signal*—a process called "frequency conversion."

Now, when two signals of different frequencies are mixed together and sent through a detector or demodulator tube circuit, the plate current will consist of many components. There will be signals at the two original frequencies, a signal whose frequency is the difference between the original frequencies, a signal whose frequency is the sum of the original frequencies, and harmonics of all four of these frequencies. Each of these plate current components will carry the original modulation. By placing a highly selective resonant or tank circuit in the plate circuit of the detector, we can tune to any signal component and thus separate it from the others. Inasmuch as it is easier to make selective high-gain amplifiers for low r.f. values, the *difference* between the two original frequencies is always selected as the i.f. value.



Courtesy Emerson Radio and Television Corp.

Battery-operated portables like this use the same basic superheterodyne circuit as is used in power-line operated sets, except for the use of battery type tubes.

If, for example, the incoming frequency is 1000 kc. and the local r.f. os-

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*The range of frequencies which can be covered by a given combination of a coil and a condenser when one of them is variable is called a *band*.

cillator signal frequency is 1175 kc., the plate current of the detector circuit will contain these two frequencies, as well as 2175 kc. (the sum frequency) and 175 kc. (the difference frequency). From what we just said, the 175-kc. frequency will be selected as the i.f. value. The following stage (the i.f. amplifier) will be designed to pass and amplify only this 175-kc. signal and such side frequencies as are required to give the desired fidelity characteristic to the receiver.

Now, when a 500-kc. signal is tuned in, a local oscillator signal of either 325 kc. or 675 kc. will produce a difference frequency of 175 kc. If the incoming signal is 1500 kc., a local oscillator signal of either 1675 kc. or 1325 kc. will produce the required i.f. value. This brings up the question of whether we should make the oscillator frequency lower or higher than the signal frequency.

► Let us consider this problem for a receiver which is to tune from 500 kc. to 1500 kc., with the i.f. at the fixed value of 175 kc. Clearly, the local oscillator must vary in frequency either from 325 kc. to 1325 kc. or from 675 kc. to 1675 kc. In the first case (325 to 1325) there is a 4 to 1 change from the highest to the lowest frequency, and in the second case (675 to 1675) there is a 2.5 to 1 change. As a practical matter, it is difficult to tune a coil and condenser combination over a range having a frequency change which is greater than about 3.3 to 1. For this reason, the local oscillator in a superheterodyne is generally made to produce a frequency *higher than that of the incoming signal.* In our example, then, the oscillator would vary in frequency from 675 kc. to 1675 kc. as the receiver was tuned from 500 kc. to 1500 kc.

► Turning now to a block diagram of a superheterodyne type r.f. amplifier (Fig. *2*), we find that there are four important sections: *1*, the preselector; *2*, the local oscillator; *3*, the mixer-first detector; and *4*, the i.f. amplifier. Before we study these sections in detail, let us see what the important functions of each are.

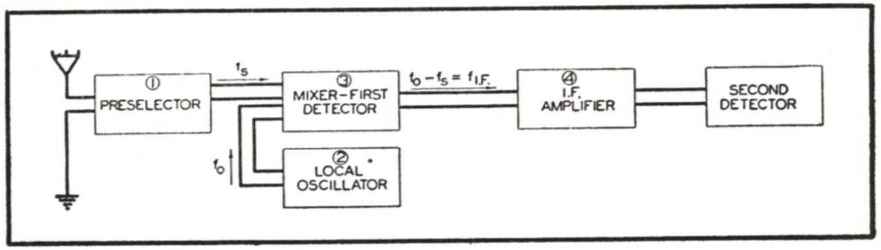

FIG. 2. A block diagram showing the four important r.f. sections of a superheterodyne; the second detector and the stages following it are identical for both t.r.f. and superheterodyne receivers, and hence are not discussed in this book.

Preselector. The preselector consists of one or more resonant circuits which can be adjusted to the frequency of the desired r.f. signal; it may or may not have r.f. amplifier stages. Theoretically, the preselector is not necessary in order to convert an r.f. signal to a lower frequency value. If you omit it, however, interfering signals will get into the mixer-first detector and they will react with each other or with the local oscillator signal to produce undesired signals at the i.f. value. Some gain (amplification) in the preselector is always desirable, because the mixer-first detector creates inherent noise which can be over-ridden only by a strong r.f. signal.

Local Oscillator. Frequency conversion cannot take place unless a local signal is produced, which differs from the incoming r.f. value by the i.f. value. A local oscillator is therefore of fundamental importance in the superheterodyne circuit. The preselector tuning condenser and the oscillator tuning condenser either can be controlled independently or can be ganged together and controlled by a common tuning dial. The latter practice is now universally followed, for with it the oscillator is always at the correct setting to deliver a signal differing from the incoming signal by the i.f. value. Besides giving single-dial tuning, ganging together the oscillator and preselector tuning condensers reduces what is known as *repeat point reception*—a phenomenon which we will discuss a little further in this lesson.

Mixer-First Detector. This is the actual point of frequency conversion. Of great importance is the ability of this section to act as a detector for both the incoming and local oscillator signals, provided they are of reasonable intensity. Its plate circuit must contain a highly selective, high Q tank circuit having a resonant frequency equal to the i.f. value (the difference frequency), so this frequency can be accepted and the other plate circuit components rejected. This tank circuit should have a low L/C ratio, so the resulting high capacity value will then act as a by-pass for the unwanted signals.

I.F. Amplifier. Here the i.f. signal, modulated with the original picture or sound signal, gets its real boost in gain. The i.f. amplifier must be able to amplify the i.f. signal and some or all of the important side-band frequencies, depending upon the type of receiver performance desired. The i.f. amplifier can be made highly selective, thus cutting out undesirable signals as well as unimportant side-band frequencies of the radio signal being received, or it can be made to have broad band-pass characteristics, thus passing a wide range of side frequencies. In the first case the i.f. amplifier is said to have good *adjacent channel selectivity,* and in the second case it has *high-fidelity* response characteristics.

Now that you've had a "preview" of the action of a superheterodyne r.f. amplifier, let's take up each section in detail. We will start with the preselector.

The Importance of the Preselector

It is possible to impress a desired signal directly (without tuning) on the grid-cathode terminals of the mixer-first detector tube in a superheterodyne r.f. amplifier circuit and to secure, with the aid of the local oscillator, a beat frequency output signal having the desired i.f. value. Of course this is never done in practice, because there are a number of undesirable results. By considering first the effects encountered in a theoretical direct-input circuit (one having no preselector), we can learn a great deal about the importance of the preselector and about the problems which may be met in service work.

Direct Input Circuit. The mixer-first detector section of a superheterodyne circuit which has no preselector is given in Fig. *3;* any signal f_s which is picked up by the antenna flows through resistor *R* to ground, and the r.f. voltage developed across this resistor is fed *directly* to the grid of the tube. The local oscillator feeds into the cathode circuit of the tube a signal which we will designate as f_o. Assume that the frequency of this signal can be independently controlled by varying the setting of oscillator tank condenser C_o. The resonant circuit in the plate lead of the tube is adjusted to the desired i.f. value $f_{I.F.}$, so that only the i.f. current produces a voltage drop across the i.f. resonant circuit for further amplification. For the present, we need not consider any other parts or sections of this superheterodyne circuit.

REPEAT POINTS (DOUBLE-SPOT TUNING)

Assume that only one signal, having a frequency of 1000 kc., is being picked up by the antenna in Fig. *3,* and that the i.f. resonant circuit is adjusted to an i.f. value of 100 kc. Under these conditions the required 100-kc. beat frequency $f_{I.F.}$ will be produced when the oscillator is tuned to 1100 kc. But we can also secure this 100-kc. beat frequency by setting the oscillator to 900 kc. Thus, there are two oscillator tuning dial settings at which the 1000-kc. incoming signal will be passed on to the i.f. amplifier. This condition is called *repeating* or *double-spot tuning,* for we have *repeat points*—two different settings at which the same station can be received—on the oscillator tuning dial. These repeat points are present in any superheterodyne circuit *when the oscillator can be separately tuned,* even if resistor *R* is replaced with a highly selective preselector circuit. The *repeat point for any one station is always separated from the correct oscillator dial setting by twice the i.f. value.*

► Of course, superheterodynes with separately tuned oscillators have long been obsolete. Ganging the preselector and oscillator will give single dial control and, in addition, will serve to eliminate repeat-point reception provided a good preselector is used.

Service Hints. A repeat point can occur in a single-dial receiver if the selectivity of the preselector is too low or is impaired by a circuit defect or improper adjustment, or if the signal from the station is exceedingly strong. In each case, you would hear a station at its correct dial setting and at a repeat-point setting which will be *below* the correct dial frequency setting by twice the i.f. value (assuming that the oscillator tunes *above* the frequency of the incoming signal). Examine the set for defects and check the alignment. If there appear to be no defects and the alignment is normal, then the condition may be due to the design of the receiver. If no interference occurs with another desired signal, then you can ignore the condition, as it is impractical to change the receiver design. (Explain it to the customer if he remarks about it.) However, if there is interference, you should follow the hints in the next section of this lesson.

IMAGE INTERFERENCE

From your own experience you know that signals of many different frequencies are always present in the antenna circuit of a receiver. Let us, therefore, assume that in addition to the desired 1000-kc. signal, there is an undesired 1200-kc. signal in the antenna circuit of Fig. *3.* The oscillator is set at 1100 kc. in order to convert the desired signal to the i.f. value of 100 kc., but the undesired 1200-kc. signal can also mix with the 1100-kc. oscillator signal and produce a 100-kc. beat frequency. Both the desired 1000-kc. signal and the undesired 1200-kc. signal will then get through the i.f. section, be reproduced by the loudspeaker, and cause interference. This occurs when an interfering signal, whose frequency is above the desired signal *by twice the i.f. value,* is heard along with the desired signal. This condition is called *image interference.*

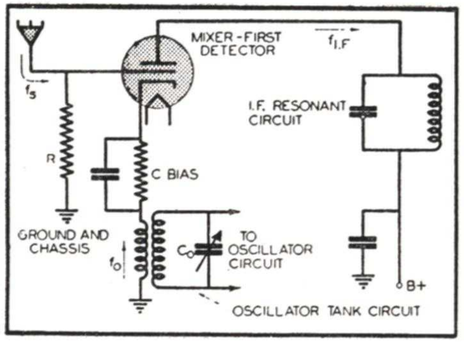

FIG. 3. Schematic diagram of the mixer-first detector section of an imaginary superheterodyne receiver which has no preselector.

► **Notice that** image interference is caused by repeat-point reception of an *undesired* station—in fact, a repeat-point signal could be called an image. The only difference is that now the undesired signal is interfering with a desired signal.

► The obvious solution to this problem is to use a highly selective preselector which is capable of tuning to the desired signal and of rejecting the image signal. However, the ideal preselector, which will allow only a single frequency or a narrow band of frequencies to pass and will absolutely reject all other frequencies, does not exist. An engineer is quite satisfied if he can design a preselector which *reduces* the strength of the interfering station (at the image frequency) 1000 times.* This number is called the *image interference ratio* and, in this case, means

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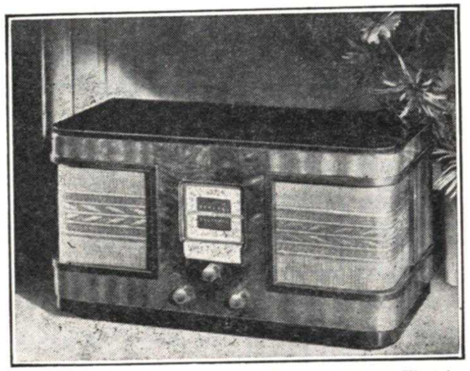
*This ratio value must be considerably higher in receivers which have high-gain i.f. amplifier sections. In all-wave receivers, however, ratios as low as 100 to 1 for the higher frequency bands are considered acceptable because it is difficult to design all-wave sets with better ratios.

that an undesired image signal (of a strength equal to that of the desired signal) will be heard 1000 times weaker than the desired signal.

► Naturally, the closer the desired and undesired frequencies are to each other, the greater the problem is of separation. When a low i.f. value is used, it often takes two or even three preselector tuned circuits in cascade to get an image interference ratio of 1000, and this increases the cost of building the receiver. Special image-rejecting circuits have been developed, but a simpler solution involves the use of a high i.f. value, somewhere between 250 and 500 kc.



Courtesy General Electric

A typical table-model superheterodyne receiver.

Let us see what advantage is secured by using a high i.f. value. Assume that a certain receiver which is tuned to a 1000-kc. signal has an i.f. of 500 kc. The oscillator will therefore be at 1500 kc., and the image interference frequency will be 2000 kc. Only a simple preselector tuned to 1000 kc. is needed here to reject the undesired 2000-kc. signal, since the difference between the frequencies of desired and undesired signals is so great. On the other hand, if the i.f. value is 150 kc., the oscillator will be at 1150 kc., and the image will be at 1300 kc. This is much closer to 1000 kc., and will require a far better preselector. Thus, superheterodynes having high i.f. values will have simple preselectors, while highly selective preselectors are imperative for sets with low i.f. values (values between about 135 kc. and 250 kc.).

Local stations of image frequency are sometimes so powerful, however, that even an image interference ratio of 1000 is insufficient to prevent interference with some desired station.

Service Hints. When a receiver is to be serviced for image interference, the first step would be to realign the preselector. Shortening the antenna is another remedy, for a very long antenna broadens the response characteristic of the first resonant circuit in the preselector, thus letting the undesired signal get through. If only one station is causing image interference, place in the antenna circuit a wave trap which is tuned to the frequency of this station.

Another possible solution would be to shift the i.f. value about 10 kc. This would move the repeat point to another frequency, away from the desired frequency. In this case, the repeat-point still exists but as long as interference with a *desired* signal is eliminated, it will not matter greatly. However, it is not always possible to make this change. It will interfere with the tracking when the oscillator tuning condenser has specially-cut plates, but it can be carried out if padder condensers are used. (You will study oscillator tracking later in this lesson.)

INTERMODULATION INTERFERENCE

When *any two* signals whose frequencies differ by exactly the i.f. value exist in the antenna circuit of Fig. 3, they can beat *with each other*, producing the i.f. value without the aid of the local oscillator. This condition is known as *intermodulation* interference.

Without a preselector, these mixed signals cause an interference sounding like garbled (unintelligible) speech which would be heard regardless of the oscillator dial setting. When a preselector is used, only those r.f. signals which get through the preselector can produce this trouble, and this reduces the number of possible interfering signals greatly.

Service Hints. If garbled speech continues even when the local oscillator is blocked or is detuned, intermodulation interference is present. Improving the selectivity of the preselector blocks out the interfering stations and thus eliminates the trouble. If this is impractical, try cutting out one of the interfering stations with a wave trap; try a shorter aerial; and try changing the i.f. value of the receiver about 10 kc. (or to a value ending in 5).

OSCILLATOR HARMONIC INTERFERENCE

We have assumed up to this time that the local oscillator is feeding only its fundamental frequency to the mixer-first detector. In many cases, especially where the oscillator and its coupling circuit are poorly designed, harmonics of the oscillator (usually only the second harmonic) may reach the mixer-first detector and react with an undesired incoming signal to produce an undesired i.f. beat signal. This condition is called *oscillator harmonic interference*. For each oscillator setting there may be two frequencies which incoming signals can have in order to beat with the second harmonic of the oscillator and produce an undesired i.f. signal. An example will explain how this occurs.

Suppose that a receiver which has a 260-kc. i.f. value is tuned to an 1160-kc. station. The oscillator fundamental frequency will be 1160 + 260, or 1420 kc. and the second harmonic of this will be 2840 kc. Now any signal, which differs from 2840 kc. by 260 kc. and which is strong enough to get through the preselector, will produce an i.f. beat frequency which can cause interference. Thus either an aircraft radio station at a frequency of 3100 kc. (2840 + 260) or a commercial station on 2580 kc. (2840 — 260), or both, could be heard on this set with the desired 1160-kc station.

You can identify oscillator harmonic interference if you can identify the interfering station as being one with a frequency either above or below the second harmonic of the oscillator by the i.f. value. (Oscillator harmonics higher than the second are so weak that they can be neglected.) The frequency difference between interfering and desired signals is so great in the case of harmonic interference that generally only strong local stations, such as amateur, police, commercial, or government code or phone stations, can ride through the preselector.

Service Hints. Either improving the selectivity of the preselector by realigning it to keep out the interfering signals, or adjusting the voltages of the oscillator to suppress its second harmonic are possible remedies for harmonic interference. However, the installation of a wave trap which is tuned to the frequency of the offending station is the simplest cure. When the interfering signal is especially strong, it may be necessary to shield the mixer-first detector to prevent the signal from acting on it directly without going through the preselector and wave trap; a filter in the power line may also be needed.

CODE INTERFERENCE

Trouble can be caused also by an undesired signal *having a frequency equal* *to the i.f. value* of the receiver. If this signal gets through the preselector, it will be passed on by the mixer-first detector to the i.f. amplifier, as there is no need for frequency conversion. Since most transmitters below 500 kc. (in the range of i.f. values) are code stations, this trouble is commonly referred to as code interference. It may be heard at any point on the tuning dial, but is strongest at the lower end of the receiver dial, around 550 kc.

Occasionally the second harmonic of a powerful local long-wave transmitter may produce code interference. For example, if a receiver has an i.f. of 480 kc., a local 240-kc. station might be heard at all points on the tuning dial. This could be produced because the second harmonic of the 240-kc. carrier is getting through the preselector, but a more likely condition is that the 240-kc. signal gets through the preselector and harmonics of it are created by the rectifying action of the mixer-first detector tube. The second harmonic, being of the i.f. value and carrying the modulation of the original code signal, would pass through the i.f. amplifier and produce interference.

Service Hints. Code interference which is heard at all settings of the tuning dial can be eliminated by installing a wave trap which is tuned to the interfering code station, by shortening the antenna, or by changing the i.f. value of the receiver.

► Bear in mind that the cures suggested here and in the previous service hints are necessary because of the inability of the preselector in the receiver to keep out undesired signals. These cures were suggested only because the fundamental cure, *redesigning* the preselector for greater selectivity, is usually impractical.

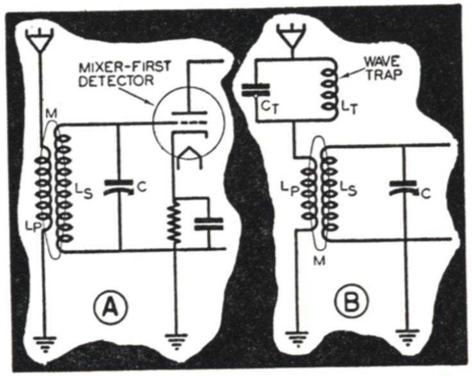


FIG. 4. A simple tuned r.f. transformer preselector is shown at A. A wave trap is added in B.

► Having studied the importance of the preselector, let us take up a few of the common preselector circuits.

R.F. TRANSFORMER WITH A TUNED SECONDARY

The simplest of all preselectors is the tuned-secondary r.f. transformer shown in Fig. *4A*. It is often quite satisfactory in a receiver which uses a high i.f. value. The selectivity of this circuit is essentially dependent upon the mutual inductance *M* and upon the frequency of the desired incoming signal; increasing either reduces the selectivity. In a receiver which is to be used with a short antenna, the mutual inductance usually is made quite large so that a strong input signal can be obtained, but such a receiver tunes broadly (has poor selectivity) when coupled to a long antenna. Even with a high i.f. value, such a circuit will tune broadly at very high frequencies (around 20 megacycles). It is for this reason that all-wave receivers ordinarily require better preselector circuits than this.

Wave-Trap Circuit. A wave trap is often connected in series with the primary of the r.f. transformer, as shown in Fig. *4B*, to eliminate the interference caused by a particular station. C_T-L_T is the wave trap; it is tuned to the frequency of the interfering station by adjusting trimmer condenser C_T. Factory-installed traps usually tune to the i.f. value, to eliminate code interference, which is one of the most annoying and prevalent of the interferences. (A serviceman can connect a similar trap in the antenna lead of any radio receiver having image interference, harmonic interference, intermodulation, or code interference troubles caused by one station. The trap is tuned to the frequency of the interfering station.)

BAND-PASS PRESELECTORS

In the preselector circuit just considered, only one tuned circuit contributes to the selectivity of the receiver. An extra tuned circuit connected in cascade as shown in Figs. *5A*, *5B*, and *5C* will greatly improve the selectivity and, consequently, will reduce interference troubles. This extra circuit also permits adjustments which give band-pass characteristics to the preselector. The circuit shown in Fig. *5A* is simply the circuit of Fig. *4A* with an additional resonant circuit, made up of L_{S2} and C_2, coupled by mutual induction to L_{S1}. Fig. *5B* shows two resonant circuits which are *directly* coupled inductively, with coil section L_{M2} common to both resonant circuits. Capacitive coupling is used in the circuit of Fig. *5C*, with condenser C_K common to both resonant circuits. For a fixed value of coupling, a single peak resonance characteristic is obtained when condensers C_1 and C_2 are tuned for maximum receiver output. Increas-

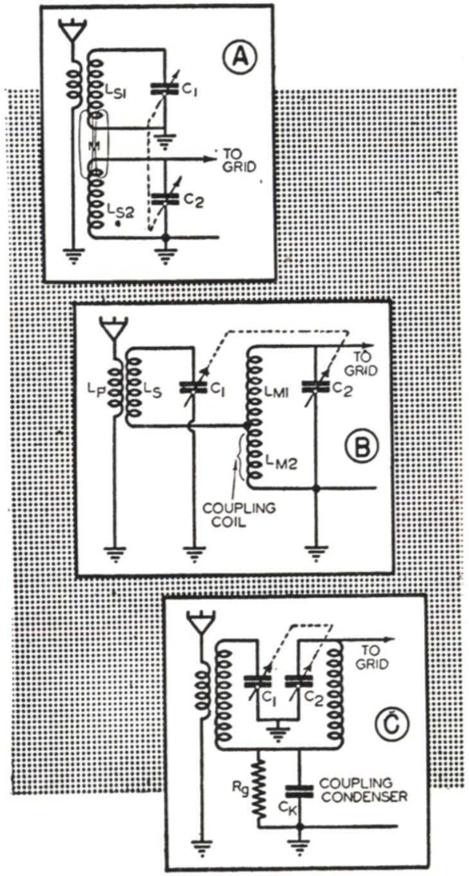


FIG. 5. Typical band-pass circuits. At A there is a band-pass preselector circuit with mutual inductance coupling. The dotted lines indicate that the two tuning condensers are ganged together to give a single-dial tuning control. B shows a band-pass preselector circuit with direct inductive coupling, coil section L_{M2} being common to both tank circuits. At C there is a band-pass preselector circuit with capacitive coupling. R_g is a .5-meg. to 1-meg. resistor which provides a d.c. grid return path to ground for the application of the C bias.

ing the coupling between the resonant circuits or tuning C_1 above and C_2 below the resonant frequency gives a flat or double-peak response characteristic. When this is done, the circuits are referred to as *band-pass preselectors.*

► Although band-pass preselectors are quite effective in eliminating (or at least reducing) the many types of interference troubles, they have one important drawback in that they considerably reduce the strength of the incoming signal. One way of overcoming this loss in signal strength is to step up the gain of the intermediate frequency amplifier section, but two undesirable effects, thermal agitation and converter noise, become annoying when this is done. Let us consider them:

1. Thermal Agitation. Free electrons are continually moving around in any conductor, producing tiny pulses of electron current. Some component of these pulses will be at the same frequency as that to which the receiver is tuned. Hence, these pulses of electron current undergo resonance step-up, along with the signal currents. The effect of these pulses of electron current is commonly designated as *thermal agitation* of electrons. It is greatest for resonant circuits which have a high Q factor, which operate at a high temperature, and which have a wide response characteristic. A hissing or frying noise which is heard in the loudspeaker and is especially loud when the receiver is tuned between stations is an indication that thermal agitation is present. Because of this effect, the practical limit to the sensitivity of a receiver is about 1 microvolt (which means that the smallest signal voltage which can be made to give 50 milliwatts output to the loudspeaker is approximately 1 microvolt).

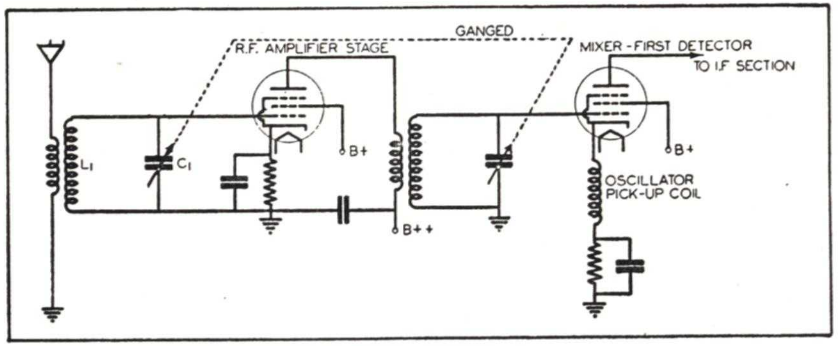


FIG. 6. A widely used preselector circuit, in which one stage of r.f. amplification boosts the strength of the incoming signal before it reaches the mixer-first detector. This additional amplification makes the desired incoming signal over-ride any noise which may be present in the mixer-first detector, and also lessens interference troubles.

2. Converter Noise. Even more troublesome than thermal agitation is an effect which occurs in the mixer-first detector tube. Although the average plate current value is controlled accurately by signal voltages, nonetheless, there are current variations caused by irregularities in the electron emission. As a result, electrons emitted by the cathode arrive at the plate in spurts or "shots." These variations are amplified by succeeding stages along with the desired signals, and are heard in the loudspeaker as a "frying" noise. This action is known as the *shot effect,* as the *electron grain effect,* or as *frequency converter* noise.* Although the shot effect is present in practically all vacuum tubes, the variation in plate current due to it is ordinarily so small in comparison to the average plate current that the effect is negligible. In a tube which operates as a detector, however, the average plate current is so low, because of the high negative C bias, that the variations in current affect an appreciable part of the total plate current. Frequency converter noise is most noticeable when a receiver is tuned to a weak signal; strong signals tend to "drown out" or over-ride the noise. The strength of the signal fed to the input of the mixer-first detector must be large enough to make the signal-to-noise ratio at the output of this section as great as possible and thus minimize the effects of frequency converter noise.

► It is highly desirable to have a stage or two of r.f. amplification ahead of the frequency converter section in order to build up the strength of the incoming signal so that it will over-ride any converter noise which is present in the mixer-first detector tube. The greater the signal strength with respect to the noise, the less disturbing will be the noise.

R.F. Amplified Type of Preselector. A widely used preselector circuit which contains a stage of r.f. amplification to increase the signal strength at the input to the mixer-first detector is shown in Fig. *6.* The amplification of this stage must be made high enough to eliminate frequency converter noise, yet not so high that it increases the total gain of the receiver to the point where thermal agitation effects in the r.f. antenna transformer will come through. The first resonant circuit, consisting of L_1 and C_1 is sometimes replaced by a band-pass resonant circuit of the form shown in Figs. *5A, 5B,* and *5C,* in order to increase further the image-interference ratio.

This amplifier stage is not intended to increase the gain greatly—the i.f. amplifier still is being depended upon for most of the amplification. However, even a small increase is helpful in increasing the sensitivity and in overcoming the frequency-converter noise. An r.f. stage like this is frequently found in all-wave receivers.

Another advantage of the r.f. stage is the extra resonant circuit it provides in the preselector. (Both the r.f. and the mixer stages have resonant input circuits.) This extra selectivity helps to improve the image rejection ratio, thus reducing the interference.

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*The mixer-first detector and the local oscillator together constitute the frequency converter section.

The Local Oscillator

If the local oscillator in a superheterodyne receiver is to perform its job satisfactorily, it must meet the following requirements:

1. At any dial setting, the frequency of the oscillator must be constant in value (there must be very little *frequency drift*).
2. The voltage which the local oscillator supplies to the mixer-first detector must be at least ten times *greater* than the voltage of the most powerful signal which is fed to the mixer-first detector by the preselector.
3. The variation in oscillator voltage output must be as small as possible as the frequency of the oscillator is changed by tuning (since absolute constancy is practically impossible, a maximum variation of 3 to 1 is considered by engineers to be satisfactory).
4. The output of the oscillator must have negligible harmonic content.
5. The oscillator itself should not radiate radio waves which would interfere with nearby receivers.
6. The oscillator must be coupled to the mixer-first detector in such a way that the frequency of the oscillator is not affected by changes in other receiver circuits.

The reasons for some of these practical requirements are important enough to warrant further explanation, so let us discuss these points before taking up typical circuits.

FREQUENCY DRIFT

The frequencies of transmitting stations are kept within extremely close tolerances by special control devices; Government laws require that the frequency of a broadcast station shall not vary to any appreciable extent. Therefore, the signal which the preselector handles is quite constant in frequency. However, any variations in the local oscillator frequency while the receiver is tuned to a station will cause the beat frequency output of the first detector to vary in frequency. If this should occur and if the i.f. amplifier is sharply tuned, the i.f. amplifier will cut off varying amounts of side frequencies, which will result in distortion and weakened receiver output. This condition can be corrected by retuning, as this changes the oscillator frequency. However, if the drift is large, you will soon reach a point where retuning has so changed the preselector resonant frequency that it cuts sidebands. Hence, this correction will work only over a limited range.

► When the oscillator operates at very high frequencies, as in an all-wave superheterodyne receiver, very slight circuit changes produce large amounts of oscillator frequency drift. This causes much trouble unless the response of the i.f. amplifier is broadened. Since this broadening will cause a loss in the adjacent channel selectivity of the receiver, it is better to use an oscillator which does not vary appreciably in frequency at any setting. Good frequency stability is secured by using in the oscillator a tank circuit which has a high Q factor and by limiting the loading of the tank circuit. Other frequency stability requirements include constant d.c. supply voltages, the locating of all oscillator parts away from any sources of heat, and the mounting of parts in such a way that they will not be set into vibration by the loudspeaker.

OSCILLATOR OUTPUT VOLTAGE VALUES

To understand why the voltage which the local oscillator feeds into the mixer-first detector must be at least ten times greater than the signal input voltage to the mixer-first detector, we must consider the action of the two types of first detectors (square law and linear) which are commonly used in superheterodynes.

1. Square Law Type of First Detector. The incoming signal in a superheterodyne, as you know, consists of an r.f. carrier frequency and many r.f. side frequencies. Each of these must beat with the local oscillator to produce, after detection, the desired i.f. carrier frequency and its side frequencies. When a square law type of first detector is used, the strength of the beat frequency depends upon the *product* of the strengths of the local and incoming signals. (This statement is the result of a mathematical analysis of the problem.) The greater the voltage supplied by the local oscillator, then, the stronger will be the desired beat frequencies. However, the oscillator output voltage must not be made so large that the detector operates outside the square law region of its curve. This is why a ratio of about 10 to 1 between the voltages which the oscillator and the preselector feed into the mixer-first detector is highly desirable.

2. Linear Type of Detector. When a linear first detector is used, mathematics and experimental tests show that maximum i.f. output is obtained when the two signals (incoming and local) which are fed to the mixer-first detector are equal in strength. On the other hand, many harmonics of the beat (i.f.) frequency are produced under this condition. These harmonics, being two, three, four, etc. times the resonant frequency of the first detector plate load circuit will be tuned out here. But, they still may feed back into the input of the mixer-first detector through the plate-to-grid capacity or through stray coupling. This feedback energy will produce annoying audio beat notes (squeals) when the receiver is tuned to a station which has approximately the same frequency as one of these harmonics.

To eliminate this problem, it was found that if either one of the signals which are fed into the mixer-first detector is many times stronger than the other, the harmonic frequencies associated with linear detection become negligible. A ratio of 10 to 1 has been found sufficient in actual practice. Since it is easier to control the local oscillator than the carrier signal input strength, it is customary to make the signal voltage which the local oscillator feeds into the mixer-first detector at least ten times *greater* than the signal voltage fed into this section by the preselector *regardless of the type of first detector used.**

Summary. With both types of detectors, then, satisfactory performance is obtained when the ratio of the local oscillator output to preselector voltage is greater than 10 to 1. When this ratio is less than 10 to 1, there will be a lowering of receiver gain (but no other undesirable effects) in the case of a square law detector. Also there will be

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*Since the incoming signal will vary considerably in strength if an r.f. amplifier stage is used in the preselector, it is important that when the first detector is of the linear type, an automatic volume control (a.v.c.) circuit is used to reduce the gain of the r.f. amplifier on strong signals and thus keep the ratio of the mixer input voltages higher than 10 to 1 at all times. A.V.C. circuits are taken up elsewhere in the Course.

an increase in receiver gain, accompanied by annoying squeals when a linear detector is used.

Variations in Oscillator Voltage. Once the amount of oscillator output has been chosen, it is desirable that this same amount be delivered, as near as possible, over the tuning range and in spite of operating voltage changes. Should the oscillator output increase greatly, the combined effect of local and incoming signals may be sufficient to swing the grid of the first detector positive. This would cause the grid to draw current and load the mixer input circuit, cutting down the peaks of the incoming modulated signal and thus producing distortion. About the only way we can have the local oscillator signal at least ten times as strong as the incoming signal at the mixer, and still keep the sum of these signals low enough so the grid cannot swing positive, is to be sure that fluctuations in oscillator voltage do not exceed a ratio of about 3 to 1. This means that the ratio of maximum to minimum oscillator output should not be more than 3.

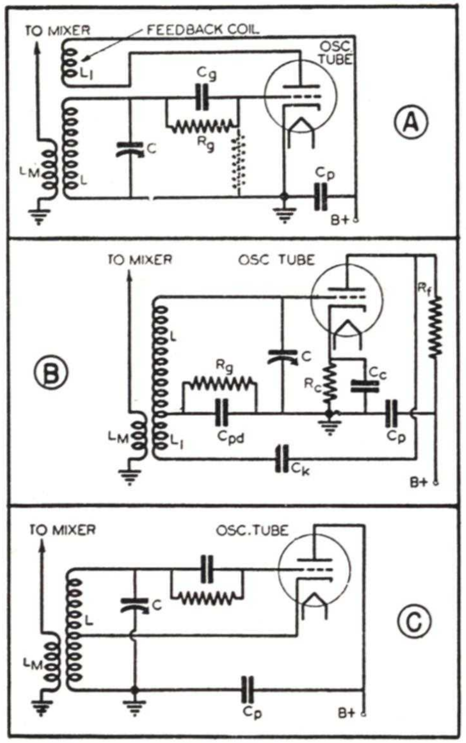


FIG. 7. Typical oscillator circuits.

Harmonics. The importance of preventing the local oscillator from feeding harmonics of its fundamental frequency to the mixer-first detector was considered earlier in this lesson, in connection with the study of harmonic interference.

Radiation. An oscillator needs only an antenna of some sort to become a midget radio transmitter. Obviously, it is the job of the radio engineer to see that such an antenna is not provided in a receiver. He does this by proper layout of circuit leads, and by using bypass condensers to prevent oscillator currents from leaking into any open wires which might serve as antennas and, in some cases, by shielding the oscillator coil.

TYPICAL OSCILLATOR CIRCUITS

Almost any oscillator circuit which has a fair degree of frequency stability will provide the local r.f. signal required in a superheterodyne receiver, but for practical reasons those circuits are used which require only one variable condenser, and which permit grounding of the rotor of the variable condenser. It is also desirable to have a circuit in which there is no high d.c. voltage across the variable condenser. Tuned grid and Hartley circuits are by far the more common, both in receivers having separate oscillator tubes and in those having combination oscillator-first detector stages. As a brief review, here are typical oscillators.

Tuned Grid Oscillators. Typical tuned grid oscillator circuits are shown in Figs. *7A* and *7B*, and in each, the frequency of oscillation is controlled by the values of *L* and *C*. *L* is varied only when changing from one band to another, as in an all-wave receiver, but *C* is ganged to the preselector tuning condensers and therefore is varied each time a new station is tuned in. Notice that in each case the rotor of *C* is grounded; this is done to simplify the construction of the ganged variable condenser of which *C* is one section.

The circuit in Fig. *7A* employs inductive feedback (coil L_1). Automatic C bias is provided by C_g and R_g (R_g often will be found connected between grid and cathode, as indicated by the dotted lines), while C_p is a bypass condenser which keeps r.f. currents out of the plate supply. One way to couple energy into the first detector is to use a pick-up coil like L_M, which is inductively coupled to oscillator tank coil *L*.

► In the circuit of Fig. *7B* the feedback is still inductive in nature, but for convenience in manufacture, coils *L* and L_1 have been combined into a single tapped coil. Resistor R_c and condenser C_c supply the customary form of automatic C bias. R_g and C_{pd} increase the C bias when the oscillator tends to develop excess tank circuit power (as it does at the higher frequencies), thus smoothing out or equalizing oscillator power variations. C_{pd} also serves as a padding condenser, the function of which will be considered later. This oscillator is shunt fed. R.F. current flows from the plate through condenser C_k, while by-pass condenser C_p and resistor R_f keep r.f. currents out of the plate supply.

Hartley Oscillator. The form of Hartley oscillator circuit in which the plate is grounded (to permit grounding of the rotor of variable condenser *C*) is used in superheterodyne receivers; a typical circuit is given in Fig. *7C*. Condenser C_p here grounds the plate for r.f. currents. Automatic C bias is used; there is no d.c. voltage across the variable condenser.

Service Hints. The oscillator stage in a superheterodyne rarely gives trouble but when it does, it usually goes dead and kills reception. The feedback is adjusted to give satisfactory results with average tubes; however, as the tubes age, its output may drop so that oscillation will not be sustained. Usually, a new tube will clear up the trouble.

Sometimes the grid resistor R_g will be at the wrong value or will change in value with age. Check its resistance. If it has changed from the rated value, use a new resistance. The resistor can be reduced in value somewhat—the tube is just made to work harder and its life is slightly reduced. Too large a value will cause self-modulation or may even stop operation.

The Mixer-First Detector

The method used for mixing the output of the local oscillator with the incoming signal is highly important, for this mixing must take place with a minimum of reaction on the oscillator. There are two methods of mixing; electronic and external. Electronic mixing occurs in the electron stream within the mixer tube, while external mixing occurs in a grid or a plate circuit of the mixer tube (external or outside the tube). Today, the electronic method has largely replaced all others, particularly when the same tube is used as both the oscillator and the mixer-first detector.

However, we should study the methods of external mixing, as they have been widely used, and receivers using these systems, are still being serviced. Typical circuits for this purpose are shown in Fig. *8*. One of the most widely used mixer connections of the external type is shown in Fig. *8A*, where the oscillator output coil L_M is connected into the cathode lead of the mixer-first detector tube. R_g and C_g furnish automatic C bias voltage. The incoming signal acts directly upon the grid, changing its potential with respect to ground, while the oscillator signal changes the potential of the cathode with respect to ground. Both, therefore, affect the plate current which produces the desired mixing.

► Another widely used mixer connection is that in Fig. *8B*, where oscillator pickup coil L_M is in series with coil L_P (which feeds the incoming signal to the detector). The disadvantage of this circuit is that coil L_M is a part of the mixer input resonant circuit. Also, changes in C_p as the set is tuned may affect the oscillator.

► Some time ago, the oscillator tank coil *L* and the preselector tuning coil L_p often were mutually coupled as in Fig. *8C*, eliminating the need for coil L_M. Both oscillator and preselector tank circuit coils were wound then on the same form and both often were placed in a shielded housing to prevent radiation. Today, however, this circuit is rarely encountered.

► Capacitive-resistive coupling between a high r.f. potential point on oscillator tank coil *L* and the control grid of the mixer tube occasionally is used, as shown in Fig. *8D*. A small coupling capacity (from 10 to 100 mmfd.) is usually sufficient. Resistor R_k, of high ohmic value, is placed in series with this capacity to help isolate the circuits and prevent interactions as they are tuned.

Coil L_M in the oscillator circuits of Figs. *7A* to *7C* can be connected also in the screen grid, suppressor grid, or plate lead if the mixer-first detector tube is a pentode, as shown in Fig. *8E*. The plate lead connection is very rare, however, for changes in plate voltage which ordinarily can be produced by oscillators have relatively little effect upon plate current. These connections are used when a large oscillator output voltage is available.

► A super-control pentode tube often is used as a mixer-first detector, for it closely approximates a square law detector on weak signals, giving distortionless frequency conversion, and it approximates a linear detector on large swings. It is necessary to use automatic volume control to make the operating point move automatically to a linear portion of the characteristic curve when a strong signal is obtained. When this is done, strong signals cannot swing the grid positive. There is some generation of harmonics with linear operation, but this is considerably less than would occur with a tube acting as a linear detector at all times.

COMBINATION OSCILLATOR-MIXER-FIRST DETECTOR

The introduction of multigrid tubes permitted a single tube to serve the function of oscillator, electron mixer, and first detector. The screen grid tetrode tube and the pentode tube were the first to be used for these combined functions.

A multi-function circuit using a pentode tube is shown in Fig. *9*; this circuit was widely used in midget superheterodyne receivers. The oscillator section of the circuit is of the Meissner type, with coil *L*, variable condenser *C*, and padding condenser C_{pd} forming the oscillator tank circuit for tube *VT*. The plate of the tube is connected to (loaded by) the oscillator tank circuit L-C through two forms of coupling: *1, Inductive*, through the mutual inductance between coils *L* and L_1 (condenser $C_{I.F.}$ has negligible reactance at the frequencies generated by the oscillator); *2, Capacitive*, through condenser C_{pd}, with the oscillator currents flowing from the plate through $C_{I.F.}$, L_1 and C_{pd} *to* ground. With this coupling arrangement the load on the oscillator tank coil is equalized over the entire band, resulting in more uniform oscillator output.

Feedback of the oscillator tank circuit voltage into the control grid circuit is obtained simply by connecting feedback coil L_M into the cathode circuit. This arrangement varies the potential between the cathode and ground. But since the grid circuit also eventually goes to the cathode, changing the potential of the cathode with respect to ground also changes the

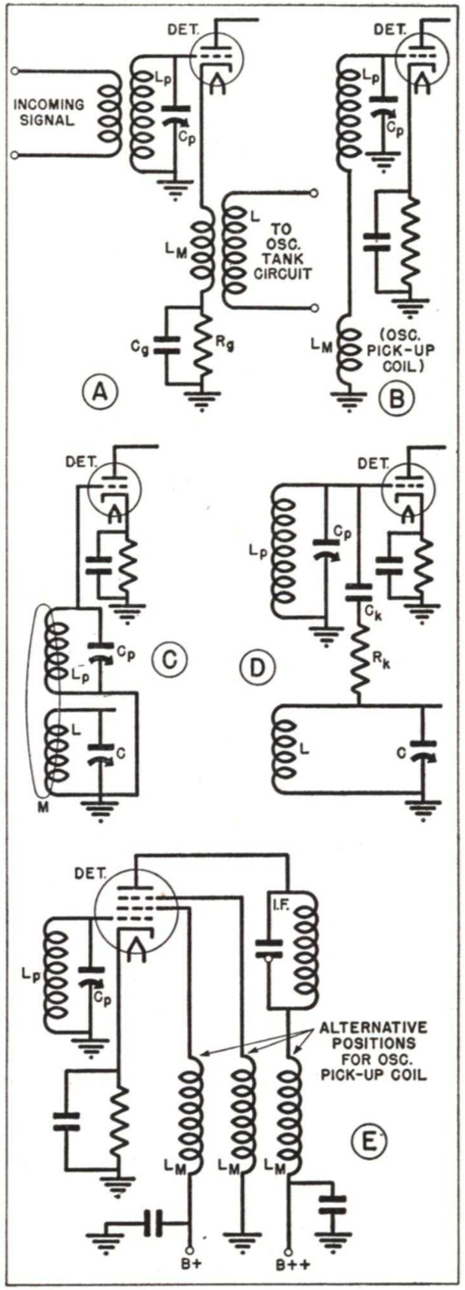


FIG. 8. Methods which have been used for feeding the local oscillator signals into the mixer-first detector of a superheterodyne. When L_M is shown, it is assumed to be coupled inductively to the oscillator tank circuit. In other cases, either direct inductive coupling or capacitive coupling is used.

potential of the grid with respect to the cathode.

Having analyzed the oscillator and mixer functions of this circuit, we shall now see how it performs the duties of first detector. First of all, observe that the plate of the tube is fed (with d.c.) through coil L_p, which serves as the primary of the first i.f. transformer and as the plate load coil for the first detector. The i.f. currents flowing out from the plate of tube *VT* thus flow through coil L_p and thence through bypass condenser C_p to ground. In addition, i.f. currents flow through the path formed by $C_{I.F.}$, L_1 and C_{pd}. The reactance of L_1 to i.f. currents is negligible, so $C_{I.F.}$ and C_{pd} together tune coil L_p to the i.f. value. (This circuit is completed from C_{pd} through the chassis and through C_p to L_p.)

Automatic C bias is furnished by C_g and R_g, the value of R_g being carefully selected to make tube *VT* function as both oscillator and detector. Optimum operation as an oscillator is more important than as a detector, because the detector characteristics are less critical.

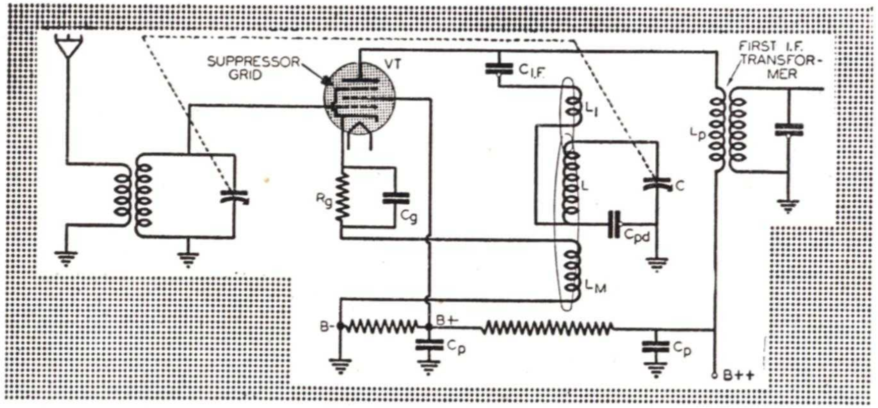


FIG. 9. Combination oscillator-mixer-first detector circuit using a pentode tube. If the suppressor grid is omitted, this circuit will apply to the screen grid tubes which were once widely used for the same purpose.

Servicing Hint. Many of these circuits were built for specially selected, high G_M tubes. As a result, the bias may be too high for an average tube, and the original tube may stop oscillating when its emission weakens with age. If a receiver using this circuit fails to work when all parts are in good condition, try lowering the value of R_g by about one-third; this often will allow the original tube and, surely, all other new tubes to oscillate. If R_g is reduced too much, however, frequency conversion will not take place.

PENTAGRID CONVERTER TUBE

So much difficulty was experienced with screen grid and pentode tubes operating as combination oscillator-detectors that tube engineers developed a special tube which would permit independent biasing for optimum oscillator and optimum detector action. The pentagrid (five grid) tube was the result. Since this tube provides all the functions of the frequency converter section, it is called a *pentagrid converter tube.*

A practical frequency converter circuit employing a pentagrid converter tube is shown in Fig. *10*. The oscillator triode section of the tube consists of

the cathode, grid *1* (functioning as a control grid), and grid *2* (functioning as plate for the oscillator triode). (This second grid is called an "anode grid", to indicate its plate action.) Any desired form of oscillator circuit may be connected to these three electrodes; a standard tuned grid, plate coil feedback oscillator circuit is shown. Coil *L*, condenser *C* (rotor grounded) and padding condenser C_{pd} constitute the tank circuit of the oscillator, while coil L_1 in the circuit of grid *2* (the oscillator plate circuit) feeds oscillator r.f. plate current back to the grid tank circuit to maintain oscillation. Condenser C_o and resistor R_o together provide automatic C bias for the oscillator. Since this bias is applied directly between grid *1* and cathode, it is independent of the automatic C bias created by C_d and R_d for the first detector.

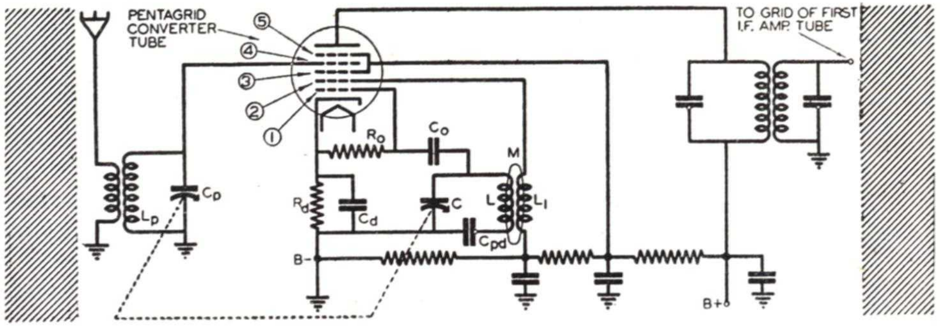


FIG. 10. A practical frequency converter using a pentagrid converter tube.

The action of the oscillator sets up, just beyond the second grid, an *electron cloud* which serves as the *virtual cathode* for the other tube elements. Thus, the detector section is furnished an electron stream which is varying at the oscillator frequency. In the detector section of the tube, grid *4* acts as the control grid, grids *3* and *5* as a screen grid, and the plate has its usual function. An incoming signal controls the plate current, which is already varying at the oscillator frequency. Thus, the local signal and the incoming signal are mixed in the tube electron stream (this is called electron coupling or electronic mixing).

The C bias produced by R_d and C_d acts upon grid *4*, thus controlling the flow of electrons from the virtual cathode to the plate. The shielding action of grids *3* and *5* is only partially effective. It is therefore necessary to choose a detector plate load (i.f. transformer primary) which will resonate sharply to the i.f., having at the same time such an L/C ratio that it will reject other signals. This is necessary in order to prevent i.f. harmonics and other undesired plate circuit signals from feeding back to grid *4* in the input circuit.

With oscillator and detector sections essentially coupled together only by the space cloud, it is possible to design the oscillator and detector sections of a pentagrid converter independently and secure optimum operation of each.

Disadvantages of Pentagrid Converter Tubes at Ultra-High Frequencies. Although the pentagrid converter tube gives excellent results at broadcast band frequencies and the lower short-wave frequencies, it is somewhat unsatisfactory at frequencies above

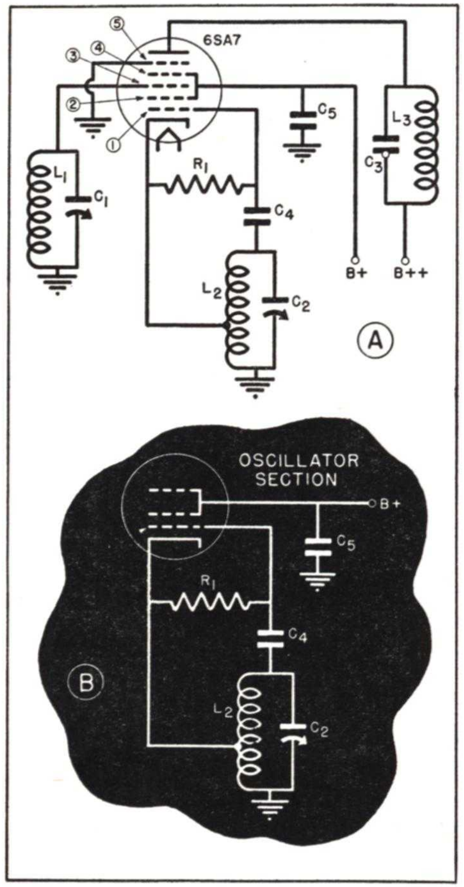


FIG. 11. Another type of pentagrid converter.

about 10 megacycles. One reason for this is that despite the use of a screen grid, the oscillator section of the tube sets up a space charge which at high frequencies affects the input circuit (grid *4* in Fig. *10*) directly. At ultra-high frequencies, the oscillator circuit will cause *regeneration* when tank circuit L-C-C_{pd} is tuned *below* the frequency of the incoming signal, and will cause *degeneration* when this circuit is tuned *above* the frequency of the incoming signal. Since the oscillator of a super is ordinarily tuned *above* the incoming signal frequency, degeneration and consequent loss in signal strength occurs in the high-frequency band and at the higher frequencies in other bands. To avoid this degeneration, the manufacturers of some all-wave receivers make the oscillator tune below the incoming signal frequency on the highest frequency band.

Excessive oscillator frequency drift at frequencies above 10 megacycles is another trouble encountered in a pentagrid converter. The tank coil of the oscillator (L in Fig. *10*) is affected by the a.c. plate resistance of the oscillator section of the tube (the resistance between grid *2* and cathode, which acts on the tank circuit through mutual inductance M). This resistance changes the oscillator frequency (as determined by the values of C, L and C_{pd}) a certain *fixed percentage* at all times. At low radio frequencies the error in oscillator frequency is so small as to be negligible, but at high radio frequencies the error is larger. The variation is relatively unimportant, however, for if the preselector is a little broad, it is only necessary to change the tuning dial setting slightly to bring in the station satisfactorily. More serious trouble occurs because of variations in carrier intensity (fading) when distant stations are being received. In any oscillator, detector, or combination oscillator-detector circuit, the a.c. plate resistance of the tube will vary with carrier intensity because variations in the carrier cause variations in the average space current of the tube. This varying a.c. plate resistance causes oscillator frequency drift, which can be very severe at the higher frequencies.

► Here is an example: Suppose that a carrier of varying strength changes the a.c. plate resistance enough to cause a maximum error of 0.1% in oscillator frequency. At 1000 kc. this percentage will give only a 1-kc. error in the i.f. beat, and the i.f. amplifier is almost always broad enough to offset such a small error. At 10 megacycles, however, this same percentage gives a 10-kc. error in the i.f. beat, and clearly there will be severe cutting of side bands. Also, if the i.f. amplifier is highly selective, the signal may even fade out entirely unless the set is retuned.

► A special form of a pentagrid converter, which uses a 6SA7 tube, is shown in Fig. *11A*. We can consider that the oscillator section of this circuit consists of the elements shown in Fig. *11B*. As you can see, this is the kind of Hartley oscillator pictured in Fig. *7C*, with the screen grid acting as the plate or anode grid. In the detector section of Fig. *11A*, grid *3* acts as the control grid, grids *2* and *4* form a screen for grid *3*, and grid *5* is a suppressor. The cathode and plate, of course, also perform their usual functions for the detector section of the tube.

This form of pentagrid converter has somewhat greater sensitivity and less tendency toward oscillator frequency drift than has the circuit shown in Fig. *10*. In addition, the 6SA7 tube is single-ended (has no grid cap) and so fits in better than other pentagrid converter tubes with the modern practice of keeping above-chassis wiring to a minimum.

PENTAGRID MIXER-FIRST DETECTOR TUBE

To overcome the inherent shortcomings of the pentagrid converter at high frequencies, engineers designed a special pentagrid mixer-first detector tube which has a *mixer* or *injector* grid. When used with a separate oscillator tube, this *pentagrid mixer-first detector tube* is a better frequency converter because it has *negligible frequency drift and negligible degeneration*, even at the very high frequencies encountered in television receivers.

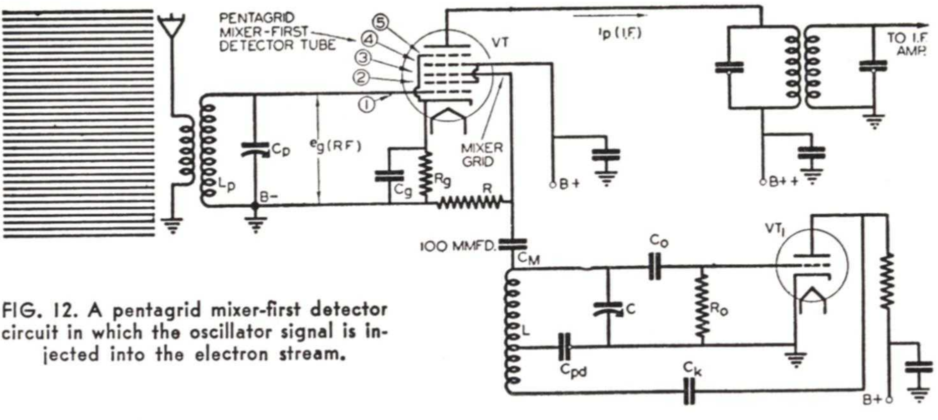


FIG. 12. A pentagrid mixer-first detector circuit in which the oscillator signal is injected into the electron stream.

A practical circuit using this tube and capable of giving excellent frequency converter action well up into the very high frequencies is shown in Fig. *12*. Tube VT is the special pentagrid mixer-first detector tube. Grid *1* is the control grid for the detector; grid *3* is the mixer grid; grids *2* and *4* are shielding grids for the mixer grid; while grid *5* is a suppressor grid.

Tube VT_1 is an ordinary triode tube connected into a conventional tuned-grid oscillator whose tank circuit consists of L, C, and C_{pd}. Condenser C_M provides capacitive coupling between the oscillator tank circuit and grid *3* of VT, which injects the oscillator signal into the electron stream of the mixer tube. The stability of the oscillator is dependent only upon the design and construction of the oscillator stage and there can be no feedback of oscillator current to the preselector (the L_p-C_p tank circuit).

► A *triode-hexode* tube has been designed which combines a triode oscillator and a hexode (6-element) mixer-detector in one envelope. A typical circuit in which this tube is used is shown in Fig. *13*. As you can see, the oscillator section of this circuit uses a standard tuned grid oscillator. The grid of this triode section is connected within the tube to the first grid of the hexode section, which then becomes an injector grid and feeds the oscillator signal into the electron stream. Mixing occurs when the incoming signal is fed into grid *3* of the hexode section of the tube. Grids *2* and *4* of the hexode section merely act as shielding screens for grid *3*.

This triode-hexode circuit has many of the advantages of the circuit in Fig. *12* for high-frequency operation and, in addition, permits the use of one less tube. Therefore, this circuit is being used more and more in all-wave receivers.

FREQUENCY CONVERTER RATINGS

When discussing the relative merits of different frequency converter systems, engineers need what might be called a "yardstick of comparison." What they really want to know is how well a frequency converter will change an r.f. signal voltage into an i.f. signal voltage—that is, frequency converter *gain*.

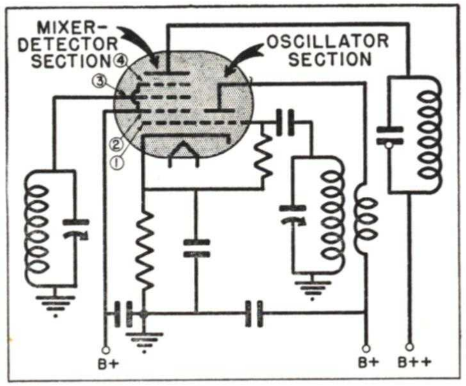


FIG. 13. A triode-hexode tube featuring electron mixing from the oscillator to the first detector.

The important factor in determining the gain is the *conversion transconductance* (sometimes called *translation conductance*) of the frequency converter; it is equal to i.f. plate current i_p divided by r.f. input voltage e_g and is designated by the symbol S_c. Knowing S_c, the gain of a frequency converter can be found by multiplying the value of S_c *in mhos* by the a.c. plate load impedance in ohms of the first detector circuit. For example, a 6A7 tube used with a reasonably powerful oscillator circuit will have a conversion transconductance of somewhere between 350 and 520 micromhos at ordinary frequencies, but this value will be reduced greatly at very high frequencies. A 6L7 pentagrid mixer-first detector used with a separate oscillator tube as in Fig. *12* will have a translation conductance of about 475 micromhos, this value changing little even at high frequencies. A commonly used value for the a.c. plate load impedance is 100,000 ohms. This load and a converter with an S_c of 400 micromhos (.0004 mhos) gives a gain of .0004 × 100,000, or 40.

Oscillator-Preselector Tracking

Ganging of the preselector and the oscillator tuning condensers simplifies tuning of a receiver and eliminates repeat points. However, new adjustment problems are introduced when we attempt to make the oscillator operate above the frequency of the incoming signal by exactly the i.f. value at all times. The oscillator must follow or "track" the preselector, hence we call the alignment of the oscillator and preselector circuits a *tracking adjustment*.

► Let us see first why tracking adjustments are necessary. Turning to Fig. *14A*, which shows both the preselector and oscillator tuning circuits, assume that the tuning condensers are set to minimum capacity, that L_p is exactly like L_o, and that C_p is exactly like C_o. Obviously, both circuits now will have the same resonant frequency. Since the oscillator circuit must tune to a higher frequency, the electrical value of either L_o or C_o must be reduced. It is not easy to reduce C_o, since its minimum capacity is due essentially to stray capacities between rotor and stator plates, so L_o must be replaced with a coil having enough *less* turns to make the oscillator tune above the preselector by exactly the i.f. value when both condensers are at *minimum-capacity* positions.

But if, after making this adjustment, we set both condensers to their *maximum-capacity* values, we find that the oscillator is no longer exactly the i.f. value higher than the preselector. (The reason is that the numerical difference in frequency between the oscillator and the preselector depends upon the numerical values of both the inductances of the coils and the capacities of the condensers.) Therefore, when we change the numerical values of the capacities of the condensers we also change the numerical value of the difference in frequency.

Curves *1* and *2* in Fig. *14B* show how the resonant frequencies of the oscillator and preselector circuits vary as the tuning dial (to which both condensers are ganged) is rotated from 100 to 0 (100 corresponding to the minimum

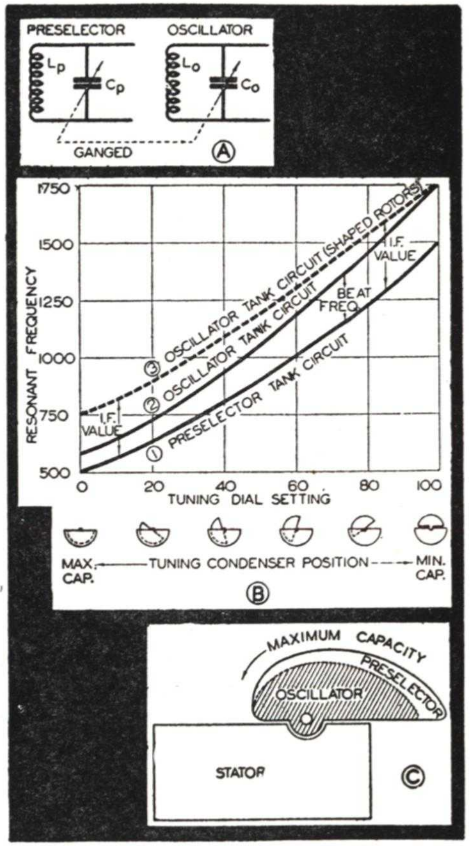


FIG. 14. Preselector-oscillator tracking adjustments are necessary because the resonant frequencies of the two tank circuits (at A) do not differ by the same amount (the i.f. value) at each tuning dial setting. The discrepancy is shown by curves 1 and 2 (at B); curves 1 and 3 show the ideal relationship, which can be secured if the rotor plates of the tuning condensers are specially shaped as at C.

and 0 to the maximum capacity of the tuning condensers). As you can see, the resonant frequency of the oscillator decreases faster than does the resonant frequency of the preselector, so the i.f. beat frequency (the difference between the two) also decreases as the condenser is turned from minimum capacity to maximum capacity. There is need for an adjustment of some sort which will keep the beat frequency constant. We cannot reduce the number of turns on the oscillator coil, for the coil is correct as it now is for the high-frequency setting. Clearly, then, it is necessary to reduce the capacity of C_o for low-frequency settings.

► A constant i.f. beat frequency over the entire tuning range can be obtained by giving the oscillator rotor plates a different shape from those of the preselector. The exact shape required can be figured out by mathematics, but the general shapes will resemble those shown in Fig. *14C*. Notice that as the frequency is lowered (by increasing the capacity), the oscillator condenser increases less in capacity than the preselector. Thus we obtain the results represented by curves *1* and *3* in Fig. *14B*.

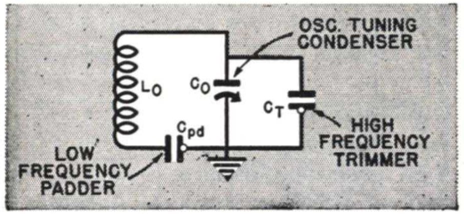


FIG. 15. Here are the adjusters used on the oscillator circuit when the tuning condenser does not have specially-cut plates.

Condensers having specially cut rotor plates are expensive to build and are good only for one particular i.f. value and oscillator coil. Hence, they are clearly out of question for all-wave receivers, because here a different shape of rotor would be required for each band. For these reasons, all-wave receivers are built with ganged tuning condensers having all sections alike, and two trimmer condensers, known as the low-frequency padder and the high-frequency trimmer, are adjusted to make the preselector and the oscillator track each other.

Cut rotor plates are used extensively in broadcast band receivers, however. Also, they find wide use in auto radio receivers, as they keep to a minimum the number of trimmer condensers which might get out of adjustment because of vibration.

Low - Frequency Padder Condenser. When ganged tuning condensers are used, the oscillator condenser will have too high a capacity when its plates are completely meshed. (Remember that the oscillator coil has less inductance than the preselector coil.) This capacity can be lowered by inserting in the tank circuit, in series with C_o, a trimmer condenser which is called a *low-frequency padder*, a *padder*, or sometimes a *lag condenser*. This padding condenser can be adjusted to lower the tank circuit capacity just enough to give perfect alignment at the 0 (lowest frequency) point on the dial. The padding condenser shown as C_{pd} in Fig. *15* (and also in Figs. *9, 10,* and *12*) is considerably higher in capacity than the maximum capacity of C_o, so that its reactance is almost negligible (it acts as a short circuit) at the 100 or high-frequency setting of the dial.

However, at the low-frequency end, it acts in series with C_o and, as you know, condensers in series have a lower capacity than either one alone. Hence, the capacity in the circuit is reduced at the low-frequency end of the band, which provides the necessary tracking.

High - Frequency Trimmer Condenser. We have assumed thus far that the exact i.f. value was produced at the 100 or minimum-capacity setting, but this seldom is the case in actual practice because, even with mass production methods, it is difficult to make coils and condensers with exactly the desired electrical values. Manufacturers of superheterodynes compensate for these errors by placing a small trimmer condenser (called the *high-frequency trimmer condenser*) in parallel with the oscillator tuning condenser. This, as well as the padder, must be adjusted to make the receiver function properly. Let us now consider how these tracking adjustments are made in a modern superheterodyne receiver.

► There are two alignment conditions: *1*, where the receiver is completely out of alignment; and *2*, where the alignment just needs "touching up" or adjusting for maximum response. Considering the first case, the following procedure would be used:

Assuming that the receiver is to be aligned for the 550-1500-kc. broadcast band, feed into the preselector input a 1000-kc. signal (supplied by a signal generator) and set the receiver tuning dial to its 1000-kc. division. Adjust the low-frequency padder C_{pd} for maximum receiver output; now you are getting exactly the correct i.f. beat for mid-dial settings. Change the signal input frequency to 1400 kc., set the receiver dial at 1400 kc., and now adjust high-frequency trimmer C_T for maximum receiver output. If there are two positions of C_T for which maximum output is obtained, choose the one at which C_T has minimum capacity; the other position is a repeat point. Now change the signal input frequency and the dial setting to 600 kc. and readjust the low-frequency padder for maximum output. It is necessary to repeat the adjustments at 1400 kc. and at 600 kc., since one trimmer has a slight effect upon the other. The final adjustment is made at 1400 kc. If the procedure has been correctly followed, the proper i.f. value will be obtained over the entire tuning range.

These alignment instructions apply to any other frequency band as well. High, medium, and low frequencies in each band are selected; the high-frequency trimmer and the low-frequency padder then must be adjusted to make the preselector and the oscillator track each other. The low-frequency padder is always adjusted for the low and mid-scale frequencies, while the high-frequency trimmer is adjusted at the high-frequency setting. This procedure is called a *three-point track alignment adjustment*. It makes the i.f. value correct for three points, insuring that the i.f. beat will not be off an appreciable amount at other dial settings.

On a few all-wave receivers, the padding condenser for some of the short-wave bands may be a fixed condenser rather than a trimmer. On such bands, there can be only a high-frequency adjustment, so only fair tracking is obtained.

► When the alignment is just to be "touched up" it is unnecessary to make the mid-frequency adjustment, as the high- and low-frequency points are the only ones likely to be off.

ALL-WAVE SUPERHETERODYNE RECEIVERS

Number of Bands Required. An all-wave superheterodyne receiver differs essentially from a broadcast band superheterodyne receiver only in that the all-wave receiver has one or more extra preselector and oscillator tuning circuits, which may be switched in as desired. Since it is difficult to tune a preselector and an oscillator over a range having a frequency ratio greater than about 3.3 to 1, it is necessary to use a new set of coils in the preselector and oscillator circuits for each band of frequencies. If the broadcast band coils for a receiver cover the range from 540 kc. to 1780 kc. (1780 being 3.3 times 540), the next band will extend from 1780 kc. to 5800 kc. (3.3 × 1780), and band No. 3 will extend from 5800 kc. to 19,100 kc. (these values are approximate). To secure this 3.3 to 1 range in each band, the variable condensers must have a low minimum capacity, stray lead connection capacity must be very low, and the coils must have a very low distributed capacity. When these requirements cannot be met because of chassis layout and design problems, or when it is desired to cover all frequencies from 540 kc. to about 22,000 kc., it is necessary to divide the entire frequency range into four bands and use four sets of coils.

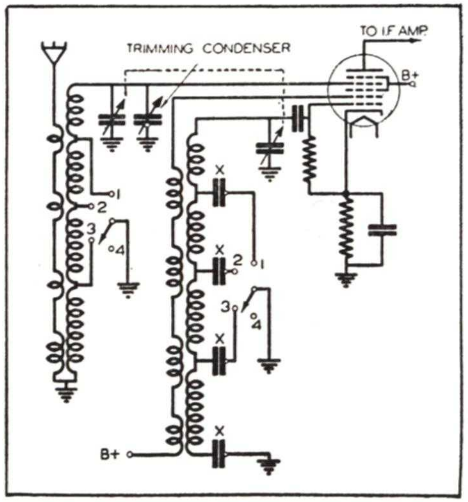


FIG. 16. Preselector and frequency converter circuits of a four-band superheterodyne receiver which employs series coil switching.

Band Changing by Switching Series Coils. Changing the number of coils connected together in series is one way of changing the frequency range of a resonant circuit. Fig. *16* illustrates how this is done in one practical four-band superheterodyne receiver. The four preselector coils are connected together in series, as also are the oscillator coils; when the band-change switches (operated by a single control knob) are set to band *1*, only the uppermost coil is in each resonant circuit. Switching to band *2* adds another coil to each resonant circuit which lowers the resonant frequency by increasing the circuit inductance. Switching to band *3* adds another coil, and all four coils are used on band *4* (which ordinarily would be the broadcast band). Notice that a different low-frequency padder (*x*) is used in the oscillator tank circuit for each band. Only one high-frequency trimmer is used, so it is possible to make the high-frequency adjustment on only one band. (Usually this adjustment is made on the more popular broadcast band.) The preselector circuits must therefore be quite broad to compensate for poor tracking in other bands. Another undesirable feature of this series switching arrangement is the fact that the unused coils may absorb energy, making it necessary to use a special band-change switch which either disconnects or shorts out the unused coils.

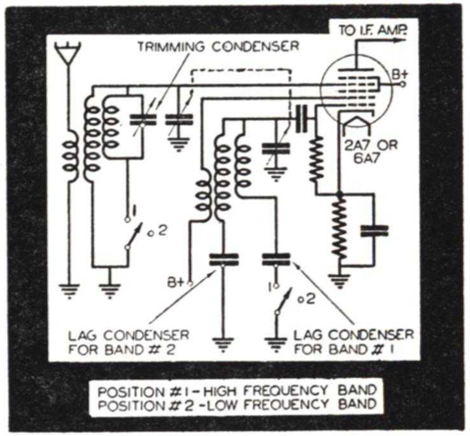


FIG. 17. Preselector and frequency converter circuits of a two-band superheterodyne employing shunt coil switching.

Band Changing by Switching Shunt Coils. Band changing can be accomplished also by adding coils in parallel; Fig. *17* shows how this is done for a two-band receiver. Each oscillator coil has its own padder condenser to insure good low-frequency tracking. A trimmer condenser is used across one preselector coil to permit a high-frequency adjustment of the higher frequency band (band *1*). Unused coils can still absorb energy in this circuit.

Quite often only one oscillator coil is used in two-band receivers, a harmonic of the oscillator being used for the higher frequency band. For example, if the oscillator range for the 550-1500-kc. broadcast band of a receiver having a 460-kc. i.f. value is 1010 kc. to 1960 kc., the second harmonic of the oscillator will vary from 2020 kc. to 3920 kc., the correct variation for the 1560-kc. to 3460-kc. band. In this case band-changing is accomplished simply by tapping the preselector coil.

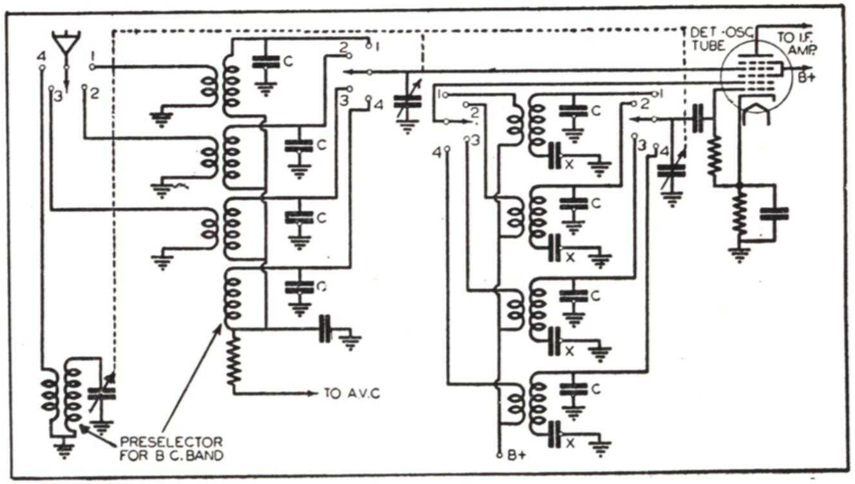


FIG. 18. Preselector and frequency converter circuits of a four-band superheterodyne receiver in which band changing is accomplished by switching complete coils. One extra tuned circuit is used in the broadcast band (band-change switch set to No. 4) to give additional suppression of image interference.

Band Changing by Switching Complete Coils. Although the band-changing circuits shown in Figs. *16* and *17* have been used in lower-priced receivers, perfect tracking on all bands is not obtainable, and energy absorption by unused coils can prove troublesome. A more practical and more widely used circuit is shown in Fig. *18* as it is applied to a four-band receiver. For each band there is a separate preselector coil with its high-frequency trimmer *C*, and a separate oscillator coil with its high-frequency trimmer *C* and low-frequency padder *X*. The change from one band to another is accomplished by a four-section (four-deck), four-point rotary switch. Since image interference is most objectionable in the broadcast band, an extra tuning circuit is inserted between the antenna and the main preselector when the band-change switch is at position *4*. With complete coils being switched, each band is electrically independent of the others and maximum operating efficiency is attained.

► An all-wave receiver circuit con-

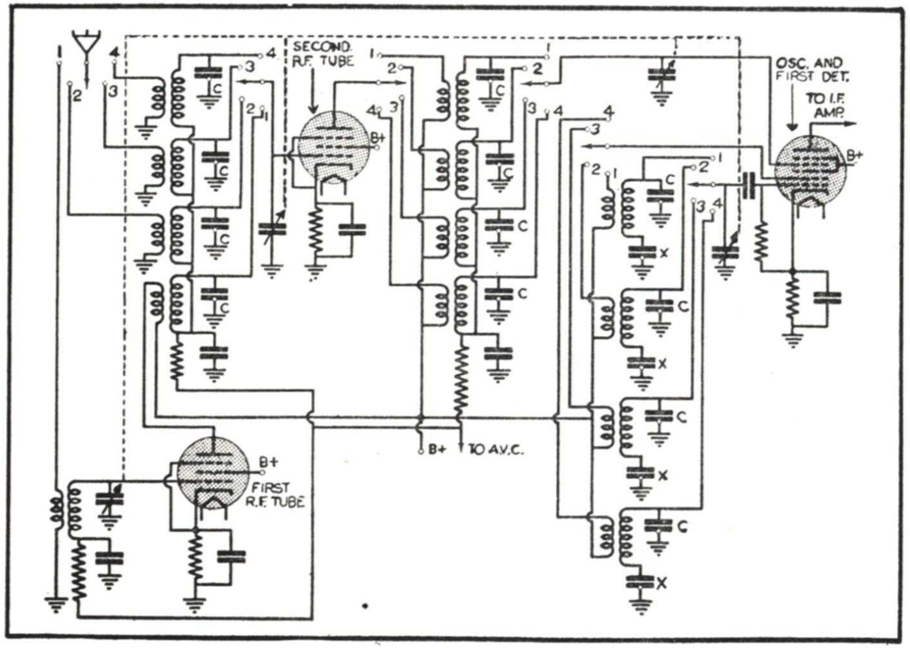


FIG. 19. The preselector in this all-wave superheterodyne circuit uses two stages of r.f. amplification for the highest frequency band (band-change switch set to No. 1) and one stage for all other bands.

taining r.f. amplifier stages in the preselector is shown in Fig. *19*. This arrangement gives better image rejection and improves the signal-to-noise ratio, thus lessening the effects of converter noise. Observe that one r.f. amplifier stage is used for the lower frequency bands (*2*, *3* and *4*) but two stages are used for band *1* to offset the reduction in the sensitivity and selectivity of the receiver at high frequencies.

Thus, you can see that all-wave superheterodynes differ from broadcast band superheterodynes only in the sections ahead of the mixer-first detector. All-wave receiver circuits may appear complicated at first glance because of the band-changing switch and the extra parts, but connections can be traced quite easily if only one band is considered at a time. Various methods for shorting unused coils will be found; these often seem to complicate preselector circuit diagrams.

Combination Receivers. When the receiver is a combination AM-FM receiver, the widely different frequency bands require special considerations. It is possible to use a band switch and another set of coils, but many combination sets switch the entire preselector-oscillator-first detector section. This is desirable to keep down losses in the very high frequency FM bands, for this eliminates the use of long leads to band switches, and permits the use of tubes specially designed for each service. These combination receivers will be studied along with FM receivers.

The I. F. Amplifier

Most of the gain in a superheterodyne receiver is furnished by the i.f. amplifier. In fact, the very purpose of frequency conversion is to permit this section of the super to do its work. The i.f. *amplifier* also contributes most of the *adjacent channel selectivity;* that is, if the i.f. amplifier is designed to pass all frequencies 5 kilocycles above and below the i.f. value, all stations producing i.f. beats which are outside this range will be tuned out or rejected by the i.f. amplifier.

CHOOSING THE I.F. VALUE

The receiver designer considers many things when he is choosing the i.f. value for a receiver. He knows that low i.f. values permit high i.f. gain and high selectivity, but require good preselector circuits to eliminate images and repeat spots. Likewise, he realizes that he can use a simple preselector if the i.f. value is high, and can still get reasonable gain by using coils which have pulverized iron cores. A high i.f. value is required if a wide band of side frequencies is to be passed. For a 10-kc. band width, the i.f. should be at least 175 kc.; and for a 20-kc. band width, the i.f. value should be about 460 kc. The 6000-kc. band width used in television may require an i.f. value of at least 15,000 kc.

Should I.F. Values End in 5? It is common practice to choose an i.f. value which ends in 5, such as 175 kc., 265 kc., 465 kc., etc. The reason for this is interesting.

Harmonics of the i.f. signal, feeding back to the preselector (through the grid-to-plate capacity of the mixer-first detector tube), produce very annoying squeals when stations are tuned in which have the same frequencies as these harmonics. For example, with an i.f. value of 175 kc., the fourth harmonic of the i.f. signal will be 700 kc. When a 700-kc. station is tuned in, the fourth harmonic of the i.f. frequency will beat with the 700-kc. carrier to produce an audio squeal frequency which will modulate the 700-kc. signal and, after frequency conversion, ride through the i.f. amplifier.

In the United States, stations in the broadcast band have frequencies ending in 10, such as 960 kc., 1440 kc., etc. By making the i.f. value end in 5, only its *even* harmonics can end in 10 and be equal to a broadcast frequency. For example, the harmonics of a 175-kc. i.f. are 350, 525, 700, 875, 1050, 1225, 1400, etc., of which 700, 1050 and 1400 represent station frequencies in the broadcast band; the harmonics of a 180-kc. i.f. are 360, 540, 720, 900, 1080, 1260 and 1440, of which all but the first value are equal to broadcast station frequencies. An i.f. value ending in 5 thus gives only half as many squeal-producing points on the dial as an i.f. value ending in 10.

The higher the i.f. value, the fewer i.f. harmonics there will be in the broadcast band, which is the band suffering the most interference. This is another factor which makes 455 and 465 kc. the most popular i.f. values.

TYPICAL I.F. AMPLIFIER CIRCUITS

The most widely used i.f. amplifier is the twin resonant circuit shown in Fig. *20A*. When C_1 and C_2, the trimmer condensers, are tuned for maximum receiver output, a highly selective (sharp resonance curve) amplifier is obtained. When C_1 is tuned below and C_2 above the i.f. value, a rounded or even a double-peak response characteristic curve is obtained, but the gain is reduced considerably. In the latter case, the mutual inductance *M* must be of the correct value for band-pass results; this is a job for the designer. Wider band width can be obtained by shunting one of the coils with a 10,000- to 100,000-ohm resistor, but this gives even further reduction in gain.

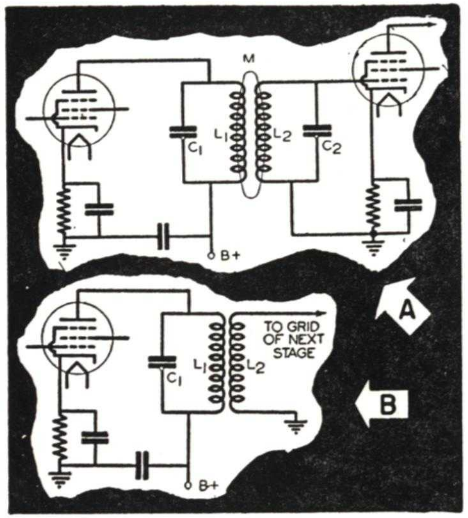


FIG. 20. Typical i.f. circuits.

In any i.f. amplifier, the i.f. transformer in the plate circuit of the mixer-first detector must be extremely selective, and must have a low L/C ratio in order to short-circuit the harmonics which are produced by detection which might otherwise feed back into the detector input. In addition, the coupling between the transformer coils must be loose; a copper screen is often placed between the two coils to reduce the coupling.

I.F. transformers, after the first one, can have higher L/C ratios and higher gain. Thus, these transformers may not all be alike—an important point when you are replacing one in service work.

► When high i.f. gain is desired with a minimum number of circuit parts, a single tuned i.f. circuit like that in Fig. *20B* is used. Trimmer condenser C_1 may be placed across either L_1 or L_2. You will find this circuit most often in midget supers. The gain is about double that of the type shown in Fig. *20A*, but of course there is less selectivity.

High-Fidelity I.F. Amplifiers. In a high-fidelity receiver the resonance curves of the i.f. amplifier must be practically flat over the entire band of frequencies being transmitted, for this section provides most of the gain of the receiver. Other sections of the receiver must likewise pass all side frequencies without excessive attenuation (unless defects in one section are compensated by a correction in another section). Thus, if all frequencies up to 8500 cycles are desired, the i.f. amplifier must have a band width of 17 kc.

Variable Selectivity I.F. Amplifiers. High-fidelity receivers perform beautifully when tuned to strong local stations, but often give squeals and garbled speech (sometimes called "monkey chatter") when tuned to distant stations. This is because the response of the receiver is so broad that the carrier or side frequencies of an adjacent channel station can interfere with the desired carrier. The remedy obviously is a control which will permit the listener to choose between high selectivity and high fidelity (poor selectivity) characteristics. Three commonly used methods for obtaining variable selectivity in a superheterodyne are given in Fig. *21;* each of these provides a continuously variable control, which allows the listener to reduce the fidelity just enough to stop the interference.

In the circuit of Fig. *21A* the selectivity is changed by varying the mutual inductance *M* of the i.f. transformer (by mechanically varying the spacing between coils L_1 and L_2). With this arrangement, the trimmers are adjusted for peak response when *M* is a minimum (weak coupling). Now, when *M* is increased, the peak of the response curve flattens out, becoming flat or perhaps even double-humped. As you learned in an earlier lesson, increasing *M* has the effect of introducing capacity into one circuit while adding inductance to the other, which is exactly what is needed to get double peak response.

► Another scheme, which has the effect of shunting each resonant circuit with a resistance, is shown in Fig. *21B;* this uses a third winding shunted by a variable resistor (*R*). The two resonant circuits originally are adjusted for peak response when *R* has a maximum resistance. Reducing *R* causes L_3 to absorb energy from both L_1 and L_2, thus acting as a load. This widens the response curve, giving higher fidelity.

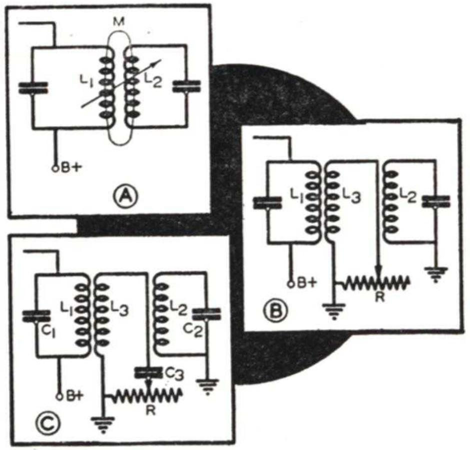


FIG. 21. Three methods of securing continuously variable control of the selectivity of i.f. stages of a superheterodyne receiver are shown here. Although only one i.f. transformer is shown, each i.f. transformer in a receiver may be identically treated and the selectivity controls ganged together.

► A third method, shown in Fig. *21C*, uses a third winding L_3 which is connected in series with condenser C_3 and rheostat *R*. Resonant circuits C_1-L_1 and C_2-L_2 are tuned for maximum receiver output when *R* is set to maximum resistance. Then *R* is set to zero resistance and C_3 is adjusted for *minimum* output. Thereafter, the circuit L_3-C_3-*R* acts as a loading circuit. As L_3 and C_3 are resonant, the amount of energy absorbed depends on the setting of *R*. With *R* at a high resistance value, little energy is absorbed and maximum selectivity is obtained. When *R* is reduced toward zero, the other circuits are effectively loaded with resistance, reducing the selectivity and gain, and thereby broadening the over-all response. This circuit is just a variation on the one shown in Fig. *21B*.

High-Low Selectivity Switches. In a variable-selectivity receiver the desired method of controlling selectivity must be incorporated in one or more i.f. circuits. To reduce costs, continuously variable selectivity is sometimes replaced with a high-low selectivity (low-high fidelity) change-over switch, as shown in Fig. *22A*. Trimmer condensers C_1 and C_2 are adjusted for single peak response (high selectivity) when the switch is set to point *1*. Moving the switch to point *2* makes coil section L_M common to both resonant circuits; this increases the mutual inductance of the coils. It also adds inductance to circuit L_1-C_1, and takes inductance away from circuit L_2-C_2, thereby increasing the band width (giving high fidelity).

► Any scheme which will increase the resonant frequency of one circuit while decreasing the resonant frequency of the other circuit by an equal amount may be used to control selectivity. Another method of doing this is shown in Fig. *22B*. When the selectivity switch is at point *1*, normal peak adjustments exist. When it is at point *2*, condenser

C_3 is in series with C_1 and L_1, increasing the resonant frequency of circuit C_1-L_1; condenser C_4 is in shunt with condenser C_2, lowering the resonant frequency of circuit L_2-C_2. Condensers C_3 and C_4 are of such capacities as to give the desired band width.

Comparison of I.F. Stages. It is interesting to compare the i.f. amplifiers of AM, FM and television receivers. Essentially, the i.f. amplifier delivers most of the amplification and selectivity in each of these receivers, and the basic design is similar. Fundamentally, they differ mostly in the degree of bandpassing and in the i.f. value used.

► Broadcast and so-called all wave AM receivers today use an i.f. value of 455 to 465 kc. (Broadcast receivers have used i.f. values of 130, 175 and 260 kc. in the past.) In AM receivers intended for long-distance reception, the usual band-width is 10 kc. or less, so peak alignment is employed. The high-fidelity types are band-passed somewhat, out to a band width of 15 to 20 kc. It is important that the characteristic be relatively flat-topped so that there will be no discrimination against the modulation frequencies.

► The FM receiver has an i.f. value of from 2 to 4 mc., because the FM process requires a very wide band—about 200 kc. Only a high i.f. value will permit such a wide band, and even here special design is necessary. It is not necessary that the response be flat-topped as the limiter stage cuts off all peaks in amplitude, as you will learn when you study FM receivers more fully. Usually, the FM receiver will have a greater number of i.f. stages, with the last one or two being designed as limiters.

► In television receivers, the i.f. value is usually 13 mc., and the amplifier must have a band width of about 4.5 mc. to pass even *one* side-band. (Single side-band transmission is used in television.) Here, special types of coupling are needed to give the necessary wide band. We will now briefly preview some of the requirements of a television receiver; there will be several lessons on these receivers further along in your Course.

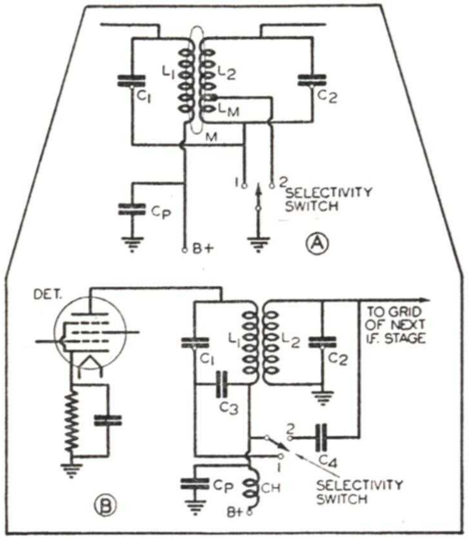


FIG. 22. Two methods for incorporating high-low selectivity switches in a superheterodyne receiver are shown here.

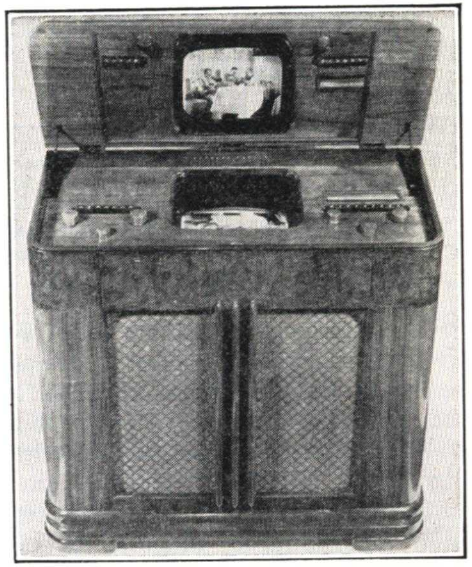
Television Superheterodyne Receivers

Aside from the use of a cathode ray tube as an image reproducer, the superheterodyne receiver used to pick up sight (video) and sound (audio) television signals is much like an all-wave sound receiver. You have already studied in your course the basic circuits used in a television receiver, for no radically new principles are involved. However, we can present here only a preview of this subject. There are a number of lessons dealing with the special adaptations made on basic circuits to fit television requirements.

The transmission of a 525-line picture which is repeated completely thirty times each second calls for a video frequency range of about 4.5 mc. Partial single side-band transmission is used for television in this country, with the lower side frequencies being partially rejected at the transmitter. Both the sight and sound modulated r.f. carrier signals are radiated by a television transmitter within a frequency channel 6 megacycles wide in the very high frequency band. Eighteen of these channels have been assigned to television; these channels are scattered over the frequency spectrum between 50 mc. and 300 mc.

In each television channel, the carrier center or resting frequency for the audio signal is .25 mc. below the highest channel frequency.* The carrier for the video signal is 4.5 mc. below the audio carrier, with side frequencies extending above and below this value in the manner shown in Fig. *23*.

► At the receiver, both the sight and sound r.f. signals are picked up by the same antenna, and both are passed through the preselector to a frequency converter stage. A single local oscillator feeding into the frequency converter stage converts both the sight and sound signals and their associated side frequencies to lower i.f. values at which greater gain can be obtained and satisfactory frequency response can be secured for all desired signal components.



Courtesy Stewart-Warner Corp.

A typical television receiver. The lid has a mirror mounted on it. The image on the television cathode ray tube is reflected by this mirror to the audience.

As the sound and picture signals are on different carrier frequencies, they mix with the single oscillator frequency to produce two different i.f. values. The sight and sound signals thus separate at the output of the frequency converter stage. The sound portion of the television program goes into a sound

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*The sound portion of a television program is transmitted by means of frequency modulation; that is, the sound intensity variation is transmitted as r.f. frequency variations. The no-modulation frequency (corresponding to the carrier in a.m. systems) is referred to as the "resting frequency." Frequency modulation is discussed in another lesson.

i.f. channel having at least a 200-kc. pass band, then to the amplitude limiters and frequency modulation detectors (which are essential in f.m. receivers), from which the sound signal feeds into the audio amplifier and loudspeaker. The sound channel includes provisions for rejecting picture signals.

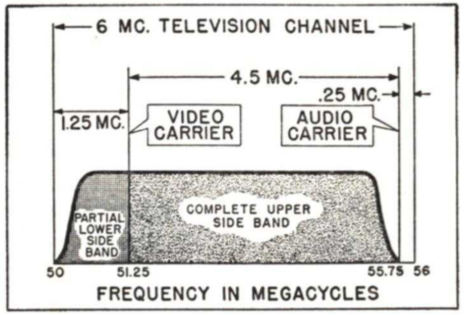

FIG. 23. Relationship between the audio carrier, the video carrier and the side frequencies in a typical 6-megacycle wide television channel. The frequency values specified below the diagram are for the 50-56 megacycle television channel.

► The sight carrier and its side frequencies pass into the video i.f. channel, which has a pass band almost 5.75 mc. wide. There are provisions in this channel for rejecting the audio carrier signal. The output of the video i.f. amplifier feeds through the video detector and video frequency amplifier to the television cathode-ray tube.

► A television picture signal includes impulses which indicate the end of a line and the end of a picture, along with the variations corresponding to detail along each line of the picture. Although the entire signal including the impulses is fed to the television cathode ray tube, only the video components corresponding to details in the scene vary the brightness of the spot on the screen. At some point ahead of the television cathode ray tube, a stage known as the clipper separates the video signals from the synchronizing impulses. After this, the line impulses are separated from the frame impulses. The separated impulses control oscillators which develop the voltages required to sweep the electron beam across the cathode ray tube screen in the proper manner to reproduce the original scene.

► The requirements for very wide pass bands—6 megacycles in the preselector, 5.75 megacycles in the i.f. amplifier, and up to about 4.5 mc. in the video amplifier stages—have given television receiver design engineers some knotty problems. These have been solved by using plate load resistances of low ohmic value and circuits having wide pass bands, but this results in low gain per stage. To compensate for this, special tubes with high mutual conductance values were developed for television receivers. These tubes also have low interelectrode capacities, to minimize attenuation of higher video frequencies.

Lesson Questions

Be sure to number your Answer Sheet 23FR-3.

Place your Student Number on *every* Answer Sheet.

***Send in your set of answers for this lesson immediately after you finish them,* as instructed in the Study Schedule. This will give you the greatest possible benefit from our speedy personal grading service.**

1. Why must the resonant load in the plate circuit of the first detector be highly selective? TUNING TO ANY SIGNAL COMPONENT AND THU SEPERATING IT FROM OTHERS
2. What two radio frequency signals in a superheterodyne receiver are combined by the frequency conversion process to produce the i.f. carrier?
INCOMING MODULATED R.F. CARRIER
LOCAL R.F. OSCILLATOR SIGNAL.
3. In addition to giving single-dial tuning, what advantage is secured by ganging the oscillator and preselector tuning condensers?
REPEAT POINT RECEPTION
4. When an interfering signal is heard along with the desired signal, and the frequency of this interfering signal is *above* the frequency of the desired signal *by twice the i.f. value* of the receiver, what type of interference is present? HARMONIC INTERFERENCE
5. How would you eliminate code interference which is heard at all settings of the tuning dial in a superheterodyne receiver?
INSTALL A WAVE TRAP
6. Why is it desirable to have a stage or two of r.f. amplification ahead of the frequency converter section in a superheterodyne receiver?
BUILD UP THE STRENGTH OF THE INCOMING SIGNAL
7. Give two reasons why the pentagrid mixer-first detector tube, when used with a separate oscillator tube, is a better frequency converter than a single pentagrid converter tube. NEGLIGIBLE FREQ. DRIFT.
AND " DEGENERATION
8. What two trimmer condensers must be adjusted in order to make the preselector and the oscillator track each other? LOW FREQ. PADDER COND
HIGH. FREQ. TRIMMER COND.
9. In what way, essentially, does an all-wave superheterodyne receiver differ from a broadcast band superheterodyne receiver? IT HAS ONE OR MORE
EXTRA PRESELECTOR AND OSCILLATOR TUNING CIRCUITS
10. What section of a superheterodyne receiver provides most of the adjacent channel selectivity? THE I.F. AMPLIFIER

SMILE

When you give a smile, you give something which is priceless yet costs nothing. Nobody can buy, beg, borrow or steal your smile, because it is of no value unless you give it away in friendly greeting.

A smile takes but a moment, but its effects sometimes last forever. A smile creates happiness among friends, brings sunshine to the sad, and promotes valuable good will in business.

You don't feel like smiling? Then force yourself to smile. Whistle, hum a tune or sing softly—act as if you were already happy, and the smile will come. A happy smile comes from happy thoughts, not outward conditions.

It isn't what you are or where you are or what you are doing that makes you happy or unhappy—*it's what you think about it.* You'll find just as many happy faces among Chinese coolies sweating in the rice paddies for ten cents a day as you will among any similar-size group of business presidents in this country.

Smile!

J.E. Smith