ESSENTIAL CIRCUITS AND STAGES

OF COMMUNICATION RECEIVERS

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For each study step, read the assigned pages first at your usual speed. Reread slowly one or more times. Finish with one quick reading to fix the important facts firmly in your mind, then answer the Lesson Questions for that step. Study each other step in this same way.

ESSENTIAL CIRCUITS AND STAGES OF COMMUNICATIONS RECEIVERS

Basic Receiver Principles

IN ADDITION to a transmitter, a complete communication system requires a receiver, no matter whether the system is used to handle voice, code, television, or other types of intelligence. The receivers used are different for each type of signal to be handled, and yet they all may be classed as "communications receivers."

The essential operating principles of a communications receiver are similar to those of a household broadcast set. There are usually great differences, however, in desired tone fidelity, the degree of selectivity, and the frequency range covered by the tuning dial. The communications receiver also may have added special features that make operation more reliable, and in general, the mechanical construction is different.

Fidelity Secondary. In a good broadcast receiver, the major emphasis is on fidelity or the degree to which the loudspeaker output sounds like the original program in the studio. In a communications receiver, the emphasis instead is on reliable reception of essential intelligence; and by intentionally sacrificing fidelity, this characteristic can be improved.

A good broadcast receiver should reproduce all frequencies from about 30 to 10,000 cycles, whereas a good voice communication receiver may respond only from about 200 to 3000 cycles. The a.f. amplifier of a telegraph code receiver need pass a frequency band of only about 30 to 100 cycles in width.

Selectivity Important. A broadcast receiver is expected to separate signals that are 10,000 cycles, or 10 kc., apart. A communications receiver, on the other hand, may be called upon to separate code signals that are only a few hundred cycles removed from each other. If this must be done at r.f. frequencies higher than those used for broadcasting, then the "sharpness" of selectivity required becomes extremely high.

Frequency Ranges. The carrier frequency employed for communications may vary from about 10 kc. up to approximately 30,000 megacycles.

It is not practical to cover all this radio spectrum in the same receiver. A slightly greater than 3-to-1 frequency range, such as from 500 to 1700 kc. or from 3 to 9 mc., is about all that can be covered with a given inductance-capacity tuning combination. This limitation is caused partly by the fact that there is an unavoidable minimum capacity in all circuits made up of the capacities between tube elements, the distributed capacities of wiring, inductance coils, etc.

To get more frequency coverage, such as 500 kc. to 40 mc., plug-in coils or some coil switching system must be used. Four switching ranges would cover the above band. These might be: 500 to 1650 kc.; 1.5 to 4.95 mc.; 4.0 to 13.2 mc.; and 12.5 to 41.25 mc. Some overlap is supplied between ranges to be sure of complete coverage. Even by this switching method, however, a single receiver seldom covers more than

an eighty-to-one range, whereas the usable radio spectrum is about three million to one.

Other Features. A communications receiver sometimes must operate unattended for months at a time, with its output fed into a telephone line or a relay transmitter. To obtain reliable service under these remote-control conditions, a high order of stability is demanded. If the receiver is of the superheterodyne type, the local oscillator must not change frequency, and the signal-frequency or intermediate-frequency amplifiers must not change performance perceptibly when the temperature, humidity, and power voltages vary.

Special features, such as a beat-frequency oscillator for code reception, noise limiters, squelch circuits, crystal filters, and others not found in broadcast sets, are likely to be incorporated in a communications set to improve the reliability of operation.

The mechanical structure and appearance of a broadcast receiver are determined by current fashion and artistic and economic considerations. The communications receiver, however, is built along functional and operating convenience lines, with appearance a somewhat secondary consideration. Reliability is usually more important than low cost.

A few examples of different types of service and how conditions influence the essential requirements of the communications receiver are:

1. *Point-to-point Telegraph.* Since radiotelegraph signals do not ordinarily require much band width (they need about 50 cycles), and since the transmitter frequency can be maintained accurately, it is customary to place such stations close together in the frequency spectrum. To prevent interference in the receiver, very high

selectivity must be provided. Selectivity required often exceeds that obtainable with the highest practical quality of L-C circuits in the r.f. or i.f. stages of the receiver, and crystal filters must be used in the i.f. section, or special audio filters may be used in the audio section.

The variation of atmospheric and ionospheric conditions and the requirement of reliability of commercial communications make high sensitivity of the receiver a necessity. By sensitivity we mean the input signal, usually specified in microvolts, to give a specified audio output with a definite signal-to-noise ratio.

With a "high-gain" receiver, however, natural static and man-made noise often may exceed the desired signal amplitude by many times, for short intervals or "bursts." Special means of reducing the paralyzing effect of these noise peaks on both the circuits and the operator's ears are required. Noise limiters that clip off the peaks or that kill the receiver output instantaneously during the peaks are used for this work.

The signal output of the code receiver frequently is made to key a local tone oscillator to give uniform frequency even though either the transmitter or receiver drifts slightly. The tone output may be fed to a telephone line for use at a communication center miles away from the receiving point.

Point-to-point radiotelegraph is used from 10 kc. up to about 30 mc. At frequencies higher than 30 mc., "skip-distance" conditions do not permit reliable long distance communication.

2. *Marine Service.* The power of a shipboard transmitter is usually lower than that of a land station, so receivers used on other ships must be extra sensitive to compensate.

A shipboard receiver is subject to continuous engine vibration as well as to large variations of temperature, humidity, and often supply voltage, during the day. The salt air will quickly ruin components that would give years of satisfactory service ashore.

A receiver for this service must be more ruggedly constructed, more accessible for servicing, and employ higher quality components than one intended for shore use.

3. *Two-way Mobile Police.* Police squad cars must operate in all parts of a city, often surrounded and badly shielded by buildings. The man-made noise from neon signs, street railways and other devices is often extremely high. The best noise limiter and squelch circuits are required.

Very good sensitivity, also, is necessary to make up for the poor antennas that must be used and for the low field strengths of signals encountered in many locations that must be covered.

In addition to these severe requirements, the receiver must be ruggedly built to withstand the shock and vibration of automotive service.

An automobile battery with a dynamotor or vibrator power supply is usually the power source. The noise created by the power supply must be kept out of the sensitive receiver, as must the noise produced by the car's ignition system.

Police car receivers are used on a wide range of frequencies from about 1700 kc. up into the hundreds of megacycles, using both frequency and amplitude modulation.

4. *Aircraft.* This service requires comparatively high performance with emphasis on small size and light weight. Servicing may be relatively more difficult because of compact construction. Special lightweight power supplies using alternator frequencies

of 400 to 800 cycles are often used.

General Requirements. We see from this preview of communication-receiver requirements for different services, that the following characteristics are important:

1. High sensitivity.
2. Selectivity suitable for the required service.
3. Uniform sensitivity and selectivity with tuning.
4. Noise reduction.
5. Stability of characteristics.
6. Ease of operation.

The superheterodyne circuit is so flexible that it is possible to obtain most of these characteristics simultaneously to a greater extent than with any other receiver circuit. Also, special circuits can be added readily to accomplish specific functions when required. For these reasons, almost all modern communication receivers are built on the superheterodyne principle.

To realize the advantages offered by the superheterodyne, we will first review the simpler receivers which preceded it, and become familiar with their characteristics, particularly with their limitations.

EARLY TYPES OF RECEIVERS

One of the earliest types of receivers was the simple crystal set illustrated in Fig. 1. These receivers, since they require no power supply, are still compulsory for emergency use in marine installations. A crystal set consists merely of a resonant tuned circuit, a crystal detector, and a pair of headphones. Although capable of giving signals of excellent quality, such a receiver is very insensitive and its selectivity is very poor. Even though the quality of the tuned circuit is high, the loading imposed by the crystal reduces the effective Q to such a point that tuning is exceedingly broad.

Some time later, the "Fleming valve" (a half-wave vacuum-tube rectifier or diode) was substituted for the crystal detector, as shown in Fig. 2. This improved the performance of the receiver because the efficiency of rectification
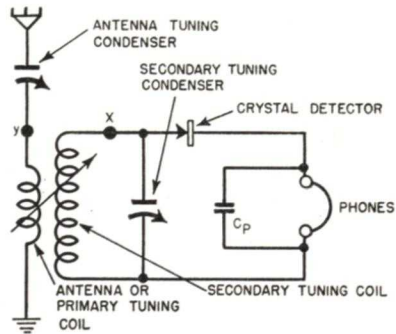

FIG. I. An early receiver consisting of tuned circuit, crystal detector, and headphones.

or detection is better. Tuning selectivity, however, is still quite low, for the "valve," like the crystal, loads the tuned circuit and reduces the effective Q.

After the advent of the three-element tube, the circuit in Fig. 3 was in wide use. The signal output of such a "grid detector" was considerably higher than that of earlier receivers. This
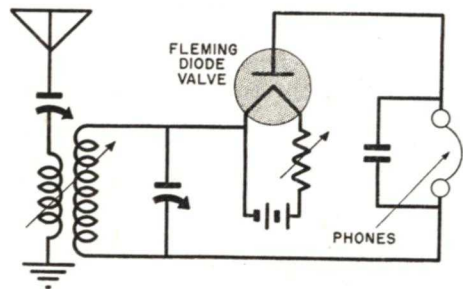

FIG. 2. An early diode tube detector circuit.

is brought about primarily because the grid acts as a diode rectifier plate, and the detected audio signals developed across C_g in the grid circuit are amplified by the triode section of the tube. Running with zero grid bias, however,

the tube grid has a relatively low impedance, and loads the tuned circuit in much the same manner as the crystal detector. The selectivity, therefore, is not appreciably greater than that of earlier receiver types.

To improve both the selectivity and the sensitivity of the three-element detector, the regenerative circuit of Fig. 4 was developed. Sensitivity is increased because any r.f. signal appearing in the output is fed back to the grid circuit to be amplified over again. If the feedback is carefully adjusted just
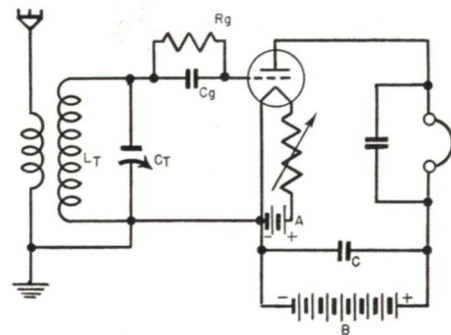

FIG. 3. One of the first triode tube detector circuits.

below the point at which oscillation begins, the sensitivity is extremely high. Selectivity of the receiver also is improved, for the energy supplied to the grid from the plate circuit tends to overcome the natural losses of the resonant circuit and thus increases the effective Q. Further, if regeneration is increased slightly so that weak oscillations are obtained, these will "beat" with incoming continuous-wave code signals to give an audible tone. No prior detector was able to permit reception of unmodulated signals.

In spite of its high sensitivity, the regenerative detector has many faults. Chief among these is that feedback adjustment is extremely critical and changes radically with tuning. For optimum performance, regeneration must

be continually readjusted as the tuning condenser is varied. The detector also is subject to "blocking" on strong signals, meaning that the output drops nearly to zero because of an abnormally high negative grid bias that builds up automatically on overload. In addition, the degree of regeneration is quite sensitive to changes in battery voltage and other disturbances.

Audio Amplification. The effective sensitivity of any of the receivers in Figs. 1 to 4, can be increased by adding one stage, or perhaps two stages, of
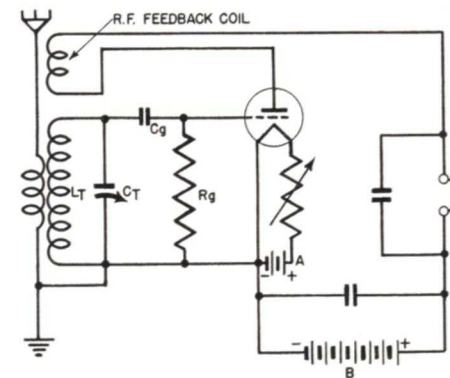

FIG. 4. The introduction of regeneration resulted in a tremendous increase in sensitivity.

audio-frequency amplification. This practice raises apparent sensitivity merely by making more of the weaker signals audible.

There is a limit, however, to the benefits from audio-frequency amplification. Every detector has a certain amount of internal noise, and both this noise and the desired signal are amplified simultaneously by the audio amplifier. As long as the signal is *greater* in intensity than is the noise, satisfactory reception can be obtained, and audio amplification is useful in making signals louder.

But since audio amplification increases noise as well as signal, thus keeping the signal-to-noise ratio con-

stant, with signals that are *lower* in intensity than detector noise, it is impossible to get satisfactory reception regardless of the amount of audio amplification employed. In other words, by audio amplification alone it is not possible to receive useful signals that are much lower in intensity than the noise level of the detector stage itself.

Also, since an audio amplifier does not affect the r.f. portion of the receiver, the selectivity of the single tuned circuit for the receivers in Figs. 1 to 4 will not be changed by audio amplification. And in general, we know that the sharpness of tuning afforded by a single resonant circuit is entirely inadequate for modern use.

Increasing Selectivity. To add selectivity to a receiver, more tuned circuits are needed. If we add a neutralized triode r.f. amplifier stage and one audio amplifier stage to the regenerative detector in Fig. 4, we arrive at the Browning-Drake circuit illustrated in Fig. 5. Because both the r.f. amplifier and the regenerative detector are tuned to the same incoming signal frequency, this type of receiver is sometimes called a "tuned-radio-frequency" (t.r.f.) receiver. Not only does the r.f. stage ahead of the detector greatly improve

selectivity because of the added tuned circuit, but also some weaker signals are raised above the noise level of the detector so that the over-all signal-to-noise ratio as well as the sensitivity are considerably improved.

The Browning-Drake receiver was used extensively for broadcast reception during the years 1925-27. If we should "dress up" the circuit by using modern pentode tubes and possibly add one more r.f. stage and a final audio amplifier, and omit the regenerative detector, we would arrive at about the

Compromise detectors, such as the plate type to be discussed later, have been used, but the performance is still far short of what is required for most modern uses.

► Possibly the worst fault is that neither the selectivity nor the sensitivity remains constant as the receiver is tuned. In general, the selectivity pass band of a t.r.f. receiver tends to have a width that is a constant percentage of the frequency to which the receiver is tuned. In other words, when tuned to a low r.f. frequency, the t.r.f. re-
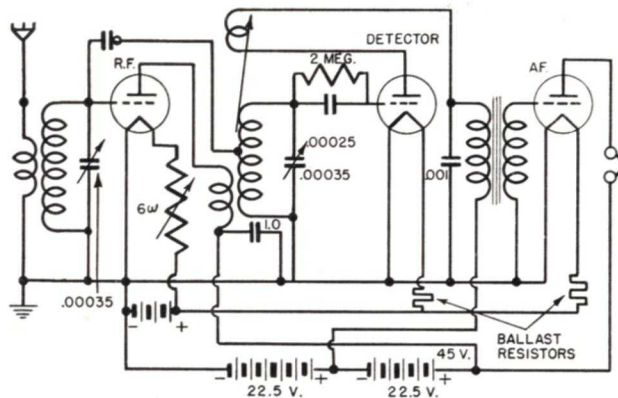

FIG. 5. One form of the famous Browning-Drake receiver circuit, the hit of the 1925-1927 period of home-made receivers.

most stable and sensitive receiver it was possible to build before the introduction of the superheterodyne.

Limitations of the T.R.F. Receiver. Although capable of being made quite sensitive and fairly selective, particularly at the lower r.f. frequencies, the t.r.f. receiver has many faults. One of these, of course, is the fact that the grid-leak detector blocks on strong signals, a defect that is aggravated by the r.f. gain preceding the detector. Crystal or diode detectors obviously can be substituted, but this reduces sensitivity, because regeneration cannot then be used, and such detectors do not have any inherent gain.

ceiver may be quite sharp; but when tuned to a high r.f. frequency, the tuning will become broad. This effect is shown graphically by the typical response curves in Fig. 6A. Note the difference in sharpness at 600 kc. and 1000 kc., respectively.

► As for the variation in sensitivity over the same tuning range, look at the curve in Fig. 6B. Since this is a plot of the signal input in microvolts required to give a definite audio output, where the curve indicates a high input signal, the sensitivity is low, and where the input signal is low, the sensitivity is greater. Note the variation of more than 3-to-1 in sensitivity over the en-

tire tuning range. This change in sensitivity is caused by the fact that the Q of a tuned circuit increases as the tuning capacity is decreased; at low capacities (high frequencies), therefore, there is a higher plate load for the tubes and a greater over-all gain.

From these curves, it is obvious that the t.r.f. receiver cannot give the most

ity can be made quite sharp. Furthermore, the selectivity obtained in this manner will be very nearly the same no matter what the original frequency of the signal being received might be. As an example, note the response curve of a typical superheterodyne given in Fig. 6C. Such a characteristic is very desirable, for it gives good selectivity at
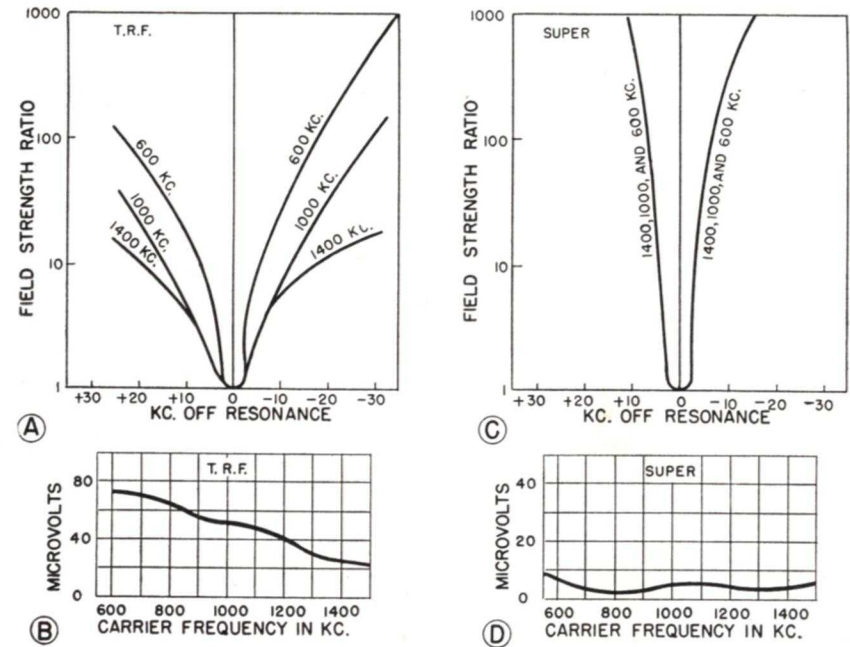

FIG. 6. These sensitivity and selectivity curves for a superheterodyne receiver and for a t.r.f. receiver having the same number of tubes show clearly the superiority of the superheterodyne circuit.

desirable performance, particularly at the higher frequencies where selectivity becomes important.

Advantages of the Superheterodyne. Reviewing for a moment, you will remember that the superheterodyne converts all signals, regardless of their frequency, to the frequency of the i.f. amplifier. It does this by heterodyning the signals with the output of a local oscillator.

Since the i.f. amplifier thus is *fixed-tuned*, it can be more complex than the usual t.r.f. amplifier, and the selectiv-

high as well as low r.f. signal frequencies.

As a further advantage, since the i.f. amplifier usually works at a frequency much lower than that of the signal being received, the gain per stage can be increased. This is possible because the tube interelectrode capacities do not limit the minimum capacity of the tuned circuits. As a result, a higher L-C ratio can be secured, thus giving greater load impedance for each tube and a consequent higher gain. The sensitivity curve for a typical superhetero-

dyne is given in Fig. 6D. Compare this with the curve for a t.r.f. receiver in Fig. 6B. Note that the sensitivity of the superheterodyne is not only much greater but is also subject to much less variation throughout the tuning range. The reason why a superheterodyne provides essentially the same gain for any frequency in its tunable range is that most of the gain in a superheterodyne is secured in the i.f. stages, very little being obtained in the circuits before the first detector where heterodyning occurs.

from the antenna are first fed into a preselector circuit. This preselector may consist of one or more resonant circuits *tuned to the signal frequency*, and it may or may not contain amplifiers to increase the r.f. signal intensity. Its main job, as the name implies, is to select the desired frequency, f_s, and reject all other signal frequencies that cannot be separated from the desired signal by the selectivity inherent in the i.f. amplifier.

The output of the preselector is fed directly to the mixer or first detector

tor lends some selectivity, this is usually negligible; the i.f. section provides most of the adjacent signal selectivity. For the most part, it is the characteristics built into the i.f. amplifier itself that give the superheterodyne its extremely good operating performance.

Following the i.f. amplifier is the second detector, necessary to demodulate the i.f. energy and reproduce the original audio-frequency intelligence signals. This detector is essentially the same as that used in a t.r.f. receiver; the main difference is that it operates at the intermediate frequency, which

is considerably lower in frequency than the signal itself.

After detection, the resulting audio signals are amplified by one or more stages of audio amplification and finally applied to the headphones, the loudspeaker, or some other form of reproducer.

Now that we recall the essential operating principles of the superheterodyne, we shall study each section individually to learn what each part does and see what characteristics are needed to give a high-performance communications receiver.
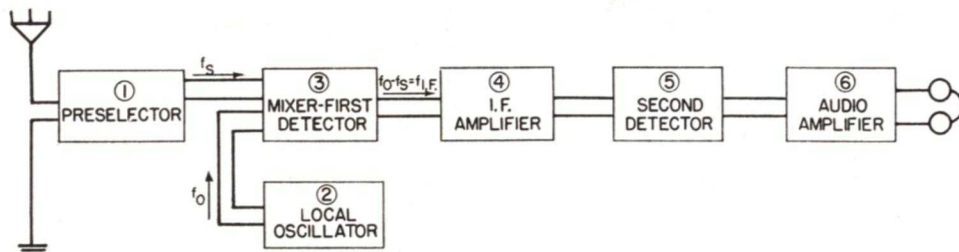
FIG. 7. A block diagram showing the six essential sections of a superheterodyne receiver.

If we study the curves in Fig. 6 for a moment and realize that these are typical performance characteristics for t.r.f. and superheterodyne receivers *having about the same number of tubes*, the superiority of the superheterodyne becomes quite obvious. Although inherently more complex, the superheterodyne has proved to be not only the most sensitive and most selective receiver, but also the most stable and the easiest to operate. As a consequence, almost all communications receivers used today are superheterodynes.

ESSENTIAL SUPERHETERODYNE SECTIONS

For a brief review, let us look at the block diagram in Fig. 7 to refresh our memory on exactly what constitutes a superheterodyne receiver.

As indicated by the drawing, signals

circuit. This mixer, as we shall see later, is actually a detector or demodulator, and it is used simply because it has the property of producing a "beat" or heterodyne frequency, usually called the intermediate frequency, which is exactly equal to the frequency difference between the original signal f_s and a signal f_o generated by a local oscillator. Thus, no matter what the original signal f_s might be, if the local oscillator frequency f_o is adjusted properly, the difference between the two, and hence, the input to the i.f. amplifier, can be made to have a definite constant frequency value.

The i.f. amplifier following the mixer or frequency "converter," therefore, always works at a fixed specified frequency. Because of this, the i.f. amplifier can be designed to have extremely high gain and very sharp selectivity characteristics. Although the preselec-

The Preselector

As Fig. 7 shows, the preselector is inserted between the antenna and the mixer-first detector stage. The preselector, therefore, operates at the original r.f. signal frequency before frequency conversion takes place. Strictly speaking, the preselector is merely one or more resonant circuits that can be adjusted to the frequency of the desired r.f. signal; r.f. amplifier stages may or may not be included.

Theoretically, the preselector is not needed to convert an r.f. signal to a lower intermediate frequency; if it is omitted, however, spurious signals will get into the mixer-first detector and there react with each other or with the local oscillator signal to produce serious interference. To appreciate the importance of the preselector and to understand more clearly the functions which it must perform, let us consider a hypothetical superheterodyne that has no preselector at all.

DIRECT INPUT CIRCUIT

The mixer-first detector section (frequency converter) of a superhetero-

dyne circuit that has no preselector is given in Fig. 8. Any signal f_s that 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 that we shall designate as f_o. Assume that the frequency of this signal f_o can be controlled by varying the setting of the
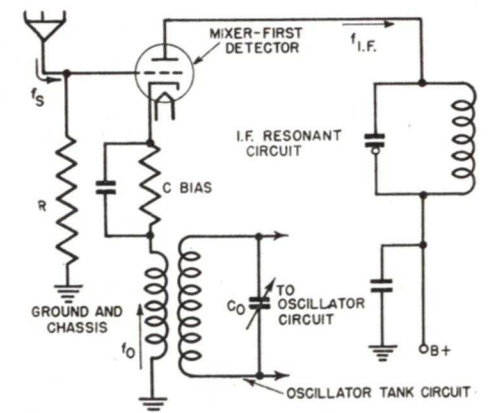
FIG. 8. Schematic diagram of the mixer-first detector section of an imaginary superheterodyne receiver that has no preselector.

oscillator tank condenser C_o. The resonant circuit in the plate lead of the tube is adjusted to the desired intermediate-frequency 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. 8, and that the i.f. resonant circuit is

"double-spot" tuning, for we have repeat points—two different points at which the oscillator tuning dial may be set to receive the same station. 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. As we shall see, ganging
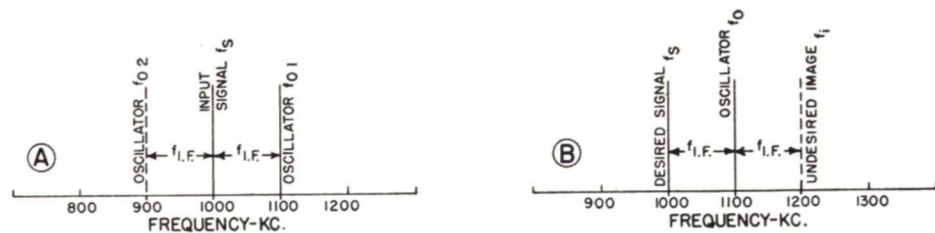

FIG. 9. As shown at left, the oscillator may be tuned higher or lower in frequency than the input signal and still produce the same intermediate frequency. Image interference results, as shown at right, if an undesired signal separated from the oscillator by the intermediate frequency is allowed to reach the mixer-first detector.

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 the frequency f_{o1} of 1100 kc. This is illustrated in Fig. 9A where the input signal f_s and the oscillator signal f_{o1} are seen to have a frequency *difference* of exactly 100 kc.

But we can also secure the 100-kc. beat frequency $f_{I.F.}$ by setting the oscillator to the frequency f_{o2} of 900 kc.; as shown in Fig. 9A, the frequency difference between the two signals in this case is also equal to 100 kc.

▶ Thus, there are *two* oscillator tuning dial settings at which the 1000-kc. incoming signal will be converted to the 100-kc. intermediate frequency. This condition is called "repeating" or

the preselector and oscillator tuning condensers on a common shaft to provide single-dial control also serves to eliminate repeat-point reception, provided a preselector that will reject the station signal at the repeat point is used.

It is obvious from Fig. 9A that for superheterodyne action we have a choice: the local oscillator can be set *higher* in frequency than the received signal, or it can be set *lower*, the only requirement being that the frequency *difference* be exactly equal to the intermediate frequency being used. The oscillator frequency in most broadcast-band superheterodyne receivers is kept *higher* than the received signal because a 3-to-1 tuning ratio is about the best that can be gotten in conventional os-

cillator circuits; if the oscillator frequency were below that of the incoming signal, the oscillator could not be made to cover the whole broadcast band. In very-high and ultra-high-frequency receivers, however, the oscillator frequency is often set below the frequency of the incoming signal.

Image Interference. But keeping the oscillator frequency always on the "high side" of the signal will not eliminate all interference troubles if there is no preselector. Let us assume that the circuit of Fig. 8 is receiving a signal f_s at 1000 kc., and the oscillator is set at a frequency f_o of 1100 kc., thus giving an i.f. output of 100 kc. This condition is illustrated in Fig. 9B.

From your own experience, you know that signals of many different frequencies are always present in the antenna circuit of a receiver. If one of these happens to be at 1200 kc., as shown by the dotted line in Fig. 9B, it can cause serious interference. This is true because the undesired signal f_1 also is separated from the oscillator frequency by 100 kc., and therefore beats with the oscillator to produce a spurious i.f. signal of 100 kc. In other words, both the desired signal f_s and the undesired signal f_1 are converted to i.f. signals and are reproduced simultaneously in the receiver output with equal intensity. This reception of an undesired signal that happens to have a frequency that is just right to produce a spurious i.f. output is called "image interference."

Notice that the image frequency f_1 is higher in frequency than the desired signal f_s and the two are separated by exactly twice the i.f. value. Actually, 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 in-

terfering with a desired signal.

Other Types of Interference. In addition to image interference, there are two other types which are troublesome if no preselector is used. One of these, called "intermodulation interference," occurs when *any two* signals whose frequencies differ by exactly the i.f. value exist in the antenna circuit of Fig. 8. These two signals can beat *with each other* to produce the i.f. value *without the aid of the local oscillator*. These self-mixed signals cause an interference sounding like garbled speech which is heard regardless of the oscillator dial setting.

Trouble also can be caused by an undesired signal *having a frequency equal to the i.f. value* of the receiver. If this signal is applied directly to the mixer-first detector, it will be passed on to the i.f. amplifier as there is no need for frequency conversion. Since most transmitters below 500 kc. (in the range of the i.f. value) are code stations, this trouble is commonly referred to as "code interference." It may be heard at any point on the tuning dial, and is not influenced greatly by the tuning of the local oscillator.

A SINGLE TUNED CIRCUIT

The obvious solution to all these interference problems is to use a selective input circuit, or preselector, that is capable of tuning to the desired signal and of rejecting all others, particularly the image signal.

The simplest method of doing this is to use the preselector circuit in Fig. 10. This is merely a tuned r.f. transformer. Antenna currents flow through the untuned primary L_p, and because of the mutual inductance between the windings, induce a voltage in the secondary winding L_s that causes a current flow in the winding. The secondary is tuned by the condenser C. The voltage de-

veloped across this condenser and applied to the mixer grid, therefore, will be maximum at the frequency for which the circuit is resonant.

If we assume that an intermediate frequency of 500 kc. is being used, and that the desired signal to which the preselector is tuned is 1000 kc., then the response of the circuit will be like Fig. 11A. Note that the response to the desired signal is many times greater than that for the image 1000 kc. higher in frequency.
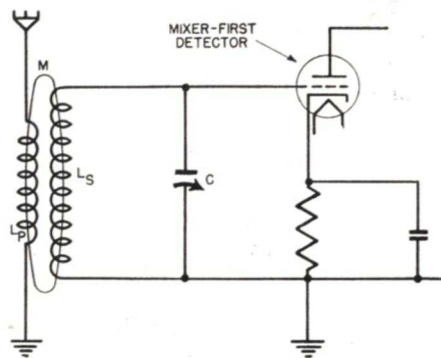
Choice of I.F. Frequency. The effectiveness of such a simple preselector as Fig. 10, however, is determined to a great extent by the intermediate frequency value. In Fig. 11A we have assumed that the i.f. value is 500 kc. The desired and image signals in this case lie 1000 kc. apart, and as shown by the figure, rejection of the latter is fairly good.

On the other hand, if a low i.f. value, such as 100 kc., is used, the performance will not be acceptable. For this condition, the desired and image signals will be separated by only 200 kc. and, as pictured in Fig. 11B, the image signal will "ride through" with very nearly the same intensity as the desired signal.

From Figs. 11A and 11B, we can see

that a comparatively simple preselector can be employed if a high i.f. value is used; but, if the intermediate frequency is low, the selectivity afforded by a single tuned circuit is entirely inadequate.

If such is the case, then why not make the i.f. value as high as we desire? Then comparatively little selectivity in the preselector will be necessary. Unfortunately, as we make the i.f. value higher, the selectivity that we can build into the i.f. amplifier itself goes down—that is, the wider the

FIG. 10. A simple tuned r.f. transformer preselector.

i.f. amplifier "pass-band," the lower its selectivity. This, of course, tends to reduce the over-all selectivity of the superheterodyne receiver.

A compromise, therefore, is necessary between too low an i.f., which requires very good selectivity in the preselector, and too high an i.f., which reduces the selectivity of the i.f. amplifier. A great number of different i.f. values have been used in broadcast-band receivers, such as 130, 175, 260, and 456 kc. Communications receivers, considering all types, may employ intermediate frequencies ranging from 455 kc. to 60 mc. For example, 5 to 10.7 mc. is widely used for f.m. Television may employ an i.f. of about 26 mc. In radar, i.f. values of 30 mc. and

60 mc. are common. High-frequency i.f. amplifiers (above 465 kc.) will be considered in another Lesson.

MULTIPLE TUNED CIRCUITS

The ideal preselector, which will allow only a single frequency or a narrow band of frequencies to pass and
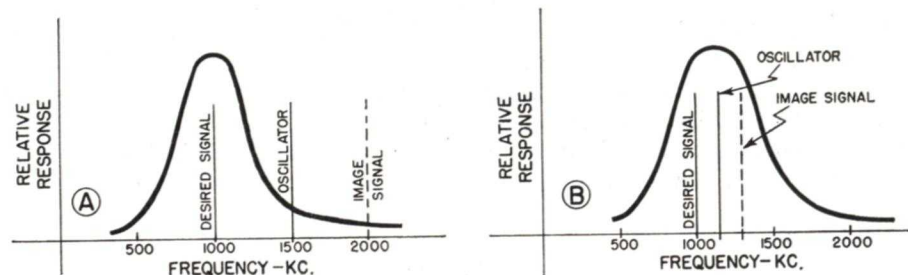

FIG. 11. With a high i.f. value, as at left, the selectivity of a simple preselector is sufficient to reject the image signal. With a low i.f. value, as at right, a simple preselector will not prevent excessive image interference.

will absolutely reject all other frequencies, does not exist. Indeed, in a superheterodyne it is unnecessary, because the i.f. amplifiers will give adjacent channel operation. In the broadcast band, stations are separated by 10 kc. Usually, if a preselector can be designed to *reduce* the strength of the interfering station (at the image frequency) 1000 times, it is considered satisfactory. This number is called the "image interference ratio" and, in this case, means that an undesired image signal will have to be 1000 times stronger than the desired signal to produce an i.f. as strong as the desired signal.

The simple preselector shown in Fig. 10 is reasonably effective in broadcast sets, but in general it is inadequate for communications receivers. Although rejection of the image frequency may be satisfactory at 1 mc., as illustrated by curve A in Fig. 12, the performance at some higher frequency, say 20 mc., will be very poor. (Image interference is generally present on the high-fre-

quency bands of all-wave home sets using the preselector shown in Fig. 10.) Curve B shows this broadening of response with increase in frequency which is typical of all resonant tuned circuits. Note that rejection of the image signal is practically nil.

To improve preselector selectivity, two or more tuned circuits in cascade must be used. Fig. 13 shows the typical improvement in selectivity at one given frequency that can be gotten by using multiple tuned circuits. Curve A is for a single tuned circuit like Fig. 10; curve B is for two circuits in cascade; and curve C shows the response when three resonant circuits are used. Note the diminishing of response at the image frequency as the number of tuned circuits is increased.

Typical Double-Tuned Circuits. Several different means of connecting multiple tuned circuits may be employed. Three common methods of
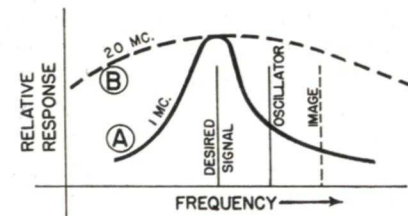

FIG. 12. A simple preselector may have adequate selectivity at 1 m.c., but at higher frequencies may permit intense image interference.

coupling double-tuned circuits for a preselector are shown in Fig. 14. In all cases, the dotted lines between the two condensers indicates that these are mounted on a common shaft and thus are ganged for single-dial control.

The circuit shown in Fig. 14A is simply the circuit of Fig. 10 with an additional resonant circuit, made up of L_{s2} and C_2, coupled by mutual induction to L_{s1}. Fig. 14B shows two resonant circuits that are *directly* coupled inductively by having coil section L_{m2} common to both resonant circuits. Capacitive coupling is used in the circuit

is considerably reduced. This improvement is secured to some degree whether coupling is increased to give a band-pass effect or left small to result in a sharp, "peaked" curve.

PRESELECTORS USING AMPLIFIERS

Although multiple-tuned preselectors are quite effective in eliminating, or at least reducing, the many types of interference trouble, they have one important drawback in that they also considerably reduce the strength of the incoming signal. This loss of signal strength can be overcome to some ex-
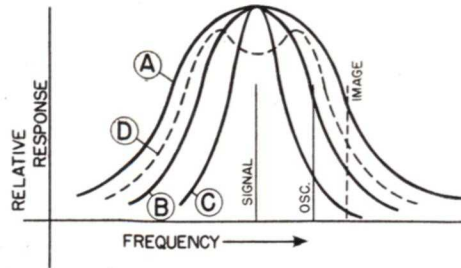
FIG. 13. As the number of tuned circuits in the preselector is increased, the rejection of the image is improved.

of Fig. 14C, with condenser C_k common to both resonant circuits.

If the coupling between the two resonant circuits in each arrangement of Fig. 14 is made quite small, a single sharp resonance characteristic similar to curve B in Fig. 13 is obtained. In some cases, particularly for high-fidelity broadcast receivers, the coupling may be increased so that the response curve does not come to a sharp peak as shown by curve D in Fig. 13. Close-coupled circuits of this sort are referred to as "band-pass" preselectors; they are not ordinarily used in communication receivers, however.

As we said, the principal merit of dual-tuned preselectors is that the receiver response at the image frequency

tent, of course, by stepping up the gain of the i.f. amplifier following the mixer-first detector. There is a limit, however, to the usefulness of this remedy.

Converter Noise. As we shall see later, the mixer-first detector stage of a superheterodyne is a veritable "melting pot" of noise disturbance. As we know, the output of any vacuum tube contains a certain amount of noise, caused principally by irregularities in electron emission. Thus, electrons emitted by the cathode arrive at the plate in spurts or "shots," and when these minute current variations are amplified by succeeding stages, they are heard in the loudspeaker as a "frying" noise. This action is known as the "shot effect."

▶ But the mixer-first detector is much worse than other types of vacuum-tube stages. Because of its mixer action, its output will not only contain shot-noise originating at the intermediate frequency, but also noises at other frequencies that may beat with each other, with the local oscillator signal, or with harmonics of the oscillator, and thus be "converted" and applied to the i.f. amplifier. The end result is that the i.f. amplifier is fed random noise voltages at the i.f. frequency that have comparatively high amplitude.

Signal-to-Noise Ratio. This inherent noisiness of the mixer-first detector is a distinct disadvantage of the super-heterodyne circuit. It is obvious that a weak input signal that is lower than the mixer noise cannot be received satisfactorily. Increasing the gain of the i.f. amplifier will not help, because the mixer noise as well as the i.f. signal is amplified and the signal-to-noise ratio is kept constant.

Mixer 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.

We see then that the signal losses resulting from a multiple-tuned preselector such as those in Fig. 14 are quite undesirable, because they reduce the effective signal-to-noise ratio.

Use of R.F. Amplification. To overcome the losses in the preselector circuit and also to raise very weak signals, which even without the preselector would result in a poor signal-to-noise ratio, it is very desirable to have a stage or two of r.f. amplification ahead of the mixer-first detector sec-

tion. In this way the strength of the incoming signal can be built up so that it will over-ride any mixer noise that is present. The greater the signal strength with respect to the noise that can be obtained, the less disturbing will be the noise.
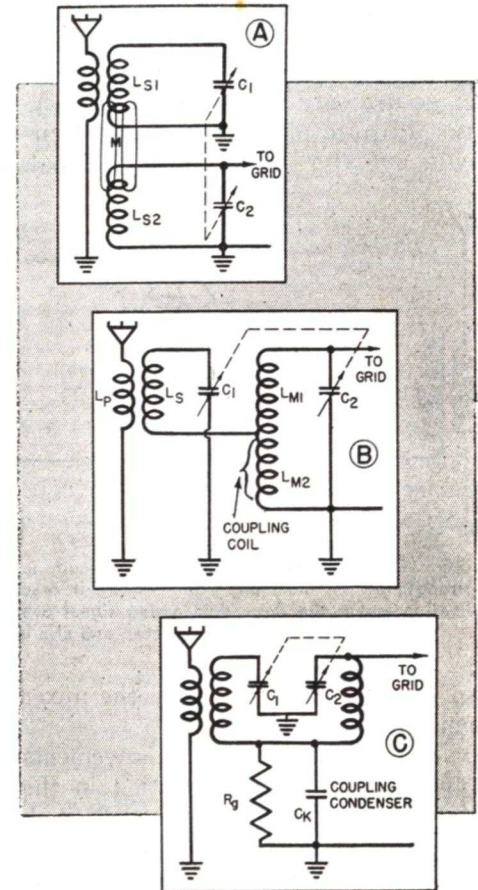
FIG. 14. Three methods of coupling double-tuned circuits for a preselector.

A widely used preselector circuit that contains a stage of r.f. amplification to increase the signal strength at the input to the mixer-first detector is shown in Fig. 15. The higher the gain of this stage, the better the receiver signal-to-noise ratio will be. Since both the r.f. and mixer stages have

resonant input circuits, we have in reality a dual-tuned circuit. Besides an improvement in signal-to-noise ratio, therefore, we also have extra selectivity which helps to improve the image rejection ratio, thus reducing interference.

In some of the better receivers, not one, but two, and sometimes three such r.f. amplifier stages may be used in the preselector. Each additional stage not only improves image rejection because of the added tuned circuit, but also builds up weak signals

receiver is tuned. We find then that if the preselector amplification is made great enough, these tiny pulses will become audible in the receiver output as a "hissing" or frying noise. These disturbances are commonly called "thermal noise."

Thermal noise itself marks the limit of preselector amplification. When tuned between stations, a good receiver with maximum preselector gain will have a slight "hiss" in the output. Shorting the input terminals will reduce the hiss slightly, indicating ther-

have learned, we shall see that a super-heterodyne preselector having one or more stages of tuned r.f. amplification serves two important purposes:

1. The more important function is the elimination of interference, particularly image interference and "double-spot" tuning. Tuning in the preselector also reduces two other types of interference: intermodulation, which occurs when any two signals having a frequency difference exactly equal to the i.f. are allowed to reach the mixer-first detector and there beat together

without the aid of the local oscillator to form a spurious i.f. signal; and code interference, which occurs when a signal exactly equal to the i.f. is fed to the mixer-first detector and is passed on to the i.f. amplifier.

2. The other important function of a preselector in which r.f. amplification is used, is to increase the intensity of very weak signals so that they will over-ride the noise normally encountered in the mixer-first detector, thus improving the over-all signal-to-noise ratio of the receiver.
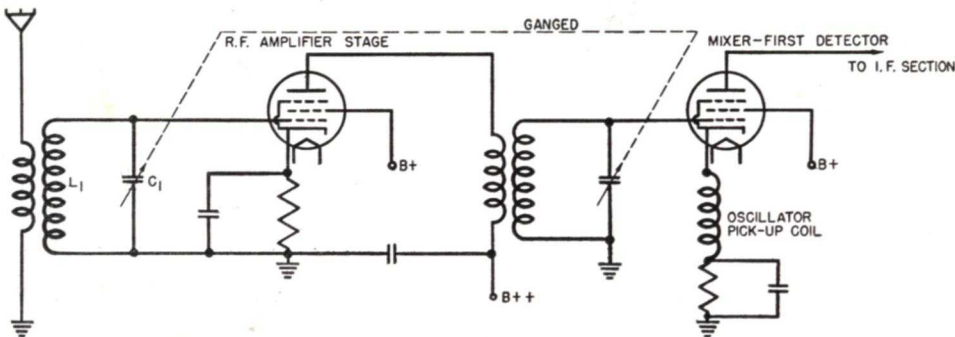

FIG. 15. A widely used preselector circuit, in which one stage of r.f. amplification boosts the strength of the incoming signal before it reaches the mixer-first detector. This additional amplification makes the desired incoming signal over-ride any noise that may be present in the mixer-first detector, and also lessens interference troubles.

so that they will over-ride the mixer noise.

Thermal Noise. The improvements afforded by r.f. amplification in the preselector, nevertheless, are limited. Eventually, as preselector r.f. gain is increased, a point will be reached at which the signal-to-noise ratio is no longer further improved; instead, noise will again become noticeable.

In any conductor—and this applies as well to the antenna and first tuned circuit in a preselector—free electrons are continually moving around from thermal agitation and producing tiny pulses of electron current. Some components of these pulses will be at the same frequency as that to which the

mal noise is present. A preselector gain greater than that which makes thermal noise just audible is not usable, for it serves only to make the thermal noise louder.

In practice, thermal noise limits the useful sensitivity that can be built into a receiver to about 1 microvolt, meaning that the smallest signal voltage that ordinarily can be made to give 50 milliwatts output to the loudspeaker with a satisfactory signal-to-noise ratio is approximately 1 microvolt.

SUMMARY OF PRESELECTOR FUNCTIONS

If we review for a moment what we

The Mixer-First Detector

After the preselector of a super-heterodyne has done its work of providing a "clean-cut" signal, relatively free from image and other interference troubles, this signal is applied to the mixer-first detector or "frequency-converter" stage. It is in this mixer stage that the received signal is combined with the signal from a local oscillator to produce a beat or heterodyne signal which is further greatly amplified by the i.f. amplifier.

We shall take up some practical mixer-first detector circuits in a moment. Before doing so, however, let us see how it is possible to generate the new intermediate frequency by this heterodyning process.

THE HETERODYNE PRINCIPLE

Suppose we have the basic mixer or frequency converter stage illustrated in Fig. 16. This is merely a triode amplifier that has two input signals: 1, the r.f. carrier from the preselector, applied to the grid resonant circuit L-C; and 2, the signal from the local oscillator, also applied to the grid through the r.f. transformer T. In the

plate circuit is the tuned tank load L_1-C_1, which is *not* tuned to either of the input signals, but instead, is adjusted for resonance at a frequency equal to their difference, which, in the case shown, is 1100 — 1000, or 100 kc.

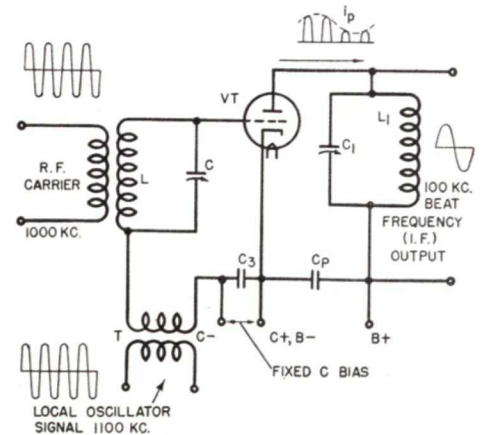**The Resultant Grid Signal.** Suppose we assume the 1100-kc. signal generated by the local oscillator looks

FIG. 16. The basic triode mixer circuit. Two signals applied to the grid heterodyne to produce a new signal having a frequency equal to the difference in frequency of the original signals.

like Fig. 17A and the incoming 1000-kc. signal like Fig. 17B. With two such separate signals fed to the grid in Fig. 16, what is the resultant grid voltage?

Since these two signals have different frequencies, their relative phase is constantly changing. When they are in phase, they add together to give a high grid voltage; a moment later, when out-of-phase, they "buck" to result in a small grid voltage. The resultant grid voltage, therefore, is the algebraic sum

swings increase and decrease at exactly the same time the positive swings rise and fall. Indeed, this wave form represents nothing more than what we started with—the sum of two different frequencies.

This means that if the vacuum tube in Fig. 16 is biased so that it operates in true *linear* class A manner with a minimum of distortion, the beat frequency signal output in the plate circuit will be zero.
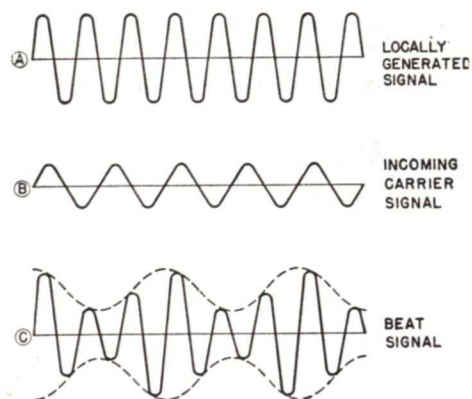

FIG. 17. How two signals of different frequencies are "added" together to produce a beat signal.

of the two separate signals and varies in amplitude like the wave shown in Fig. 17C. This "beat" or heterodyne signal is actually formed by adding the two waves shown in Figs. 17A and 17B.

Note that the envelope of the beat signal, as indicated by the dotted lines, closely approaches the shape of a sine wave, and that the frequency of this envelope, (the number of times per second it rises and falls) is exactly equal to the *difference in frequency* between the two signals producing it.

Need for Rectification (Detection). In spite of its complex shape, however, the beat signal wave shown in Fig. 17C contains *absolutely no energy at a frequency of 100 kc.* Such is the case because the negative voltage

Suppose, however, we deliberately make the operation of the tube in Fig. 16 *non-linear*. We can do this most simply by increasing the C-bias applied to the tube to the plate current cut-off point. Operated in this manner, the tube now has a rectifier (or detector) characteristic like that shown in Fig. 18B.

If we now apply two mixed r.f. signals, as illustrated in Fig. 18A, to the tube, the plate current will flow in uni-directional pulses like Fig. 18C. Such is the case because with the tube at cut-off, a negative grid swing can have no effect on plate current, whereas a positive grid swing will reduce the instantaneous grid bias and bring about a pulse of plate current flow.

Now these uni-directional plate current pulses shown in Fig. 18C *do* contain energy at the 100-kc. beat signal frequency. This is indicated by the dotted envelope outline. With the negative pulses "chopped off," the effective current flowing in the plate circuit becomes a pulsating direct current that varies at beat frequency. (Fig. 18D).

Actually, the plate current pulses that flow through the plate circuit of the tube in Fig. 16 contain other frequencies besides the 100-kc. beat frequency. These pulses carry energy at the original incoming 1000-kc. signal
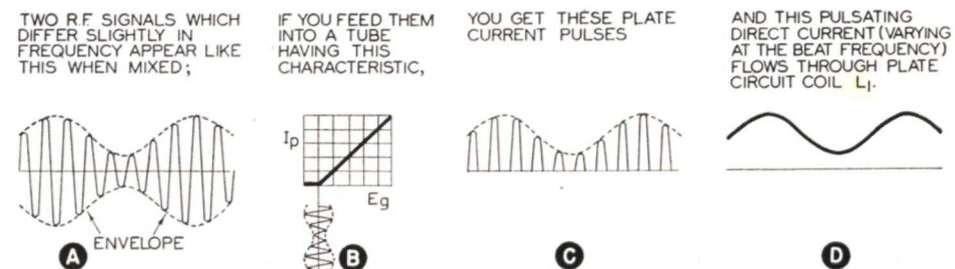

FIG. 18. Wave forms showing how beat frequency energy is obtained only after rectification (detection) has taken place.

frequency, and at the 1100-kc. local oscillator frequency, together with numerous harmonics of these and the beat signal frequency. At all of these frequencies, however, the impedance of the plate tuned circuit L_1-C_1 is very low, and these signals are "shorted out." At the beat signal frequency only is the impedance of L_1-C_1 high enough to present an effective load to the tube. The tank circuit L_1-C_1, therefore, acts as a filter that selects only the beat signal from a great number of other signals.

There is one possible difficulty that this filtering action will not overcome. Suppose that, in a receiver using an i.f. of 456 kc., a very strong signal is received from some code station having a frequency of 228 kc. (half the i.f.). If this signal can get through the

preselector and be rectified by the first detector, its second harmonic (228 × 2 = 456 kc.) will be produced by the detector action and will appear in the first detector output, and, since it is equal to the i.f., will be passed on to the i.f. amplifier.

Reviewing the action of the mixer stage in Fig. 16, we can see that the incoming signal at 1000 kc. has been changed to an entirely new frequency of 100 kc. It is also easy to visualize that if the original 1000-kc. signal had been amplitude modulated, the resulting beat signal also would be modulated in the same manner and to the same degree. This heterodyning action resulting from the mixing and rectification of two separate signals is often called "frequency conversion."

The First Detector. One important fact mentioned above should not be overlooked: *It is absolutely necessary that a mixer tube be operated in a non-linear manner.* As a matter of fact, if the mixer tube does not rectify (detect) or distort the mixed signals in some way, it is impossible to obtain a beat frequency signal. When we biased the tube in Fig. 16 to plate current cut-off, as we shall see later, we made it operate exactly like a plate-circuit detector. For this reason, the mixer stage in a superheterodyne is frequently called a "first detector." (Some call it a "translator.")

METHODS OF INJECTION

The 1000-kc. incoming signal and the 1100-kc. signal from the local oscillator shown in Fig. 16 are effectively in series and are applied to the same control grid. Although this method of mixing can be made to operate fairly efficiently, it does have some disadvantages.

Probably its worst fault is that tuning the preselector condenser C will react on the local oscillator by changing its loading and thus vary both the oscillator frequency and the output voltage. This makes tuning of the receiver unreliable, because any spurious change in oscillator frequency alters the resulting beat or intermediate frequency and hence mistunes the receiver. In addition, there is some "pulling" of the oscillator—that is, strong incoming signals will shift the oscillator frequency slightly.

Several other methods of injecting the local oscillator signal into the mixer tube have been devised. These are shown in Fig. 19. Some of these are somewhat better in preventing interaction between the preselector and oscillator tuning.

Grid Shunt Injection. Instead of feeding the oscillator and incoming signals in series to the mixer control grid, these two signals may be fed in parallel. Such an arrangement is shown in Fig. 19A, where coil L_p and condenser C_p make up the preselector tuned circuit, and coil L and condenser C form the oscillator tank circuit. The local oscillator signal is fed directly to the mixer-detector grid through the coupling capacity C_k. The resistor R_k is an isolating resistor, and the larger this resistor is made, the less the spurious coupling between the preselector and oscillator tuned circuits. If resistor R_k is made extremely large, however,

an excessive oscillator voltage must be developed to produce sufficient voltage at the mixer grid. This circuit, therefore, is at best a compromise.

Cathode Injection. An improved method of injection is shown in Fig. 19B. Here the incoming signal is fed to the mixer-detector grid as before; the oscillator signal, however, is fed into the cathode circuit by means of a small pick-up coil L_m. Mixing occurs within the tube because the instantaneous plate current is determined by the grid-to-*cathode* voltage rather than the grid-to-ground voltage. Grid-to-cathode potential is equal to the algebraic sum of the incoming and oscillator signals, so a beat frequency is obtained as before. The cathode resistor R_g, of course, must be of sufficient size to bias the tube near cut-off to produce non-linearity.

Since the two signals are supplied to separate mixer tube elements, the stray coupling between preselector and oscillator circuits is greatly reduced. The little coupling that does remain occurs because the impedance of the grid is affected by the cathode potential, and the cathode impedance into which the oscillator works is in turn, influenced by the effective grid-to-ground voltage.

Screen Grid, Suppressor Grid, or Plate Injection. Mixing between two signals will occur if these are fed to *any two* tube elements and the tube is operated in a non-linear fashion. Thus, as shown in Fig. 19C, if the incoming signal is fed to the mixer control grid, the local oscillator can be fed to the screen grid, suppressor grid, or even the plate of a multi-element tube.

For the cases of screen-grid and suppressor-grid injection, since the oscillator has no connection to other circuits except through the electron stream

within the tube, the preselector and oscillator circuits are very well isolated. These methods are sometimes called "electron coupling."

Conversion Gain. In general, for all the injection methods shown in Figs. 16 and 19, the performance will be about the same if the mixer tube is adjusted for optimum operation. Mixer performance usually is measured in *transconductance* or *conversion gain*, the latter being simply the ratio of the beat-frequency output signal in volts to the incoming signal in volts. And for experiment, it has been found that a given tube will give about one-third the gain as a mixer as it will as a "straight-through" r.f. amplifier in which no frequency conversion takes place.

From this rule of thumb, it is reasonable to expect that a pentode mixer tube would give more conversion gain than a triode. This is usually true. With multi-element tubes, however, since the total cathode current divides into screen grid and suppressor grid currents as well as plate currents, there is much more opportunity for spurious current fluctuations to give rise to noise. For this reason, the signal-to-

FIG. 19. Methods which have been used for feeding the local oscillator signals into the mixer-first-detector of a superheterodyne.

noise ratio ordinarily is slightly lower with a pentode than with a simple triode mixer.

Voltage Requirements. You will remember when we discussed the beat frequency signal shown in Fig. 17C, we said this envelope closely approached a sine wave. This is only approximately true. Indeed, if the incoming signal and the signal from the local oscillator have exactly the *same* amplitude, as shown, the beat signal envelope will not be a sine wave at all; instead, it
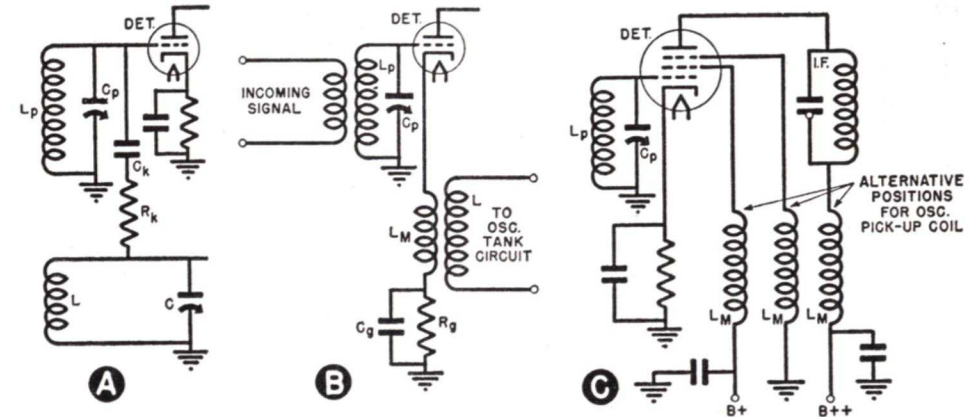
will have a complex shape indicating the existence of the desired beat frequency signal *plus a great many of its harmonics*.

These harmonics of the desired beat frequency are not directly harmful, since the tuned circuit L_1-C_1 in Fig. 16 will reject them and accept only the desired beat frequency or i.f. signal. These harmonics, however, will heterodyne with noise impulses originating within the mixer tube and thus "convert" some noise voltages that would not otherwise appear in the mixer output. This means that the signal-to-noise ratio of the mixer circuit will be poor.

On the other hand, if the local os-

cillator signal shown in Fig. 17A is made at least three times, and preferably about ten times as great in amplitude as the incoming signal in Fig. 17B, then the envelope of the beat frequency in Fig. 17C will be much closer to a sine wave. Under these circumstances, the harmonics of the beat frequency will be greatly suppressed; and this, of course, diminishes the spurious noise voltages that may be heterodyned to appear in the mixer output. *For the very practical reason that the signal-*

oscillator frequency to drift towards that of the preselector). It is found, however, that the oscillator voltage must be large to get a satisfactory amount of conversion gain with low noise. Since it is difficult to design a local oscillator that will deliver the required voltage and yet have sufficient frequency stability, screen grid or suppressor grid injection methods are not often used.

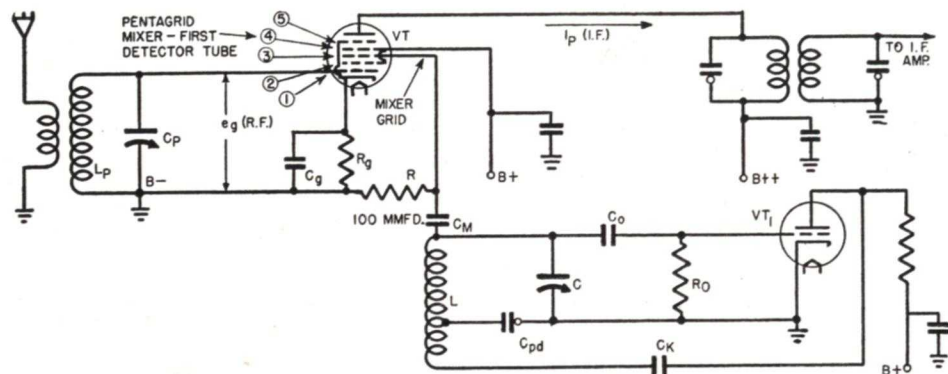Of all the mixer circuits shown in Figs. 16 and 19, the cathode injection

tubes that have not one, but two control grids, one for the incoming signal, and one for the local oscillator signal injection.

A typical pentagrid mixer stage with a complete oscillator circuit is shown in Fig. 20. Grid 1 of VT in this figure is the conventional control grid to which the incoming signal is applied. This grid is kept negative with respect to the cathode by the self-biasing cathode resistor R_g. Grids 2 and 4, which are connected together within the tube, act as a screen grid to reduce the internal capacity between the plate and control grid 1. Grid 5 is a suppressor grid that reduces the effects of secondary emission from the plate.

Grid 3 is the oscillator signal injection grid. For non-linearity and proper mixing action, this grid is biased highly negative, not only by the cathode resistor R_g but also by the additional bias voltage developed by rectified grid current flowing through the grid leak resistor R. Since the oscillator voltage is applied to a separate grid

and thus modulates the electron stream, this really is a form of electron coupling. Also, since grid 3 is surrounded on *both* sides by the screen grids 2 and 4, there is very little capacity between this injection grid and any of the other tube elements. In this way, the stray coupling between the oscillator circuit and both the preselector and i.f. circuits is reduced.

Although the oscillator VT_1 must drive grid 3 of VT positive so that it draws current, the peak voltage required ordinarily is only 13-15 volts. This is not a severe load, and the oscillator can be made quite stable with little frequency drift. In addition, since the mixer tube VT is essentially a pentode as far as effects of grid 1 are concerned, the conversion gain of the stage is relatively high. In general, the pentagrid mixer in Fig. 20 is one of the most satisfactory first-detector circuits it has been possible to devise. Almost all modern, high-quality communications receivers either use this basic circuit or some direct modification of it.

FIG. 20. A pentagrid mixer-first detector circuit in which the oscillator signal is injected into the electron stream.

to-noise ratio is improved, all communications receivers are designed so that the local oscillator voltage fed into the mixer-first detector is kept from three to ten times as great in amplitude as the incoming fed from the receiver preselector.

Comparison of Injection Methods. This requirement that the local oscillator voltage be kept considerably greater than the incoming signal, nevertheless, sometimes proves to be a handicap. Inspecting the mixer circuits in Fig. 19C, we have already found that screen grid or suppressor grid injection gives the most isolation between oscillator and preselector circuits because the electron coupling reduces "pulling," (the tendency of the

method given in Fig. 19B probably is the best compromise. Although there is still some stray coupling between preselector and oscillator tuned circuits, the local oscillator voltage supplied to the cathode need be only three to ten times the incoming signal grid-to-ground voltage. In general, this is the most satisfactory injection method when any ordinary triode or pentode tube is used for the first detector.

Use of Pentagrid Mixer Tubes. To reduce the stray coupling between oscillator and preselector circuits and yet keep the voltage requirements of the local oscillator quite low, a number of special pentagrid mixer tubes have been developed expressly for first-detector service. There are multi-element

The Local Oscillator

The oscillator stage in Fig. 20 is a conventional Hartley oscillator circuit. Almost any other type of oscillator, such as Meissner, Colpitts, etc., can be used just as well. Two typical oscillator circuits often used are given in Fig. 21.

Fig. 21A, although a Hartley circuit, differs from Fig. 20 in that the plate instead of the cathode is kept at r.f. ground potential; also, the tuning capacity C is shunted across the entire tank coil L. This arrangement permits tuning to a given frequency with a slightly smaller tank inductance L, but there is some danger of a.c. hum arising from the cathode being kept at an above-ground potential. In Fig. 21B we have an ordinary tuned-grid oscillator with a plate tickler coil L_1 for feedback coupling. This particular circuit is convenient, for the entire tank coil L is utilized and the cathode is grounded. The necessity for providing a separate tickler coil, however, is a disadvantage.

In general, there is little preference between the various possible types of oscillators. Electrically, all perform about the same. The decision upon one particular oscillator type usually is a matter of personal choice and depends to some extent upon such factors as number of components necessary, the expense of manufacture, etc.

OSCILLATOR REQUIREMENTS

No matter what particular oscillator circuit is used in a superheterodyne receiver, there are a number of requirements that must be met for optimum performance. In order of importance, these are:

1. At any dial setting, the frequency of the oscillator must be very nearly constant so that frequency drift will be reduced to a minimum.
2. The oscillator must be coupled to the mixer-first detector in such a way that the frequency of the oscillator is least affected by changes in other circuits.
3. The output of the oscillator must have negligible harmonic content.
4. The oscillator itself should have little stray radiation.
5. The variation in oscillator output voltage as the oscillator frequency is changed by tuning must be kept within reasonable limits.

Some of these requirements are so important that they warrant further explanation.

Frequency Drift. In the earlier part of this Lesson we found that the intermediate or beat frequency signal that results when the receiver input signal is converted is exactly equal to the *difference* in frequency between the input signal and the local oscillator. From such a relation, it is easy to see that any spontaneous frequency change of the local oscillator results in an equal shift in the i.f. signal fed to the i.f. amplifier. When the oscillator operates at very high frequencies, as it does when the superheterodyne receiver is tuned to the shorter wavelengths, very slight circuit changes produce large amounts of oscillator frequency drift. This can cause much trouble, for if the undesired oscillator drift is severe enough, the beat signal will shift so far from the desired intermediate frequency that the receiver will be completely out-of-tune and little or no signal will be received.

The only satisfactory remedy for this mis-tuning is to design the local oscillator so that frequency drift is reduced as much as possible. In practice, good oscillator frequency stability is secured by using a tank circuit that has a high Q factor and by keeping the loading upon the oscillator at a minimum. Other steps necessary are keeping the oscillator plate supply voltage constant and locating all oscillator components away from sources of heat is to use the pentagrid mixer tube.

Choice of a good mixer tube, however, takes care of stray coupling only within the first-detector tube itself. As a further precaution, the entire oscillator stage should be shielded and preferably well-separated from all other tuned circuits. This keeps undesired oscillator frequency changes as small as possible.
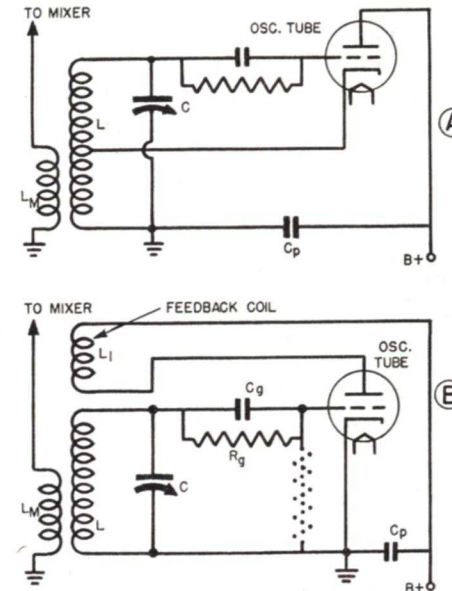

FIG. 21. Typical oscillator circuits.

or from those positions where they might be set into vibration by the loudspeaker. Finally, the i.f. amplifier is usually designed to pass a frequency band somewhat wider than is absolutely necessary; this will take care of any normal oscillator drift.

Oscillator Isolation. We have already discussed the merits of various types of mixers and found those that give a minimum of stray coupling between the oscillator and preselector tuned circuits. Probably the best way to prevent oscillator frequency shift as a result of tuning the preselector

Oscillator Harmonics. Referring back to Figs. 16 and 17, we recall that the beat frequency is numerically equal to the difference between the incoming signal frequency and the frequency of the local oscillator. But what happens if the local oscillator signal contains a large number of harmonics?

Within the mixer tube, these harmonics, just like the fundamental oscillator frequency, will heterodyne with the incoming signal to give various beat frequencies. All of these spurious beat frequencies, however, will be much higher in frequency than the desired

beat frequency and hence, will be "shorted" by the tuned circuit L_1-C_1 and not appear in the output.

Then what harm is done? Unfortunately, although harmonics do not convert the incoming signal to give a spurious output, they do heterodyne with random noise voltages present at all frequencies. This means then, that some noise that otherwise would not be bothersome will be converted to appear in the output.

▶ As a general rule, it can be said that the more harmonic energy present in a superheterodyne receiver oscillator, the greater will be the average noise level. This fact is not always appreciated.

Fortunately, the very steps taken in the design of an oscillator to reduce frequency drift also improve the output voltage waveform. Thus, the use of a high-Q, lightly loaded oscillator tank not only improves the frequency stability but also reduces the intensity of harmonic frequencies.

Oscillator Radiation. Any oscillator, of course, is capable of performing as a miniature transmitter. The only thing needed to radiate considerable energy is an antenna. In designing a superheterodyne receiver, care must be taken that such an antenna is not inadvertently supplied. This is done principally by using short, direct wire leads and often by enclosing the entire oscillator stage in a shield can.

In a given superheterodyne receiver, radiation from the oscillator stage may find its way into the preselector circuits and there heterodyne with various signals to give a series of whistles and squeals as the receiver is tuned. This form of self-interference is often called "birdies." Stray radiation from the oscillator of one receiver also is capable of interfering with other receivers at relatively long distances away.

Oscillator Voltage Output. It is virtually impossible to construct a simple oscillator that will maintain its output voltage constant as the frequency of oscillation is changed by tuning. Luckily, the intensity of the beat frequency signal obtained from a mixer-first detector will be very nearly independent of the local oscillator voltage, *provided the oscillator voltage is at least three times and preferably ten times as great as the incoming signal.* You will recall that this is also the condition for least mixer noise and hence, best **signal-to-noise ratio.**

In most superheterodyne receivers, if the oscillator voltage does not vary more than 3-to-1 over the tuning range, the design is usually considered satisfactory. The *minimum* oscillator voltage in this case, of course, must be several times larger than the incoming signal level from the preselector so that the mixer noise level will be kept low.

SELF-EXCITED CONVERTERS

Up to this point, all the mixer-first detector circuits we have seen have required the injection of a local signal from a separate oscillator stage. This separate oscillator, however, requires an extra tube; and since this tube does not contribute directly to the gain of the superheterodyne receiver, many methods have been developed to eliminate the separate oscillator.

In most cases, the oscillator tube is eliminated by making the mixer-first detector stage perform two functions simultaneously—that is, generate a local signal itself, and mix this with the incoming signal at the same time. Mixer circuits of this type that do not require external excitation from a separate oscillator are quite properly called "self-excited" converters.

The Pentode Converter. One of the first self-excited converters made

use of an ordinary pentode as combination oscillator-mixer-first-detector. A typical circuit is shown in Fig. 22.

As you can see, the preselector tuned circuit feeds directly to the control grid and the plate current flows through the conventional i.f. transformer primary L_p. Note, however, that the i.f. tuning condenser, $C_{I.F.}$, is not connected directly in parallel with L_p, but instead is wired in series with plate tickler coil L_1. Tickler coil L_1 then is inductively coupled to the oscillator tank L-C,
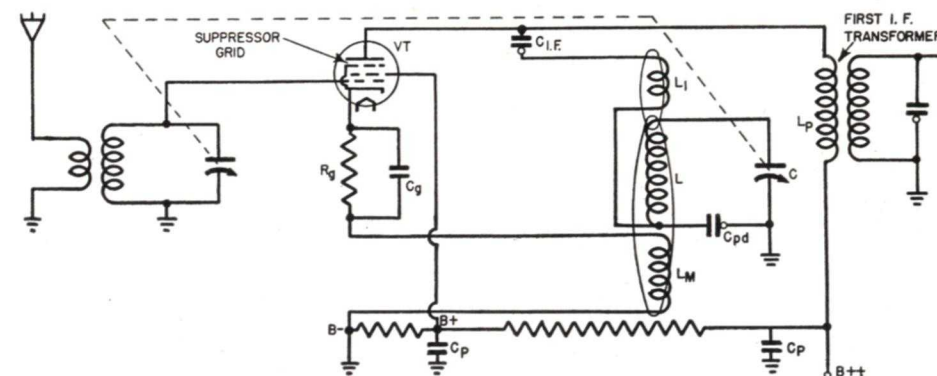

FIG. 22. Combination oscillator-mixer-first detector circuit using a pentode tube. If the suppressor grid is omitted, this circuit will apply to the screen grid tubes once widely used for the same purpose.

which in turn is coupled to the cathode tickler coil L_m for oscillator feedback. We have then a modified form of Meissner oscillator. Mixing between the signal on the control grid and that generated by the tube occurs directly within the tube. The self-bias cathode resistor R_g must be of proper value to make the tube non-linear and give optimum conversion gain.

Although the pentode circuit does work, and indeed a number of the inexpensive broadcast receivers were constructed around this arrangement, the performance is not too satisfactory. For one thing, the condenser $C_{I.F.}$ performs "double-duty"—it is not only the i.f. tuning condenser, but it is also

present in the oscillator circuit. This means that when the i.f. transformer is first tuned by changing $C_{I.F.}$, tuning of the oscillator will be affected; likewise, as the oscillator is tuned, the i.f. transformer tuning will be disturbed. Also, since the transconductance of the pentode tube is altered when self-oscillation is brought about, the over-all conversion gain of the mixer is somewhat low and the noise level is high. The elimination of a separate oscillator tube, therefore, has resulted in considerable loss of efficiency.

Above about 6 mc., the circuit in Fig. 22 or variations of this circuit are completely unsatisfactory because of parasitic oscillation, "pulling" of the oscillator frequency by the preselector, and partial or complete failure to oscillate.

The Pentagrid Converter. To retain the convenience of a self-excited converter and yet secure high conversion gain with a minimum amount of coupling between preselector and oscillator circuits, a number of special multi-element tubes have been developed. One of these "pentagrid converter" tubes arranged in a self-excited circuit is shown in Fig. 23.

In this particular circuit, grid 1

serves as the oscillator grid and grid 2 acts as the oscillator plate. Grid 2, to which a positive voltage is applied, draws current through the feedback tickler coil L_1. Radio-frequency energy, therefore, is fed back through the mutual inductance M to the oscillator tank L-C, which in turn, is connected to the oscillator grid 1.

Grids 3 and 5, which are connected together within the tube, comprise a conventional screen grid. These are by-passed directly to ground; since they

converter arrangement is shown in Fig. 24A. With this tube, the incoming signal from the preselector is fed to the mixer control grid 3. Grid 5 is a suppressor grid used to prevent secondary emission from the plate. As before, grid 1 is the oscillator grid. Grids 2 and 4, however, serve not only as the screen grid but also as the oscillator plate. Since these grids must be by-passed to ground for proper screen action, the cathode must be "tapped up" on the oscillator tank L_2-C_2. The exact
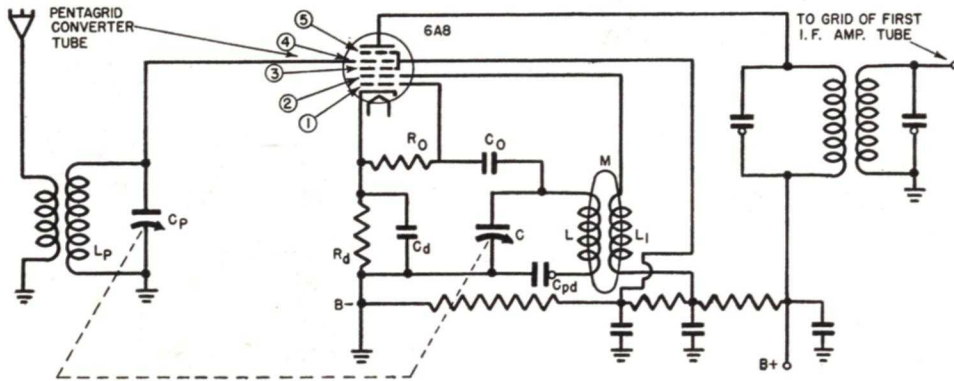

FIG. 23. A practical frequency converter circuit using a pentagrid converter tube.

surround the preselector control grid 4 completely, the oscillator circuit is fairly well isolated.

Since the oscillator grids 1 and 2 are nearest the cathode, the electron stream flowing through the remaining grids to the plate is modulated at the local oscillator frequency. The preselector signal applied to grid 4, therefore, will be mixed with this locally-generated signal to supply the desired beat frequency or i.f. output in the plate circuit. The bias for mixer action is essentially determined by the cathode self-bias resistor R_d, and the oscillator action is set by the voltage developed across the oscillator grid-leak resistor R_o from rectified grid current.

Another Pentagrid Circuit. Still another type of self-excited pentagrid

manner in which the cathode, grid 1, and grids 2 and 4 are connected in a modified form of grounded-plate Hartley oscillator is illustrated in Fig. 24B.

Advantages and Disadvantages of Self-Excited Converters. Comparison of the self-excited converters in Figs. 23 and 24 with the "injection-type" of converter in Fig. 20, which uses a separate oscillator, shows that the respective pentagrid tubes are similar but by no means identical. Actually, the pentagrid tube in Fig. 20 also can be arranged in a self-excited circuit. This is sometimes done and the tube will give about the same conversion gain. Such use, however, makes the mixer circuit subject to the limitations common to all types of self-excited first-detector arrangements.

Let us review these limitations. In the first place, since the oscillator elements as well as the mixer-first-detector elements of a self-excited converter tube all operate within the same electron stream, it is virtually impossible to isolate the preselector and oscillator tuned circuits entirely. This means that in spite of generous use of shielding and screen grids, there will be some "pulling" of the oscillator, and tuning of the preselector will affect the oscillator frequency and stability. At broadcast frequencies, this stray coupling is usually small, and self-excited circuits operate very well. As a matter of fact, their stability and their conversion gain are as good as that given by any separate-oscillator arrangement. At ultra-high frequencies, however, the effects of stray coupling become worse. Not only will the oscillator frequency stability become very poor, thus giving receiver detuning with oscillator drift, but in some cases degenerative feedback effects may set in so that the over-all conversion gain drops off sharply. The loss becomes so great above 20 mc. that this type of circuit is unsuitable.

As an additional disadvantage, the self-excited converter is always noisier than a separate-oscillator first-detector circuit. This is brought about primarily by the fact that all oscillator harmonics that may be present are generated directly within the tube and cannot be prevented from reaching the mixer-first detector portion of the tube. All oscillator harmonics, therefore, can heterodyne with various noise frequencies, converting them to appear at the output in the form of increased noise level. With the separate-oscillator type of converter, since there is no direct connection between oscillator and mixer tube elements, the oscillator tank circuit is more effective in filtering out

such harmonics so that the resulting mixer noise level is somewhat lower.

The Triode-Hexode Tube. To get the low noise level and good high-frequency operation of the separate-oscillator circuit and still use only one tube, another type of mixer tube has been developed. This is not a pentagrid
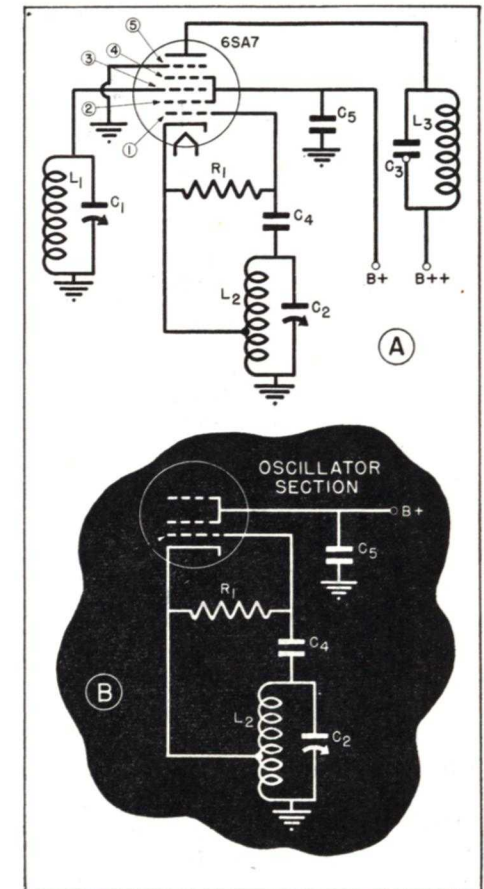

FIG. 24. Another type of pentagrid converter.

tube, but rather a triode oscillator and a multi-element mixer tube all contained in one envelope.

Such a "triode-hexode" tube in a typical circuit is shown in Fig. 25. Note that the triode portion to the right is connected in a conventional grid-tuned oscillator circuit. The oscillator grid,

however, is connected internally to grid 1 of the mixer-detector portion to the left. Grids 2 and 4 form a screen grid surrounding grid 3, which receives the incoming signal from the preselector. Grid 1, therefore, really is an "injection" grid, and this circuit has many of the advantages for high-frequency operation of the separate-oscillator pentagrid converter in Fig. 20, in addition to permitting the use of one less tube. For this reason, this circuit is being used more and more in all-wave receivers.
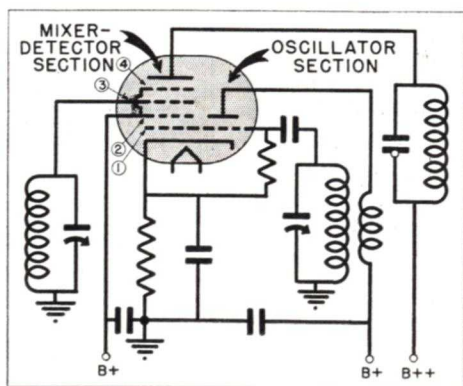

FIG. 25. The "triode-hexode"—really two tubes in one envelope—has many of the advantages of the separate-oscillator type of converter.

Oscillator-Preselector Tracking

If we review for a moment what we have discussed, you will remember that in a superheterodyne receiver the output of a local oscillator is combined with the incoming signal to produce a new signal, which can be further amplified by the following intermediate-frequency amplifiers. In this heterodyning process, it is immaterial whether the oscillator frequency is higher or lower than the incoming signal, but in either case the frequency *difference* must be exactly equal to the desired intermediate frequency. It follows, then, that in tuning a superheterodyne receiver over a given band, the oscillator frequency must always be kept a given number of cycles away from the frequency of the incoming signal to which the preselector is tuned.

In some of the first superheterodyne receivers this requirement was easily met by the use of two separate tuning controls, one for the preselector and one for the local oscillator. Two separate controls, however, are inconvenient at best, and double-spot tuning, which we discussed previously, sometimes can be confusing because the same station will be received at two points on the oscillator dial, one where the oscillator frequency is lower than the signal and at a second where the oscillator frequency is higher.

All modern superheterodynes secure one-dial control, thus eliminating double-spot tuning, by ganging the preselector and oscillator tuning condens-ers on one common control shaft. Simultaneous adjustment of preselector and oscillator tuned circuits, however, introduces new problems. Ordinarily, unless precautions are taken, the oscillator will not "track" properly, that is, the oscillator frequency will not always be a definite number of cycles away from the received signal. But before we discuss some of the methods by which an oscillator can be made to vary its frequency in the proper manner, let us determine just why such tracking methods are necessary.

THE NEED FOR TRACKING

Suppose we have, as illustrated in Fig. 26A, the preselector tuned circuit L_p-C_p and the oscillator tank L_o-C_o of a superheterodyne receiver. The two tuning condensers are ganged together on a common control shaft as indicated by the dotted line.

Let us assume that the receiver is to tune over the broadcast frequency range of 500 to 1500 kc. The resonant frequency of the preselector tuned circuit L_p-C_p, therefore, should vary with different settings of the dial in the manner shown by curve 1 in Fig. 26B.

But how should the resonant frequency of the oscillator tank L_o-C_o vary for the same dial settings? If we assume an intermediate-frequency of 250 kc. is being used, then we know perfect tracking will be secured if the oscillator is always 250 kc. higher in frequency at each point on the control dial. The way we would like the oscillator frequency to vary then is illustrated by the "ideal" curve 3 in Fig. 26B. Notice that when the preselector is resonant at 1500 kc. (curve 1) for minimum tuning capacity, the oscillator frequency is 1750 kc.; and for maximum tuning capacity, when the preselector is tuned to 500 kc., the oscillator tank circuit is tuned to 750 kc. The frequency *difference* between the signal from the oscillator and that delivered by the preselector, therefore, is always exactly 250 kc. and an i.f. signal of proper value will be produced.

Unfortunately, however, the simple oscillator tank L_o-C_o in Fig. 26A will not perform in this ideal way. If we
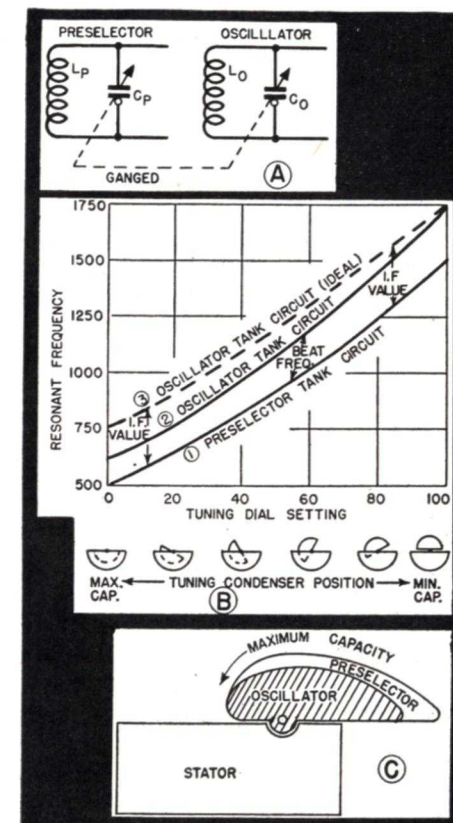

FIG. 26. Preselector-oscillator tracking adjustments are necessary because the resonant frequencies of the two tank circuits (at A) do not differ by the same amount (the i.f. value) at each tuning dial setting. The discrepancy is shown by curves 1 and 2 (at B); curves 1 and 3 show the ideal relationship, which can be secured if the rotor plates of the tuning condensers are specially shaped as at C.

assume the two condensers C_p and C_o are identical in value, the only way the oscillator tank L_o-C_o can be tuned to a higher frequency than the pre-

selector circuit L_p-C_p is to make the oscillator coil L_o somewhat *smaller* than the coil L_p. If we do reduce the number of turns on L_o, then at one end of the tuning band, say 1500 kc., we can adjust the oscillator to be resonant 250 kc., higher, at 1750 kc.

As we turn the tuning dial, however, to increase the capacity of both condensers in an endeavor to tune the receiver to 500 kc., we find that instead of following the ideal tracking curve 3 in Fig. 26B, the oscillator now will change frequency too rapidly in about the manner indicated by curve 2. Even though the oscillator was 250 kc. higher in frequency than the preselector at 1500 kc., at 500 kc. it is only approximately 83 kc. higher. This means the difference frequency does not remain constant at 250 kc. but drops to 83 kc. Obviously, such poor oscillator tracking cannot be used.

But what causes this bad tracking? You will remember that condensers C_o and C_p are identical. Their maximum and minimum values of capacity, therefore, will be very nearly the same. From this we can expect, even though the oscillator coil L_o has been changed, that the *ratio* of highest to lowest frequency to which the oscillator circuit can tune will still be equal to the same ratio for the preselector. This can be corroborated by inspecting the curves in Fig. 26B. Note that the preselector (curve 1) tunes from 500 to 1500 kc., a ratio of 3-to-1. The oscillator (curve 2) tunes from about 583 kc. to 1750 kc., about the same 3-to-1 ratio.

METHODS OF TRACKING

From the curves in Fig. 26B, you can see that we cannot get the ideal tracking curve 3 unless we devise some means of diminishing the capacity change of the oscillator tuning condenser. In other words, the capacity

of the oscillator condenser must vary a smaller amount than the preselector condenser for a given angle of rotation of the common control shaft. There are two practical methods of accomplishing this.

Use of Shaped Rotors. One direct method of getting good tracking is to make the rotor of the oscillator condenser a different shape. Thus, as shown in Fig. 26C, if the oscillator condenser rotor is somewhat smaller than the preselector rotor and specially shaped, it is possible to get almost perfect tracking. This particular method is used extensively in broadcast receivers.

The method does, however, have one serious disadvantage: It is not possible to construct a shaped rotor that will perform satisfactorily on more than one frequency band. For an all-wave receiver, therefore, it becomes necessary to provide a different oscillator tuning condenser for each band. The cost of such a system can be prohibitive.

Use of a Padding Condenser. With identical tuning condensers for oscillator and preselector, it is possible to diminish the capacity change of the oscillator tuning condenser, and hence get good tracking, if a special "padding" condenser is inserted in series with the oscillator tank circuit. Such a padder is illustrated by condenser C_{pd} in Fig. 27. This is an electrical rather than a mechanical method of reducing the oscillator condenser maximum-to-minimum capacity ratio.

Padding condenser C_{pd} ordinarily is about three to five times *larger* in capacity than the tuning condenser C_o at maximum capacity setting. When tuning condenser C_o is set at *minimum* capacity, therefore, the total effective capacity across the coil L_o is only slightly less than the true capacity of

C_o. In fact, the very small "trimmer" condenser C_T adds sufficient capacity to tune the oscillator properly at the *high-frequency* end of the tuning range.

When condenser C_o is fully meshed and thus has maximum capacity to tune to the *low-frequency* end of the band, the capacity of trimmer C_T is so relatively small that it has little effect on the oscillator frequency. Padder condenser C_{pd}, however, which is in series with C_o, now reduces the effective capacity across the coil L_o to something like 70 to 80% of the true capacity of C_o. The exact amount of the
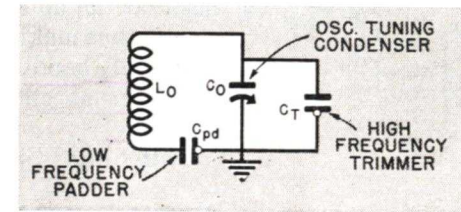

FIG. 27. Showing how padder and trimmer condensers are added to the oscillator tank circuit for tracking.

effective capacity in the tuned circuit, and hence, the oscillator frequency *at the low-frequency* end of the dial, is controlled precisely by the setting of the padding condenser C_{pd}.

The insertion of the padding condenser, therefore, reduces the apparent maximum-to-minimum capacity ratio of the tuning condenser C_o. By this means, tracking very close to the ideal curve 3 in Fig. 26B can be obtained. Actually, perfect tracking is secured at only three points on the dial, one near the low-frequency end, one at the high-frequency end, and a third near the mid-band frequency. With good design and proper choice of oscillator inductance, nevertheless, tracking errors at other points can be made quite small.

Referring to Fig. 27 again, since the

padder C_{pd} is most effective when tuning condenser C_o is fully meshed and the oscillator is tuned to a low frequency, this padder condenser is used to align the oscillator stage at the low-frequency end of the tuning band. Naturally then, the padder is often referred to as a "low-frequency trimmer" or "low-frequency padder."

On the other hand, trimmer condenser C_T has negligible effect except when C_o is set at minimum capacity to tune the oscillator to its highest frequency in a given band. For this reason, condenser C_T is used only to adjust just the oscillator at the high-frequency end of the band and is often called a "high-frequency" trimmer.

In practical receivers, even the preselector condensers have trimmer condensers like C_T. These are necessary usually to compensate for slight differences in coil inductance, small variations in capacities of wiring, tubes, etc., and particularly to allow adjustment for small differences in the minimum capacities of each tuning condenser.

BAND SWITCHING

Almost all communications receivers tune over a comparatively wide frequency spectrum, such as 500 kc. to about 30 mc. 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 divide up the total tuning range into a number of bands. Operation in any one band is then accomplished by switching in a new set of coils in the preselector and oscillator circuits. This
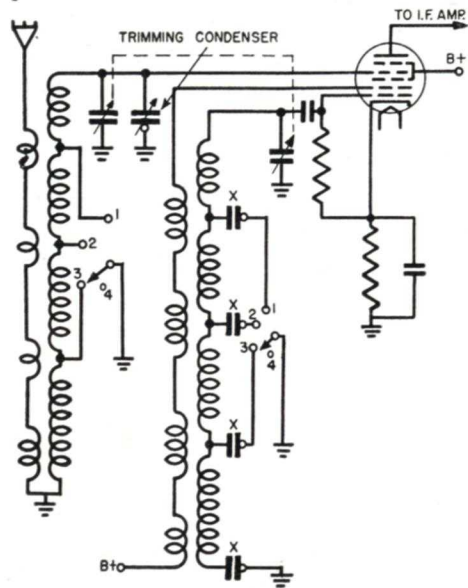

FIG. 28. Preselector and frequency converter circuits of a four-band superheterodyne receiver which employs series coil switching.

band switching may be done in various ways.

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. 28 illustrates how this is done in one practical four-band superheterodyne receiver that used a self-excited mixer-first detector.

The four preselector coils are connected together in series as are also 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, thus lowering the resonant frequency by in-

creasing 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, if the receiver were a home set.

Notice that a different low-frequency padder condenser X is used in the oscillator tank for each band. Only one high-frequency trimmer, however, is used, so it is possible to make the high-frequency adjustment on only one 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, thus making it necessary to use a special band-change switch that either disconnects or shorts out the unused coils.
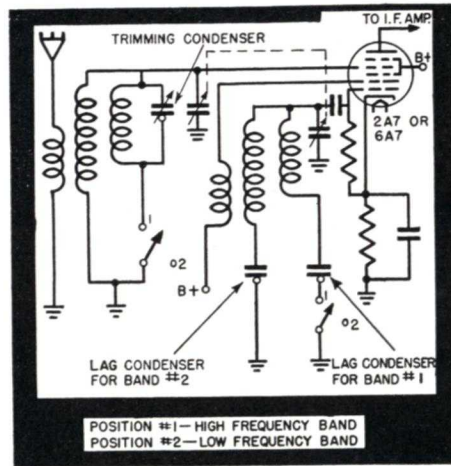
Switching Shunt Coils. Band

FIG. 29. Preselector and frequency-converter circuits of a two-band superheterodyne employing shunt coil switching.

changing can be accomplished also by adding coils in parallel. Fig. 29 shows how this is done for a two-band set.

Each oscillator coil has its own padder or "lag" condenser to insure good low-frequency tracking. As before,
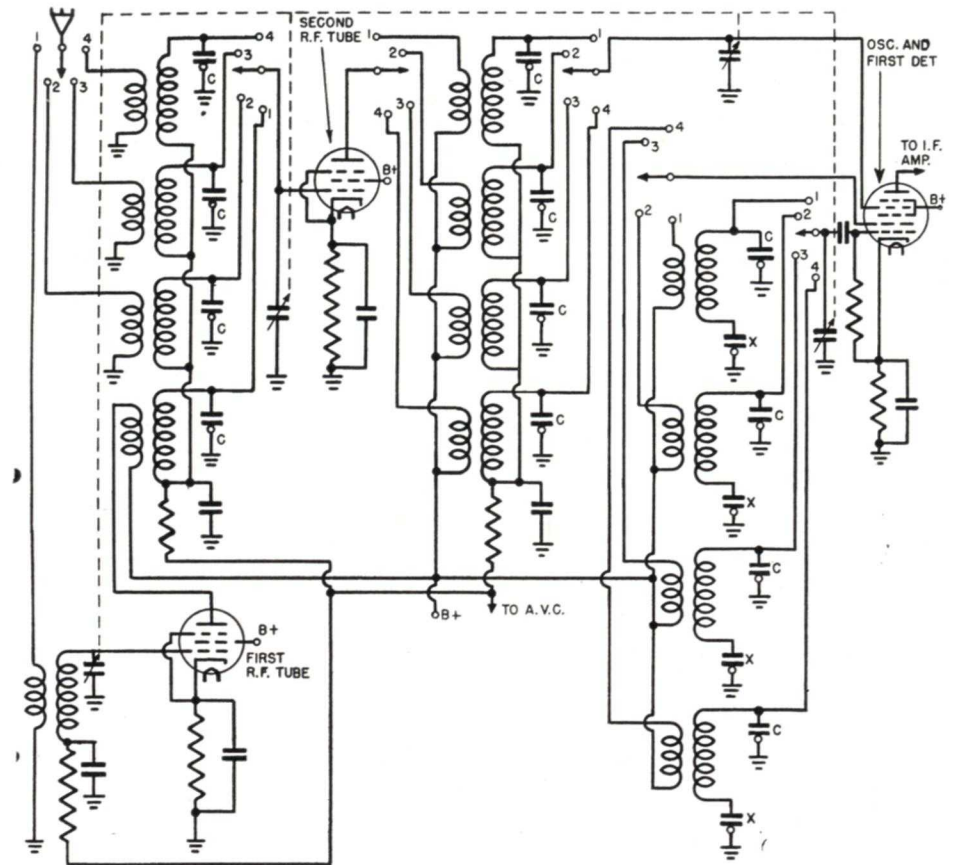

FIG. 30. The preselector in this all-wave superheterodyne circuit uses two stages of r.f. amplification for the highest frequency band (band-change switch set to No. 1) and one stage for all other band.

however, a trimmer condenser is used across only one preselector coil; this gives good high-frequency adjustment on one band only, and the tracking on the second band will be poor.

This switching system, too, suffers from the ill effects brought about by unused coils absorbing energy from the resonant circuits unless special switches are used to short out or disconnect the idle coils.

Switching Complete Coils. Although the circuits shown in Figs. 28 and 29 have been used in lower-priced receivers, perfect tracking on all bands is not obtainable and energy absorp-

tion by unused coils can prove troublesome. A more practical and more widely used circuit is shown in Fig. 30 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 six-section (six-deck), four-point rotary switch. With complete coils being switched, each band is electrically independent of the others, and maximum operating efficiency is attained.

Note that this preselector uses a single r.f. amplifier stage on three bands and two r.f. amplifiers on the fourth. This arrangement gives better image rejection and improves the signal-to-noise ratio by building up the signal to over-ride converter noise. The extra r.f. stage on the highest frequency band offsets the normal reduction in sensitivity and selectivity at the high frequencies.

LOOKING AHEAD

In this Lesson, we have outlined the prominent features of the superheterodyne communications receiver and discussed in some detail the requirements of the preselector, oscillator, and mixer-first-detector stages.

It must be remembered that the purpose of these particular stages is merely the changing of the frequency of the incoming signal so that the converted signal can be amplified at the intermediate frequency by the following i.f amplifiers.

In the process of frequency conversion, the preselector, of course, does give some selectivity to the complete receiver. Indeed, some preselector selectivity is necessary to eliminate double-spot tuning and the reception of image signals. Likewise, some gain in the preselector is desirable to subdue mixer noise and deliver a "clean-cut" signal to the i.f. amplifier.

The total selectivity or gain secured in the preselector and mixer circuits, however, is small compared to that obtained in the following i.f. amplifier of the receiver. It is the tremendous amplification and high selectivity built into the fixed-tuned i.f. section that lend such superior performance to the superheterodyne. In the next Lesson we will investigate the characteristics of these all-important i.f. stages.

Lesson Questions

Be sure to number your Answer Sheet 33RC.

Place your Student Number on *every* Answer Sheet.

Most students want to know their grade as soon as possible, so they mail their set of answers immediately. Others, knowing they will finish the next Lesson within a few days, send in two sets of answers at a time. Either practice is acceptable to us. However, don't hold your answers too long; you may lose them. Don't hold answers to send in more than two sets at a time or you may run out of Lessons before new ones can reach you.

1. Why does a superheterodyne provide essentially the same gain for any frequency in its tunable range?

2. What section of a superheterodyne provides most of the adjacent signal selectivity?

3. If a superheterodyne is receiving a signal on 1000 kc. and the local oscillator is tuned to 1465 kc., what is the intermediate frequency?

4. Suppose we have two superheterodynes, one using an i.f. of 175 kc. and the other an i.f. of 456 kc. Which of these receivers will require the more selectivity in its preselector?

5. The presence of what kind of noise voltage limits the practical sensitivity it is possible to secure in a receiver?

6. For what two reasons is it desirable to include one or more stages of tuned r.f. amplification in a preselector?

7. Why will a code signal of 228 kc. cause interference in a superheterodyne having an i.f. of 456 kc.?

8. What provision is made in the design of a superheterodyne to take care of normal oscillator drift?

9. For what two reasons should the oscillator voltage applied to a mixer-first detector be several times greater than the maximum incoming signal voltage?

10. In a superheterodyne using identical tuning condensers for the preselector and oscillator sections, what two adjustments must be made to make the oscillator and preselector track properly?

TOWERS IN THE SKY

Above the dust and clamor here below
These sentinels of mind and spirit rise;
Deftly their fingers touch the vibrant skies
Where winged words are passing to and fro.
They dwell on high, where rarer currents
    flow—
Perhaps behold, in pity and surprise,
The low estate of recompense we prize,
The narrow round of things we seek to know.

O stalwart towers, unshakeable, serene,
Make us more worthy of your office here!
Refine our message, whatsoe'er it be;
Attune our thoughts to listeners unseen.
On far horizons may our words ring clear,
Proclaiming there the truth which makes
    men free!

—GEORGE P. CONGER