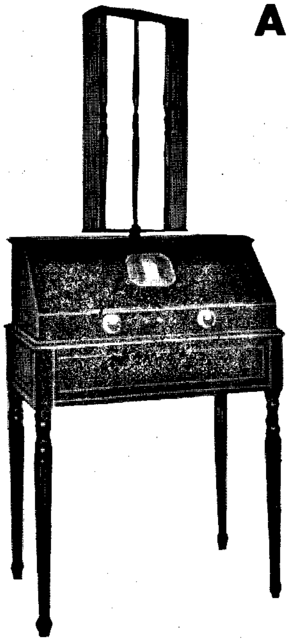
● *Section* 2

THE MYE TECHNICAL MANUAL

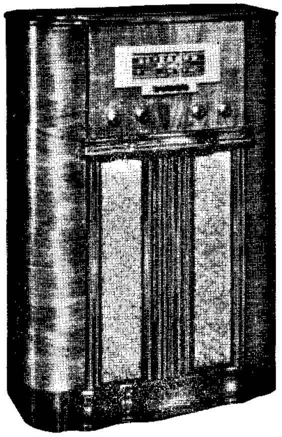
Superheterodyne First Detectors and Oscillators

P. R. MALLORY & CO. Inc.
MALLORY

SUPERHETERODYNE FIRST DETECTORS AND OSCILLATORS



One of the first Superheterodyne Receivers (RCA Radiola 28)



A recent Superheterodyne incorporating modern design practices (RCA 27K)

Introduction

The heart of a superheterodyne is its frequency-changer—the first detector-oscillator system which converts the frequency of any incoming signal to the fixed frequency of an intermediate frequency or long wave R.F. amplifier; where subsequent stages of amplification build up the signal to the desired level.

It is the purpose of this article to review the development of the various circuits which have been used or proposed for this application, to point out the advantages and disadvantages of each, and to give service hints, so that the service engineer or radio repairman can proceed with confidence in making any required adjustment.

Why the Superheterodyne?

Let us begin by briefly explaining the advantages of the seemingly roundabout way employed in superheterodynes for the amplification and selection of radio signals, as compared with the direct method of amplifying the signal at its original frequency (or tuned radio frequency amplification).

The advantages are:

1. Better adjacent channel selectivity
2. Uniform selectivity
3. Better circuit stability
4. Uniform gain at various frequencies
5. Lower cost for equivalent performance

The advantages listed above arise directly from the use of a fixed tuned radio frequency amplifier (I.F.), operating generally, but not necessarily, at a lower frequency or a longer wave-length than the received signal. Precision adjustment for optimum performance is made when the receiver is constructed, and these adjustments will retain their correct setting for extended periods of time. The amplifier constants, such as the inductance of the coils, the coupling of the coils, and the value of the tuning capacitors, have been selected to give the best results at the desired frequency. Physically such an amplifier can be built with great compactness since adjustable compression type mica condensers or small fixed condensers are used for tuning; as compared with the bulky and expensive air dielectric gang tuning condensers required for a tuned radio frequency amplifier.

Even the least expensive superheterodynes usually have a total of five tuned circuits contributing to the selectivity of the receiver—a tuned antenna stage and two tuned circuits in each I.F. transformer. A comparable T.R.F. receiver would have to employ a five-gang variable condenser—a form of construction so expensive as to limit its use to only the most expensive sets. Furthermore, gang condensers are bulky, and require long leads for connections. This, in turn, causes coupling between circuits so that elaborate shielding must be used to provide isolation and to prevent the amplifier from oscillating. Such shielding is obviously costly.

When amplification occurs at signal frequency, the amplifier must be tuned to the signal, and in conventional engineering practice this is accomplished by connecting a variable air dielectric capacitor across each inductance. Thus, the L/C ratio (the ratio of inductance to capacity) varies as the condenser is adjusted for various frequencies, and the selectivity characteristics are not constant with frequency. The changing L/C ratio varies the Q of the circuit. The Q of a circuit is the ratio of inductive reactance to resistance and constitutes a figure of merit for a tuned circuit since the higher the Q, the sharper the tuning. The effect of variable capacity also makes it exceedingly difficult to design R.F. transformers having uniform gain with frequency, since the gain is a function of the impedance of the tuned circuit, which varies with the Q. Even more difficult is the designing of double-tuned transformers (tuned primary—tuned secondary type) since coupling varies with capacity.

The fixed tuned I.F. amplifier of a superheterodyne is not open to any of these objections.

There is another advantage of the superheterodyne circuit which is inherent to all such receivers using an intermediate frequency lower than the frequency of the received signal, namely—arithmetical selectivity. Radio stations on the broadcast band are located with 10 kc. channel spacing. It is highly desirable for a radio receiver to discriminate against interference from an adjacent channel. The percentage of difference between the frequency of the desired signal and the signal on an adjacent channel varies with the frequency, thus, at 550 kc. the adjacent channels are off-resonance by 1.8%. At 1,000 kc. the difference is 1%, while at 1,500 kc. the difference is only 0.66%.

In a superheterodyne the incoming signal is converted to the frequency of the I.F. amplifier. An adjacent channel station is still removed by 10 kc. at the intermediate frequency. Thus, with a 465 kc. intermediate frequency the percentage difference between the adjacent channels becomes over 2.1%. This percentage difference is constant at any portion of the broadcast band.

In this connection it is interesting to note that the percentage difference increases with lower I.F. frequencies. With a 175 kc. I.F. the adjacent channels are separated by almost 6%, while at 50 kc. (a value used by some manufacturers in the very early days of the industry) the percentage difference is 20%.

However, the problems of images and spurious responses increases rapidly with decreasing I.F. frequency so that the industry has largely standardized on values near 465 kc. The possible presence of such interference constitutes the main objection to the superheterodyne principle, and consequently the subject will be discussed in a later paragraph.

How the First Detector-Oscillator Works

The fundamental operation of the first detector and oscillator is shown by the block diagram, Figure 1. The incoming signal is fed into a vacuum tube, which may be a diode, triode, tetrode, pentode, or one of the more complicated types. The output of a local oscillator is also fed into this tube, where the two inputs are combined to produce the intermediate frequency. By means of special tubes or special circuits it is possible to combine the oscillator and mixer functions in a single tube—however, the fundamental operating principles remain the same.

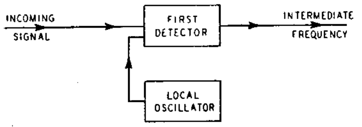


Fig. 1

The local oscillator of a superheterodyne receiver serves two functions. First, it provides a frequency which will combine with the radio-frequency signal and produce, through detection, a new radio frequency wave called the intermediate frequency. For this purpose the local oscillation need only be of the same order of amplitude as the signal.

When the signal and the local oscillator voltages are combined in the same circuit, at a given instant they may be either opposing or aiding one another. If the frequency of the signal and that of the oscillator differ (as is the case in a superheterodyne receiver), then the two voltages will be alternately aiding and opposing each other at a repetition rate equal to the frequency of the new signal voltage. This combining of the two radio-frequency voltages is called heterodyning, or beating. The beat frequency, called the intermediate frequency, is not produced immediately as a result of combining the two radio frequencies. There are still only the original frequencies present but the envelope of the combined wave is varying in amplitude at the beat frequency rate. To create the new intermediate frequency, this wave must pass through a detector.

The second function of the local oscillator is to raise the efficiency of detection. If the incoming signal impressed on the detector is of the order of 1 millivolt and the local oscillator voltage impressed on the detector is of about the same value, the rectified output would be practically zero. The amplitude of the voltage impressed on the detector must be of such a magnitude that the tube characteristic is different for the positive and negative half cycles of oscillation. Increasing the local oscillation voltage beyond the requirements for producing the beat envelope will result in raising the efficiency of rectification. The amount of local oscillation required for most efficient conversion of the radio wave into the intermediate wave is determined by the detector tube design and usually runs between 5 and 15 volts in conventional circuits.

It will be seen from the above discussion that the efficiency of conversion of a heterodyne detector in a superheterodyne receiver does not follow the customary square-law response as does the second detector and that no matter how weak the incoming signal may be, there is no threshold below which the detector fails to operate.

The first detector is operated over a non-linear part of its characteristic. The local oscillation may be supplied from a separate tube and impressed on the grid circuit of the detector through a coupling in its cathode lead, or it may be supplied from other tube elements within the same detector tube. Some of the tube elements may serve the double purpose of both oscillator and detector. In this latter case the local oscillations may not appear in the signal input grid circuit. They will, however, serve their purpose of changing the operating characteristic of the detector by altering the electron flow through the detector part of the tube as the local oscillation swings through its cycle. The detector tube is, in effect, cut off on the negative cycles. This is the condition required for detection. In addition to serving as a detector and sometimes as an oscillator, the first detector tube also acts as an intermediate frequency amplifier since the detection takes place in the grid circuit. The amplification thus obtained is approximately one-half the value which would be obtained if the tube were used as a conventional intermediate frequency amplifier. This is due to the fact that the local oscillator swings over the low gain part of the tube characteristic on its negative half cycle.

The first detector and the local oscillator of a superheterodyne receiver each perform two important functions: The detector creates and amplifies the intermediate frequency; the oscillator raises the efficiency of detection and combines with the signal to produce the intermediate frequency signal.

The Desired Signal, Images, and Spurious Responses

The Desired Signal

We have stated that the intermediate frequency signal is produced by combining the incoming signal with R.F. energy from a local oscillator. The combining of frequencies for the production of beats or heterodynes follows simple arithmetic in that the two frequencies are simply added or subtracted. However, there are a number of practical considerations which prevent the dismissal of the subject with this brief statement. We believe the matter can be most easily explained by using specific examples.

Let us assume that we have a desired signal of 1,000 kc., and an intermediate frequency of 465 kc. The conventional way of producing the I.F. frequency is by operating the oscillator at a higher frequency than the incoming signal—thus:

Oscillator —	Signal =	Output
1,465 kc.	1,000 kc.	465 kc.

Although the intermediate frequency could be obtained by operating the oscillator at a lower frequency than the signal:

Signal —	Oscillator =	Output
1,000 kc.	535 kc.	465 kc.

The reason the oscillator is not used on the low side for broadcast band reception is that a greater tuning range would be required for the oscillator than for the antenna or R.F. tuning—thus:

Signal	Oscillator	Output
550 kc.	95 kc.	465 kc.
1,500 kc.	1,035 kc.	465 kc.

A tuning range of 95 kc. to 1,035 kc. would be impossible to secure without band switching.

When using the oscillator on the "high side" the tuning range of the oscillator is less than tuning range of the antenna.

Signal	Oscillator	Output
550 kc.	1,015 kc.	465 kc.
1,500 kc.	1,965 kc.	465 kc.

It will be noticed that while the antenna frequency tuning range has a ratio of roughly 3 to 1 between maximum and minimum, the oscillator tuning range is approximately 2 to 1.

To provide the single dial control required of modern receivers, some method must be used to restrict the tuning range of the oscillator so that a uniform separation of the value of the intermediate frequency is maintained between the signal tuning and the oscillator tuning. If a 465 kc. intermediate frequency is used the oscillator tuning must always be 465 kc. removed from the signal. This cannot be accomplished by simply using a smaller coil for the oscillator, the effective tuning capacity must also be reduced. This may be accomplished by connecting a condenser in series with the oscillator section of the tuning condenser to reduce its effective capacity. The series-connected condenser is called the low-frequency pad and its adjustment is, or should be, familiar to all servicemen. Another way of accomplishing the same object is to use a gang condenser in which the oscillator tuning section has specially shaped plates of smaller area than the plates of the variable condenser sections used to tune the antenna and R.F. stages.

It is interesting to note that if the receiver is designed with the oscillator operating at a lower frequency than the signal, the low frequency pad or pads would be placed in the antenna and R.F. sections of the circuit. This unorthodox method of using a "low side" oscillator would prove of advantage in designing an ultra-high frequency receiver, since the oscillator would have greater output and stability when operating at a lower frequency. The difference between the "low side" or lower frequency oscillator operation and "high side" or high frequency oscillator operation amounts to twice the intermediate frequency, and with a 465 kc. I.F. the difference in efficiency would be negligible. However, with a 5 megacycle I.F. the difference in oscillator frequency of 10 mc. between the two methods of operation could result in a considerable improvement in oscillator performance.

Images and Spurious Responses

We approach the subject of "Images and Spurious Responses" with some hesitation, because in this section it is necessary to point out the essential defects of the superheterodyne system. It is difficult to point out how various forms of interference originate within the superheterodyne without appearing to condemn the principle of the receiver. Therefore we wish to state emphatically that the superheterodyne is truly the king of radio receivers, and that while various improvements will undoubtedly occur, the fundamental design will remain. This fact has been recognized for many years.

The difficulty arises in the inability to give a quantitative analysis of the intensity of the various unwanted responses of the circuit as compared with normal interference which originates in the turmoil of our broadcast band.

After all, it must be realized that there are only 95 channels for broadcasting stations in the frequencies lying between 550 kc. and 1,500 kc. and on these 95 channels are located over 600 broadcasting stations. Satisfactory reception can be obtained only on the few clear channels; or from local stations which have sufficient power to over-ride interference originating from perhaps a dozen other broadcasting stations operating on the same wave length. An unwanted whistle or squeal does little harm when it lands on a channel which at the location of the receiver is unusable anyway; so that most of the effects to be described will never be noticed by the average listener.

So far, we have been discussing the desired signal. However, many signals other than the desired signal reach the first detector, since the selectivity of the usual input circuits of the average receiver is anything but perfect. Signals from the adjacent channels are rejected by the selectivity of the intermediate frequency amplifier. However, there are numerous signals and combinations of signals that can produce heterodynes which will pass through the I.F. amplifier. These spurious responses can cause annoying interference, and a short resumé of their causes is of interest.

Images

Let us revert to the specific example used previously. Assume we have a standard superheterodyne receiving a 1,000 kc. signal, and using a 465 kc. I.F. Then the normal operation of the receiver is:

Oscillator — Signal = I.F.
1,465 kc. 1,000 kc. 465 kc.

However, if a nearby station is operating at 1,930 kc. with sufficient intensity to produce an appreciable signal on the first detector grid, the resulting signal will be passed by the I.F. Thus:

Undesired Signal } — Oscillator = I.F.
1,930 kc. 1,465 kc. 465 kc.

The image is simply the "low side" oscillator response, and the image is always removed from the desired signal by twice the value of the intermediate frequency.

A corollary of this is that the higher the intermediate frequency, the farther the image is removed from the desired signal. Naturally, the farther the image is displaced from the signal, the easier the problem of preselection. With receivers using the old standard 175 kc. I.F., the image response to frequencies between 550 kc. and 1,250 kc. was in the broadcast band (900 kc. to 1,600 kc.), so that the possibility of spurious response and interference is considerable. **This is the reason why 175 kc. has** been largely dropped by the industry; and why the better class of receivers that employ this I.F. frequency will be found to use two, three, or even four tuned circuits before the first detector. With 456 and 465 kc. I.F. amplifiers the image (except for a few channels) falls outside the broadcast band; furthermore the percentage of difference between the frequency of the desired signal and the image becomes so large that the rejection of a single tuned circuit, such as a tuned antenna stage, becomes adequate for ordinary household reception. The mathematical ratio of the response of a receiver to a wanted signal, as compared to the response to the image, is frequently called the image ratio, and the greater the ratio, the better the receiver.

Spurious Responses from Harmonics

The strength of the harmonics emitted by modern transmitters is very small in comparison with the power of the fundamental wave, and in most instances the actual harmonics cause little interference. The regulations of the Federal Communications Commission take care of this. However, strong harmonics of a signal may be generated in the first detector tube; and the effect will be exactly the same as if the harmonics originated at the transmitter, except that the locally generated harmonics will be present only on the stronger signals.

The production of harmonics by the first detector generally occurs by reason of grid rectification, the incoming signal having sufficient amplitude to override the grid bias. This effect and its cure is described on page 10. It is the purpose of this section to point out the spurious responses which may result from the harmonics. Thus the second harmonic of a 1,000 kc. signal would be 2,000 kc.; and if the harmonic possessed a reasonable intensity it could be picked up when the receiver was tuned to that frequency. In this example, little harm would result to the broadcast listener since 2,000 kc. is outside of the broadcast band. However, second harmonics of stations from 550 to 800 kc. fall in the broadcast band in frequencies from 1,100 kc. to 1,600 kc. As an example, the harmonic of a 700 kc. station could spoil reception from a 1,400 kc. station—the effect would be the same as two stations on the 1,400 kc. channel.

Third, and higher harmonics are occasionally encountered in high frequency reception—their intensity is usually considerably less than the intensity of the second harmonic, but their presence may fool the listener into believing that he is listening to a distant short-wave station, when the signal actually is originating in a local transmitter.

If the harmonics originate at the transmitter, the harmonics are actual radiated waves and they will be picked up by any receiver of adequate sensitivity, regardless of its design. The effect of generating the harmonics at the receiver is more pronounced in the first detector of a superheterodyne than in other types of radio circuits. Proper circuit design, including the use of preselection, provides a satisfactory answer to the problem. A modern short wave receiver with one or two stages of tuned R.F. amplification before the first detector rarely shows this defect.

Oscillator Harmonics

The oscillator of a superheterodyne can, and usually does generate an abundance of harmonics. In fact, this effect was deliberately used in the early Radiola 2nd Harmonic Superheterodynes, in which the fundamental frequency of the oscillator was one-half the desired frequency. The purpose was to prevent interlock because the low intermediate frequency employed would normally place the resonant points of the oscillator and the detector input coils very close together. The second and higher harmonics of the oscillator are capable of beating with an incoming signal, and if the difference in frequency between the two equals the intermediate frequency the resultant output will pass through the I.F. amplifier. As specific examples:

Oscillator — *Desired* Signal = I.F.
1,465 kc. 1,000 kc. 465 kc.
2nd Harmonic of 1,465 kc.=2,930

kc. This 2,930 kc. oscillator input can beat either of two frequencies to the I.F. frequency:

2,930 kc. — 2,465 kc. = 465 kc.
3,395 kc. — 2,930 kc. = 465 kc.

3rd Harmonic of 1,465 kc. =4,395 kc.

4,395 kc. — 3,930 kc. = 465 kc.
4,860 kc. — 4,395 kc. = 465 kc.

These examples will explain why a short-wave station will occasionally be tuned in on the broadcast band. The input of such a station will be greatly attenuated because the frequency is far removed from the resonant frequency of the detector grid tank (input tuning circuit), so that the effect is generally limited to very close stations. Many radio amateurs are blamed for spoiling broadcast reception when the real trouble lies in the fact that the broadcast receiver does not have adequate preselection. Adequate preselection, plus reasonable shielding of exposed grid wires will eliminate the trouble, or at least reduce the trouble to a negligible value.

Harmonics Beating Harmonics

Although seldom actually causing trouble in receivers of modern design using the higher intermediate frequencies and modern mixer tubes, it is perfectly possible for the harmonic of a station carrier to beat with the harmonic of the oscillator to a value which will be passed by the intermediate frequency amplifier. Because both harmonics will have less amplitude than the fundamental frequencies, such responses are generally quite weak.

For those who are interested in a pastime let us suggest that instead of working a cross-word puzzle, the reader try figuring all the various combinations and permutations by which an oscillator and its harmonics can beat on a signal and its harmonics to produce a signal at intermediate frequency. The practical value of such calculation is doubtful, because the higher the order of the harmonic the weaker the amplitude, but the number of such combinations is amazing, and the reader will be assured of a full evening of entertainment.

Heterodynes Between Stations

There is a very good reason why the even numbered intermediate frequencies of 450, 460, 470, etc. are not generally used in broadcast receivers. Broadcasting stations are located in 10 kc. channels—and if two signals differing from each other in frequency by the value of the intermediate frequency enter the first detector, they will beat with each other to produce a third signal of I.F. value. The result would be a continuous background jumble of the two stations, regardless of where the receiver was tuned. Odd numbered intermediate frequencies are used, such as 465 kc., 456 kc., etc., since broadcasting stations are never spaced by such an odd interval. Here is one of the strongest arguments to the serviceman that his test oscillator should be accurate, since a discrepancy of 4 or 5 kc. will align a receiver so as to be susceptible to interference from inter-station heterodynes. Another point—an intermediate frequency amplifier does not accept a single frequency—it accepts a band of frequencies. Also, while the unmodulated carrier has, or should have a single frequency, the modulated carrier with its side bands may occupy the full 10 kc. allotted channel. Consequently, in locations where the receiver is very close to two powerful broadcasting stations separated by an interval approximating the I.F. frequency, say 460 kc. or 470 kc. with a 465 kc. I.F., a jumble of the two stations may be heard all over the dial. Assuming that the antenna is of reasonable length, and assuming that the receiver is properly aligned, there is still one remedy left to the serviceman. Simply realign the intermediate frequency a few kc. higher or lower than the specified value. In the example given above, realignment at 475 kc. or 455 kc. will probably cure the trouble, and there is sufficient range in the trimmers of most I.F. transformers to permit this. Realignment of the I.F. will also call for readjustment of the gang condenser trimmers and low frequency pad. After realignment the dial scale may be slightly "off" but this can not be avoided, and is a small price to pay for the elimination of the interference.

Overall Feed-back

There is one curious form of interference which is fairly common in receivers using a 175 kc. intermediate frequency, and that is the inability to receive stations on 700 kc., 1,050 kc., and 1,400 kc. without a strong whistle being heard. This whistle has been found to originate through overall feed-back. Some of the R.F. energy at 175 kc. frequency passes from the second detector through the output system of the set and is picked up by the input. The fourth harmonic of 175 kc. is 700 kc.; the sixth harmonic is 1,050 kc.; and the eighth is 1,400 kc. If this disturbance suddenly appears in a receiver which has previously been free from the trouble, one should immediately suspect the failure of the R.F. bypass condenser connected to the plate of the second detector tube, the opening of the ground lead between the receiver chassis and the loud-speaker, or the failure of other R.F. bypass condensers which may be connected in the plate or grid circuits of the audio system. If the trouble seems inherent to the receiver, and if reception of the three frequencies listed is important, a very slight retuning of the I.F. transformers will shift the interference to adjacent channels. A 465 kc. I.F. can cause trouble at only one point in the broadcast band through overall feed-back—930 kc.

Direct Interference at I.F. Frequencies

It is apparent that if the signal of a transmitter operating at or near the intermediate frequency appears on the grid of the first detector, this signal will be passed and amplified by the receiver. Fortunately there are not many transmitters operating on the common intermediate frequencies. Efforts are being made to reserve a channel from which all long wave transmitters are barred to totally eliminate such interference. However, this reservation has not been secured as yet and there are some locations where the interference is annoying. Airport "A-N" beacons are the chief offenders for 262 kc. I.F. With higher frequency I.F., interference may be experienced from low frequency telegraph transmitters. The remedy is to install a wave trap in the antenna circuit of the receiver. Alignment of the wave trap can be accomplished by feeding the output of a signal generator through a dummy antenna to the antenna and ground binding posts of the receiver. The signal generator is adjusted to the intermediate frequency and then the trimmer of the wave trap is adjusted for *minimum* output of the receiver.

The second harmonic of a long wave station (actual, or generated in the first detector of the receiver) may fall in the band accepted by the I.F. amplifier and thus cause interference.

Direct interference can also be eliminated by realigning the I.F. amplifier to a different frequency.

Oscillator Performance in Superheterodynes

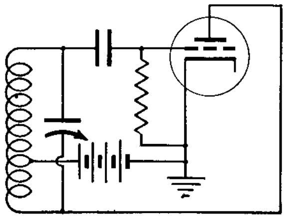
Theory

The optimum performance of a superheterodyne receiver depends to a large extent upon the correct adjustment and alignment of the local oscillator used to heterodyne the incoming signal to the frequency of the intermediate amplifier. The frequency range, tracking, stability, and amplitude of the oscillations must meet rather exacting requirements if maximum performance in the receiver is to be realized.

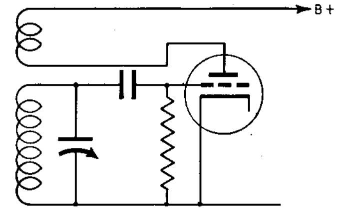
During the past thirteen years of superheterodyne design and development more than one hundred different oscillator-detector combinations have been employed. A review of the circuits more widely used and a consideration of the service problems common to them should be of much help to servicemen. These circuits appear to differ greatly from each other, whereas actually they have many electrical characteristics in common and can all be traced back to the five basic oscillator circuits shown in Figure 2.

Five Basic Circuits Used

The Hartley oscillator circuit shown in Figure 2A is not in common use in superheterodyne receivers, but is very popular in commercial and amateur transmitters. Much used variations of this circuit are the grid tuned oscillator of Figure 2B and the plate tuned oscillator of Figure 2C. Radio amateurs will recognize in Figure 2C the circuit of the T.N.T. oscillator (if plate and grid coils are not inductively coupled, and if the grid coil is broadly resonant to part of the plate circuit tuning range). The Meissner circuit of Figure 2D may be considered a tuned circuit with two tickler coils. The fourth variation of the Hartley oscillator is shown in Figure 2E.



HARTLEY
Fig. 2A



GRID TUNED OSCILLATOR
Fig. 2B

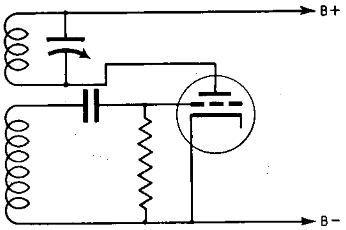
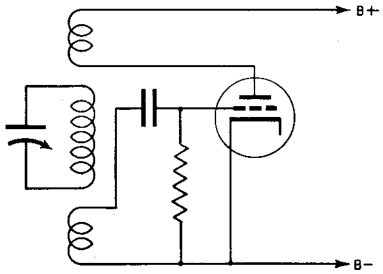
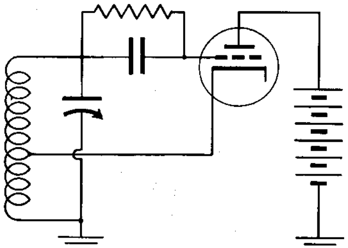


PLATE TUNED OSCILLATOR
Fig. 2C



MEISSNER
Fig. 2D



MODIFIED HARTLEY
Fig. 2E

This circuit is substantially the same as Figure 2A except the ground point has been changed from the cathode to the junction of the coil and the rotor of the tuning condenser. There are several advantages to this change. First, the rotor of the condenser is at ground R.F. potential, which permits the employment of a bath-tub type gang condenser for tuning. In this form of construction the rotors of the various gang sections are common and grounded.

The second point is that the grid condenser is no longer required to prevent plate voltage from being applied to the grid of the oscillator. The D.C. voltage across this condenser now consists solely of the D.C. bias voltage developed through grid rectification and consequently a condenser with comparatively little insulation will be satisfactory in the application. B+ is applied directly to the plate (or oscillator anode) of the tube, and this potential does not appear in the tuning capacitor. This last type of circuit is used in the new single-ended pentagrid converters, types 6SA7 and 12SA7.

It is obvious that this circuit can only be used conveniently with tubes having indirectly heated cathodes which are insulated from the heater circuit. Filamentary cathodes require R.F. chokes in the heater supply circuit so that the cathode may be "off ground" at R.F. potentials.

Colpitts Oscillator

The Colpitts circuit (Fig. 2F) differs from the Hartley in one important respect—the division of the circuit is made by tapping the capacitance rather than by tapping the inductance.

In a Hartley circuit the separation of the plate and grid circuits is obtained either by tapping the coil, or by using separate grid and plate coils in an inductive relationship. In a Colpitts circuit the effect of a tapped condenser is obtained by connecting two condensers in series.

The Colpitts circuit is frequently used in push button tuning circuits employing permeability tuning, and is also used for the long wave "weather" band of some receivers.

Combination Colpitts and Tickler Oscillator

Figure 2G shows a combination circuit employing both tickler and capacitive feed-back. This circuit has several important advantages. By proper selection of constants the oscillator output can be made quite uniform with frequency. Because of the capacitive feed-back, the number of tickler turns can be kept quite small, so that trouble from tickler resonance is avoided.

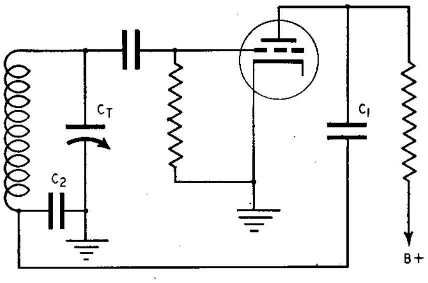
In the circuit illustrated the oscillator low frequency pad C_p serves also as the feed-back condenser.

Tuned Circuits and Oscillations

In each of these circuits a tuned circuit consisting of an inductance and variable capacitor determines the frequency at which the circuit will oscillate. This tuned circuit may be in the grid circuit, the plate circuit, or in a separate circuit coupled to the grid and plate circuits. It is essential that some method be used that will couple part of the developed A.C. voltage on the plate back to the grid circuit. In each of five of the circuits shown in Figure 2, this is done inductively. It is only necessary that the tickler coil be connected in the right way and sufficient coupling be supplied to make the tube oscillate. Whether or not the circuit will oscillate during a complete rotation of the tuning condenser, however, is another matter, and one that is controlled almost entirely by the coupling between plate and grid coils. In almost every oscillator circuit the developed voltage will be greatest near the high frequency end and will decrease as the frequency is decreased. If sufficient feed-back is not provided, the tube will stop oscillating before it reaches the low frequency end of the tuning range. It is very necessary to have enough feed-back, especially in the new all-wave receivers, in which, for economic reasons, it is necessary to cover the greatest frequency range with the fewest coils. There are two ways in which greater coupling can be secured between two coils. One method is to increase the number of turns in the tickler coil and the other method is to place the two coils closer to each other.

If the first method is used, it will be found that after the number of turns reaches a certain value, the resonant frequency of the tickler will fall within the tuning range of the tuned circuit. This will result in the frequency of oscillation being controlled by the tickler instead of by the tuned circuit, and the tuning condenser may be turned through many degrees without affecting the frequency. This is, of course, very undesirable. On the other hand, if the two coils are coupled tighter by placing them closer together, the tuning range will be sacrificed because the tickler coil adds capacity to the tuned circuit and this limits the frequency range. This indicates that a compromise must be effected to secure: (1) The maximum number of turns on the tickler that will not cause it to resonate within the desired frequency range. (2) Close coupling between tickler and tuned circuit with the minimum capacity effect. (3) The greatest frequency range that can be covered.

This compromise is easy to effect on the broadcast band but becomes increasingly difficult with an increase in frequency. On the broadcast band, if only the range 550 kc. to 1,500 kc. is to be covered we cannot increase the coupling too much or another undesirable trouble is encountered—that of parasitic oscillation. When an oscillator is forced to generate a high A.C. voltage, it produces simultaneously a number of harmonics and it also has a tendency to oscillate at a second frequency usually higher than the original. This is called parasitic oscillation and in a superheterodyne oscillator causes squeals and whistles at the high frequency end of the band. Too great a coupling between plate and grid coils in an oscillator causes parasitic oscillation on the high frequency end, and too loose a coupling may result in the oscillator stopping at the low frequency end of the band. Somewhere between these two conditions will be found the proper degree of coupling. In service work, some sets will be found where the coupling is at a critical point so that a matched oscillator tube will work, but one that is on the low side of the mutual conductance limit will stop oscillating somewhere near the low frequency end of the band.

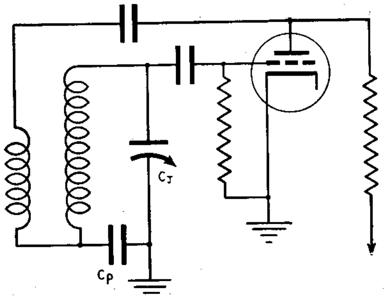


COLPITTS OSCILLATOR
FIG. 2F

The Grid Leak and Condenser

The function of the grid condenser and leak common to all seven circuits shown in Figure 2 may not be apparent at first glance. These two necessary items are used to secure an automatic grid bias for the oscillator tube.

With the grid connected to the cathode by the grid leak, the bias on the grid is of course zero when the tube is not oscillating. A tube so operated is very sensitive to any circuit change and is very unstable. With a positive voltage applied to the plate and the heater current turned on, the first surge of electrons from the cathode to the plate will cause the tube to start regenerating and within a few cycles this will build up sufficient feed-back voltage to cause the



COMBINATION COLPITTS & TICKLER OSCILLATOR
FIG. 2G

tube to oscillate. With the tube oscillating, the voltage feed-back from the plate circuit will alternately make the grid positive, then negative. When the grid goes positive, it will act as a diode plate and attract some of the electrons that would otherwise go to the plate, and these electrons flowing through the grid leak will develop a voltage that will bias the grid negative. If the grid condenser and leak are of the proper value to prevent all of these electrons from leaving the grid during the negative cycle, the grid will maintain this bias as long as the tube is oscillating. This effect can be shown in two ways—first by connecting a 0-1 milliammeter in series with the grid leak and, second, by connecting a milliammeter in series with the plate return circuit. When the tube is not oscillating, the plate current will be higher than when it is oscillating. The use of a meter in series with the grid leak gives a very good indication of the actual voltage developed by the oscillator. It is only necessary to multiply the grid leak resistance in ohms by the grid current to determine this voltage. Since the voltage developed by an oscillator is proportional to the coupling, this grid current measurement gives a good test for determining the condition of coupling which, we have seen, is very important. This current is larger than would be supposed because when the grid is positive, the plate voltage is at minimum and the grid attracts a relatively large percentage of the electrons. Since the translation gain of the first detector oscillator combination is a function of the oscillator voltage, it is very important that this developed voltage be of satisfactory amplitude.

Engineering and Service

It is apparent from the foregoing discussion that an oscillator circuit that will cover the desired frequency band with a satisfactory developed oscillator voltage so as to give good translation gain and yet not cause parasitic oscillation trouble at the high frequency end of the band, is one that has been very well engineered and one that must be intelligently adjusted in the field, if satisfactory receiver operation is to be maintained.

Coupling Between Oscillator and First Detector

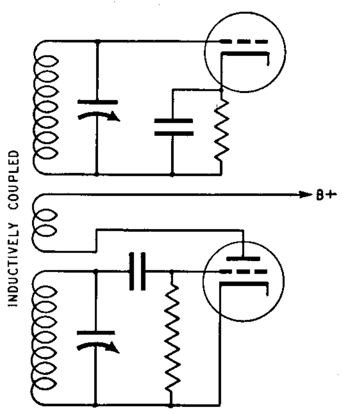


Fig. 3A

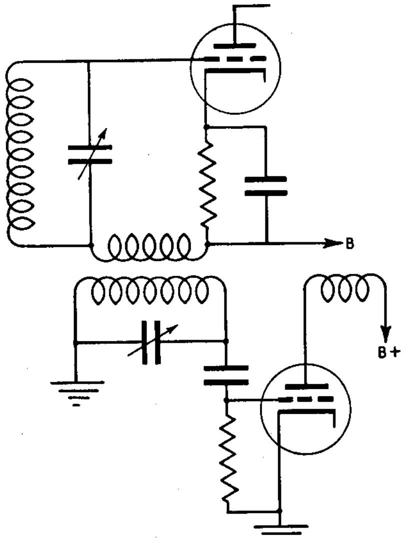


Fig. 3B

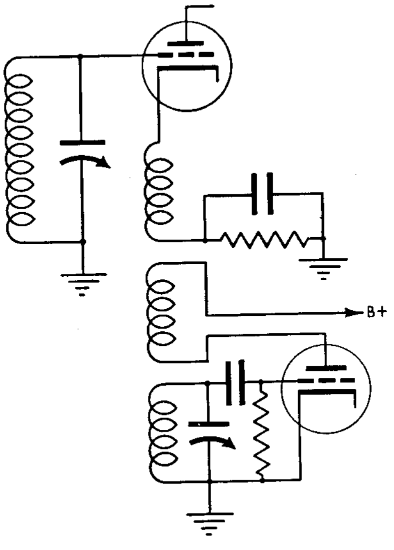


Fig. 3C

The first commercial superheterodyne receivers employed triode tubes throughout and were, of course, battery operated. These early sets are now between ten and fifteen years old, and if they have not already been, should be retired in favor of newer and much better sets. We will therefore ignore these early receivers and consider only screen grid type receivers.

To secure an intermediate frequency in the plate circuit of the first detector, the voltage from the local oscillator is beat against the incoming signal in the control grid, cathode, or screen grid circuit of the first detector. Five general methods of coupling the first detector with a separate oscillator tube have been used. These are:

1. Inductive coupling of the oscillator coil to the first detector grid coil, as illustrated in figure 3A.
2. Inductive coupling of the oscillator coil to a separate coil connected in the grid return circuit of the first detector, as illustrated in figure 3B.
3. Inductive coupling of the oscillator coil to a coil in series with the first detector cathode circuit, or by capacity coupling between oscillator cathode and first detector cathode, as illustrated in figures 3C and 3D.
4. Electron coupling by introducing the oscillator voltage in the first detector screen-grid circuit by conductive, inductive, or capacitive coupling as illustrated in figures 3E, 3F, and 3G.
5. Electron coupling by introducing the oscillator voltage into the first detector by using a tube having an additional grid structure, such as the suppressor grid of an R.F. pentode; or the oscillator grid of a 6L7, as illustrated in Figure 3J.

The first two systems (1 and 2 above) introduce the oscillator voltage into the control grid circuit of the first detector and require either a relatively weak oscillator voltage or very loose coupling between the oscillator and first detector control-grid coils. The second method is the more satisfactory of the two although too close a coupling between these two coils may cause the tuning of one circuit to affect the tuning of the other circuit. This type of interaction is very undesirable, and in extreme cases causes the two circuits to "lock" together, making proper trimming and tracking very difficult.

Assuming that the oscillator and first detector coupling is satisfactory from a non-interaction standpoint, there is still one other source of trouble to consider. This is the possibility that the oscillator voltage may be so high (or the first detector grid bias so low) that it will drive the control grid of the first detector positive. This usually occurs at the high frequency end of the band, where in most cases the oscillator develops its maximum voltage. When the second detector control grid is driven positive, grid current flows in the grid circuit and the sensitivity of the R.F. stage as well as that of the first detector is seriously reduced. If this condition is suspected it can be easily checked by connecting a 0-1 milliammeter in series with the first detector grid coil (between the low potential end of the coil and ground) and rotating the tuning condenser through its entire tuning range. If at any time the meter needle moves, the first detector bias should be increased or the oscillator voltage reduced. The oscillator voltage may be reduced by reducing the coupling between first detector and oscillator coils, by reducing the coupling between the two oscillator coils, by reducing the plate voltage of the oscillator, or by reducing the grid leak or condenser—or both—of the oscillator. To maintain the oscillator developed voltage at a more constant level in many sets a fixed resistor is connected in series with the oscillator grid as shown in figure 3H.

A vacuum tube voltmeter may be used to measure the value of the oscillator voltage induced in the control-grid circuit of the first detector. If the vacuum tube voltmeter is calibrated in R.M.S. volts, the oscillator voltage measured must be multiplied by 1.4 to find the peak voltage. This peak voltage should never equal the bias voltage of the first detector.

The third system of inductive coupling, in which the oscillator voltage is induced into the cathode of the first detector (illustrated in figures 3C and 3D), gives less trouble due to interaction between the first detector tuned circuit and the oscillator tuned circuit, but the balance between first detector bias and maximum oscillator voltage must be given the same consideration as in the previous systems. In 3D the small bypass condenser across the cathode resistor of the first detector provides a convenient method of reducing the oscillator voltage at the high frequency end of the band, since its reactance will be lower at high frequencies where the oscillator voltage is usually greatest. If the oscillator voltage is too high, increasing the capacity of this condenser will cure the trouble.

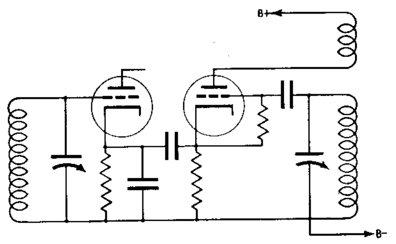


FIG. 3D

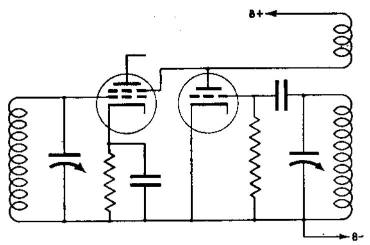


FIG. 3E

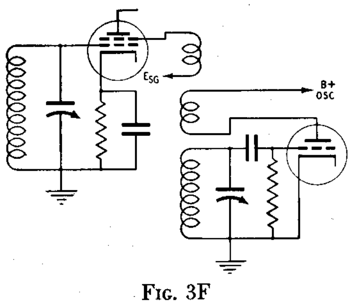


FIG. 3F

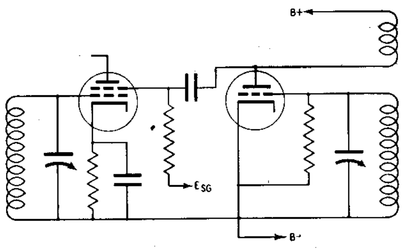


FIG. 3G

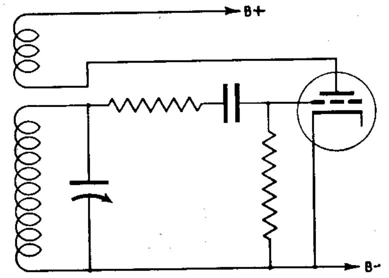


FIG. 3H

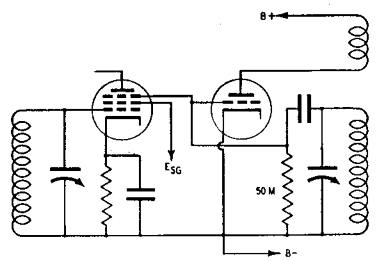


FIG. 3J

The coupling methods illustrated in figures 3E, 3F, and 3G introduce the oscillator voltage into the screen grid of the first detector, where it is electronically mixed with the signal voltage appearing on the control grid of the tube. The electron stream and the small capacity existing between control-grid and screen-grid are the only links between the two circuits. There is, therefore, no chance for the oscillator to override the bias of the first detector and very much less trouble due to interaction between the two tuned circuits. Because the screen-grid has less control over the electron stream than the control grid, the oscillator voltage applied to it must be greater to give the same translation gain in the first detector. For this reason, assuming the same oscillator coils in each case, circuit 3E may not give as good results as circuit 3F and 3G in which the oscillator plate voltage can be higher than the first detector screen-grid voltage, and as a consequence develop a higher oscillator voltage. Circuit 3F is not as economical to produce as types 3E and 3G because of the three coil feature, and for the same reason will give more trouble in the field due to difficulty of maintaining proper coupling between the three coils.

Electron Coupling with Suppressor Grid Injection

With R.F. pentode tubes having the suppressor grid connection brought out to a separate base pin, good operating results can be obtained by injecting the oscillator voltage in the suppressor grid rather than in the cathode circuit as has been described. The suppressor control of the plate current is as complete as that of the control grid under proper conditions, provided that enough control voltage is used. The above statement may be clarified somewhat by saying that if the control grid is held at any fixed potential, the plate current may be varied between cutoff and the value corresponding to zero suppressor grid bias.

SUPPRESSOR GRID PLATE CHARACTERISTICS
TYPE 78 TUBE

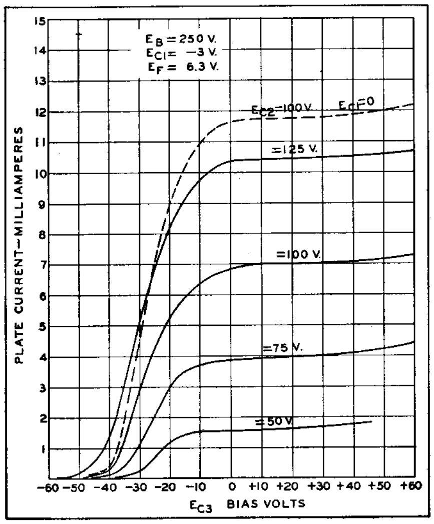


Fig. 4

For example, Figure 4 shows the variations of I_p of a 78 tube with the suppressor grid voltage. If the suppressor grid is made negative enough, the plate current is cut off for any of the screen and control grid voltages. The principal control effect of the suppressor grid occurs in a range of −15 volts to −40 volts suppressor grid bias, and at more positive values the suppressor grid has comparatively little control on the plate current flow. The curves are all for —3 volts on the control grid except the dotted curve which is for zero potential.

Some discussion of the suppressor grid control characteristic is in order. No specifications for the suppressor grid control on the plate current have been published or standardized. A wide range of turns per inch on the suppressor grid may be found in various makes of tubes. This wide range is permissible from the standpoint of the rated characteristics given with the suppressor grid at zero potential, and no serious trouble has resulted even in the case of combined oscillator-detector service.

The plate resistance is reduced when the suppressor grid potential is made negative. The suppressor grid potential varies over wide limits however, so that the average plate resistance is much higher than the low values that would be measured for a negative suppressor grid with small signal.

Provided the injected voltage is kept above a certain minimum value, the sensitivity varies but little with variations of the voltage injected in the suppressor grid. The suppressor grid current drawn when the suppressor grid is swung positive is so small that it can be neglected. With cathode injection, on the other hand, the value of the injected voltage is quite critical if optimum results are to be obtained, because the sensitivity is reduced if the injected voltage is reduced, and grid current is drawn if the injected voltage is too high. From this standpoint, suppressor grid injection is to favored.

A separate bias source was used in making the measurements shown in figure 4. There is no reason, however, that the suppressor could not be tied to the grid of the oscillator tube and the oscillator bias furnish the bias on the suppressor grid also. A 20,000 ohm grid leak will give between 50 and 60 percent rectification efficiency, say 55 percent. A value of 35 volts D.C. bias would thus be suitable for both injection and D.C. bias. A resistor of 50,000 ohms could be used also and the proper oscillator strength could be found directly from the data given, as the rectification efficiency for 50,000 ohms is about 70 percent so that the R.M.S. values of injected voltage are the same as the rectified voltage. No trouble would be had in obtaining this voltage from a separate oscillator. Figure 3J shows a typical circuit diagram.

RELATIVE POSITION OF ELECTRODES OF THE 6L7

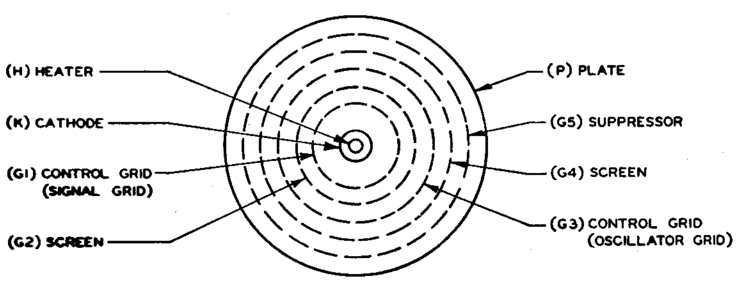


Fig. 5

The 6L7 Mixer Tube

From the preceding data it will be seen that there are both advantages and disadvantages when using suppressor injection of oscillator voltage.

The advantages are:

1. Freedom of coupling between the R.F. and oscillator tuning circuits, which prevents any tendency toward "pulling" or "locking-in" of the oscillator.
2. The value of the injected voltage is comparatively non-critical, as long as there is enough of it. There is no danger of excessive oscillator input causing the control grid to go positive, causing the flow of grid current with its attendant evils.

The principal disadvantages of using an R.F. pentode tube with suppressor injection are:

1. The oscillator must develop a comparatively high output if complete modulation of the signal is to be secured.
2. A negative bias on the suppressor grid of an R.F. pentode greatly lowers the R.F. plate impedance, which is harmful to selectivity.

These effects have prevented the suppressor injection methods from achieving wide popularity. However, by modifying the construction of the detector tube, these defects can be eliminated. The modification would consist of increasing the amplifying action of the suppressor grid; and the addition of a screen between the suppressor and the plate will maintain the plate resistance at a satisfactory value. A further refinement may be made by inserting a grounded suppressor between plate and oscillator screen. This hypothetical tube, which is substantially the new 6L7, thus requires five grids for good mixing at high radio frequencies.

Figure 5 shows the relative positions of the elements of the 6L7. The tube consists, as may be seen, of a heater, a cathode, five concentric grids, and a plate. Grid No. 1, which is nearest the cathode, is one of the two control grids. It is of the remote cut-off type and, because the R.F. signal to be converted is applied between it and cathode as shown in Figure 6, it may be referred to as the signal grid. The remote cut-off characteristic of this grid minimizes R.F. distortion and cross-modulation effects when its bias is under the control of the A.V.C. system. Grid No. 2 serves the same purpose as the screen in a conventional tetrode; it accelerates the electrons toward the plate and reduces the G_1-G_3 capacitance to a small value. (The numerical subscript denotes the grid number.) Grid No. 3, interposed between screens G_2 and G_4, is the second control grid of the tube and has a sharp cut-off characteristic. This grid may be referred to as the oscillator grid, because the output of the external oscillator is connected to it. Grid No. 4 is another screen; it increases the plate resistance of the tube, reduces the G_3-P capacitance, and functions similarly to the screen in a conventional tetrode. G_2 and G_4 are connected together internally and serve to limit the effects of secondary emission from the plate. Because of the suppressor, it is possible to operate the tube at low plate voltages. Figures 7 and 8 show typical radio receiver circuits using the 6L7 tube.

CONNECTIONS OF THE 6L7 AS A MIXER

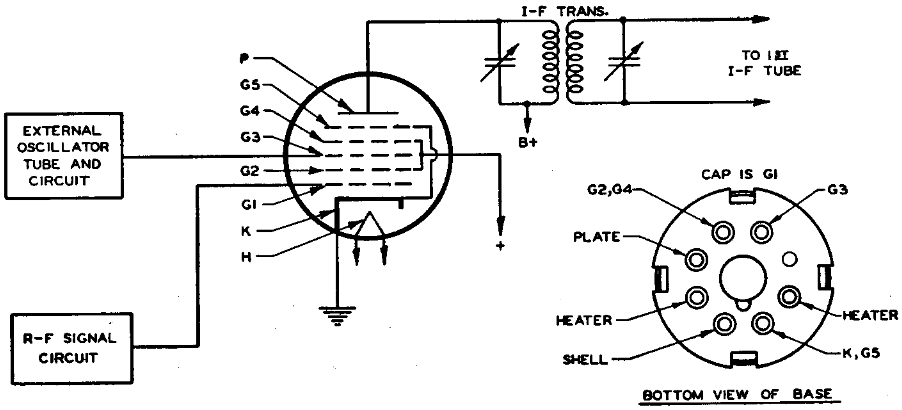
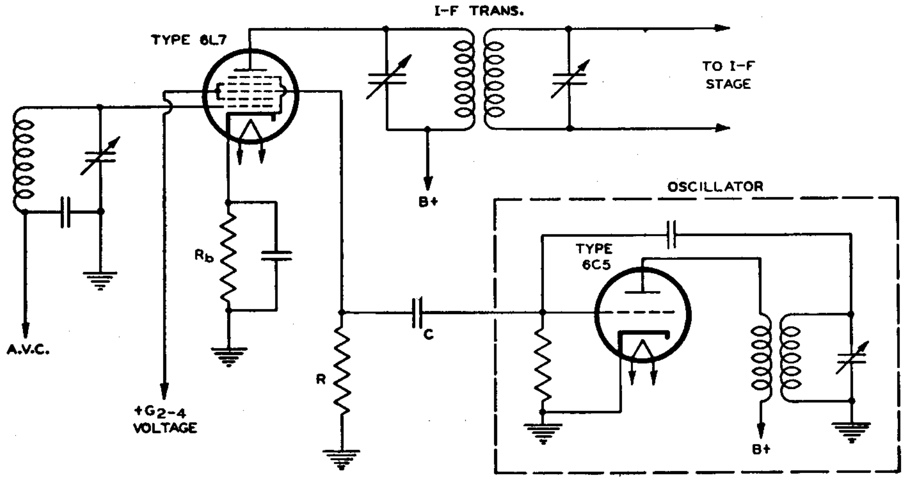


FIG. 6

TYPICAL OSCILLATOR-COUPLING CIRCUITS FOR THE 6L7



$$R_b = \begin{cases} 350 \text{ OHMS FOR } E_{C1} = -3 \\ 500 \text{ OHMS FOR } E_{C1} = -6 \end{cases}$$

R = 50 000 OHMS (MAX.)

C = 100 $\mu\mu f$

FIG. 7

The 6J8G Converter Tube

The 6J8G construction is identical to that of the 6L7 except that it has an additional triode section mounted at the bottom of the common cathode. This triode section is used as the oscillator. The No. 1 grid of the triode is tied internally to the No. 3 grid of the heptode. The combining of the two tubes in one envelope results in a cost saving in radio receiver construction.

Autodyne First Detector Combinations

The autodyne reached its greatest popularity and development during the beginning of the depression when a great deal of research work was done on small and inexpensive superheterodynes in which it was necessary to reduce the number of tubes and other parts to a minimum. The greatest impetus to low cost receiver development was, of course, the series heater principle made possible by the 6.3 volt, 0.3 ampere tubes. Prior to the introduction of the 6A7 tube and multi-band receivers, the autodyne detector was used very extensively and a complete knowledge of its mode of operation and adjustment is very necessary to the serviceman.

An R.F. type of pentode tube, such as the 6C6, in which three grids are brought out to independent base terminals, can be used in three basic ways as an oscillator. Feed-back from the plate circuit to the control grid, screen-grid, or suppressor grid will cause the tube to oscillate at a frequency determined by the constants of the circuit elements. In practice the screen grid is not used because of instability caused by operating the screen grid above R.F. ground

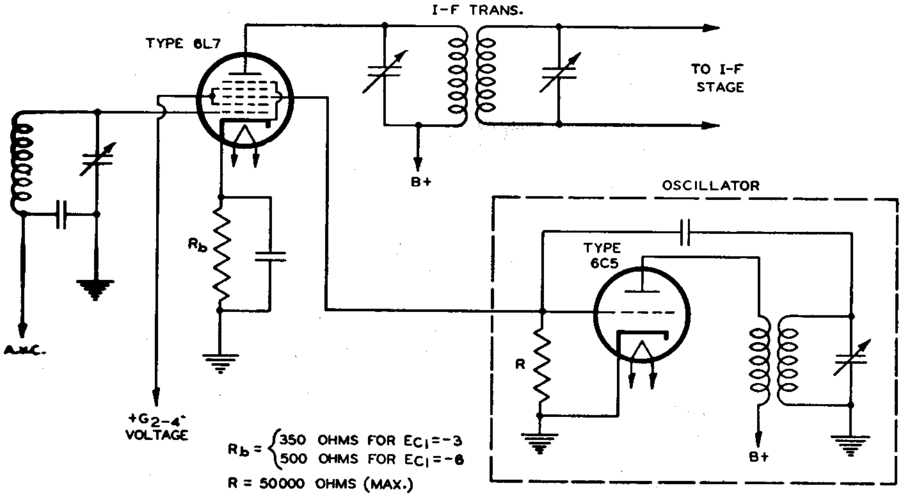


FIG. 8

potential, and because of the load imposed on the tuned circuit by the relatively low internal screen to ground impedance within the tube. Therefore, for purposes of analysis, we can divide all autodyne detectors into two major groups—the control grid types, in which feed-back is between plate and control grid, and the suppressor grid types in which feed-back is between plate and suppressor grid. Both of these types for ease of description will be further subdivided. The tetrode tube cannot, of course, be used as a suppressor grid type autodyne detector.

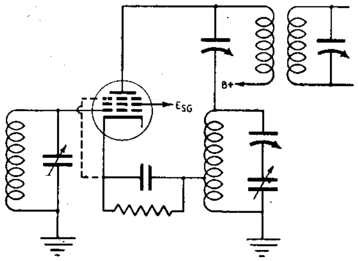


FIG. 9A

Control-Grid Types of Autodyne Detectors

The control-grid type of autodyne detector has been the most popular because of the ease with which proper oscillator amplitude can be secured. (This follows because the mutual conductance between control grid and plate is much higher than that between suppressor grid and plate, and because it can be used with either the tetrode or pentode type of tube construction.)

In Figures 9A, 9B, 9C, 9D, and 9E are shown the three fundamental systems of control grid type of autodyne detector. There are, of course, many other variations, but these will be found upon analysis to be simple modifications of one of the circuits illustrated. In looking over the five circuits mentioned it will be noted that in each case a coil is shown in the cathode circuit of the tube. This is a reliable method of determining that the autodyne under consideration is a control grid type since the suppressor grid type of autodyne detector does not have a coil in the cathode circuit.

The function of the coil in the cathode circuit may not be apparent at first glance. Upon a moment's consideration, however, it will be evident that since all circuits in a vacuum tube must return to the cathode, a coil in the cathode circuit is common to the control grid, screen grid, suppressor grid, and plate circuit, and because a given voltage impressed on the control grid will have a much greater effect on the plate current than the same voltage impressed on either of the other grids or the plate, we can ignore the other effects and, for the purpose of this explanation, consider the voltage impressed on the cathode coil as acting exactly as though we had impressed this voltage on the control grid alone. The A.C. voltage feedback from the plate circuit, at a frequency determined by the L.C. of the circuit, causes the cathode to vary in potential with respect to the control grid, which is, of course, the same effect as varying the control grid voltage with respect to the cathode. Assuming that the coil system has not been damaged and that no other fault exists in the autodyne detector circuit, trouble may be experienced with an improper value of cathode bias resistor. This will show up usually when it is necessary to replace the original tube. It may be found that several tubes must be tried before one can be found that will operate properly. This undesirable condition can usually be corrected by changing the value of the cathode resistor to 10,000

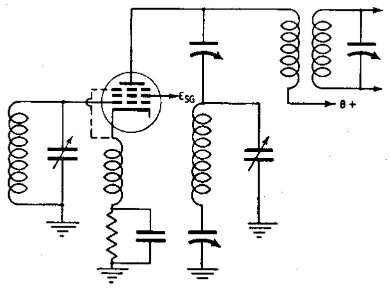


FIG. 9B

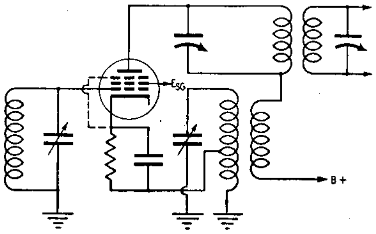


FIG. 9C

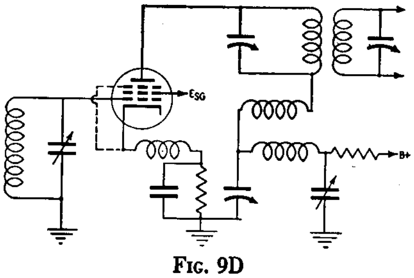


FIG. 9D

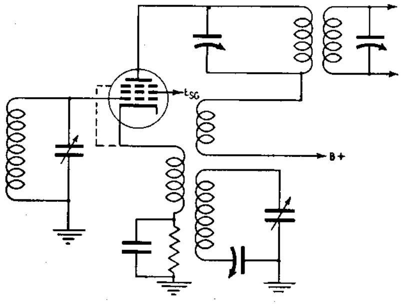


FIG. 9E

ohms. In general it will be found that this value of resistance will give the most uniform oscillator performance. This bias value is very important to secure the optimum detector sensitivity and uniform oscillator amplitude. In special cases experimenting with various values of cathode resistors may improve the autodyne detector action and make it unnecessary to pick tubes. It must be kept in mind, however, that the value suggested (10,000 ohms) is the best average compromise between uniform oscillator performance, most sensitive detector action and the ability of the detector to handle large local station signals.

In Figure 9A, a single coil is used and a cathode tap is provided which has the same effect as the separate tickler coil shown in Figures 3B and 3C. You will note in all five diagrams that no grid leak and condenser is used such as was shown in each oscillator circuit of Pages 9 and 10. These units are not required in the control grid autodyne circuit because the oscillator grid—which is also the signal control grid—must not be driven positive by the peak positive cycle of the oscillator wave (should this occur, the signal input circuit will be seriously loaded and poor sensitivity, selectivity and distorted tone quality will result.) We can consider that the oscillator section of the autodyne detector is functioning like a class "A" amplifier, that is, the peak signal applied to the control grid (composed of the incoming signal voltage and the oscillator voltage feed-back from the plate circuit) must be less at any signal frequency or signal amplitude than the bias appearing across the 10,000 ohm cathode resistor. From this it can be seen that the grid cannot rectify a portion of the oscillator voltage or, in other words, draw grid current, as is necessary for bias purposes in the single tube oscillator or in the 6A7 oscillator section, and so a grid leak and condenser are unnecessary. Figures 9A and 9B are examples of the tuned plate, grid tickler types of control grid autodyne. Figure 9C is a tuned grid, plate tickler type and Figures 9D and 9E represent the three coil Meissner circuit in which two tickler windings are coupled to a tank circuit.

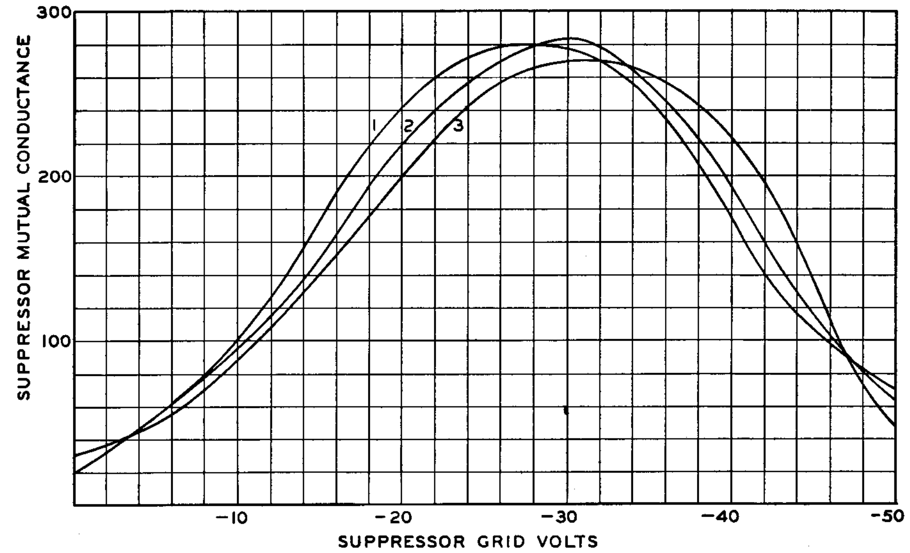


Fig. 9J

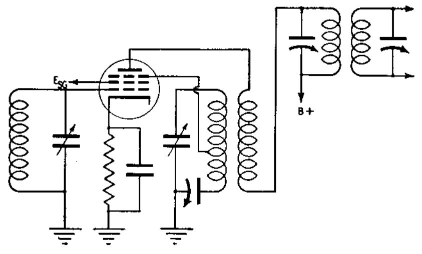


Fig. 9F

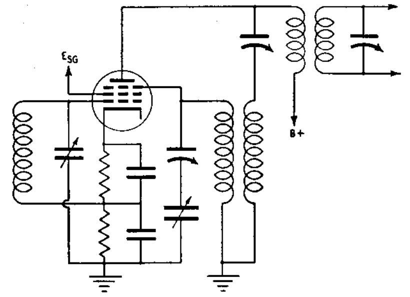


Fig. 9G

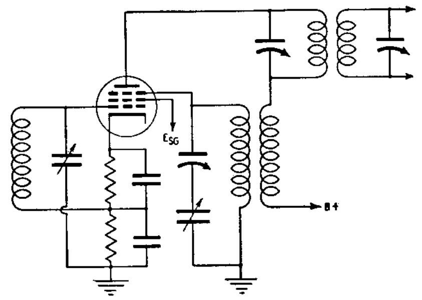


Fig. 9H

Suppressor Grid Type of Autodyne Detector

In Figures 9F, 9G, and 9H are shown three typical examples of the suppressor grid type of autodyne detector. Figure 9F is one of the earliest systems used and has a serious disadvantage in that if a proper bias is secured with the cathode resistor to give good detector action, the mutual conductance of the suppressor grid to plate is so low that it is difficult to secure sufficient oscillator amplitude. On the other hand, if the bias is high enough to give a good suppressor mutual conductance so that the tube will develop a good oscillator voltage, the control grid bias would be so high as to reduce the plate current to such a low value that the system would give very poor gain. There is no satisfactory compromise to eliminate this trouble short of using two resistors in the cathode circuit, such as shown in Figures 9G and 9H, so that the control grid and the suppressor grid may each be biased separately. When this is done, we can bias the control grid 3 or 4 volts negative (measured with a high resistance voltmeter from the midpoint of the two resistors to cathode), and the suppressor grid from 30 to 34 volts negative (measured with a high resistance voltmeter between cathode and ground), and secure both good detector and good oscillator performance. Figure 9J indicates how three good tubes may vary in suppressor grid to plate mutual conductance. Notice that with a —15 volts bias on the suppressor grid only one of the tubes would have a high enough mutual conductance to give good oscillator performance, whereas at 30 volts all three tubes would work equally well. In adjusting a suppressor grid autodyne, it must be remembered that the developed oscillator voltage will vary through the band and since this in turn varies the plate current (which must of course flow through the cathode circuit resistors) the control grid bias will likewise vary throughout the band. It is important that the control grid bias be maintained at a minimum of 2 volts throughout the entire band. If the control grid bias falls below this value, a strong local signal may drive the control grid positive and cause greatly reduced sensitivity and selectivity, and poor tone quality. All of the autodyne detector circuits discussed have three limitations. These are: 1. low translation gain, 2. limited frequency range (usually the broadcast and police bands only), and 3. the gain of the autodyne detector cannot be controlled by the A.V.C. voltage. For these reasons, almost all present day receiver designers have abandoned the autodyne detector oscillator combination in favor of the later and superior pentagrid converter type of tube—such as the 2A7, 6A7, 6A8 and 6A8G. In repairing some of the older receivers having critical autodyne circuits, there is much to be said in favor of replacing the tube socket and rewiring the receiver for a pentagrid converter.

Pentagrid Converters

The operation of a well designed pentagrid converter stage is so dependable, and the number of circuit components required so few, that it is easy to gain the mistaken impression that if the performance of this stage is unsatisfactory the trouble must be due to the tube. This remark is not intended as absolving the tube of all responsibility, since it is realized that the pentagrid converter is harder worked than any other tube in the receiver with the possible exception of the power tube, but rather to point out at the beginning that making a set work by replacing the pentagrid converter tube—only to have the set again quit operating one to four months later—cannot be considered a reliable method of service procedure. To guarantee service work the serviceman must be satisfied that the method he has employed to correct the trouble really effects a permanent cure, and does not just supply a crutch that permits the circuit to limp along under a heavy handicap of power loss or unfavorable circuit adjustment.

We found in the previous types of oscillator circuits discussed that the set engineer designed the oscillator circuit to give the best compromise between several conflicting considerations—the same thing is true of the pentagrid converter circuits. An intelligent appreciation of these factors, their theory, cause, and cure will make service work much easier and certainly, by eliminating some of the return calls, more profitable.

Pentagrid Converter Theory

Tube types 1A6, 1C6, 1D7G, 1C7G, 2A7, 6A7, 6A8, 6A8G, and 6D8G are all pentagrid converters designed to function as a combined first detector and oscillator to "convert" the incoming signal frequency to an intermediate for the purpose of securing selectivity and sensitivity without fear of interlocking and tetrode section grid current. The word "pentagrid" is a compound word made up of the Greek prefix "Pente" (or "penta" in the English translation) meaning five, and grid—literally, 5-grid. These five grids, numbering from the cathode, are: 1. the oscillator control grid, 2. the oscillator anode, 3. the inner screen grid, 4. the signal control grid, and 5, the outer screen grid. There are, of course, beside these grids a heater or filament, plate and, in the indirectly heated tubes, a cathode. Grids 3 and 5 are connected together inside the tube. Grid No. 2, the oscillator anode, is made in current practice without horizontal wires and consists only of the two side rods. These two side rods are called the oscillator anode (meaning plate) but in circuit diagrams are shown schematically as a grid for simplicity.

The pentagrid converter may be considered as operating very much like a conventional variable-mu tetrode first detector with an associated triode oscillator, except that the oscillator triode grid is located next to the cathode and is common to both the first detector variable-mu tetrode and the oscillator triode. The tetrode section of the tube is modulated by the control grid voltage on the oscillator triode in such a manner that there is no danger of driving the control grid of the tetrode positive. Electrons emitted from the cathode surface are influenced by the various grid and plate voltages and divide up so that grid No. 1 receives 7 per cent of the electrons, the oscillator anode receives 37 per cent of electrons, grids 3 and 5 (screen grid) receive 28 per cent of the electrons, and the plate receives the remaining 28 per cent.

Because of the oscillator grid's strategic position next to the cathode, any oscillator voltage on this grid will modulate the entire electron stream regardless of the ultimate destination of the electrons. Referring to diagram 10, it is interesting to observe the action that takes place within the tube when it and the associated circuit components are operating normally. When the set is first turned on, the No. 1 grid is at zero potential because it is tied to the cathode by the 50,000 ohm grid leak. As the cathode heats up and starts to emit electrons, the feed-back between oscillator anode and grid causes regeneration which immediately starts the triode circuit to oscillating. When the oscillator circuit is oscillating, the No. 1 grid is driven alternatingly positive and negative. While the grid is positive, grid current flows through the grid leak in such a direction as to make the No. 1 grid negative with respect to the cathode. This grid swing may make the grid negative by as much as 30 to 40 volts, and this becomes the grid bias point about which the grid varies in amplitude alternately in a positive and then a negative direction under the influence of plate circuit feed-back. From this it can be seen that the maximum instantaneous negative voltage on the No. 1 grid may be 60 to 80 volts. This voltage would ordinarily be more than sufficient to reduce the tetrode plate current to zero were it not for a secondary source of electrons available to the No. 4 grid. This second electron source is referred to as a virtual cathode because it is employed exactly as though it were another electron emitting cathode. The reason for its existence is that most of the cathode's supply of electrons go through the No. 1 grid while it has a positive or slight negative charge, and are accelerated out of the No. 1 grid's field of influence by the relatively high positive potential on the No. 3 grid. The next grid—tetrode section control grid—has at all times a negative bias on it so that a great many of these electrons are slowed down and form a cloud of electrons between the No. 3 and No. 4 grid. It is from this cloud of electrons (virtual cathode) that most of the plate current is secured during that portion of a cycle that the No. 1 grid is at its maximum negative potential. It is easy to see from this action that the tetrode section works independently of the triode section, except that the tetrode plate current is modulated by the triode grid voltage. The No. 3 grid shields the triode section from the tetrode section and prevents interaction. The tetrode grid No. 4 is shielded from the plate by the other screen grid, No. 5. Grids 3 and 5 are connected together inside the tube. Automatic volume control bias may be applied to the tetrode section without affecting the performance of the oscillator section, since the oscillator triode secures its plate current first, direct from the cathode.

Oscillator Coil Coupling

The value of heterodyning voltage developed by the triode section of the tube is determined largely by the degree of coupling between the tank or grid circuit, and the tickler or plate circuit. On the long wave band, 150 to 350 kc., and to a lesser extent on the broadcast band little trouble is encountered in securing sufficient coupling. In fact, care must be taken to prevent too much feedback in order to avoid causing the tube to oscillate so strongly that parasitic oscillation will result. By "parasitic" oscillation is meant the generation of extraneous frequencies, besides the fundamental desired, that are usually higher in frequency than the fundamental. These usually occur at the high frequency end of the band and may make the receiver sound as though some other part of the receiver system were oscillating. This condition may be difficult to trace to its source if the true reason for its existence is not suspected, because any change in circuit constants that affects the voltages on the various elements of the pentagrid converter will change the frequency or amplitude or both of its characteristics. The proper cure for this trouble is either to space the two coils farther apart or to reduce the number of turns on the tickler winding. The latter method is preferable because it has the least effect on the tracking of the oscillator, since very little change is made in the capacity to ground of the tank circuit. This change may be necessary on the long wave and broadcast bands of sets that were manufactured shortly after the 2A7 and 6A7 were introduced, because it was found necessary to increase the triode section mutual conductance of these tubes in order to provide satisfactory operation on the short wave receivers that were just becoming popular at that time. The first sign of this condition will occur when a new tube is used to replace the one originally supplied with the receiver. If the receiver is designed for broadcast only, any trace of parasitic oscillation may be eliminated by connecting a 500 to 1,000 ohm resistor from the oscillator grid terminal of the socket to the common point of the grid leak and condenser as shown in Figure 10. This suppressor resistor will tend to equalize the developed oscillator voltage over the broadcast band. It should not be used on receivers having short wave bands. The reason for this is that it is almost impossible to secure too much coupling between oscillator coils on the higher frequencies. This problem is just the reverse of that encountered on broadcast and long wave bands. On the short wave bands every effort is made to secure the greatest mutual inductance between the two coils, so that the developed oscillator voltage will be as great as possible. The problem is even more acute on those receivers that use a large capacity tuning condenser to secure the greatest frequency coverage on each band, since it is usually true that the greater the band width covered the lower the oscillator voltage will be and hence the lower the converter stage gain. For the high frequency bands the tickler and tank coils are placed very close together and often the two windings are interwound to secure the maximum possible coupling. When the maximum band width is to be covered, stray capacities must be kept at a minimum, and in order to reduce the coil's distributed capacity to a minimum only a few turns of the tickler can be interwound with the low potential end of the tank coil. This necessitates a compromise between developed oscillator voltage and the band width that can be covered. A practical compromise is to adjust the oscillator voltage (by means of the coupling between tickler and tank coils) to give about .1 ma. grid current through the oscillator grid leak at the low frequency end of the short wave band and then reduce wiring and circuit capacities to give the greatest spread between the minimum and maximum frequencies that can be secured with the variable condenser being used. In the absence of a vacuum tube voltmeter, this method is the most reliable method of determining the developed oscillator voltage. Connect a 0-1 ma. meter in series between cathode and 50,000 ohm grid leak so that D.C. current flowing through the resistor will indicate on the meter. The oscillator A.C. voltage is then equal to the current multiplied by the resistance of the grid leak. For A.C.-D.C. receivers this current may vary between .05 ma. and .25 ma. depending upon the frequency at which the oscillator is set. The minimum current will flow at the low frequency end of the highest frequency band and the maximum current will be around 1,200 to 1,600 kc. in the broadcast band. For A.C. receivers this grid current will vary from .1 to .75 ma. If the oscillator stops oscillating at the low frequency end of the short wave band and the suggestions mentioned under "Grid Block-

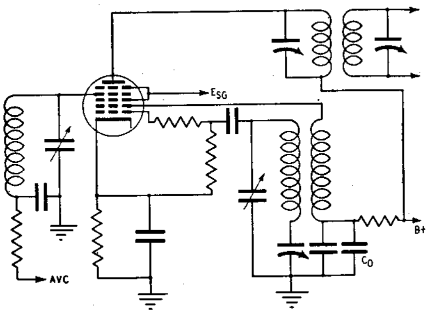


FIG. 10

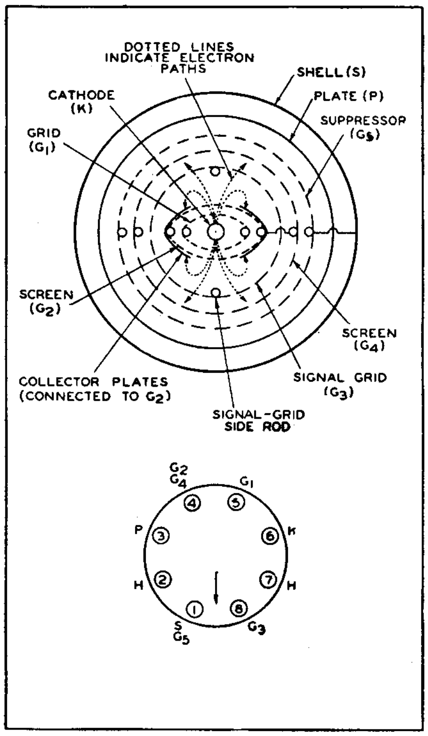


FIG. 11

ing Condenser" and "Grid Leak Resistor" (see page 19) do not eliminate this trouble, the coupling between tank and tickler coils should be increased. Usually it will not be possible to add more than one or two turns to the tickler coil to effect this increase in coupling or the tickler coil will resonate within the band and cause trouble. If this increase is insufficient to correct the difficulty, make sure the coil is dry and that the "B" supply voltage is normal, then push the two coils as close together as possible and accept the slight loss in band coverage that will result. Such drastic action is seldom necessary unless new replacement coils are unobtainable for the set. Varying the size of the grid blocking condenser will often prove effective in increasing the developed oscillator voltage.

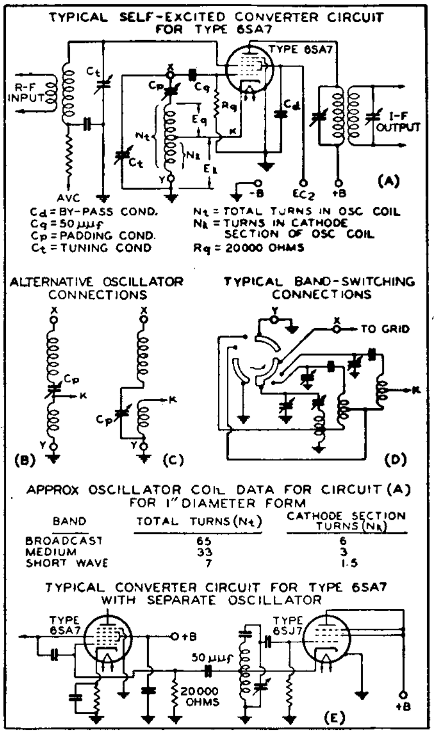
Single-Ended Converters

The 6SA7 and 12SA7 are single-ended pentagrid converters designed to perform the functions of oscillator and mixer in all-wave receivers. Since the 6SA7 and 12SA7 tubes are identical except for heater current and voltage, the designation —SA7 in the following text refers equally to either type of tube. Structurally, these tubes differ from **other converter tube types in two important respects:** (1) all electrodes including the signal grid terminate at base pins, and (2) there is no electrode which functions only as oscillator anode.

The single-ended construction employed in the —SA7 effects an appreciable saving in installation cost because a flexible grid lead and top-cap connector are not required; in addition, the lead connecting to the signal-grid terminal of the socket can be made short and rigid. Because there is no electrode in the —SA7 that serves only as oscillator anode, the oscillator circuit shown in Figure 12A is recommended for use with this tube type. In this circuit, the screen and the plate function as oscillator anode and are at ground potential for the oscillator frequency. The construction of the oscillator coil and the switching arrangement suggested in Figure 12 for use with the —SA7 are simpler than those often employed with other converter tube types. As a result, an appreciable saving in coil and circuit cost may be realized.

Description of the 6SA7-12SA7

As shown in Figure 11, the —SA7 consists of a heater, cathode, a grid (G_1) for the oscillator function, a screen (G_2 and G_4), a pair of collector plates mounted on the side rods of G_2, a signal grid (G_3), a suppressor (G_5), and a plate. The suppressor is connected to the shell, and the two grids forming the screen are connected together inside the tube. The presence of the suppressor increases the tube's plate resistance and, therefore, increases conversion gain. This action of the suppressor is especially important when the tube is operated with a plate-supply voltage as low as the screen voltage, as in an A.C.-D.C. receiver. An important function of the screen and collector plates is to minimize the effect of signal-grid voltage on the space charge near the cathode. The negative voltage on the signal grid repels electrons traveling toward the plate and turns some of these electrons back toward the cathode. Any of these electrons which reach the region near the cathode affect space-charge conditions in this region. It can be seen from Figure 11 that, because of the position of the signal-grid side rods with respect to the **collector plates, the collector plates intercept** most of the returning electrons. The electrons returned by the signal grid, therefore, have little effect on the space charge near the cathode. Because of the shielding effect of the screen, the electrostatic field of the signal grid also has little effect on the space charge. Thus, the collector plates and the screen serve to isolate the cathode space charge from the signal grid.



BAND	TOTAL TURNS (Nt)	CATHODE SECTION TURNS (Nk)
BROADCAST	65	6
MEDIUM	33	3
SHORT WAVE	7	1.5

FIG. 12

The result is that a change in signal-grid voltage produces little change in cathode current. Although a change in signal-grid voltage produces a change in plate current, this change is accompanied by an opposite and almost equal change in screen current. An R.F. voltage on the signal grid, therefore, produces little modulation of the electron current flowing in the cathode circuit. This feature is important because it is desirable that the impedance in the cathode circuit should produce little degeneration or regeneration of the signal-frequency input and intermediate-frequency output. Another important feature is that, because signal-grid voltage has little effect on the space charge near the cathode, changes in A.V.C. bias produce little change in oscillator transconductance and in the input capacitance of the No. 1 grid. There is, therefore, little detuning of the oscillator by A.V.C. bias.

Adjustment of the Oscillator Circuit

In the circuit of Figure 12A, the oscillator circuit provides peak plate current at the time when the oscillating voltage (E_k) on the cathode (with respect to ground) and the oscillating voltage (E_g) on the No. 1 grid are at their peak positive values. For maximum conversion transconductance, this peak value of plate current should be as large as possible. The effect on plate current of the positive voltage on the cathode is approximately the same as would be produced by an equal voltage, of negative sign, applied to the signal grid. Hence, the amplitude of oscillating voltage on the cathode limits the peak plate current. This amplitude should, therefore, be small, and the cathode tap should be placed as close to the ground end of the coil as satisfactory operation will permit.

During the negative portion of an oscillation cycle, the cathode may swing more negative than the signal grid. If this occurs, the signal grid will draw current unless the oscillator grid is sufficiently negative to cut off cathode current. This signal-grid current will develop a negative bias on the signal grid and may also cause a negative bias to be applied to the R.F. and I.F. stages through the A.V.C. system. As a result, sensitivity will be decreased. In order that signal-grid current should be prevented, the D.C. bias developed on the oscillator grid should be not less than its cut-off value.

Because the peak plate current depends on how far positive the oscillator grid swings with respect to cathode, it is desirable that this positive swing be as large as possible. It follows that the oscillator grid-leak resistance should be low. This resistance, however, should not be so low as to cause excessive damping of the tank circuit. It has been found, for operation in frequency bands lower than approximately 6 megacycles, that all these requirements are generally best satisfied when the oscillator circuit is adjusted to provide, with recommended values of plate and screen voltage, a value of E_k of approximately 2 volts peak, and an oscillator-grid current of 0.5 milliampere through a grid-leak resistance (R_g) of 20,000 ohms. With a 20,000-ohm grid-leak resistance, the rectification efficiency of the No. 1 grid is approximately 0.7. Since the bias on this grid is 10 volts (0.5 milliampere $\times$ 20,000 ohms), the peak value of E_g is approximately $10/0.7 = 14$ volts. With a 10-volt bias and a peak oscillator-grid voltage of 14 volts, the peak positive voltage of the oscillator grid with respect to cathode is 4 volts. If a higher value of R_g were used, the rectification efficiency would be higher; hence for the same value of E_g, the peak positive voltage of the oscillator grid with respect to cathode would be lower, and, therefore, the conversion transconductance would be lower.

In the low- and medium-frequency bands, the recommended oscillator conditions can be readily obtained. However, in the frequency band covering frequencies higher than approximately 6 megacycles, the tank-circuit impedance is generally so low that it is not easy to obtain these oscillator conditions, especially at the low-frequency end of the band. For optimum performance in this band, it is generally best to adjust the oscillator circuit for maximum conversion gain at the low-frequency end of the band. This method of adjustment has the disadvantage that when the oscillator is tuned to the high-frequency end of the band, E_k will be greater than 2 volts peak and conversion gain will, therefore, be less than the maximum obtainable. However, this disadvantage is usually outweighed by the considerations that overexcitation at the high-frequency end of the band improves frequency stability, that some decrease in conversion gain at the high end of the band can be tolerated because the R.F. tuned circuits have higher impedance at this end of the band, and that a good factor of safety is provided against the possibility of oscillation being stopped by a decrease in line voltage.

Maximum conversion gain at the low-frequency end of the high-frequency band is usually obtained by adjustment of the oscillator circuit to give a value of E_k of approximately 2 volts peak and an oscillator-grid current of 0.20 to 0.25 milliampere, with a grid leak of 20,000 ohms. Because the oscillator-grid bias voltage developed under these conditions is less than the cut-off value, some signal-grid current may be observed. In tests which have been made on typical receivers, this signal-grid current and the resultant signal-grid bias have been small and have caused no difficulty.

The use of a tube voltmeter connected across the cathode coil is suggested as the simplest method of obtaining approximately optimum oscillator adjustments in all bands. Since the impedance of the 6SA7 cathode circuit is never very high, the requirements with respect to voltmeter input conductance and capacitance are not very severe; a diode with a 100,000-ohm resistor and a microammeter would be satisfactory. Adjustment should be made for approximately 1.5 volts R.M.S. at the low-frequency end of each band; when push-button circuits are used, the cathode voltage for each push-button position should be in the range from approximately 1 volt to 3 volts R.M.S. for best results.

Space-charge coupling between the No. 1 grid and signal grid is present in the 6SA7, as in other converter types. This coupling is due to the effect of No. 1-grid voltage on the space charge in the region of the signal grid. An important effect of space-charge coupling is to cause a voltage of oscillator frequency (f_o) to appear across the signal-grid circuit. This voltage is 180 degrees out of phase with the No. 1-grid voltage when f_o is greater than the signal frequency (f_s). Thus, in the usual receiver in which f_o is greater than f_s, the effective modulation of the signal-grid-to-plate transconductance by a voltage of oscillator frequency is reduced; the value of conversion transconductance, which is proportional to this modulation, is also reduced.

In many converter tube types, the effects of space-charge coupling can be reduced by connecting a small condenser between No. 1 grid and signal grid. Although this scheme reduces the voltage of oscillator frequency that appears across the signal-grid circuit, it is not recommended for use in self-excited circuits using the 6SA7. Tests in receivers with such a condenser show that: (1) sensitivity at frequencies in the region of 18 megacycles is not greatly improved, (2) the tendency to flutter increases, (3) frequency stability decreases, and (4) pull-in between signal and oscillator circuits increases. Because these undesirable effects are produced in self-excited circuits by capacitance between the No. 1 grid and signal grid, the direct interelectrode capacitance between these grids has been made small. The base pins are arranged so that stray circuit capacitance between these grids can also be made small.

The conversion transconductance of the 6SA7 for the 250-volt operating conditions is approximately 450 micromhos; the tube's plate resistance is approximately 0.8 megohm. The conversion gain, which is the ratio of I.F. voltage across the plate load to R.F. voltage input, is given by:

$$\text{Conversion Gain} = \frac{g_c r_p R_L}{r_p + R_L}$$

where g_c is the conversion transconductance of the tube, r_p is the plate resistance of the tube, and R_L is the resonant impedance of the I.F. transformer measured across the primary terminals.

Operation of the —SA7 with a Separate Oscillator

The —SA7 may be used with a separate oscillator. A typical circuit for such operation is shown in Fig. 12E. With separate excitation, there is no oscillating voltage on the cathode. The amplitude of oscillation, therefore, can well be made higher than the amplitude used in self-excitation. As a result, somewhat higher conversion transconductance can be obtained with separate excitation than with self-excitation. When separate excitation is used, it may be desirable to neutralize the effects of space-charge coupling by connecting a small capacitance between the No. 1 grid and No. 3 grid, as shown in Figure 12E.

Suggested Circuits

Alternative oscillator connections for the circuit of Figure 12A are shown in Figures 12B and 12C. In Figure 12B, the tank current of the oscillator circuit flows through the cathode coil and contributes to grid-plate coupling; this contribution is not present in the circuit of Figure 12C. These circuits are recommended when the series padding condenser is to be adjustable. Figure 12B places this condenser at a small R.F. potential, and is satisfactory in most cases. Figure 12C permits grounding one side of the condenser. Typical waveband switching connections for the oscillator circuit are shown in Figure 12D. The optimum oscillator conditions for these circuits are approximately the same as those for Figure 12A.

Operation of the 6SA7 with Reduced Screen Voltages

In some applications, it may be desirable to operate the 6SA7 with a screen voltage less than 100 volts. Screen voltage can be made considerably less than 100 volts without excessive loss of conversion gain. For example, measurements on a typical receiver show that sensitivity is reduced only about 25 per cent when the screen voltage of the 6SA7 is reduced from 100 volts to 70 volts. When the 6SA7 is operated with self-excitation and reduced screen voltage, the adjustment of feed-back voltage on the cathode should be made so as to insure that oscillation will continue when line voltage is low.

Circuit Constant Considerations

(All Type Converters)

Grid Blocking Condenser

The oscillator grid blocking condenser has three major functions. These are: 1. it separates the A.C. and D.C. circuits so that the D.C. path (from grid to ground) may have a resistance of 25,000 to 50,000 ohms to develop grid bias and the A.C. circuit may be a nonconductor for D.C. which is desirable when we wish to use a padder condenser for alignment as is usually the case; 2. it stores up electrons during that portion of a cycle that the grid is driven positive and releases them during the time the grid is negative to maintain an almost constant negative grid bias; and 3. it reduces the reflected capacity within the tube to a smaller value in order that the tuning range of the band may be increased. This reduction in capacity is simply a matter of placing a condenser in series with the effective grid-cathode capacity of the tube (two capacities in series are of course equal to less than the smaller of the two).

The usual value of .00025 mfd. or 250 mmf. for this capacitor has been found too large for some all wave sets where it is necessary to secure the greatest tuning range on each band in order to reduce the number of bands required. Its value varies in different sets between 50 mmf. and 250 mmf. depending on the design of the oscillator coil. Unfortunately, when we reduce the value of this condenser we also reduce the percentage of total oscillator voltage (appearing across the tank circuit) that is applied to the control grid of the oscillator. Here again we must compromise between the tuning range and the developed oscillator voltage. When the oscillator refuses to oscillate on the low frequency end of the short wave band, increasing the capacity of this condenser will often correct the trouble at the cost of a slight sacrifice in tuning range on that band. Care must be taken to see that this added capacity does not cause parasitic oscillation on the high frequency end of the broadcast or long wave band.

Grid Leak Resistor

The grid leak resistor is fairly well fixed by oscillator grid bias requirements and should be of such value that:

1. The electrons stored in the condenser do not all leak off before the oscillator grid is again driven positive.
2. It does not provide too low a shunt resistance across the tank circuit so that ample A.C. voltage cannot be developed.
3. It will not cause motor boating or "super regeneration" due to the time constant of the resistor and condenser combination.

A value of 50,000 ohms is a very satisfactory compromise between these three considerations, and if trouble is encountered in a receiver having a lower value than this it is well to change this resistor to 50,000 ohms.

In pentagrid converter circuits having A.V.C. voltage applied to the tetrode control grid the oscillator grid leak resistor should be returned to the cathode rather than ground. If it is connected to the ground the oscillator grid bias will vary with the A.V.C. voltage because of the varying current through the cathode resistor.

Oscillator Anode Resistor

On all pentagrid converters except the —SA7 types, a 20,000 ohm resistor is recommended in series with the anode "B" voltage supply on A.C. receivers having 250 volt B supplies to prevent excess anode current should the oscillator stop oscillating or should the receiver be operated for any length of time at a frequency where the developed oscillator voltage is low. When the oscillator voltage is low the oscillator grid bias is low and the oscillator anode current is higher than normal—this may have an injurious effect on the tube if continued for any length of time. The 20,000 ohm resistor eliminates this trouble by dropping the anode voltage to a safe value during periods of excess anode current. Often the value of this resistance is increased and a condenser added to provide a hum filter to permit the oscillator anode voltage to be secured ahead of the regular power supply choke. The advantage of this is to make the oscillator anode voltage less dependent on the D.C. drop through the choke, which of course, varies with the plate current of the power tubes. This method of securing a more constant anode voltage is especially useful on the short wave band. The effect of a varying oscillator anode voltage on high frequencies is to tune out the signal until the plate current on the power tube drops to normal—which returns the anode voltage to normal which then tunes in the signal. This sequence of events makes the receiver "motorboat." Any hum appearing on the oscillator anode will modulate the oscillator, which in turn will modulate the signal, causing "tunable hum" which can, of course, be cured by proper filtering.

Voltage on Elements

As may be expected in such a complicated tube structure, the use of other than recommended voltages on the various elements will result in improper electron distribution patterns within the tube and will cause unsatisfactory circuit performance. For example, reducing the screen voltage will adversely affect oscillator performance and will make the plate current cut-off point lower, which will result in a loss in sensitivity and cause more "hiss" for a given input signal. A heater voltage 0.5 volts or more below normal may, in critical sets, cause the oscillator to stop oscillating on the low frequency end of the short wave band. Too low a tetrode control grid bias may cause poor performance on strong local signals.

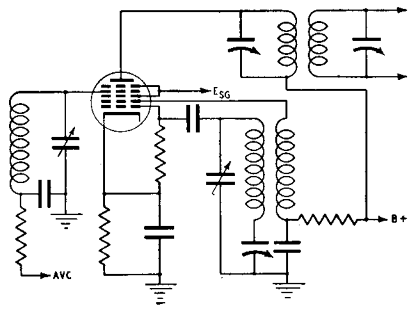


Fig. 13A

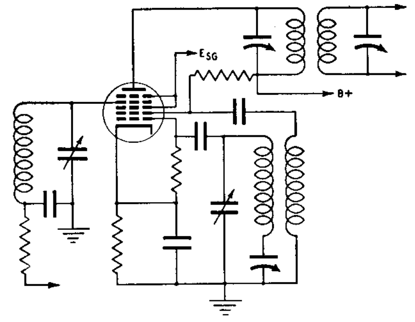


Fig. 13B

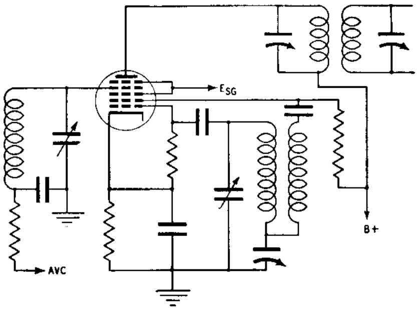


Fig. 13C

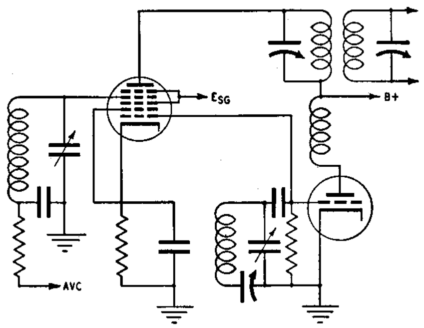


Fig. 13D

The total cathode current should not exceed 14 ma. maximum and will usually average about 11 ma.

Typical Circuits

Figure 13A indicates the average pentagrid converter circuit with A.V.C. voltage applied to the tetrode section control grid. Figure 10 is the same circuit with suppressor resistor and an anode hum filter added. The capacity of the electrolytic condenser will depend upon the amount of filtering required and is usually shunted with a paper condenser, and on short wave sets also with a mica condenser for more effective high frequency by-pass action.

To make wave band switching problems easier the shunt fed circuit of Figure 13B is often used. One end of the tickler is grounded and the other end is connected to the oscillator anode through a blocking condenser.

A method of maintaining more constant oscillator voltage over the band is shown in Figure 13C. In this circuit, the tickler coil is shunt fed and the low potential end is connected to ground through the padder condenser to increase the coupling on the low frequency end of the band.

In Figure 13D is shown a method sometimes used to increase the oscillator voltage—a separate tube is used as an oscillator and the oscillator grid is used as an injector grid. This provides a worthwhile gain in sensitivity, especially on the high frequency bands where the oscillator, because of increased grid circuit losses and insufficient coupling between oscillator grid and plate coils, develops a much smaller voltage. The usual oscillator anode is not used and is connected to the cathode, screen grid, or ground.

SUMMARY

It is the purpose of this section to summarize the characteristics of the various mixer tubes; and to compare their relative merits and demerits. The 6SA7 and 12SA7 types are omitted from this discussion except for the reference in Figure 15, inasmuch as their application and characteristics have been described in previous paragraphs.

Each type converter and mixer has inherent characteristics that differentiate it from the others. Considering the 6A8 and 6A8G as being representative of the first group of pentagrids, comprising the 2A7, 6A7, 1A6, 1C6, 1C7G and 1D7G, we now have the types 6A8, 6A8G, 6L7, 6J8G, and 6K8. The 6A8 and 6A8G are considered separately because of a difference in interelectrode capacitance that gives them slightly different characteristics in some applications. The material to be discussed compares characteristics of the several types and shows inherent advantages and limitations of each.

The chart Figure 14 was prepared to show the constructions used in the several types. The 6A8 and 6A8G, normally known as five grid tubes, are shown as they are made, with four grids and a pair of side rods. The side rods are the oscillator anode.

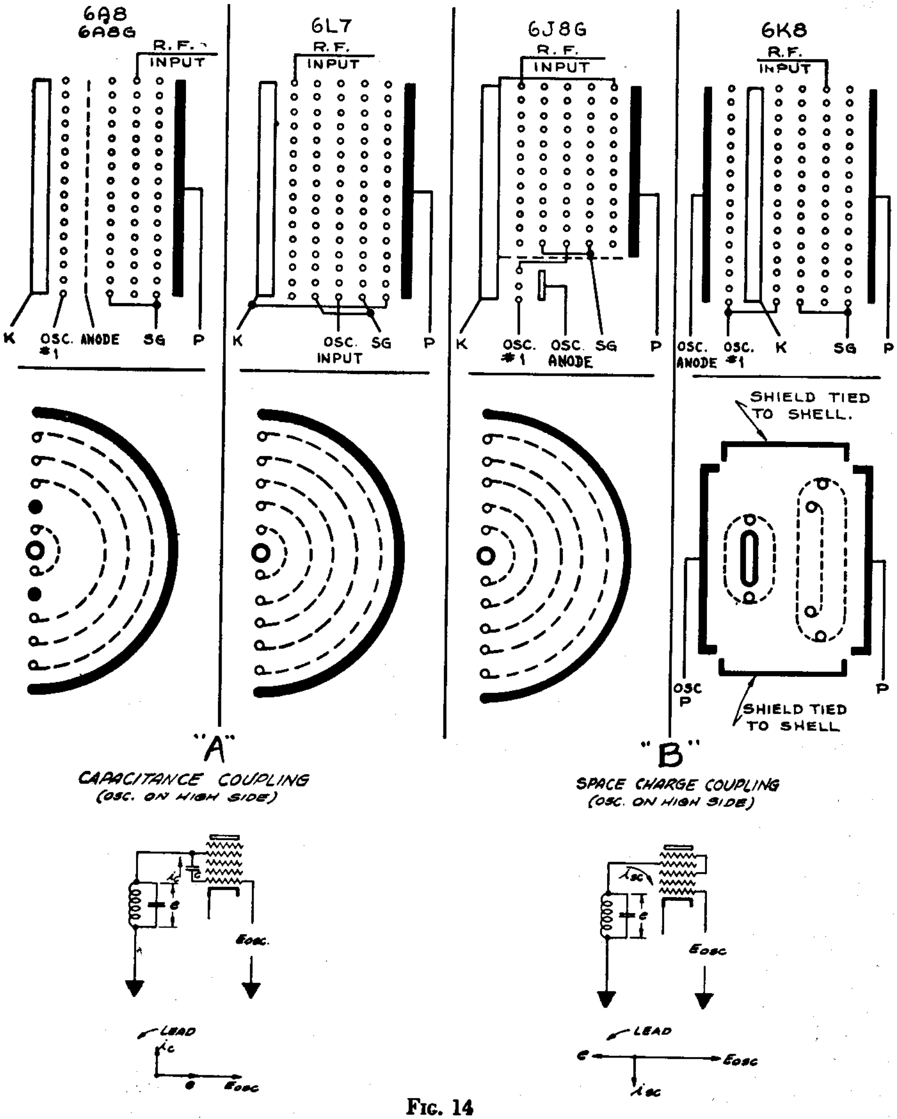


FIG. 14

The 6L7G construction, designed for mixer service, uses five grids. The No. 1 grid is the R.F. input grid, the No. 2 and No. 4 grids are the screen, the No. 3 grid the injector grid, and the No. 5 grid the suppressor.

The 6J8G construction is identical to that of the 6L7 except that it has an additional triode section mounted at the bottom of the common cathode. The grid of the triode is tied internally to the No. 3 grid of the heptode.

The 6K8 is of an entirely new construction best shown by the bottom sketch at the right of the page. A single flat cathode is used with a common No. 1 grid for the oscillator and hexode section. A flat plate is used for both the oscillator and hexode. The screen and R.F. input grids are positioned approximately as shown on the sketch. The shields as shown are placed to give a suppressor action to the hexode section thus raising its plate resistance and making possible the use of the screen and plate at the same potential.

The ability of the tube to develop a current at an intermediate frequency is given by the conversion conductance, which by definition is the ratio of an incremental change in intermediate frequency current to the incremental change in R.F. signal voltage that produces the current. This conductance in micromhos is published on all converters and its use to calculate stage gain is analogous to the use of mutual with R.F. amplifier pentodes. The gain equation for a single tuned load is:

$$\text{Gain} = \frac{G_c\, R_p\, R_L}{R_p + R_L}$$

The above equation involves only one other tube characteristic, and that is plate resistance. Published values of plate resistance and conversion conductance can therefore be used to calculate stage gain.

In application there are certain phenomena that alter characteristics or circuit parameters and the results are a gain value somewhat different than calculated from published data. These unpublished characteristics are essential in selecting a tube for a particular service.

Assuming the use of rated voltages and oscillator grid current there are in general the following effects that occur in the several tubes:

1. Degeneration at the R.F. signal frequency.
2. D.C. current flow in the R.F. signal grid circuit that upsets operating conditions.
3. Oscillator voltage appears in circuits other than those associated with the oscillator. This voltage may be in phase or out of phase with the normal oscillator voltage and the resulting plate current at oscillator frequency may be increased or decreased. As conversion conductance and gain are functions of the plate current, the measured gain is different from that calculated.
4. Negative or positive loading in the signal grid circuit affects the antenna or interstage gain driving the converter tube. Calculations are often upset because of this phenomenon.

To facilitate comparison of the five converter and mixer tubes, the chart Figure 15 was prepared. It lists eight separate phenomena found in the several tubes. In addition, a tabulation of the more important interelectrode capacitances and of the two characteristics, plate resistance and conversion conductance, is given.

CONVERTER COMPARISON

CHARACTERISTICS	6A8	6A8G	6SA7	6J8G	6K8	6L7
CAPACITY COUPLING OSCILLATOR TO SIGNAL GRID	YES	YES	YES	YES	YES	YES
SPACE CHARGE COUPLING OSC. TO SIGNAL GRID	YES	YES	NO	NO	YES	NO
CAPACITY COUPLING FROM ANODE TO SIGNAL GRID	YES	YES	NO	NO	NO	——
DEGENERATION AT R.F. SIGNAL GRID TO PLATE CAPACITY	NEGL.	YES	NEGL.	NEGL.	NEGL.	NEGL
OSCILLATING VOLTAGE IN SIGNAL GRID DUE TO G-P CAPACITY	NEGL.	YES	NEGL.	NEGL.	NEGL.	NEGL
DIRECT CURRENT IN SIGNAL GRID DUE TO TRANSIT TIME	NO	NO	NO	YES	NO	YES
DEGENERATION DUE TO NEGATIVE S_M SIGNAL GRID TO ANODE	YES	YES	NO	NO	NO	NO
INPUT LOADING AT HIGH FREQUENCIES	NEG.	NEG.	NEG.	POS.	NEG.	POS.
CAPACITY R.F GRID TO PLATE	.03	0.3	.013	.01	.03	.0005
CAPACITY R F. GRID TO ALL	12.5	8.5	9.5	4 7	6.6	8.5
CAPACITY PLATE TO ALL	12.5	9.0	12.0	8.7	3.5	12.5
CAPACITY OSC GRID TO ALL	6.5	7.0	4.4	12.2	6.0	11.5
CAPACITY OSC. PLATE TO ALL	5.0	5.5	——	5.7	3.2	——
PLATE RESISTANCE (MEGOHMS)	.36	.36	0.8	4.0	0.6	1.0+
CONVERSION CONDUCTANCE	500	500	450	290	350	350

NEG.= NEGATIVE NEGL.= NEGLIGIBLE

FIG. 15

The first phenomenon, capacity coupling from oscillator to signal grid, is experienced with all tubes. The capacitance, not shown, is approximately .1 mmfd. for each type. The result of the coupling is mainly that oscillator voltage appears across the signal grid tuned circuit. At extremely high frequencies the impedance of the signal grid circuit to the oscillator frequency is quite high, and the magnitude of the voltage becomes high enough to over-ride the bias and cause grid current. If the voltage does not produce grid current, the effect is either to increase or decrease the conversion conductance and conversion gain. If the voltage is sufficient to cause grid current to flow, the D.C. current upsets the operating conditions, with attendant loss in sensitivity.

The oscillator voltage in the signal grid return, as a result of capacity coupling, is in phase with the normal oscillator voltage if the oscillator is on the high side of the resonant frequency of the tuned circuit in the signal grid circuit. The phase can be traced easily and is shown by A of Figure 14. The oscillator voltage E_{osc} is represented as the vector E_{osc} in the vector diagram. The current i_c through the capacitance between electrodes is practically ninety degrees out of phase with the oscillator voltage because of the high reactance of the interelectrode capacitance in comparison with the reactance of the tuning condenser in the signal grid circuit. The current flow leads in a capacitive reactance and the vector i_c is drawn leading by ninety degrees. The phase of the resulting voltage across the tuned circuit is shifted an additional ninety degrees and since the oscillator is on the high side, the reactance is capacitive, the voltage lags by ninety degrees, and the resulting voltage e is in phase with the oscillator. The result is a higher effective conversion conductance and higher gain. With the oscillator grid on the low side the tuned circuit in the signal grid return would be inductive and the resulting voltage would be out of phase. A lower conversion conductance and gain results. The magnitude of the effect is greatest at high frequencies where the frequency separation between the oscillator and signal grid circuit is small.

The interelectrode capacitance is offset in the case of the 6A8, 6A8G, and 6K8 by the space charge coupling. Space charge coupling is coupling between the oscillator and signal grid circuits because of the change in space charge around the signal grid by the oscillator voltage on the No. 1 grid. On negative swings of the oscillator grid, in the above types, the cathode current is cut off. On positive swings a cloud of electrons forms in the region of the signal grid. This cloud of electrons, or space charge, appearing at oscillator frequency, causes a displacement current to flow in the signal grid circuit and a voltage results across the grid return whose magnitude and phase depend upon the constants of the tuned circuit. The space cloud, being a negative charge, drives electrons out through the signal grid circuit. The current flow is therefore 180° out of phase with the current flow due to the interelectrode capacitance and in types having space charge coupling the capacitance between the two grids partially offsets the space charge coupling. By adding additional capacitance the space charge can be neutralized.

The voltage in the signal grid circuit due to space charge coupling is out of phase with the oscillator voltage when the oscillator is on the high side and in phase when it is on the low side. The effect of this voltage in the signal grid circuit is the same as the voltage resulting from capacity coupling.

The phase of the oscillator voltage in the signal grid circuit as a result of space charge coupling is shown by the diagram B of Figure 14. The oscillator voltage is drawn as E_{osc} and the current flow i_{sc} is drawn lagging by ninety degrees. The current is 180° out of phase with the capacitive current i_c in "A." With the oscillator on the high side, the voltage e resulting from i_{sc} lags by ninety degrees because of the capacitive reactance of the signal grid circuit. The resulting voltage e is out of phase with the normal oscillator voltage E_{osc} with the oscillator on the high side. By shifting the oscillator to the low side the voltage will be in phase.

The space charge coupling can be neutralized with a capacitance, and its magnitude is conveniently expressed in the value of the capacitance required to obtain neutralization. Since the interelectrode capacitance is approximately .1 mmfd. it can be seen that the space charge is the major effect in the 6A8, 6A8G, and 6K8. Also, since the voltage produces a loss in sensitivity when the oscillator is on the conventional high side it is imperative that neutralization be made.

It is customary to neutralize the space charge by adding a "gimmick" between the stators of the signal grid and oscillator tuning condensers. A piece of wire with low loss insulation is used. One end is soldered to the lug on the stator of either condenser and the other end is looped through the eyelet in the other lug.

The capacitance can be adjusted to give maximum sensitivity or to give minimum oscillator voltage across the signal grid tuned circuit. In most applications with no neutralization at frequencies of fifteen megacycles the voltage in the signal grid coil will cause the flow of grid current. At extreme high frequencies, such as fifty megacycles, it is difficult to neutralize sufficiently to eliminate grid current. With such a condition it is recommended that the converter not be controlled by the A.V.C. A maximum grid return resistance of 100,000 ohms is recommended. The use of the 6L7 or 6J8G having no space charge coupling is no solution to the problem because these tubes have a D.C. current flowing in the signal grid as a result of a peculiar transit time effect. This phenomenon will be explained in detail later in this text. In a typical commercial receiver designed to tune to 70 megacycles data were taken with a 6L7 as a mixer and the 6K8 as a converter. It was found that with either tube a current of several microamperes was measured in the grid return. To offset the effect, the tube was run with no A.V.C. with a .1 megohm filtering resistor for isolation. Satisfactory operation was experienced with either tube. The 6K8 was somewhat difficult to neutralize perfectly but neutralization sufficient to obtain comparable sensitivity to the 6L7 was not at all difficult. In using "gimmicks" at high frequencies the wire and its insulation must be of the low loss variety. At 50 megacycles the loss with a poor "gimmick" wire can easily offset the advantage of neutralization. A "gimmick" found to be satisfactory was made out of enameled wire using only the enamel for insulation.

The loss in sensitivity due to space charge coupling does not amount to more than two or three db unless the voltage is of sufficient magnitude to drive into grid current regions. Any new design of a receiver should be checked to determine the voltage in the signal grid circuit through either capacitance or space charge coupling. Preferably the voltage should be measured with a vacuum tube voltmeter but not having that a microammeter can be inserted in the grid return to determine if the grid is being driven positive.

Oscillator voltage can be coupled capacitively into the signal grid circuit in two additional ways. That is through the anode to signal grid capacitance and through the signal grid to plate capacitance. In the former case, the type 6A8 and 6A8G have an anode to signal grid capacitance of approximately .1 mmfd. and oscillator voltage is coupled back by virtue of the fact that the anode load contains considerable oscillator voltage. Since the voltage in the anode winding is approximately 180° out of phase with the voltage in the grid coil the voltage coupled into the signal grid circuit is of the same phase as space charge coupled voltage. Neutralization of the space charge in the conventional methods also neutralizes this voltage. The effect is negligible in the 6J8G and 6K8 because of their lower interelectrode capacitance. The anode to signal grid capacitance with these tubes is approximately .01 mmfd.

Another effect of the high grid to plate capacitance of the 6A8G that is of more importance is degeneration to the signal frequency. The capacitive plate load of the I.F. transformer fulfills the requirement for degeneration. This is evaluated most easily by measuring the input conductance or by measuring the change in coil Q of a tuned circuit in the grid return as a result of loading with the input conductance. The conductance can be calculated from the change in Q. Since the results of the degeneration are loss in gain in the driver and since gain is usually calculated in terms of the coil Q the actual loss in Q is of more importance than the input conductance.

The degeneration is greatest at frequencies near the I.F. frequency because the reactance in the plate load increases rapidly as the I.F. frequency is approached. With a 456 kc. intermediate the greatest degeneration takes place on the low frequency end of the broadcast band. With the conventional I.F. coil at this frequency the I.F. tuning condenser is approximately 100 mmfd. At 550 kc. the effective capacitance is of the order of 35 mmfd. Calculations show that with these values a reflected resistance of approximately 100,000 ohms is obtained with the 6A8G. The equation used for calculating the loading effect due to degeneration is as follows:

$$R_g = \frac{C}{S_m C_{g-p}}$$

Where R_g = Resistance component of input impedance.
S_m = Mutual conductance from signal grid to plate.
C = Effective capacitance of the load.
C_{g-p} = Grid to plate capacitance of the tube.

The mutual conductance for most pentagrids with the oscillator section oscillating is approximately 700 micromhos.

The G-P capacitance of all types except the 6A8G is low enough to be practically negligible. The 6A8G, shielded, has a capacitance of approximately .3 mmfd. Unshielded the value will be somewhat higher and will be influenced by other factors such as position of grid leads, etc. In general .6 mmfd. can be considered an average value.

The effective capacitance of the load depends on the frequency under consideration. At high frequencies it is approximately the capacitance required to tune the I.F. to the intermediate frequency. At lower frequencies, approaching the I.F. frequency, the effective capacitance is much lower. For example at the low end of the broadcast band with a 465 kc. intermediate frequency it may be as low as one-third the capacitance of the padder. The value should be estimated or calculated for the frequency under consideration.

The equation for input resistance shows the need of a large condenser for the I.F. primary. Coils designed with a high inductance primary to give a high tuned impedance will produce more degeneration because of the lower value of padder capacitance required. This practice is satisfactory with tubes having a low grid to plate capacitance.

As was mentioned previously, the 6J8G and 6L7 at high frequencies have a D.C. current flow in the signal grid circuit that upsets operating conditions and causes a loss in gain. Electrons that are accelerated through the No. 2 screen grid approach the No. 3 injector grid. At high frequencies where the time of transit between cathode and No. 3 grid is an appreciable portion of the period of oscillation, electrons accelerated by the No. 3 grid on its positive swings reach the grid at a time when it is going negative and are repelled and turned back toward the screen. On the way back they are accelerated by the positive potential on the screen and by the increasing negative potential of the No. 3 grid. Many of these returning electrons reach the screen and are drawn off as additional screen current. Some of the electrons, however, pass very close to the screen and are accelerated toward the No. 1 grid at high velocity. Many of the electrons obtain sufficient energy to overcome the negative potential of the No. 1 grid and flow in the external No. 1 grid circuit. This flow of current is a D.C. current flow in a direction such that the drop in the external resistance increases the bias. If the tube is operated from the A.V.C. string as in the conventional case, the total return to ground is of the order of two megohms. A current of several microamperes increases the bias sufficiently to cause an appreciable loss in gain. The current can be eliminated for frequencies up to approximately eighteen megacycles by increasing the bias. The 6L7, for example, is rated with —6 volts bias and 150 volts on the screen. The additional screen voltage offsets the lowering of the gain by the high bias. The limit to the bias increase is the maximum screen dissipation. 150 volts is the maximum allowable screen voltage for the 6L7.

For frequencies above eighteen megacycles where it is not possible to increase the bias sufficient to overcome the grid current the only alternative is to eliminate the high grid return resistance by using the converter without A.V.C.

The current resulting from transit time is a direct current and can be measured in the grid return with the tuned circuit shorted. It is the effect of this current through the high resistance A.V.C. return that causes trouble in the receiver.

The 6J8G and 6K8 are designed with a higher oscillator mutual than the earlier 6A8 and 6A8G. The high mutual gives greater oscillator amplitude at high frequencies where adverse oscillator conditions are found. A comparison of oscillator characteristics in terms of the mutual conductance of the oscillator section at zero bias and 100 volts on the plate is given by the following tabulation.

Type	*Oscillator Transconductance in Micromhos*
6A8—6A8G	1,000
6J8G	1,700
6K8	3,000

The high mutual conductance of the oscillator section of the 6K8 gives satisfactory oscillator performance at 100 volts. The 6K8 can therefore be operated efficiently with 100 volts on the plate, screen and oscillator anode. This is of decided advantage in A.C.-D.C. receivers.

The chief disadvantages of the 6A8 and 6A8G have been instability of the oscillator, and frequency shift with terminal voltage variation. The construction of the 6A8 is such that the oscillator mutual is very much a function of the signal grid bias, and anode and screen voltage. In operation at high frequencies with power supplies having poor regulation characteristics, motorboating often results. The phenomenon occurs as follows: As the signal is tuned in, the audio signal causes an increase in current drain which changes the "B" voltage. The resulting voltage shift detunes the oscillator, the voltage returns to normal, the oscillator retunes to the signal and the cycle repeats iself.

Instability with the 6A8 and 6A8G results mainly because of the changes in oscillator mutual with signal grid bias. Increasing the bias from –3 volts to cut-off practically doubles the oscillator mutual. The increased mutual increases the oscillator amplitude and shifts the frequency. When operated on the A.V.C. string the 6A8 and 6A8G sometimes motorboat as a result of the time constant in the grid return circuits.

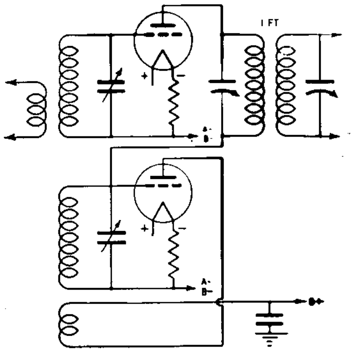
Another effect is that with severe fading the A.V.C. voltage fluctuates with the signal, detuning the oscillator, and high distortion results because the signal is not properly tuned to resonance at all times. The new tubes, the 6J8G and 6K8, have been designed to minimize this effect. The increase in oscillator mutual on the 6A8 and 6A8G for a bias increase from –3 volts to cut-off is approximately one hundred percent. For a similar increase in bias on the 6K8 the oscillator mutual increases approximately five percent. The oscillator mutual of the 6J8G is independent of signal grid bias.

Another factor influencing coupling and instability is negative mutual conductance from the signal grid to the oscillator anode. The characteristics of the 6A8 and 6A8G are such that an increase in negative bias on the signal grid causes an increase in anode current. This constitutes a negative mutual conductance, and under normal conditions this mutual is of the order of 400 micromhos. This effect is practically eliminated in the 6K8 construction. Measurements show a value of approximately twenty-five micromhos. The 6J8G with its separate triode has negligible coupling resulting from this characteristic.

Conclusion

The omission of the battery tube converters and the converters of the Loktal family in this article is not due to any lack of importance of these tube types. In any summary of this kind the difficulty is not in finding adequate material, but in deciding what material must be sacrificed to meet the space requirements of the publication.

It is the feeling of your editors that the descriptions and characteristics of the tubes presented herein will give the service engineer a working knowledge of the principles involved, and that armed with this information, the application principles of other converter tube types will be apparent. Research continues in the great laboratories of the major tube companies, and further developments of the art can be expected.



Lecault "Ultradyne"

MISCELLANEOUS CIRCUITS

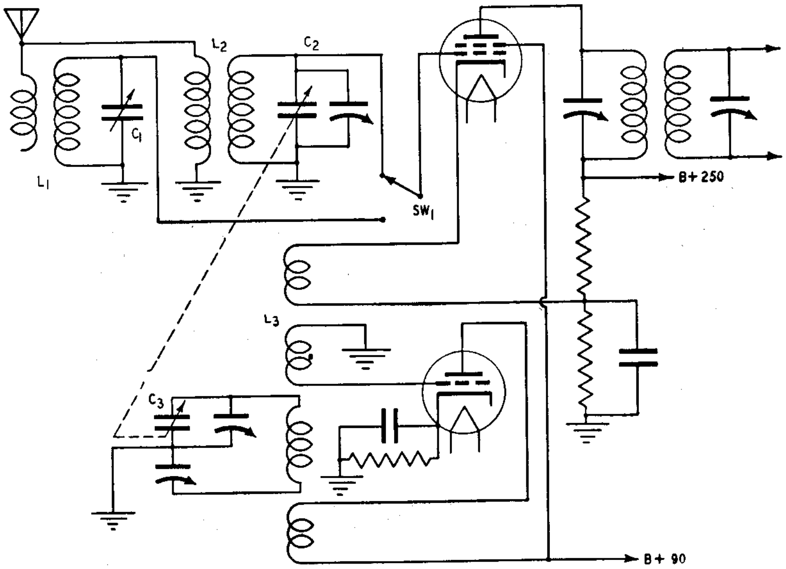
This section shows several detector oscillator circuits of especial interest either because they illustrate some special application of the features discussed in the preceding text, because of their unconventional design, or because they represent a new trend in radio construction.

Converter Circuit, Silver Marshall Model R

This circuit illustrates several points discussed in the text. The oscillator uses the Meissner circuit with an added pickup coil for cathode injection of the oscillator voltage.

On the broadcast band the oscillator operates at a higher frequency than the signal. On the police band the oscillator operates on the low side. Switching between broadcast and police bands is accomplished by means of the simple single pole-double throw switch SW_1.

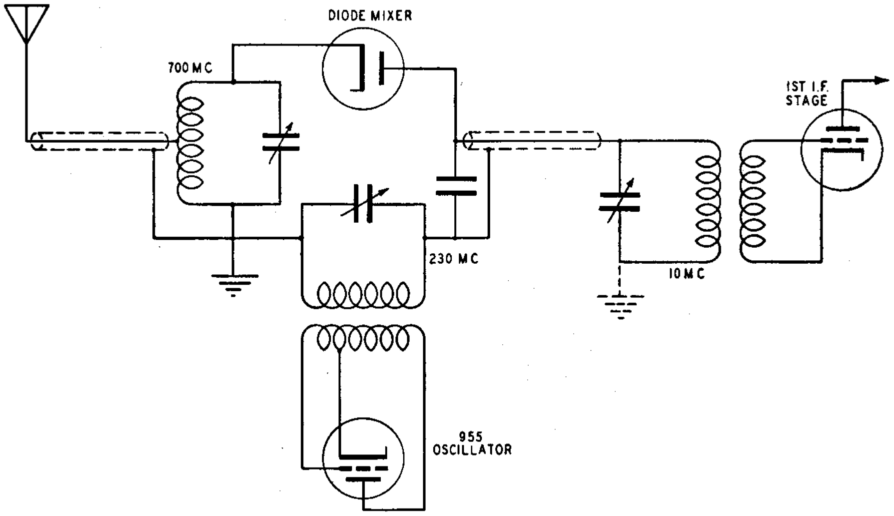
The police band antenna tuning condenser C1 is not ganged, but is brought to a separate knob on the front panel. On the police band this receiver has two tuning controls.



Silver Marshall Model R

Lecault "Ultradyne"

A circuit which will bring back fond memories to the old timers is the Lecault "Ultradyne." Note that the plate potential for the mixer is A.C. derived by returning the low side of the primary I.F. transformer winding to the grid of



COURTESY OF ELECTRONICS

Ultra High-Frequency Diode Converter

the oscillator. This could be considered as one of the earliest examples of electron oscillator-mixer coupling.

Diode Converter

For those interested in the unusual, the converter circuit of the 700 Mc ultra-ultra short wave receiver developed in collaboration between the Civil Aeronautics Authority and the Massachusetts Institute of Technology is shown here. There are three very unusual features about this circuit.

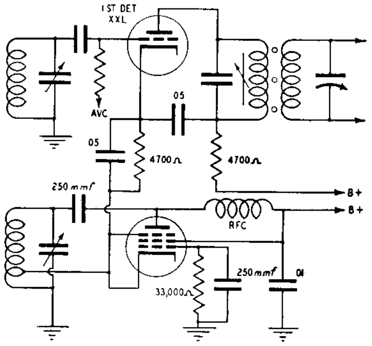
1. The 1st detector is a diode.
2. The third harmonic of the oscillator is used to provide the required beat frequency.
3. The oscillator operates on the low frequency side. The oscillator operates at 230 Mc. The third harmonic of this is 690 Mc, which beating against the 700 Mc signal gives the 10 Mc I.F.

New Philco Converter

Diagram (Simplified) showing the triode first detector-oscillator circuit as used in the 1941 Philco Models, 41-608 and 41-609.

Note the Condenser between the cathode of the detector and the B+ lead of the first I.F. transformer, which prevents feed-back through the cathode circuit; also the Hartley Oscillator with grounded grid, and tuned plate load circuit.

The XXL tube is a new type designed by Philco engineers especially for this circuit. Advantages claimed are improved signal-to-noise ratio and reduced cross-modulation.



DATA COURTESY OF PHILCO