HOME STUDY COURSE IN ELECTRONICS — II

Simple Radio Receivers

Limitations of a diode or "crystal" set — amplified crystal sets and audio amplifier stages — active detectors and their operation — reaction or regeneration — two stage receivers with transformer and resistance-capacitance coupling — additional audio stages — output power considerations — overload and gain or volume control.

Having used the crystal receiver to learn some of the basic facts about radio reception, we are now in a position to discuss simple transistor and valve receivers.

As we saw in the last chapter, a crystal set is a very useful and interesting device. It is simple to make, it costs nothing to operate and it demonstrates, in a practical way, many important radio principles.

For all that, however, a crystal set has very serious limitations. The only energy available to it is the radio frequency energy picked up by the aerial and earth system from the desired transmitter. This is selected, demodulated and made available to the earphones as an audible signal.

As the distance between receiver and transmitter is increased, the energy available becomes less and less until, at a distance which may be as little as 25 miles, the signal becomes inaudible. Only in very exceptional circumstances are the signals from a crystal set ever strong enough to operate a loudspeaker.

Yet another serious problem is that of poor selectivity, a crystal set often being unable to separate the wanted signal clearly from other strong signals in the receiving area.

In the face of such limitations, it is not surprising that engineers, very early, sought to improve the performance of crystal receivers or, alternatively, to supplant them altogether. Nor is it surprising that they have been relegated, in this modern age, to the role of a "beginner's set."

As you have probably guessed, the answer was found in a device we have already discussed — the thermionic valve. If you've forgotten this earlier discussion, we suggest you turn back to chapter 6.

Strangely enough, the very first valve receivers were no more ambitious in their performance than crystal sets — in fact, there were plenty of early radio operators of the day who claimed that they were not as good.

These early valve receivers were just like crystal sets, in fact, except that they used a diode in place of the metallic crystal and "catswhisker" detector.

As we explained in the earlier chapter, diodes exhibit the same rectifying properties as a crystal, being able to pass current only in one direction. They make signals audible in the phones by the same process as explained for a crystal set.

The main advantage of the valve or thermionic diode was that it needed no critical adjustment. This advantage was very real in a day when the surface of crystal diodes had to be probed with the "catswhisker" contact to discover a sensitive spot.

Against this, of course, the diode valve needed a filament battery, which was something of a nuisance. Hence the arguments of the day as to which was the better proposition.

The development of the triode valve settled such arguments, because it brought with it the ability to amplify the incoming signals. Instead of being utilised to operate the phones directly, the signals were applied to the grid to control plate current flowing from a B-battery. The resultant and larger plate current excursions, dependent on the grid signal, produced much louder signals in the phones.

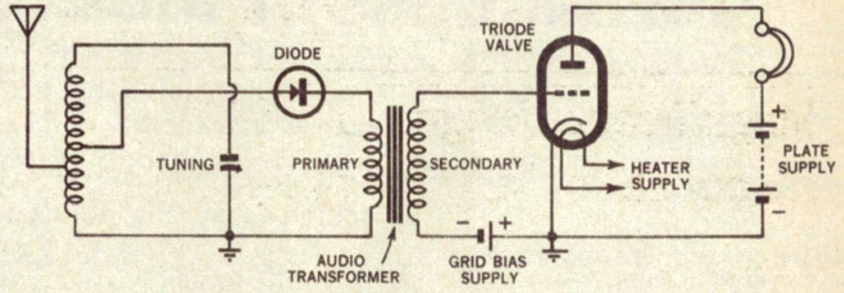
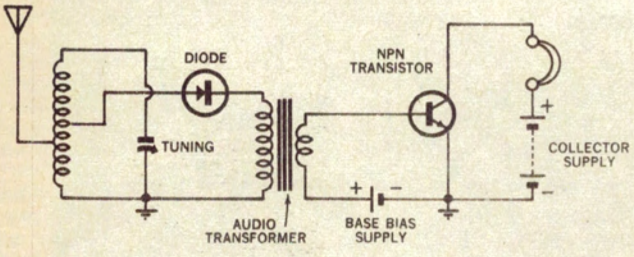
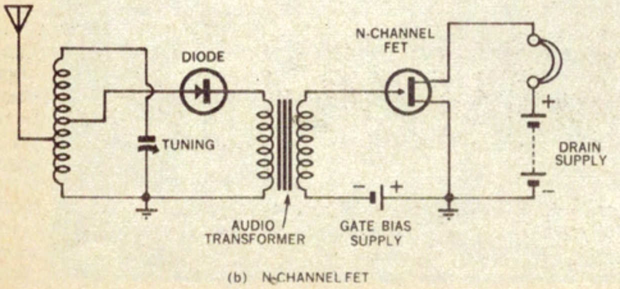


Figure 1: An early type of receiver which used a triode valve to amplify the demodulated signals produced by a diode detector circuit.



(a) NPN BIPOLAR TRANSISTOR



(b) N-CHANNEL FET

Figure 2: Bipolar Transistor and FET versions of the receiver in figure 1, showing the similarities between the three types of device.

Figure 1 shows a type of receiver which was quite popular in its day — the combination of what is virtually a crystal or diode receiver and a triode amplifier stage.

The incoming signal is selected by the tuning circuit and applied to the detector. This later may be either a semiconductor diode or a thermionic diode, which suppresses half the incoming carrier and delivers to its output circuit what we described, in the last chapter, as a series of unidirectional pulses proportional in strength at each instant to the modulated carrier.

Instead of being passed directly through the phones, to produce an audible sound, these pulses are passed through the primary winding of an audio transformer. Perhaps we should pause here to explain these terms, at least in brief.

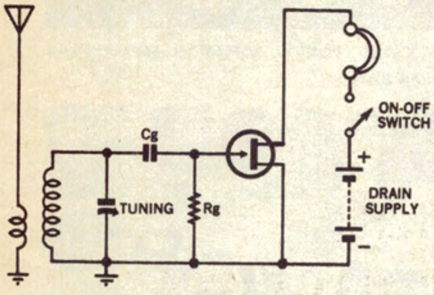
The word "audio" comes from the Latin verb "to hear" and is used in electronics to describe any circuit or component which handles signals at a frequency within or adjacent to the range of sound frequencies. Thus an audio amplifier stage is one which amplifies signals at audio frequencies.

By the same token, an audio transformer is one which is designed to handle, or transfer, or couple signals at audio frequencies.

The principles of transformers generally have been discussed in an earlier chapter and obviously cannot be repeated here. An audio transformer is usually wound on a core made up from iron laminations. It normally has two windings, and each may comprise many thousands of turns of fine wire.

The input signal is fed to the winding normally referred to as the primary, while signal is taken for the following circuit from the secondary.

It is possible to secure a step-up in signal voltage from a transformer by winding more turns on the secondary than on the primary. Old-style transformers, which often come into the hands of experimenters, typically have a turns ratio of 1 to 3 or 1 to 5 from the primary winding to the total secondary winding. More modern transformers intended for transistor circuits may have less turns on the secondary than on the primary. This gives a step-down in voltage, but a step-up in current.



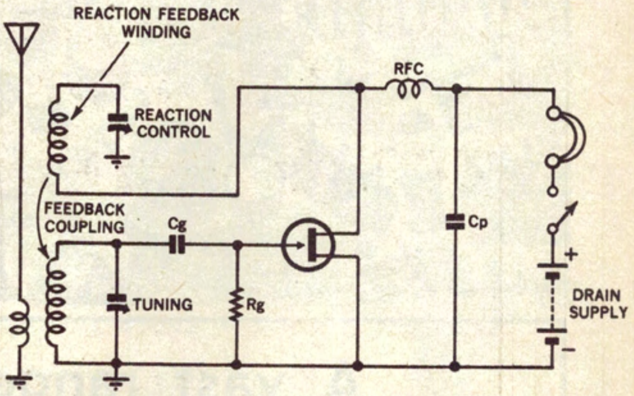


Figure 3 (above): The basic circuit of an active detector circuit using a FET. Figure 4 (right): The way in which the performance may be improved by applying positive feedback or "reaction".

Now back to figure 1.

The signal currents from the diode detector flow through the primary winding of the transformer. Now the transformer is no more able to respond to individual unidirectional carrier pulses than the earphones referred to in the last chapter.

However, the current through the primary winding, and therefore the magnetic field it produces in the core, tends to merge into a pattern, which follows the rise and fall of the incoming carrier with modulation.

The changing magnetic field, due to current through the primary winding, induces current in the secondary winding and a corresponding signal voltage between its two ends.

These two ends are connected respectively to the grid and cathode circuit of a triode amplifier valve and the audio voltage between them therefore constitutes a grid signal controlling the flow of electrons through the valve from cathode to plate.

For the reasons explained in chapter 6, a bias voltage is normally provided to keep the grid slightly negative with respect to filament, the optimum bias depending on the type of valve and its other operating conditions. When the incoming signal carries the grid more negative than the standing bias, current through the valve is reduced. Conversely, when the signal makes the grid less negative, current through the valve is increased.

This ever-changing current, flowing from the High Tension or B-battery through the phones produces much more output from the phones than could the small current pulses available from the detector.

Figure 2 shows the circuits for receivers which are the transistor and FET counterparts of that in figure 1. In (a) an NPN bipolar transistor is used in place of the triode valve, and is supplied with base bias voltage and collector supply voltage with the polarities shown. The audio transformer used with the transistor usually has a step-down primary-secondary turns ratio rather than a step-up ratio, because as we saw in chapter 7 transistors have a relatively low input resistance and are current amplifiers rather than voltage amplifiers.

While fewer turns in the secondary of the transformer than in the primary give a step-down voltage ratio, as mentioned earlier it actually gives a step-up current ratio, and this suits the transistor perfectly. It also "matches" correctly the relatively high-resistance detector circuit in the primary and the low resistance transistor input circuit connected to the secondary.

Figure 2(b) shows how an N-channel FET would be used in a similar type of simple receiver. The circuit is very similar to those for the valve and bipolar transistor versions, as may be seen. Note that the polarity of the gate bias supply is opposite in polarity to the drain supply, pointing to the similarity between FETs and thermionic valves.

Simple receivers along the lines of figures 1 and 2 are capable of substantially better performance than an ordinary crystal set. Sound volume from near-by stations is increased. Range is effectively improved because signals which might otherwise be inaudible are amplified to listenable strength.

Even the effective selectivity can be improved because amplification from the audio stage allows the tappings on the coil to be moved closer to the earthed end, than would otherwise be the case. Selectivity is improved as a result.

Still further improvement would be possible by providing two or even three audio stages after the crystal detector. In practice, however, this is seldom done because better overall performance can be obtained by following different circuit principles, at least for simple beginner's type receivers.

What is involved, primarily, is the elimination of the crystal or diode detector and the substitution of an "active" detector stage using a transistor, FET or valve.

Figure 3 shows the basic circuit for a simple receiver using an N-channel FET as an active detector.

To understand its operation, one must remember that the gate and channel regions of a FET are separated by a P-N junction which is virtually identical with the P-N junction of a normal semiconductor diode. Normally, the junction of the FET is reverse-biased, and its depletion layer is used to control the source-drain current flowing through the channel. But if the gate-channel junction is forward biased, it will itself conduct current, just like a normal diode.

Now in the circuit of figure 3, the input signal selected by the tuned circuit is fed to the gate of the FET through a coupling capacitor marked "Cg" (this kind of notation is often used to facilitate discussion of electronic circuits, by the way; thus "Cg" is short for "capacitor connected to the gate", and so on). In a typical circuit, the value of the capacitor might be between about 100pF and 470pF. There is no fixed reverse bias on the gate of the FET, so that the gate-channel junction will tend to be forward biased during each positive half-cycle of the RF input signal, and reverse biased during the negative half-cycles.

During the half-cycles in which the junction is forward biased, it conducts current. The pulses of current which flow in this fashion tend to charge up capacitor Cg to the peak value of the RF voltage developed across the tuned circuit. There is thus built up across the capacitor a DC voltage whose size is proportional to the peak value of the RF input voltage, and whose polarity is such that it tends to reverse-bias the gate-channel junction of the FET — ie, in this case with negative connected to the gate.

The gate-channel junction of the FET naturally cannot conduct current during the half-cycles of the RF input voltage which tend to swing it in the direction of increased reverse bias. In fact during these half-cycles the charge on capacitor Cg tends to "leak away" through resistor Rg. The discharge current flows down through Rg and back up to the capacitor via the low resistance of the tuned circuit coil.

Far from being undesirable, however, this discharging action is actually necessary if the circuit is to be used to detect or demodulate any audio or other information impressed on the RF signal. Without resistor Rg, the charge on Cg would simply rise to a value corresponding to the highest positive peak of the input RF voltage, and stay at this value. Even if the RF signal were then completely removed, it would tend to remain at this value, dropping only very slowly due to leakage through the FET and through the dielectric of Cg itself.

In a nutshell, the "gate leak" resistor Rg is necessary to ensure that the charge developed by capacitor Cg due to gate current flow can leak away fast enough to follow any downward changes in RF signal strength. Resistor Rg is thus given a value such that it can discharge Cg fast enough to correspond to the "downward slopes" of the waveform of the highest modulating frequency which it is desired to detect. This value usually lies between about 220K and 2.2 megohms.

Capacitor Cg, resistor Rg and the gate-channel junction of the FET thus act as a detector circuit very similar to that in the "crystal" receiver described in chapter 10. The flow of gate current during positive peaks of the RF voltage developed across the tuned circuit results in the building up of a unidirectional charge across Cg, and because of the action of Rg this charge is able to vary in size to follow faithfully any variations in the RF signal corresponding to modulation.

But this is only half the story. While the gate-channel junction of the FET is thus arranged to function as a detector, the FET as a whole is still able to function as an amplifying device. Because the drain-source current is related to the gate-channel bias by the transconductance, as we have seen in chapter 7, the varying reverse bias developed across capacitor Cg by the detector action results in magnified variations in the average drain current flowing through the phones. The sounds produced by the phones are thus considerably louder than they would be if the phones were connected directly into the detector circuit.

It is because this type of circuit performs both the functions of detection and amplification together that it is called an "active detector".

Although the circuit of figure 3 uses an N-channel FET to illustrate the operation of an active detector, other devices can be made to operate in the same way. Thus a thermionic valve may be substituted for the N-channel FET, and would operate in virtually identical fashion provided it was supplied with filament or heater power and a suitable plate supply. A P-channel FET could similarly be used, simply by reversing the polarity of the drain supply.

NPN and PNP bipolar transistors may also be used as active detectors, although these require a slightly different biasing circuit to work efficiently.

Although an active detector circuit of the type shown in figure 3 is quite interesting from a technical viewpoint, as it stands it cannot boast any special order of performance. The performance is not markedly different from the circuits of figure 1 and 2, in fact, so that the main advantage offered is that it eliminates the need for a separate detector diode and an audio transformer.

That is not the end of the story, however. A simple addition to the circuit can make an enormous difference to the whole performance. It involves the use of reaction or regeneration or positive feedback, terms which all mean much the same thing. Figure 4 shows a FET detector incorporating what is probably the best-known reaction circuit.

It must be emphasised that this is not by any means the only possible arrangement for a receiver using reaction. It is a popular and typical arrangement but it would be possible to produce a quite imposing article on the many circuits which have been evolved during the last 30 or 40 years around regenerative detectors.

The tuning, detection and amplifying action are basically the same as for figure 3. However, advantage is taken of the fact that, over and above the detected audio voltage, there is present on the gate of the detector some of the original RF input signal. This is amplified and the signal at the drain contains the audio component, which operates the phones, plus an amplified RF signal.

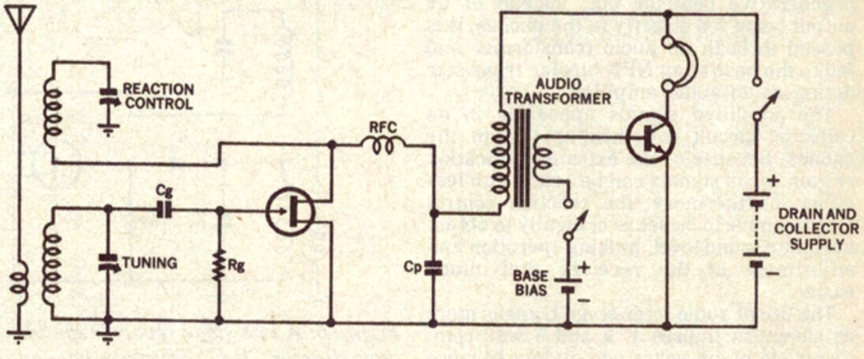


Figure 5: The addition of an audio amplifier stage to further increase sensitivity. In this case the amplifier is shown using a bipolar transistor, and is coupled to the detector using an audio transformer.

When reaction is employed, this amplified RF signal is coupled back into the tuning coil in such a way that it adds to the signal energy already present. This involves placing a reaction winding close to the tuned winding and so arranging the connections to it that the signals tend to add rather than to cancel.

Assume, for example, that there is a positive signal pulse at the gate at a particular instant. This increases the drain current and causes a negative pulse at the drain. By impressing this pulse across the reaction winding and suitably arranging the connections, its phase can be reversed; ie, coupled into the tuned winding as a positive signal. This augments the original signal and produces a far greater total effect on the drain current than would the original signal without the feedback.

The effect of this type of feedback, therefore, is to make every positive signal excursion much more pronounced than it would normally be and every negative excursion likewise. The changes in signal level due to modulation are made much more evident and therefore the audio signal delivered to the phones is greatly increased.

The letters "RFC" in the circuit stand for "radio frequency choke." This component, which is usually a honey-comb-wound coil, is inserted between the drain and the phones to ensure that RF energy at the drain is not bypassed to earth by capacitance of the phone cords. The RF is therefore retained for use by the reaction feedback winding and control.

At the same time, RF energy is undesirable in the phone cords, because it can radiate into space and back into the aerial tuning circuit, causing the reaction adjustment to be upset by random movement of the phone cords or even by the person wearing the phones.

The radio frequency choke (inductor) is intended to prevent this trouble, its effect being augmented by the capacitor Cp shown in the circuit. This bypasses any RF energy to earth which may still be present but it does not bypass the audio components, which have a much lower frequency than the RF carrier.

Again, although figure 4 shows an N-channel FET in the circuit, the principle of regenerative or reaction feedback can just as easily be applied to active detectors using other devices. And active detectors using thermionic valves or bipolar transistors, show an equally marked improvement in performance when this is done.

For a regenerative detector of this type to operate correctly it is most important that the amount of feedback be properly adjusted. If there is insufficient feedback, only limited benefit is obtained from the scheme. If there is too much feedback, the detector will oscillate of its own accord and begin to act as a generator of RF energy, exactly as described in the chapter on radio transmitters.

To give the necessary control over reaction it is customary to connect a small variable capacitor in series with the reaction winding, as shown in figure 4. When this is fully meshed, maximum RF feedback current can flow from plate, through the reaction winding to earth. As the capacitor plates are opened, the impedance of the circuit rises and less feedback energy can flow through the coil.

To adjust the reaction in bipolar transistor circuits it is sometimes more convenient to place a potentiometer across the feedback winding.

When the reaction control of the circuit in figure 4 is set so that the detector is just below the point of active oscillation, the gain and selectivity of the detector and its tuning circuit is increased enormously. Used with an efficient aerial and earth, a one-FET or one-valve or one-transistor reaction set can receive signals under favourable conditions from transmitters thousands of miles away.

From the foregoing description, it might possibly be assumed that a one-stage regenerative set is all that should even be necessary to receive radio signals. But such is not the case.

Compared with a crystal receiver, a one-stage set has an enormous advantage in terms of sensitivity and selectivity — terms which relate to its ability to pick up a wanted signal and separate it from other signals. For all that, however, its performance is still capable of substantial improvement.

For example, the signals heard in the phones from a distant station may be quite weak, requiring a good deal of concentration to follow them. The usefulness of the set can be increased greatly by adding an audio amplifier stage after the detector, exactly as already described in figures 1 and 2 for a crystal set.

This gives a basic circuit such as that shown in figure 5.

As before the FET is used as a regenerative detector but, instead of its output being fed directly to the phones, it is passed through an audio transformer and fed to the base of an NPN bipolar transistor acting as an audio amplifer.

The amplified signals appearing in its collector circuit are then applied to the phones. Because of the extra amplification or gain, weak signals can be heard with less effort. Furthermore, the reaction control may not have to be set so critically to obtain adequate sound level, making operation and adjustment of the receiver that much easier.

The use of audio inter-stage transformers as shown in figures 1, 2 and 5 was commonplace many years ago mainly because of the step-up they could give in the signal voltage. This supplemented, very usefully, the rather limited gain that was available from early valves.

As a component, however, audio transformers have always been rather bulky and expensive, prone to breakdown and liable to introduce distortion of one type or another. As a result, the growing tendency through the years has been to avoid them by using alternative coupling methods. One such method is resistor-capacitor or R-C coupling, which is illustrated in figure 6.

A resistor Rd, normally called the drain load resistor, is connected between the FET drain and the battery in place of the audio transformer primary winding. With no input signal, a certain drain current flows through this resistor and produces a corresponding voltage drop across it. The actual voltage at the drain of the FET is thus somewhat less than the battery voltage.

The base of the following audio amplifier transistor is fed with its appropriate bias as before, but not in this case by means of a separate battery as in figure 5. It is necessary to supply the bias from a source having a reasonably high impedance, and although this can be done in a variety of ways, the method shown in figure 6 is that most often used with bipolar transistors. Here the bias is derived from the main drain-collector supply battery using a voltage divider formed by resistors Ra and Rb. The relative value of the resistors determines the proportion of the battery voltage applied to the transistor, so that the bias is adjusted by altering the resistor values.

Between the FET drain and the transistor base is the coupling capacitor, Cc. Since the capacitor is connected between the drain, a point in the circuit at relatively high voltage, and the base, a point in the circuit at relatively low voltage, it will initially acquire a charge equal to the voltage difference between the two. And the capacitor is always made large enough with respect to the resistors Rd., Ra and Rb that it cannot alter this charge appreciably at an audio rate.

Now, when an audio component swings the FET drain current up and down, the voltage drop across the drain load resistor varies. As a result, the drain voltage itself varies at an audio rate.

Since the capacitor cannot alter its charge at an audio rate, it simply transfers the variations in voltage to the following base, the variations appearing at the base as an alternating audio signal. The signal is then amplified by the transistor in the ordinary way.

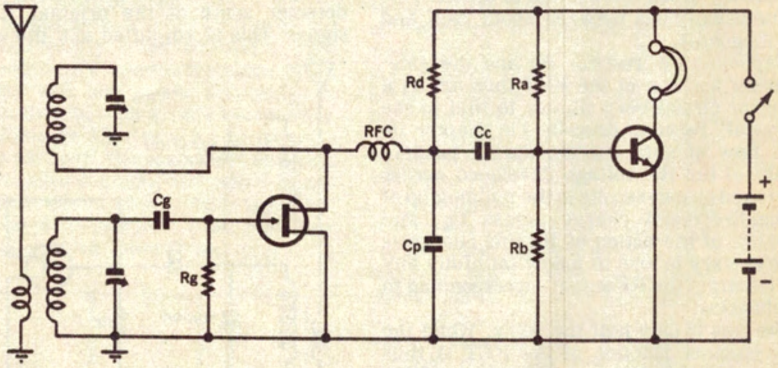


Figure 6: A two-stage receiver similar to that of figure 5, but in this case using resistor-capacitor or "R-C" coupling between the detector and audio amplifier stages. This avoids the relatively costly audio transformer.

In other words, the coupling capacitor transfers the AC audio signal from the drain to the base, while at the same time preventing the relatively high voltage at the drain from upsetting the somewhat lower bias voltage at the base.

Much more could be said about resistance-capacitance coupling, but the foregoing should convey the general idea. Needless to say the technique is equally suitable for coupling between transistors, FETs and valves, or any combinations of these devices.

Just as the addition of one audio stage to a detector makes for a more sensitive and versatile receiver, so can further improvement be obtained by using two audio stages, with either transformer or resistance-capacitance coupling. In point of fact, many domestic receivers in the early days of radio were designed around a detector and two audio stages.

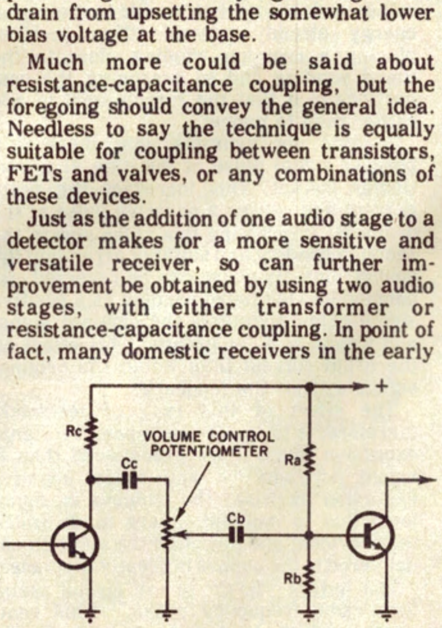


Figure 7: Showing the way in which a potentiometer or "pot" is used as a gain or volume control.

In such a case the amplification can be of such an order that the use of a loud speaker can be considered, rather than headphones. The convenience of a loud speaker is obvious but it does need to produce a great deal more sound output than phones, if it is to be heard properly.

This raises a special difficulty. If a loudspeaker has to produce a lot more sound output or acoustic power, it has to be supplied with a lot more audio power in the form of electrical energy.

If we can cut a lot of corners to make the point clear, we can say that most loud speakers and, of course, earphones operate by virtue of a changing flow of current through their windings. Therefore a lot of acoustic output requiring a lot of audio electrical power can also be thought of as requiring a large change of current flowing through the windings.

Now if a transistor, FET or valve is to amplify without distortion, its output current cannot swing beyond the limits of zero to twice the standing or "no signal" current. Therefore, if the last transistor in a receiver is intended to draw only 1 milliamp of standing collector current, the maximum current change it can effect through phones or a loud speaker is plus and minus 1 milliamp — that is, from zero to 2 milliamps.

Such a change might be plenty for phones but it certainly would not be enough to produce much output from an ordinary loudspeaker. To operate a loudspeaker, therefore, it is necessary to use in the last stage of a receiver a device which can draw a higher standing current. With a signal, the current can then swing through wider limits.

Transistor and valve manufacturers in fact provide devices expressly designed for use as power amplifiers. Such devices are designed to be capable of passing relatively large currents, and dissipating relatively large amounts of power, without damage.

It is beyond the province of this chapter to discuss the many circuit arrangements possible using transistors, FETs and valves, and, from the beginner's point of view, individual designs have to be accepted and constructed on their merits. As knowledge increases, the general ideas conveyed by this chapter will gradually be supplemented by other knowledge.

It should however be mentioned that the provision of high gain or amplification in a receiver can introduce the problem of overload. The word is almost self-explanatory.

On weak signals, the amplification available in a receiver may be just enough to raise their level sufficiently to operate the phones or loudspeaker.

If the same amplification is applied to signals which are already fairly strong, they will be amplified so much in, say, the first stage that they are too great for the second stage to handle. As a result, the stage overloads and produces a very distorted output signal — sounding rough and harsh to the ears.

To avoid this difficulty, it is often necessary to include in a receiver some means of varying the amplification. To use another phrase, some method of volume control or gain control must be included.

A certain amount of gain or volume control effect can be obtained by varying the setting of the reaction control. The more nearly this control approaches the position for oscillation, the louder will the signals become, and vice versa.

The big difficulty with this method is that the setting of the reaction control also affects selectivity and it may easily happen that a position which gives adequate signal level may not give enough selectivity to select the wanted from the unwanted signals.

Ideally, the reaction control should be operable for best detector performance, with an entirely separate control for gain.

Over the years many methods of gain control have been devised, including in valve circuits the variation in filament voltage with a rheostat, variation in plate voltage or grid bias or variation of screen voltage in a pentode or tetrode. All of these schemes are open to criticism because, in reducing gain, they also limit the valve's ability to handle strong signals, thereby introducing distortion in many cases.

Nowadays the method almost universally adopted in audio circuits using any of the normal amplifying devices — transistors, FETs or valves — is that illustrated in figure 7. A potentiometer is connected between the output of one stage and the input of the next in such a fashion that it may be used to adjust the proportion of output coupled between the two.

The audio AC developed across the load resistor Rc is fed by the coupling capacitor Cc across the whole of the potentiometer. The position of the moving arm of the potentiometer then determines the proportion of this AC voltage which is coupled through the second capacitor Cb into the following base. Thus moving the arm of the potentiometer up and down the resistance element varies the volume of sound heard in the phones or loudspeaker, and allows the volume to be adjusted to a convenient level.

In designing a radio receiver or audio amplifier, it is usual to connect the volume or gain control ahead of the first stage in the circuit which is likely to be overloaded in the event of a strong input signal. In simple radio receivers of the type which we have looked at in this chapter, the control would generally be connected between the detector stage and the first audio amplifier.

In the next chapter we will progress to look at more complex radio receivers.