Radio Transmission

Electromagnetic radiation — radio waves — the escape of energy from charging and discharging reactance — the transmitting aerial — the use of a high-frequency carrier — frequency and wavelength — generating the RF carrier — RF oscillators — RF amplifiers — keyed CW transmission — amplitude modulation and AM transmitters.

In the first eight chapters, we have been introduced to the basic components or "building blocks" of electronics — resistors, capacitors, inductors, valves, transistors, and so on. We have also seen something of the various ways in which these components may be connected together to make elementary circuits.

It is important that one has a firm grasp of these matters before one attempts to delve into the more practical aspects of electronics. However, there are no doubt many readers who have so far been thinking along the lines — "All these components may be very interesting, but how are they used to send messages and music — or even pictures — to a distant place, without any physical connection?"

With this chapter we begin to answer such questions, for we are now in a position to start examining how electronic components may be put together to transmit intelligence (whether it be messages, music, or pictures) from one point to another — without wires. In other words, we are now going to look at the basic principles of radio transmission and reception.

The whole of radio depends upon the fact that a certain form of energy, called "electromagnetic radiation," can travel from one place to another practically instantaneously, and even through a vacuum or the near-vacuum of outer space.

You are already familiar with at least two types of electromagnetic radiation — light and heat. You are also aware that these two forms of energy radiation can travel through the near-vacuum of space — step out into the sunlight, and you have proof that energy is traversing the 93 million or so miles between the sun and you. It warms your body, it can stimulate the retina of your eye, it can be used to evaporate water, and so on.

Radio waves are simply another sort of electromagnetic radiation, along with light and heat. We shall see in a moment how these three forms differ from one another; first we must learn just what electromagnetic radiation really is. To explain this fully we would need to delve into lots of mathematics, but we're deliberately going to simplify the story so that you will be able to form a mental picture of just what is going on.

In an earlier chapter, we saw that the application of a voltage or EMF to a capacitor caused the capacitor to "charge up." We saw that this was a process whereby the space between the two capacitor plates became "strained" or in a state of tension. We called this state of tension an electric field, and we said that it was stored energy which could be returned to the circuit when the capacitor was discharged.

In another chapter, we saw that passing a current through an inductor sets up a magnetic field around the inductor. The magnetic field, like an electric field, is a state of tension in space, but it is a different type of tension. It represents another sort of stored energy, which we said could be returned to the circuit when the field was allowed to collapse.

Now, in implying that all the energy stored in electric and magnetic fields could be returned to the circuit, we were simplifying the situation slightly. We did it to emphasise the difference between the basic energy storage behaviour of reactance (capacitance and inductance), as opposed to the energy dissipation (conversion to heat) behaviour of resistance.

In actual fact, however, not quite all the energy stored in an electric or magnetic field is returned to the circuit. Some is lost — it escapes, and flows or radiates away from the capacitor or inductor like the ripples from the surface of a pond disturbed by a stone. It can be picked up at a distant spot, by a suitable detecting device.

It happens that the form in which it radiates is the same in both cases — it doesn't escape from the capacitor as electric field alone, nor from the inductor as magnetic field alone. In both cases, the energy is radiated as combined electric and magnetic fields — hence the name, "electromagnetic" radiation.

The reason why the energy radiated is in the form of a combined field is that a changing field of either type is always accompanied by the other type. One can't have a changing electric field without a magnetic field along with it, nor can there be a changing magnetic field without an electric field. This is just a fact of life; no-one knows why, nor do we know just why the energy "radiates."

Let's just summarise these ideas about electromagnetic radiation before we go any further: the total energy "stored" in a capacitor or in an inductor, in their respective types of field, can never be fully returned to the circuit, because some of it escapes or "radiates" away. It escapes as a combined electromagnetic field, which is produced during the charging and discharging processes when the fields are changing (building up or collapsing) because whenever one type of field changes

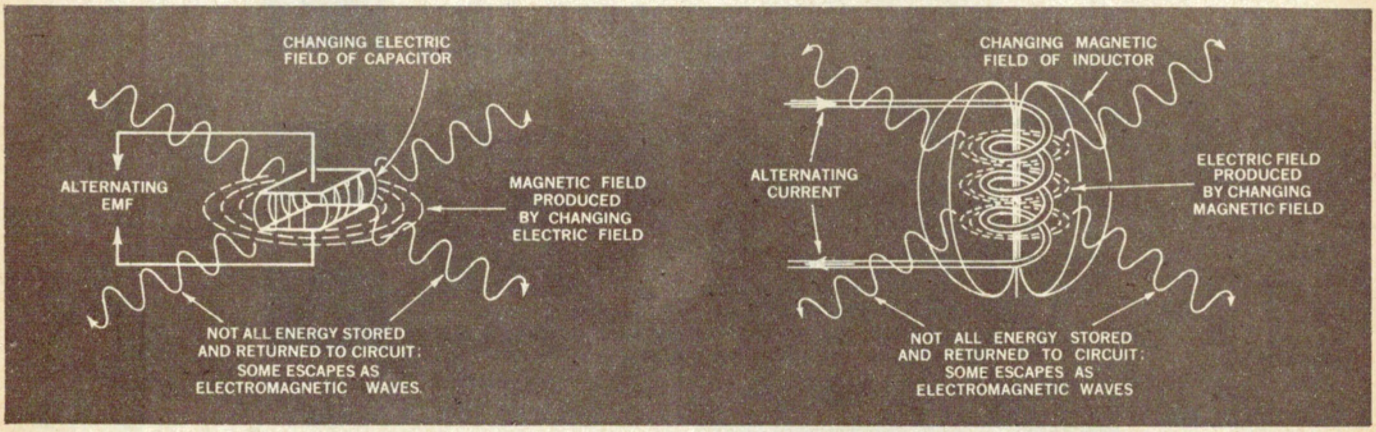


Figure 1 (left): The alternating electric field produced when a capacitor is connected to an alternating EMF is accompanied by a similarly alternating magnetic field. Figure 2 (right): With an inductor the converse occurs. In both cases some energy escapes as radiation.

it produces the other type.

When the field of a capacitor or of an inductor is built up or allowed to collapse, then, a small "wave" of electromagnetic energy radiates away in all directions. But if we apply an alternating EMF to the capacitor or inductor, a continuous series of electromagnetic waves will be produced. The continuous build-up-decay-reversal nature of the field in the capacitor or inductor will produce electromagnetic energy which will radiate away in waves, the waves having the same frequency as that of the alternating EMF.

What we know as radio waves are electromagnetic waves produced by currents so that they have a frequency of from about 10,000 Hertz to about 100,000,000,000 Hertz.

Incidentally, when discussing the frequency of radio waves or of the currents which produce them, the simple unit of frequency the Hertz (Hz) often becomes unwieldy. Things are simplified by using the Kilohertz (KHz), which is equivalent to 1,000 Hz, the Megahertz (MHz), which is equivalent to 1,000,000 Hz, and the Gigahertz (GHz), which is equivalent to 1,000 MHz.

The radio frequency spectrum thus extends from about 10 Kilohertz (10KHz) to about 100 Gigahertz (100GHz). The alternative descriptions in terms of wavelength (long-, short-, medium-, micro-waves, etc.) are less often used, but describe the length of one cycle of the electromagnetic waves concerned.

The lengths of electromagnetic waves are inversely proportional to frequency, which means that the higher the frequency, the shorter the wavelength, and vice-versa. Wavelength is measured in metres, and the length of a wave in metres is given by its frequency in Megahertz (MHz) divided into 300. Waves of a frequency of 100 MHz thus have a length of 3 metres, and so on.

We said before that light and heat were electromagnetic radiation, but that they differed from radio waves in some way. In fact, they differ in terms of frequency. Heat radiation is in effect super-high-frequency radio waves or "Extra-short" microwaves, while light radiation is a higher frequency again. Light waves are so short that their wavelength is measured in Angstrom units (an Angstrom is a ten-thousand-millionth of a metre).

But let us return to radio waves and their generation. When people first observed that energy was radiated from a changing electric or magnetic field, and saw that it could be picked up at a distant spot, they started thinking.

Surely, they reasoned, this effect could be used to transmit intelligence from one point to another. And thus was born the idea of using radio waves as a means of communication.

Experiments showed that radio waves could be radiated in more efficient ways than from a simple capacitor or inductor. There have thus been developed various types of special radiating devices, which you will probably be familiar with as aerials. A properly designed aerial stores very little energy fed into it — it lets most of it escape, as radiation.

At this stage, it might be thought that to transmit messages by radio, one need simply speak into a microphone, amplify the resulting voice-frequency voltages with a valve or transistor amplifier, and feed the amplifier to an aerial. Then, it might be reasoned, one would only need another aerial and an earphone to receive the message at a distant spot.

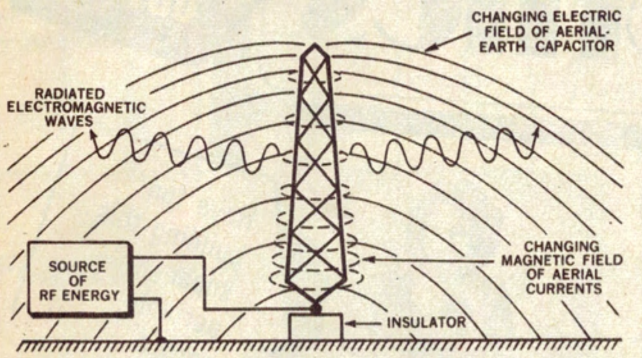


Figure 3: A transmitting aerial is a device specially designed to radiate energy. It combines the features of a capacitor and an inductor.

Now while messages can be and have been sent in this way, it actually proves quite difficult to satisfactorily transmit electromagnetic waves with frequencies as low as those we can hear (between about 30 Hz and 16 KHz). Transmitting aerials miles in length are needed if practical amounts of energy are to be radiated. There are also other difficulties associated with the transmission of such low frequencies, but these need not concern us here.

It so happens that higher frequency waves are easier to radiate. Efficient aerials may be made in convenient sizes, which will radiate suitable amounts of energy if high frequencies are used.

In practice, then, we do not radiate voice-frequency radio waves. We radiate at considerably higher frequencies, called radio frequencies (RF), by supplying the aerial with alternating current generated by an RF oscillator and amplified by an RF amplifier. These may use valves or transistors, as we shall see a little later on.

The broadcast radio stations radiate waves with frequencies in the range 550KHz-1500KHz. Long distance communication stations operate from about 2MHz to 30 MHz, in what is called the "short wave" or high-frequency (HF) band. Television stations transmit waves at frequencies between about 50 MHz and 250 MHz (the VHF band), and so on.

Radiating at radio frequencies is desirable from the ease-of-transmission-of-energy point of view, then, but it complicates the procedure of sending messages. Unfortunately, human beings can neither talk nor hear at radio frequencies!

Means must, therefore, be used whereby our RF waves can be used as a vehicle or "carrier" for the information to be transmitted. This is called "modulating" the RF carrier.

The simplest way of doing this, and the way that was first used, is to arrange that the alternating RF currents fed to the transmitting aerial are turned on in bursts or pulses. The pulses are arranged to be either long or short in duration, and various combinations of long and short bursts made to correspond to letters of the alphabet and numerals.

This type of transmission is known as keyed carrier wave transmission, or just "carrier wave" (CW) transmission. And the code used to pulse the carrier wave in short ("dots") and long ("dashes") bursts is, of course, the familiar "Morse" code.

With CW transmission the operator is provided with a "key," which is a switch connected to the transmitter. The key is arranged so that in its rest position the RF oscillator and RF amplifier send no energy to the aerial. When the key is pressed down, however, the oscillator and amplifier are turned "on", and by pressing the key briefly or for slightly longer the operator can send short or long bursts of RF energy to the aerial — to be radiated as dots and dashes.

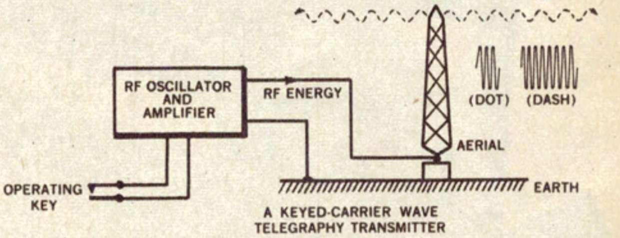


Figure 4: A keyed-carrier or CW transmitter is a system for radiating messages as long or short bursts of RF waves.

A long burst followed by three short bursts means "B", for instance, while a short burst followed by a long means "A." Each letter of the alphabet and numeral is represented by a particular combination of short and long bursts.

Keyed carrier wave transmission is quite satisfactory as a means of transmitting simple messages, but it obviously lacks something where speech, music or pictures are concerned. Who would be able to recognise their favourite piece of music translated in to dots and dashes?

Fortunately, there are other ways of modulating the RF carrier in order to send information, besides the simple on-off modulation of keyed CW transmission. Although there are quite a large number of alternative modulation systems, we will confine ourselves here to the discussion of only one — that used by all the normal "radio" broadcasting stations.

The broadcasting stations amplitude modulate (AM) the RF carrier. Rather than switch the carrier through only two steps of amplitude (off and on), they vary its amplitude continuously. In this way, the continuous variations of the human voice or music can be transmitted faithfully, as similar variations in the strength of the radiated waves.

In the remainder of this chapter, we will see how this is done. Following chapters will be devoted to the operation of the receiving end of the system, to show how the receiver is able to recover the original transmitted voice or music from the amplitude modulated waves.

Before we examine how the signals to be transmitted are made to amplitude modulate the RF carrier, we should have a look at the way in which the RF carrier is generated in the first place. In other words. We should look at the RF oscillator, which perhaps can be regarded as the "heart" of any radio transmitter.

You may remember that in chapter 5 of this course, we saw that a capacitor and an inductor may be connected in parallel to form a parallel tuned circuit. We saw that when such a tuned circuit is fed with a short burst of energy, it tends to oscillate, producing a decaying or "damped" alternating voltage.

The frequency at which the circuit oscillates, which is the frequency of the alternating voltage, is determined by the resonant frequency of the tuned circuit. This in turn depends upon the values of the capacitor and the inductor, as one might expect.

In fact, the frequency of the voltage produced is given by

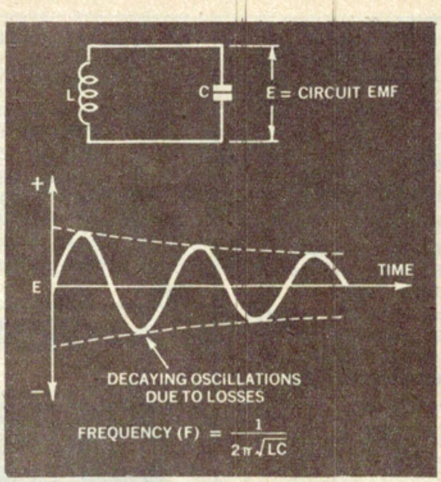
$$F = \frac{1}{2\pi\sqrt{L.C.}}$$

where F is the frequency in Hertz, pi is 3.1416, L is the coil inductance in Henries, and C is the capacitor value in Farads.

A tuned circuit can thus be used to generate an alternating EMF of any desired frequency, by suitable choice of the inductor (coil) and capacitor. So if we want to generate an RF carrier of a certain frequency, we can select a capacitor and coil to resonate at this frequency.

But a tuned circuit alone is not sufficient, for it has coil resistance and other losses which make the alternating voltage decay and die away. To produce a continuous, steady supply of alternating EMF at our carrier frequency, we must arrange for the tuned circuit to be continually fed with energy, to overcome its losses and keep it oscillating.

Here is where valves or transistors or other amplifying devices enter the picture, for by means of a valve or transistor we can keep the tuned circuit oscillating steadily.



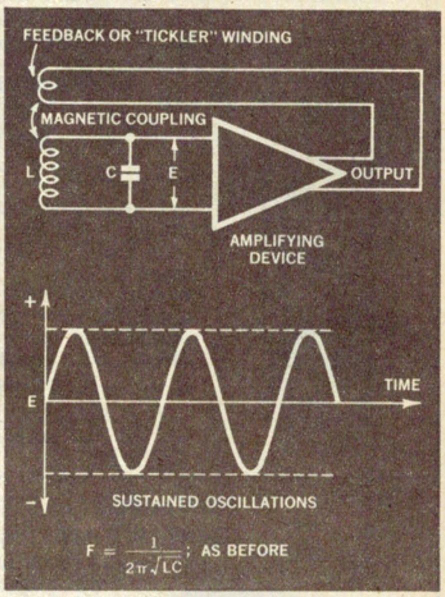


Figure 5 (above): Oscillation of a parallel tuned circuit. Figure 6 (right): Using an amplifier to maintain the oscillations.

By the way, note that wording carefully. It is always the tuned circuit which oscillates, not the valve or transistor. The amplifying device simply keeps the tuned circuit going.

Figure 6 shows the basic operation of a simple tuned circuit oscillator. The amplifying device is connected so that it picks up the oscillatory voltage E appearing across the tuned circuit. The output of the amplifying device is then connected to a feedback or "tickler" winding which is placed close to the inductor of the tuned circuit.

The feedback winding is arranged so that it can magnetically induce voltages into L which re-enforce the voltage E, when fed with an amplified version of E by the amplifying device. In this way, the tuned circuit is fed with energy which keeps it oscillating steadily.

The amplifying device may be a valve, a transistor, or anything else capable of doing the same job. Figure 7 shows simplified circuits for tuned oscillators using a valve and a transistor.

In the valve circuit, the tuned circuit voltage is fed to the input of the valve, which passes the corresponding amplified plate current oscillations through the feedback winding to supply energy back to the tuned winding.

The transistor circuit does the same thing in a different way. It connects the tuned circuit in the collector (output) circuit of the transistor, and uses a small feedback winding to supply the input circuit of the transistor. Thus small oscillatory voltages induced in the feedback winding are amplified by the transistor and fed directly to the tuned circuit.

In all oscillator circuits of this type, the amplifying device not only supplies the tuned circuit with enough energy to overcome losses and keep it oscillating. It supplies more than enough, so that a small amount of the oscillatory energy of the tuned circuit can be picked off for external purposes — in our case, for amplification and supply to the transmitting aerial.

This "output" of the oscillator can be obtained in a number of different ways. A third winding may be used, magnetically coupled to the tuned and feedback windings, to produce an induced EMF, as shown in the valve circuit. Or a connection may be made directly across the tuned circuit, as shown in the transistor circuit. Or various other methods may be used, depending on the sort of oscillator actually used and the amplifier circuit which is to be connected to the output.

In our discussion of oscillators so far, we have been talking in terms of L-C parallel tuned circuits. However, oscillators using such tuned circuits tend to waver or "drift" in frequency. Only to a small degree, if the circuit is well designed, but generally enough to make them unsuitable as a source of RF carrier energy in a broadcast transmitter — for transmitters must radiate on a fixed frequency, or one would never quite know where to find them on the receiver dial!

Actual radio transmitters do not use L-C tuned circuits in the RF oscillator, for this reason. They use instead a carefully prepared wafer of quartz crystal, which has the property of resonating mechanically when an EMF is applied to opposite sides of the wafer. When it is made to oscillate, it does so with very much less frequency drift than a normal tuned circuit, particularly if it is kept at a constant temperature in a thermostatically controlled oven.

The frequency of such crystal-controlled RF oscillators is set by the dimensions and preparation of the quartz crystal. To change the frequency, the crystal must either be

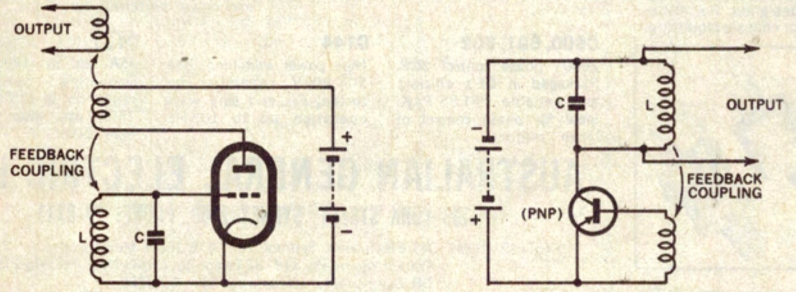


Figure 7: Elementary tuned oscillators. One uses a valve to provide the amplification, the other a transistor. The circuits illustrate different ways of providing feedback and output coupling.

replaced by another, or taken out and altered in size.

So much, then, for the source of the RF carrier energy in our transmitter. But the output of the oscillator is seldom strong enough to be fed direct to the transmitting aerial. Usually, it must first be amplified by one or more valve or transistor stages in the RF amplifier, as we mentioned before.

An RF amplifier using a pentode valve is shown in Figure 8. It has a tuned circuit in both the grid and plate circuits, and both tuned circuits are made to resonate at the oscillator frequency. Other types of RF amplifier stage called "multipliers" have the plate circuit tuned to a multiple of the oscillator frequency, and the stage is arranged to multiply the frequency. This is used where the required carrier frequency cannot conveniently be generated directly by the oscillator.

For instance, multiplier-type RF amplifiers must be used with crystal-type RF oscillators if very high carrier frequencies are required, as it is impractical to make quartz crystals to oscillate at very high frequencies.

Link windings couple the tuned circuit of the RF oscillator to the input of the amplifier, in this case. If the RF oscillator used a crystal rather than an L-C tuned circuit, one of the other types of coupling would generally be used.

Negative bias is applied to the grid of the valve to ensure that it operates at a convenient point and amplifies efficiently. The amplified RF carrier which appears in the plate tuned circuit (the so-called "tank" circuit) is coupled to the next stage — or to the aerial if this is the last stage — via another coupling loop.

We have now seen something of those parts of a radio transmitter responsible for the generation of the RF carrier energy. By adding a Morse key to this, we would have a keyed-carrier or CW transmitter, but let us progress a little further and see how the carrier may be varied in strength so that it can be used to transmit voices, music, or even pictures. In other words, let us see how continuous amplitude modulation is performed.

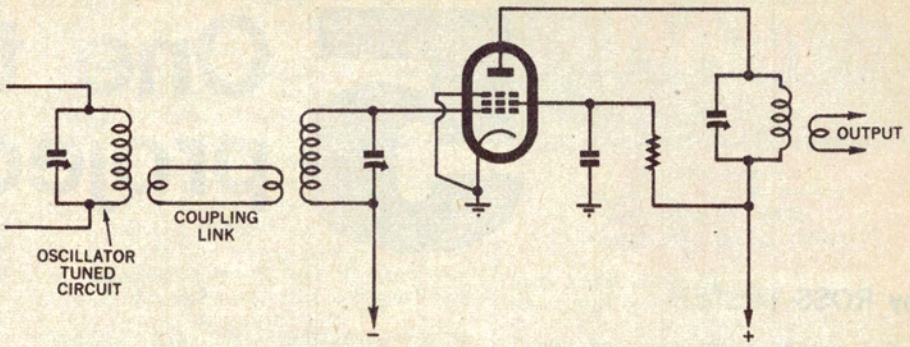
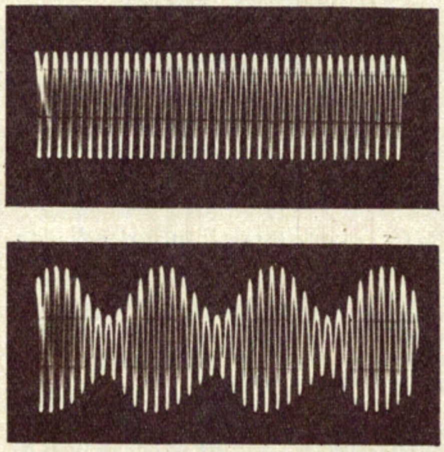


Figure 8: The basic form of an RF amplifier stage, using in this case a pentode valve. Transistors are also used for this purpose.



Two photographs taken from the screen of an oscilloscope, an instrument which allows us to "look at" electrical EMFs and currents. The upper pattern shows an alternating RF "carrier" signal, and the lower pattern the effect of modulation.

The strength of the RF carrier fed to the aerial depends on a number of things, but one of these is the supply voltage of the final RF amplifier stage. The output is, in fact, proportional to the plate voltage, with a circuit like that of figure 8.

Because of this, to vary the strength of the RF carrier — to amplitude modulate it — all that need be done is superimpose the audio (sound) frequency signals on the plate supply voltage. In this way the audio signals add to and subtract from the plate voltage, and vary the strength of the RF carrier in sympathy with the sound waves reaching the microphone.

There are other ways of amplitude modulating the carrier, but they all produce much the same effect and need not concern us here. The basic idea of a plate-modulated AM transmitter is shown in figure 9.

There is an RF oscillator and an RF amplifier, as with the CW transmitter, in order to generate the RF radiation energy. However, added to this section is the microphone, an audio amplifier (the "modulator") and a transformer used to superimpose the amplified audio frequency signals on to the plate voltage of the RF amplifier.

The audio amplifier may use either valves or transistors, and builds up the strength of the tiny voice-frequency voltages generated by the microphone. The output of the audio amplifier is fed to one winding of the modulation transformer.

The other winding of the transformer is connected in series with the plate circuit of the final RF amplifier, so that the amplifier receives its plate current through the transformer winding. In this way, the amplified alternating audio voltages induced in this winding of the transformer add to or subtract from the supply voltage, and can vary the strength of the carrier fed to the aerial.

The small waveform sketch shows what the modulated carrier would look like if we could see it. In fact, we can see it if we use an instrument called an oscilloscope, as the two photographs show.

Instead of the microphone, we can use a gramophone pickup, a tape recorder, and so on. In television transmission, we would use cameras, film scanning machines and video tape recorders instead.

And with the description of a basic AM transmitter, we must end this chapter. Now that we are reasonably familiar with the nature of radio waves and at least two of the ways in which information can be transmitted, we are ready to look at the way in which the radiated radio waves are used. In the next chapter, then, we will start at the "other end" of the radio system — the receiver.

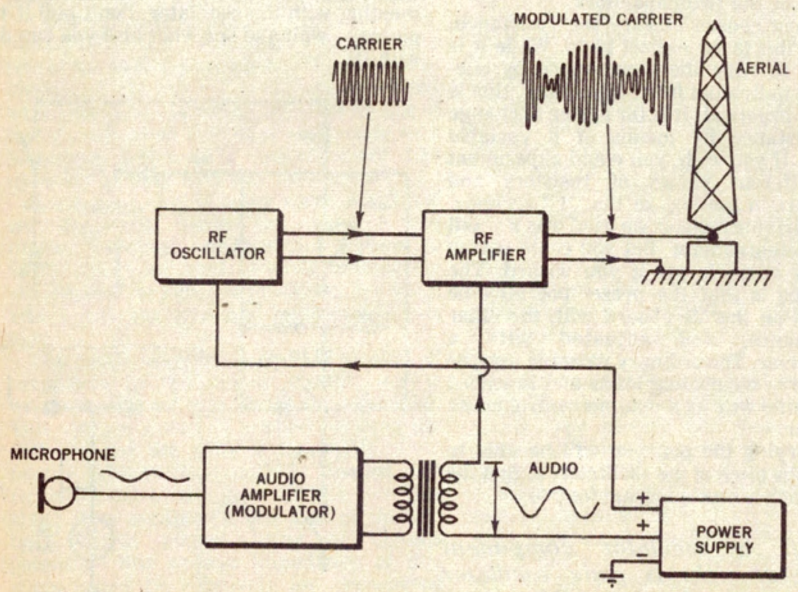


Figure 9: An elementary AM transmitter, showing how the RF signal is made to function as a "carrier" of the audio information.