Some principles of antenna operation

How to obtain better TV reception: Pt. 3

By far the most important factor in obtaining good TV reception is the antenna. And having some understanding of antenna principles will help you to select an antenna for best reception in your location.

by LEO SIMPSON

A great many people living in Sydney do not have good reception of channel 0 and many of these people blame the station when they really should be blaming their own antenna. Some of these people even go to the trouble of installing a new antenna which does little to solve their problem. With knowledge of the principles involved, anyone who presently has good reception can get equally good reception of channel 0.

To gain some idea of how an antenna works it is necessary to understand the nature of a radio or television signal. The usual description goes something along the lines that "a radio signal is a form of electromagnetic radiation which travels at the same speed as light (in air or vacuum) at 300,000 kilometres per second". The term "electromagnetic" is the essential clue since it implies that a radio wave has two components: electric and magnetic.

How do these two components come about? In fact, wherever there is a varying electric field there is always an associated magnetic field although it is customary to ignore the existence of magnetic fields in much of electronics.

How a radio signal is radiated

Consider a length of wire to which is applied an AC voltage. Because of the voltage a given alternating current will flow through the wire and this will set up an associated magnetic field around the wire which will vary in exact unison with the current. The magnetic field will be perpendicular to the wire and thus perpedicular to the voltage field applied to the wire.

Fig. 1 shows the relationship between the voltage field and the magnetic field. The voltage field is, in fact, the electric field referred to earlier. Many people have trouble visualising an electric field although they have no trouble visualising a magnetic field. The evidence of a magnetic field can be made visible by sprinkling iron filings on a piece of paper which lies over a bar magnet. This shows the lines of force of the magnetic field which run from the north pole to the south pole of the magnet.

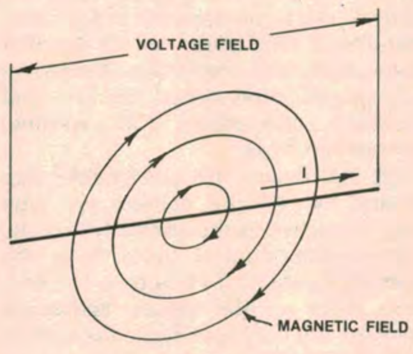

Fig. 1

Similarly, an electric field (also known as an electrostatic field) has lines of force which run from a positively charged point to a negatively charged point. Fig. 1 shows the direction of the lines of force of both the magnetic and the electric fields.

So the length of wire in Fig. 1 has an electric field and a magnetic field associated with it and this will be radiated out from the wire with both fields becoming weaker as the distance from the wire increases. In fact, the wire can be regarded as a rudimentary antenna radiating energy out into space in the form of magnetic and electric fields.

Think about that for a moment. Can energy be radiated in the form of magnetic and electric fields? Yes. We can also store energy in magnetic and electric fields. Consider the energy stored in the magnetic field of an automotive ignition coil or the energy stored in the electric field between the plates of a high voltage capacitor (such as used in the capacitor-discharge ignition system).

The units of electric field intensity are volts/metre and the units of magnetic field intensity are ampere-turns/metre. As we shall see, RF signal strength, as radiated from an antenna, usually refers to the electric field and is measured in volts/metre or in practice, in millivolts/metre.

Before leaving Fig. 1, we can say that it radiates an electromagnetic wave which moves at 300,000km/sec into space and which varies at the frequency of the alternating voltage applied to the wire. If we move some distance away from the wire, we can visualise this wave as two planar fields at right angles to the direction of motion. Fig. 2 shows three axes for such a wave.

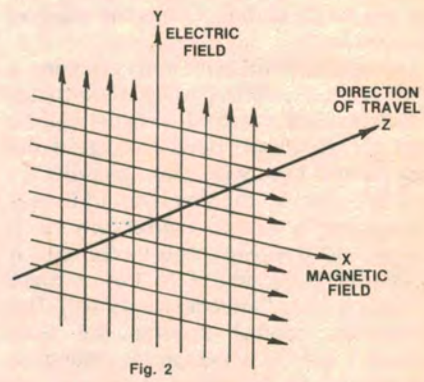

Fig. 2

The z-axis represents the direction of motion; the y-axis the direction of the electric field and the x-axis the direction of the magnetic field. In antenna parlance, the electric field is said to be the E-field and the magnetic field is said to be the H-field.

At this point, we are ready to have a look at how a basic antenna receives or picks up such an electromagnetic wave. Let's place a length of wire in the path of the wavefront of Fig. 2. Further, let's position the wire so that it is parallel to the lines of the electric field. This means that as the wavefront passes the wire, the lines of magnetic force will cut it. This will cause a current to flow in the wire and a voltage to be developed across it.

The voltage developed across the ends of the wire will be the product of the length of the wire and the field strength of the wavefront. For example, if the length of wire was one metre and the field strength was one volt/metre, the voltage induced between the ends of the wire would be one volt.

If the reader was to stop at this point

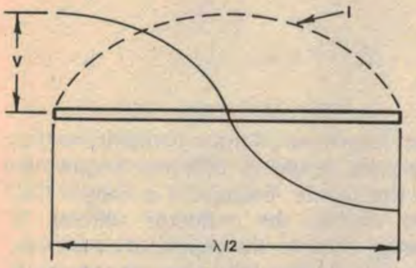

Fig. 3

he could easily conclude that the foregoing is all you need to know. He might well say "the antenna wire picks up signal in proportion to its length. Therefore, the longer I make the antenna, the better". Well that happens to be true for antennas which are used for relatively low frequencies, such as for the AM broadcast band but for higher frequencies we need to consider the concept of wavelength.

Wavelength

Just as sound waves have a wavelength which is found by dividing the velocity by the frequency then so do electromagnetic waves. In this case, the velocity (in vacuum) is the same as for light, being 300,000km/s or 3×10^8 metres per second. So if the frequency of the electromagnetic wave we are concerned with is 150MHz, then the wavelength will be two metres.

Wavelength is the distance between two successive corresponding points, peaks or troughs, on a wave. If we then take a one-metre length of wire and place it so that it is cut by an electromagnetic wave (ie, so that it is parallel to the lines of the electric field) with a frequency of 150MHz. we would find that a current would flow between the ends of the wire and a voltage would be induced between the ends.

But by having a length of one metre we note a special relationship between the voltage, current and the wavelength. If we were to measure the voltage and current at various points along the wire we would find the values depicted in Fig. 3. This shows the voltage maxima at the ends of the wire while the current minima are at the same points.

This photo is repeated from last month's article on ghosting because it was not reproduced properly. The faint vertical bar about one-tenth of the width of the picture is the ghost of the horizontal sync pulse. In most cases it is darker but it may also be lighter than the rest of the picture.

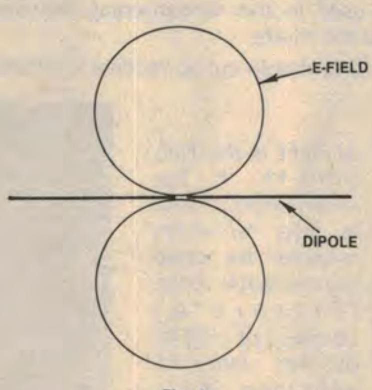

Fig. 4

What we observe along the wire is, in fact, a "standing wave" and it is analogous to a standing wave in a taut length of string. The current minima in the wire (at the ends) are equivalent to the nodes (stationary points) in the oscillating string. This is resonance.

If we now cut this half wavelength of wire in two we have a resonant dipole, the basic building block used in just about all TV antennas.

Polarisation

The dipole is often referred to as a "doublet" because of the shape of the electric field radiated by it when used as a transmitter or the response pattern when used as a receiver.

If we looked down from immediately above a dipole used as a transmitter and plotted the amplitude of the electric field radiated in all directions from it we would find a characteristic double-lobe pattern, as in Fig. 4. Hence the name "doublet". Such a horizontal antenna is said to be horizontally polarised. Note that polarisation refers to the direction of the electric field, not the magnetic field.

As hinted above, a dipole antenna has the same polar pattern for transmission as for reception by the law reciprocity. This means that if a horizontal dipole is used as the transmitter than the receiving antenna must also be a horizontal dipole (or variant thereof) to pick up the horizontally polarised transmitted wave. If a vertical receiver antenna was used it would be at right angles to the electric field and parallel to the magnetic field and, in theory, it would pick up no signal at all. In practice, it would pick up some signals but the resulting reception would be awful.

From Fig. 4 it can be seen that the signal pickup end-on to the dipole is at a minimum or "null" while it is maximum at any direction exactly at right angles (including above and below).

Therefore, for the dipole antenna to work correctly it must have the same polarisation as the transmitting antenna and it must be oriented (ie, pointed) so that it is broadside to the wavefront from the transmitter.

From the shape of the pattern in Fig. 4 the dipole antenna is said to be bidirectional which means that it has the same response from the front as it has from

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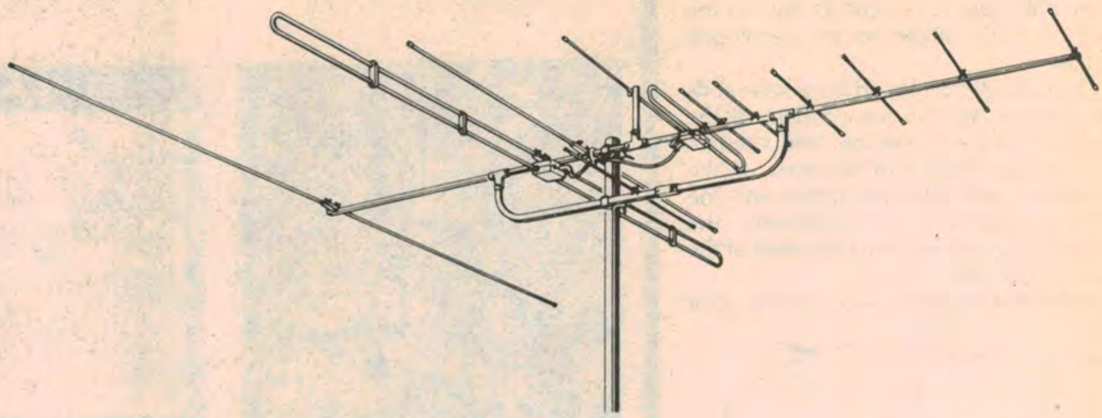


This German-made Wisi FC12 antenna covers channels 0 to 2 and channels 6 to 11. The three long elements cover the low band while the rest cover the high band. (Diagram by courtesy of Paul's Antenna Service Pty Ltd, Narrabeen, NSW.)

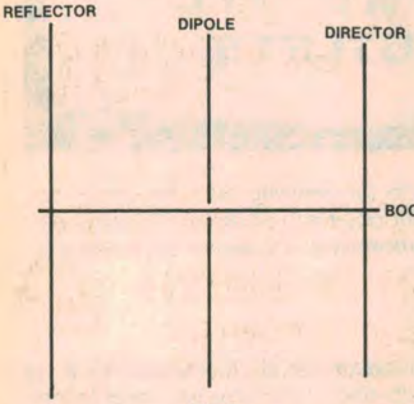


Fig. 5

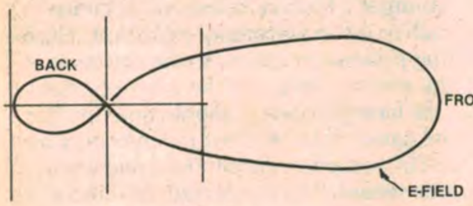


Fig. 6

the back. In fact, the terms back and front are quite meaningless.

While dipoles are used as the most basic TV antennas, for example, TV "rabbit ears" and caravan antennas, the doublet pattern is not very suitable for getting rid of ghosts unless by some fluke the ghost was exactly at right angles to the direction of pickup whereby it would fall in the null.

There is another reason why the simple dipole may not be adequate and that is that the signal picked up by it may be insufficient for satisfactory reception. For completely noise-free reception a typical TV receiver requires a signal of as much as one millivolt RMS (regardless of the frequency), although signals very much less than that may be deemed "watchable".

If the TV is to be driven with this amount of signal, the product of the dipole length and the electric field strength must equal one millivolt. For reasons which should now be obvious, we can't vary the length of the dipole; it must be at its resonant length and because of the way in which standing waves occur in an antenna, increasing its length will not yield any increase in received signal. In fact, if a dipole is to be used and still obtain its basic "doublet" response pattern it must be operated at or near its fundamental resonance or at its odd harmonics, ie, 3rd, 5th and so on. Normally, for TV reception, dipoles are only used in the fundamental and 3rd harmonic mode.

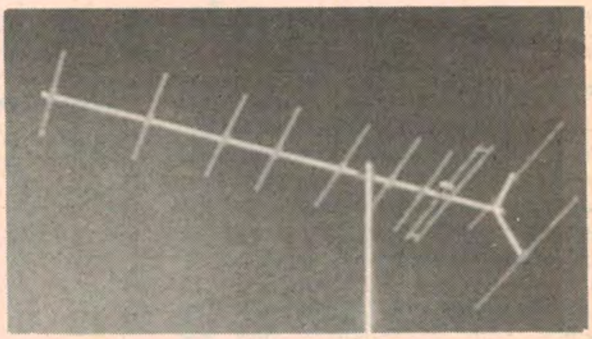
So for a dipole cut to receive a certain frequency, the signal picked up will depend solely upon the field strength. If that is not enough an antenna with more gain has to be used. Gain in a resonant dipole antenna can be obtained in two ways only. First, elements may be stacked to increase the effective capture area of the resultant antenna or other elements may be added in front and back of the dipole to change the shape of its response pattern. Antennas of the latter form are known as Yagis after the Japanese inventor, Hidetsugu Yagi, who devised the first such antenna in 1928. The simplest form of Yagi is depicted in Fig. 5. It has two other elements besides the dipole.

The shorter element in front of the dipole is known as a director while the slightly longer element behind the dipole is known as a reflector. These are also known as parasitic elements as they resonate at slightly different frequencies to the dipole. Because it is longer than the dipole, the reflector reflects RF energy back to the dipole, thus increasing the effective field strength seen by it.

Antenna gain

In a less obvious way, the resonance of the director is close to the dipole resonant frequency and radiates some of the signal picked up by the director back to the dipole to again increase the field strength seen by it. Both of these effects have the result of changing the polar response pattern as well as increasing the gain. Reference to Fig. 6 shows how the lobe to the rear of the Yagi has been much reduced while that at the front has been elongated to indicate the greater gain in the forward direction and the reduced forward "acceptance". Now the pattern has a recognisable front and back (compared to a dipole). We can now talk about front/back ratio which is expressed in decibels and is a measure of the antenna's ability to reject unwanted (ghost) signals from the rear.

At right is the Hills Y10/6-11. It has seven directors and a two element reflector for good front-to-back ratio. (Picture by courtesy of Hills Industries Ltd, Edwardstown, SA.)



Also expressed in decibels is the gain of the antenna. Compared to a dipole, a three-element Yagi typically has a power gain of around 6dB. If the gain is referred to an isotropic antenna which is a hypothetical concept of an antenna which radiates equally in all directions, the gain figure is increased by 2.1dB. The

Most TV antennas are variations on the basic dipole antenna as described in this article. This large array is for Channel 0 in Sydney. The large dipoles can be easily recognised, ie, the hefty lengths of horizontal pipe painted white.

first gain figure should really be expressed in the form "dBd" while the second is "dBi".

The foregoing gain figure of 6dB compared to a dipole assumes that all elements have been cut for maximum gain at a particular frequency. Unfortunately though, a TV transmission encompasses a band of frequencies about 7MHz wide. In order to cover this range, several measures are adopted. First, the dipole is folded, and appears rather like a squashed loop. Second, the reflector is cut longer and the director is cut shorter, to spread the range.

These measures increase the bandwidth but they also reduce the gain so that for a typical three-element array for single-channel TV use, the gain may only be 5dB. The situation gets worse, as viewers normally want to watch more than one channel.

Widerange Antennas

With the best will in the world, antenna designers have great difficulty in arranging for a Yagi to cover more than about one-third of an octave (ie, a range of 1.3:1) and such an antenna would have a lot of directors while not having a great deal of gain.

As an example of an antenna which just about represents the limit to which a single Yagi can be developed for TV coverage, consider the Hills Y14/611. This Australian made antenna has 11 directors and covers the frequency range 174-225MHz for channels 6 to 11. It has a gain of 8 to 10.5dBd, depending on the particular frequency and a front-to-back ratio of 20 to 26dB. Its overall length is 2.25 metres.

To gain coverage down to channel 0 (or channel 2) it is usual to construct two Yagis on the one boom and couple them together. Such an antenna is the Hills 215 which covers channels 2, 7, 9 and 10 or the Hills 3-5/0 which covers from 0 to 11 inclusive. Such antennas are, at best, a compromise. It is very difficult to obtain usable gain together with a flat response and good front-to-back ratio for all channels.

Resonance required

That such antennas do give reasonable results is a tribute to the designer but one point can be emphasised. No physical rules have been broken. To gain this frequency coverage it is necessary to have at least one element in the antenna which resonates at close to a particular frequency in the total range. The reflector for example, is always cut to be resonant within the channel space of the lowest to be received.

In practical terms, for an antenna which covers channel 0, the reflector must be a little over three metres long, to resonate at about 49MHz. If your antenna is an older design which covers the range down to channel 2 the reflector will be about 2.2 metres long and thus the gain will be well and truly deficient for channel 0. The result will, at best, be a picture which is prone to lose sync and subject to "pulling" at the top, due to the sharply curtailed low frequency response. More likely, the result will be a snowy picture and one which is unwatchable.

Remember also that if the antenna reflector is cut for channel 2, the polar response will be far from ideal for channel 0. So even if you have reasonably ghost-free reception of channel 2, you could easily be plagued with ghosts on channel 0, even though, in Sydney at least, it is radiated from the same mast.

(To be continued)