Antenna Matching

THE ANTENNA AND its feeder are vital parts of an amateur radio station. The best transmitting and receiving equipment in the world will be almost useless if it is not connected to a good antenna and the best antenna in the world will be equally useless if the RF signals are not carried to and from your radio along an efficient feeder. What's more, an effective antenna system is something that you will have to create for yourself and what is best for you will depend to some degree on your own circumstances. Everyone's roof or garden is different, and your constraints are not the same as anyone else's.

Even if the rest of your station consists of commercial equipment, your antenna is more likely to be home made. Therefore it is important that you know some of the theory, so that you can put up the most effective. It will also be useful for the exam!

A little revision

DOUBTLESS YOU WILL remember from your Foundation training that one of the most commonly used antennas is the half-wave dipole (see **Fig 72**). This is more often referred to simply as a 'dipole'.

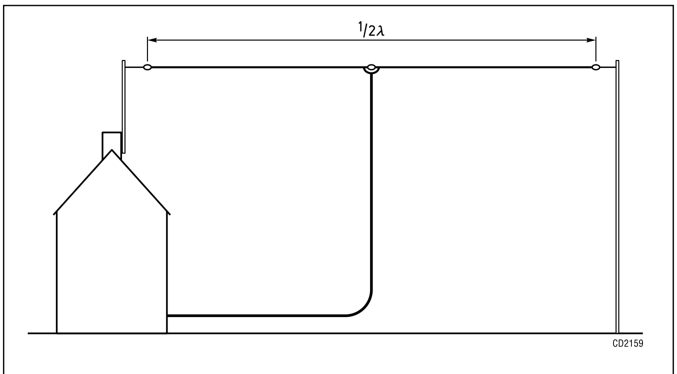

Fig 72: A dipole mounted horizontally in a garden.

Radio amateurs probably use the dipole more than any other antenna on the HF bands. It is also the basis for many VHF and UHF antennas. After a few simple calculations, a dipole can be constructed easily. It is simple to feed and can be working in a matter of an hour or so.

As you will remember from your Foundation assessment, a dipole has to be adjusted or cut to the correct length. Because we are talking about a 'half wave' dipole, you would be correct in guessing that this antenna should be one half of the wavelength in use. In reality, factors such as the closeness of the ground affect the exact length required, so amateurs usually make the antenna too long to begin with, then cut equal lengths off each end until a good SWR reading is found. How does this work?

A transmitter needs a load (5e.1)

TRANSMITTERS ARE designed to transfer energy into a load. The antenna system (i.e. the antenna and its feeder) normally provides that load. If there is no load, or a load that is not what the transmitter is designed for, the power amplifier can be severely damaged.

To illustrate this point, think about pushing a trolley in the supermarket. If you are expecting a heavy load you will push hard, but if the load turns out to be very light the trolley will be pushed away and you may fall flat on your face. On the other hand, if the load turns out to be much heavier than you had expected, you could pull a muscle or injure your back. Either way, you could be 'damaged' by a load that you were not expecting.

Most modern amateur transmitters are designed to transfer energy into a load with an impedance of 50Ω. If the impedance varies too much from this value, the transmitter could be damaged. Some transmitters have an automatic power-reducing circuit to avoid damage caused by incorrect matching, but you should not rely on this.

It is true that a 50Ω resistor can be used as a load for a transmitter to work into, for example, as a dummy load for test purposes. However, in an antenna system, instead of the transmitter power being absorbed in the load, as in the dummy load, the power is transferred through the feeder to the antenna to produce a radio wave.

We don't have to investigate the theory in any detail here, it is simply sufficient to know that a properly tuned antenna system will only provide the correct load if we feed it from a transmitter at the correct frequency.

So what makes the antenna system impedance equal to 50Ω?

Feeder impedance (5b.1)

THE FIRST COMPONENT in the antenna system is the feeder.

The feeder is the cable that carries the RF signals between your radio and the antenna. Why don't we plug the antenna straight into the back of the radio, instead of using a feeder? The answer to this question is that the maximum signal, both on transmitting and receiving, is obtained by having the antenna in the open and as high as possible. This is also part of good EMC housekeeping.

Several types of feeder are used by radio amateurs and each type has a 'characteristic impedance'. As mentioned in an earlier worksheet, impedance is not the DC resistance of the wire but an AC characteristic; where there is resistance and reactance present in the same circuit you have impedance. In a feeder, the wire has some resistance and the two conductors form a kind of elongated capacitor that introduces some reactance; the two together give us impedance. The characteristic impedance of coax is determined by the diameter and spacing of the conductors. Coaxial cables for amateur radio are normally 50Ω impedance, to suit modern transmitters. The coax used for television downleads is normally 75Ω and satellite TV coax tends to be 90Ω.

Generally speaking, if you buy a length of feeder, you should make sure it has the characteristic impedance that you want. If the coax is correctly terminated (that is terminated by a resistive load that is equal in value to the characteristic impedance of the coax) the length of the coax will have no effect on the impedance – if there is a 50Ω load at one end, Z will be 50Ω at the other end.

You should also note that the characteristic impedance determines the ratio of the RF RMS potential difference to the RF RMS current in a correctly terminated feeder. Any calculations required on this topic would be exactly the same as the other impedance calculations covered earlier ($Z = V_{RMS} / I_{RMS}$).

The next part of the system is the antenna itself, and antennas also have impedance.

Feedpoint impedance (5c.1)

ANTENNAS ARE generally formed from metal wires, rods of tubes, which have some resistance. The antenna elements are conductors separated by air, which forms a kind of capacitor, which has some reactance. Some antennas include coils, which also have some reactance. All antennas therefore have impedance or, more accurately, each antenna has a feedpoint impedance.

You should recall that a half-wave dipole has two sides or 'elements'. When it is cut to the correct length for the frequency in use, the impedance at the centre of the dipole is somewhere around 50Ω. Different antennas have different feedpoint impedances, but because the dipole is so common, most amateur antenna systems are calculated by reference to an impedance of 50Ω.

The feedpoint impedance of an antenna is not fixed, it is related to the dimensions of the antenna and the wavelength of the signal you are feeding it with. You should recall adjusting an antenna during your Foundation Licence assessment. As you changed the length of the antenna to suit the wavelength of the signal you were using the feedpoint impedance of the antenna was also changing. When the length of the antenna was correct the feedpoint impedance was close to the 50Ω that the transmitter was designed to use.

Taking this a little further, you should be able to see that if you apply an RF potential difference across the antenna feedpoint impedance, some RF current will flow in the antenna. Following what we have already learned about Ohm's law in AC circuits it should be no surprise to find that the RF current (Amps) flowing in the antenna is related to the feedpoint impedance (Ohms) and the potential difference of the applied signal (Volts). In general, you will get maximum radiation from the antenna when you have maximum RF current flowing in the antenna and you will only get maximum current flowing when the feedpoint has the correct impedance.

Matching

WE NOW KNOW that modern transmitters are designed to transfer energy into a load of 50Ω, that commonly-used coaxial cable has a characteristic impedance of 50Ω, and we have discovered that a dipole has a feedpoint impedance of about 50Ω when it is used at its designed frequency. If the transmitter, feeder and antenna all have the same impedance, we say that they are 'matched'.

The benefit of using a matched system is that no matter how long the feeder is, the impedance at the transmitter will always be the same as the impedance at the antenna, just as if the feeder were not there. In such circumstances the transmitter will not be damaged and we will have the most efficient transfer of energy from our transmitter to the antenna.

But what happens if there is a mismatch? There are two points where this can happen, between the transmitter and the feeder and at the junction of the feeder and antenna. Let's investigate this further, starting at the antenna.

Mismatch at the antenna (5c.1 & 5d.1)

IF AN ANTENNA is not adjusted to the correct length for the frequency in use, some of the RF power arriving from the transmitter will be reflected back down the feeder, as **Fig 73** shows. The reflected power is not lost, but it will combine with the power travelling up the cable to form what are called 'standing waves'. These are points of high and low voltage, and if you could see the pattern they form, it would look a little like stationary waves along the cable. You measured Standing Wave Ratio (SWR) as part of your Foundation assessment.

The reason that some of the power is reflected is that if the antenna is not the right length for the frequency in use, the feedpoint impedance will no longer be 50Ω. The antenna will only present the correct impedance when the antenna's length is correct for the wavelength of the signal being used. Maximum transfer of energy can only occur when the impedance of the antenna matches that of the feeder, so if there is any mismatch some power will be reflected.

The proportion of power that is reflected depends on how much of a mismatch there is. When using a feeder of 50Ω impedance, we might have an antenna with an impedance of 70Ω. This is reasonable, and would actually be considered a

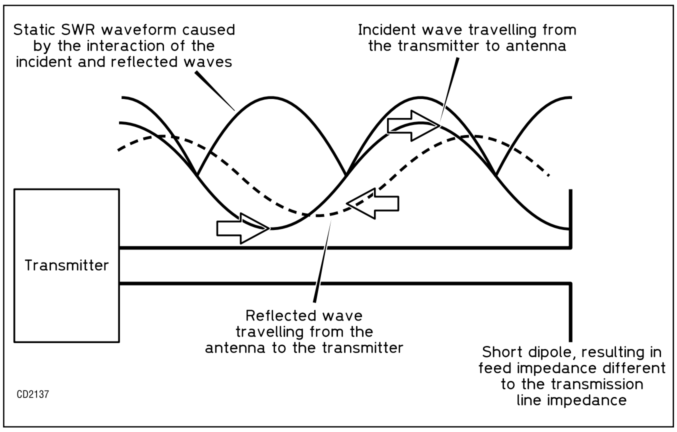

Fig 73: Standing waves on the feeder of an antenna.

fairly good match. On the other hand, if the feedpoint impedance of an antenna were 500Ω, this would be a pretty bad mismatch.

The amount of power reflected is related to the size of the mismatch and the reflected power sets up the standing waves, so it is easy to visualise that the amount of standing waves depends on the size of mismatch. The greater the mismatch, the greater the standing waves. When we measure the SWR on a feeder we are, in effect, finding out to what extent our antenna system is mismatched. A lower SWR means a better match.

Mismatch at the transmitter (5d.1 & 5e.1)

THE MAIN PROBLEM of having a mismatched antenna is that the reflected signal with change the input impedance of the feeder so that it is no longer the characteristic impedance and the feeder will not then present the correct load to the transmitter. Instead of the 50Ω of a well-matched system, the transmitter will instead be connected to some other impedance. We don't need to know how to calculate this, it is enough to say that the transmitter will not operate at full effectiveness if there is a mismatch between the transmitter and the feeder.

Most transmitters can tolerate a small amount of mismatch. This is why we can successfully use a single antenna over a whole amateur band. When we change frequency within the band the match between the antenna and feeder will change because the wavelength will be slightly longer or shorter, but the antenna stays the same length. As a result, the level of standing waves will change and the transmitter will 'see' different impedances at its antenna socket. However, because the mismatch will be quite small, the transmitter should be able to cope without difficulty.

Antenna matching units (5e.1)

WHAT HAPPENS if the change in frequency is much greater? On the HF bands it is common practice to use a single antenna on several different bands. Such an antenna will only be perfectly matched at one spot frequency and will normally only present an acceptable impedance across one band. On all the other bands the rather large mismatch will result in a high SWR. If this is the case, you can use an Antenna Tuning Unit (ATU) between the transmitter and feeder.

An ATU can change the mismatched impedance that the antenna system presents to the transmitter to something more acceptable. This will allow the transmitter to feed power through the feeder into the antenna. This is why ATUs are sometimes called Antenna Matching Units (AMUs).The position in which an ATU would be used in your station is shown in **Fig 74**.

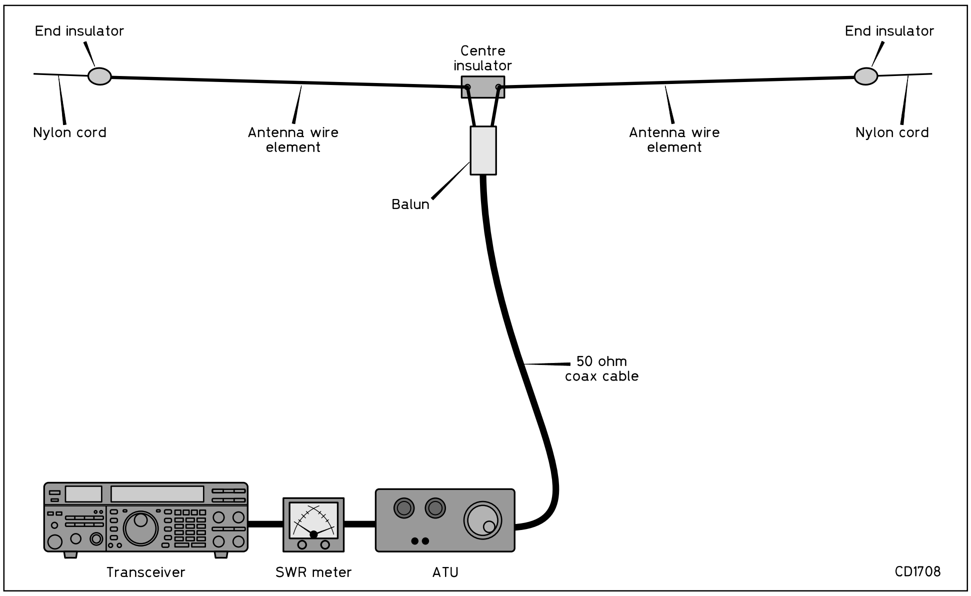

Fig 74: Layout of a transceiver, SWR, ATU, feeder, and antenna system.

An ATU connected between the transmitter and the feeder will not remove the mismatch between the antenna and the feeder. Neither will it change the level of standing waves on the feeder. What it will do is let the transmitter 'see' the correct impedance and so feed the maximum power into the antenna system.

You should note that an ATU connected to a transmitter as shown in **Fig 74** does *not* change the feedpoint impedance of the antenna, so although you may have a 'perfect' SWR reading at the transmitter the antenna may not radiate very well. Remember that a dummy load presents an excellent match, but it is not a good radiator!

You should also be aware that when the transmitter output is correctly matched, an ATU can provide additional protection against the radiation of harmonics.

Safety note (9c)

THE QUEST FOR AN effective antenna system may require you to work at some height. The use of ladders and/or the lifting of long support poles are hazards that pose some risks. However, if you are aware of the risks, you can guard against them causing any real harm.

The first thing to be aware of is the presence of any overhead power lines. Any contact with high voltage cables will undoubtedly kill you. Even if you only get close to them, electricity can arc across the gap. *Never* work under or near overhead power cables and always think what might be hit if the ladders or poles were to fall!

The second thing to think about when working at height is to make sure that ladders are secured at the top and/or that you have another person standing on the bottom rung of the ladder. Younger amateurs should make sure that there is always an adult around when working at height.

As shown in **Fig 75**, all ladders should be set at the correct angle and you should not reach away from the ladder such that you cannot keep two feet firmly on the same rung.

If you need to take tools up a ladder, you may find a tool belt useful to prevent heavy objects falling onto your assistant(s) - who should be wearing suitable hard hats anyway! Tool belts and hard hats can be purchased at most good DIY retailers and builders' merchants.

Further information

IF YOU WOULD LIKE to learn more about antennas, there are many sources to refer to, but two RSGB books come highly recommended. *Practical Antennas for Novices* is a good starter, whilst *Backyard Antennas* takes things a bit further. Both books contain designs for building antennas, together with some of the technical background.

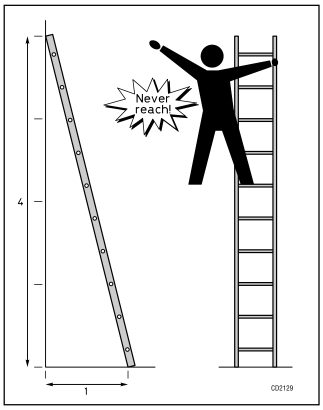

Fig 75: Make sure you use a ladder at the correct angle. Don't lean out!