# Antenna matching and all that

## *Editorial note*

*Due to an editorial production mistake the version of this article that appeared in the January 2020* RadCom *was an uncorrected draft. This version contains the author's corrections and some additional material. We apologise unreservedly to G3XJE for our error.*

**I have heard it said that your antenna needs to be matched to its feeder for best performance.**

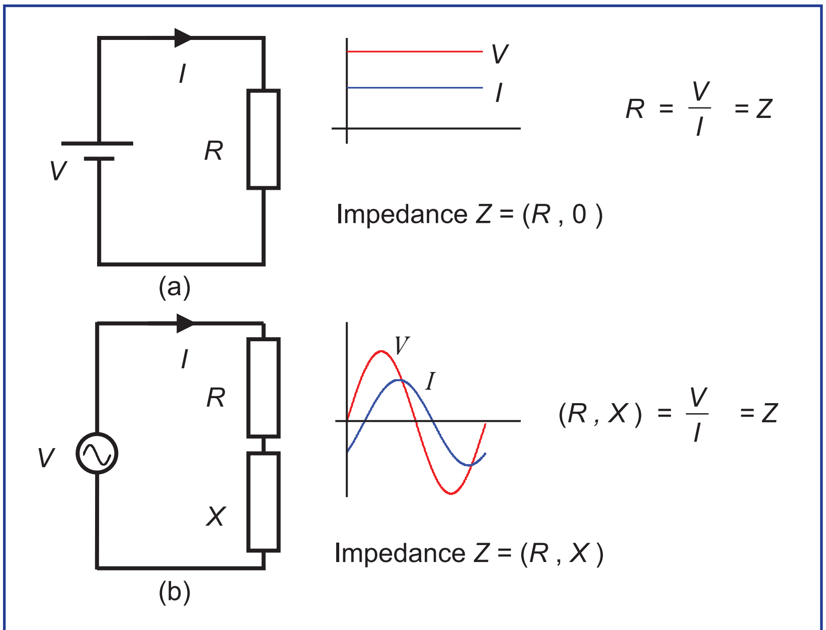

FIGURE 1: Illustrating impedance (a) in a DC circuit and (b) in an AC circuit.

The feeder could be a coaxial cable or an open-wire ladder line, but the impedance presented by the antenna should be as close a match as possible to the characteristic impedance of the feeder. But is this statement really true? Does it actually matter? Well, yes and no. Let me explain.

First, a word about impedance. This is simply the voltage across a circuit divided by the current flowing through it and it is measured in ohms (Ω). **Figure 1** shows how it goes. This is easy to understand in the case of a DC voltage applied across a pure resistance, as in Figure 1a. In this case, the voltage and the current have constant values, so it straightforward to divide one by the other to get the value of the resistance. However, when the voltage is oscillating (Figure 1b), as in the case of the high-frequency RF voltage at the output of your transmitter, a complication arises when the current and the voltage are not in phase with one another. The impedance is still the voltage divided by the current, but now we have to include an extra component to take account of the phase difference between them. We need two numbers, not just one.

You could treat this mathematically in a number of ways, but the common method is to express the voltage and the current as complex variables and to use the mathematics of complex numbers to manipulate them. We need not be concerned with all that here, but should just be aware that the impedance must be expressed as two numbers: the first is the resistive part and the second is the reactive part. Only the resistive part is non-zero in the DC case shown in Figure 1a. The resistive part is just that which we commonly understand as the resistance and always has a positive value. The reactive part is associated with inductance (expressed as positive) and capacitance (expressed as negative). The difference in signs allows us to cancel out the reactive element by adding an inductance or capacitance of opposite sign but having an equal reactive magnitude, often achieved using an antenna tuning unit (ATU). The unit contains inductors and capacitors which can be altered, either manually or automatically, in such a fashion that the impedance presented by the feeder is transformed so that the transmitter is presented with an entirely resistive impedance of 50Ω.

The important point here is that *power can be dissipated only in resistive elements.* The *reactive* elements *cannot* dissipate any power when averaged over one cycle of the oscillation. Thus a pure inductance, or a pure capacitance, or a mixture of the two, cannot dissipate any power on average, and the reactive part of your antenna's impedance likewise does not radiate any power. That is not to say that it plays no part in radiating radio waves. It *does* affect the amount of power being dissipated in the resistive part because it alters the amplitude of the current flowing in the antenna. We usually want to make the current amplitude as large as possible, because greater current amplitudes produce larger electromagnetic fields and hence more-powerful radio waves. We could cancel out the reactive part at the antenna by adding a reactance of opposite sign and of just the right value, thereby 'tuning out' the reactive part. However, we do not need to do this at the antenna terminals, as I shall discuss.

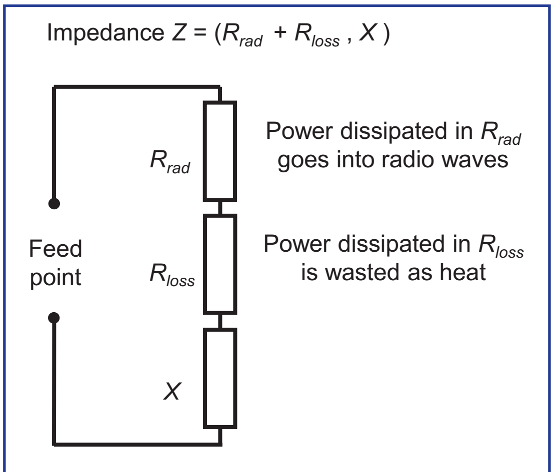

FIGURE 2: Equivalent circuit of an antenna.

We can imagine that an antenna behaves just like a two-number impedance, as shown in **Figure 2**. The resistive element itself generally comprises two parts, the 'radiation resistance' and the 'loss resistance'. When we transmit, the radio waves we generate take power away from the antenna. We can model this behaviour as a fictitious resistance in which the radiated power is dissipated. This is called the 'radiation resistance'. Let me say that again: the radiation resistance of an antenna is how we 'explain away' the power that is actually radiated, by pretending that it is instead just heating up a resistor. The higher the radiation resistance figure in proportion to the loss resistance, the greater the proportion of your hard-earned RF that is actually finding its way out into the great wide world. The loss resistance, on the other hand, represents the lossy elements of our antenna such as the resistance of the wires used to make it, or loss in ground currents associated with the induction fields of the antenna. Power dissipated here ends up as waste heat and not as radio waves. Our aim is to dissipate as much power in the radiation resistance as we can. The reactive part of the antenna impedance takes account of the phase difference between the voltage and the current.

The feed point of the antenna is often up in the air and remote from the output terminals of the transmitter, so we use a feeder of some sort to connect the two together. This is a transmission line, usually a coaxial cable or a ladder line and, if it has negligible loss associated with it, the line does a near-perfect job of transferring power from the transmitter to the antenna.

If the antenna and operating frequency are such that the impedance at the feed-point is purely resistive (and equal to 50Ω), and if we use a feeder with a characteristic impedance equal to it (ie 50Ω coaxial cable), then a resistive load of 50Ω is presented unchanged to the transmitter's terminals (**Figure 3a**). There are no standing waves on the line, indicating that all the power in the line is being carried by forward-moving voltage and current waves without anything going the reverse direction. If the feeder has a different characteristic impedance, it presents a two-part impedance to the transmitter terminals, with both a resistive and a reactive part (**Figure 3b**). The values depend on several factors such as the length of the line and its characteristic impedance. There are now standing waves on the line, indicating the presence of both forward-travelling and reverse-travelling waves, because some of the power is reflected by the mismatch at the antenna. However, if you now insert an antenna tuning unit between the transmitter and the end of the feeder, you can both 'tune out' the reactive part of the impedance and also transform the resistive part to the value of the load resistance for which the transmitter has been designed, usually 50Ω. In these circumstances, all of the power delivered by the transmitter into the antenna tuning unit is delivered by the feeder to the antenna and dissipated in the radiation and loss resistances (on the assumption that the antenna tuning unit has no loss associated with it) despite there being standing waves on the line. Note that this must be the case since there are no resistive elements in our system except the radiation and loss resistances associated with the antenna.

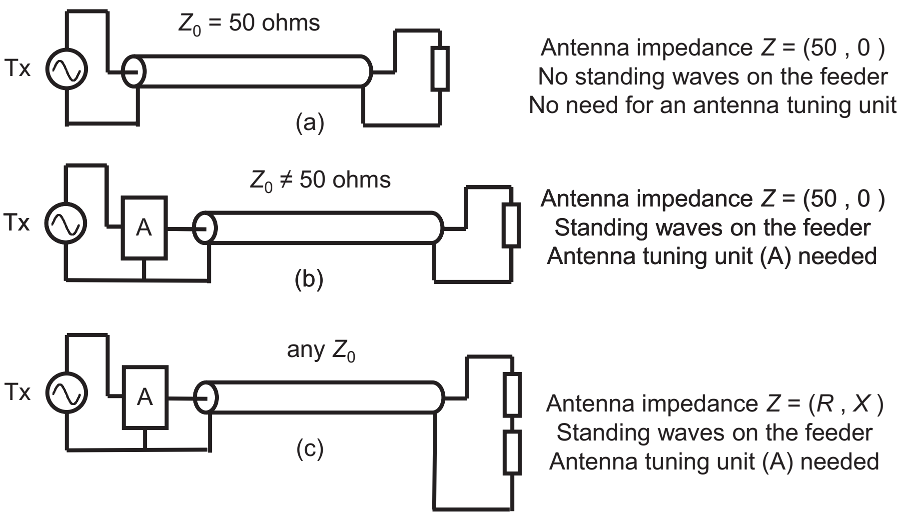

FIGURE 3: Using a feeder to connect the transmitter to the antenna: (a) perfectly-matched system; (b) using a different feeder; (c) the general case.

The more-usual case is that the impedance at the antenna's feed-point has both resistive and reactive parts, and neither value is near the characteristic impedance of the feeder (**Figure 3c**). Once again there will be standing waves on the line, and a two-part impedance with a resistive and a reactive component will be presented to the antenna tuning unit. But once again the (lossless) antenna tuning unit can be set to tune out the reactive part and transform the resistive part to 50Ω, hence all the power delivered by the transmitter will be dissipated in the radiation and loss resistances of the antenna.

The antenna tuning unit and feeder together form a transformer, converting the resistive part of the antenna impedance to 50Ω and cancelling out the reactive part so that the transmitter is presented with a pure resistance of 50Ω. So the answer to the question is – no – it does not matter if the (low-loss) feeder and the antenna are mismatched at the antenna and there are standing waves on the line, provided that – yes – there is an antenna tuning unit between the transmitter and the feeder set to tune out the reactive part and transform the resistive part to 50Ω.

All of this discussion does assume that you are using a feeder and antenna tuning unit and that there is negligible loss associated with them. This is often a good approximation at HF if you're using low-loss coaxial cable or ladder line and if the antenna tuning unit is made from top-quality components. If you have an especially-long feeder, or are forced to use a cable with a higher loss, then there may be an advantage in reducing the standing wave ratio on the line by improving the match between the cable and the antenna as this can increase the radiated power. I have never needed to do this in practice. Remember that doubling the radiated power makes a difference of only half an S point at the receiving end, so it is usually not worth doing this.

How much difference does loss in the feeder actually make? I will be discussing this in more detail in a following article entitled SWR and all that, but for now it is worth giving a couple of examples. Suppose that the loss in your feeder is 3dB. That automatically means that half the power delivered by your transmitter is lost as heat in the cable if the antenna is perfectly matched. You can only improve on this by replacing the cable with a lower-loss version. But there is even more loss if there is also a mismatch at the antenna. When the mismatch at the antenna feed point produces a VSWR of 3:1 in the cable at that point, a further 1dB of attenuation is added, making the total 4dB (or slightly over half an S-point at the receiving end). If the VSWR at the antenna feed point is 10:1, then the situation is worse and a further 4dB of attenuation is added, making a total of 7dB, or slightly more than 1 S-point at the receiving end.

To summarise, you should always use low-loss cable and an antenna tuning unit at the transmitter end of your feeder, and not worry too much about the actual impedance presented at the feed point of your antenna.

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