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Chapter 9
SIGNALS and NOISE

Some radio astronomer boys
Heard the Spice Girls through one of their toys
But amid "oohs" and "aahs"
"We've found life in the stars!"
..was it signal, or merely some noise?

Signals revisited.

In general, we regard a signal as simply a voltage or current which varies some way with time. In an earlier section of the notes some types (and sources) of electrical signals were briefly discussed. In general, we tend to meet two types of signal:

(a) Those which are artificially generated and purposely consist of some sort of regular, (or at least predetermined) pattern of voltage or current. Sources of signals such as these are usually referred to as *signal generators*, or *oscillators*, depending on the context in which they are used. These signals might be used for test purposes (such as measuring the gain of an amplifier), as part of a larger system for processing signals (for example, as part of a radio receiver), or perhaps as an information *carrier* (where another information-containing signal is "piggy-backed" onto it using *modulation*). These last two cases will be looked at a little more closely in later chapters.

(b) Those which carry information. Examples of this might be a voltage from a microphone, the signal received by your television antenna, the output signal from your VCR, or the output of a temperature sensor in your car engine.

Information-carrying signals are usually the most interesting to us, and we often need to know what limitations exist in their information content. One such limitation we have already met is that of *bandwidth* –the range of frequencies present in a signal. So, for example, the signals in telephone systems are deliberately restricted to a frequency range of about 300 Hz to 3500 Hz in order to conserve bandwidth without compromising voice intelligibility too much. Compare this with the signal recorded on a CD, which can include frequencies from about 20 Hz to 20 kHz.

Aside: *Signal bandwidth vs information capacity.*

Some of you may be aware that computer modems for use on normal telephone lines can transmit up to about 56000 bits/second of information. How is this possible with a bandwidth of only about 3.5 kHz? The answer is rather complicated, but in essence you can't directly equate the bandwidth of a signal or a system with the number of bits of information you can send each second. At any instant of time, the value of the voltage or current in the signal can actually represent more than one *bit* of information –at least to sufficient accuracy to make the whole thing work.

Noise

But there are other limitations. The most important of these is the presence of unwanted *noise* along with the signal. Noise is best thought of as an interfering background signal which is present along with the signal that we happen to be interested in. Even if all the frequencies present in a signal are preserved when it is transmitted from one place to another, noise will ultimately limit the accuracy with which the original information can be extracted when it is received.

In the case of sound, this sort of situation is probably not unfamiliar to you. If you are listening to your walkman on a busy street corner, it may be difficult to understand all of the song lyrics if the traffic is heavy. If you are watching TV and your little brother or sister insists on turning up the stereo system to compete, you will have no hesitation in telling them to "turn down that noise!". (This, incidentally, illustrates another point. There are some situations where "one person's signal is another person's noise", since to little brother/sister your TV program is probably just as annoying. Indeed, there are some multi-user communications systems where this principle is deliberately exploited.)

There are many sources of noise which can interfere with other signals. Some of these originate in other equipment. Some examples are car ignition noise, which you may often hear on your AM car radio when you are in a tunnel, or interfering noise radiated from a computer (try putting a portable AM radio next to your PC). Where interfering noise occurs through radio frequency *radiation*, it is known collectively as *RFI* (*radio frequency interference*). However, there are also many natural sources of noise. For example, an AM radio will often crackle due to distant lightning (but note that FM radio transmissions are a lot more resistant to this type of interference).

One of the most important types of natural electrical noise occurs in all electronic circuits. This is known as *thermal* or *Johnson* noise and is due to the unavoidable random jiggling of electrons in a conductor. It has power at all frequencies, and as the temperature rises, so does the noise level; the only way to remove it entirely is to cool a circuit to absolute zero temperature (about -273 degrees Celsius). Another fundamental type of noise (*shot noise)* is due to the fact that electrical current is not a continuous fluid, but discrete electrons. You can think of this as being the difference between water and sand flowing through a pipe –for large currents they behave fairly similarly, but for very small currents the sand flow is relatively much more "grainy".

Both thermal and shot noise show themselves as a background "hiss", of the sort that most FM radios produce when they are tuned between stations. A typical waveform for these types of noise is illustrated below; it is essentially random, and although we won't examine it any further here, its statistical properties are important in digital communications, which we will look at briefly in a later chapter.

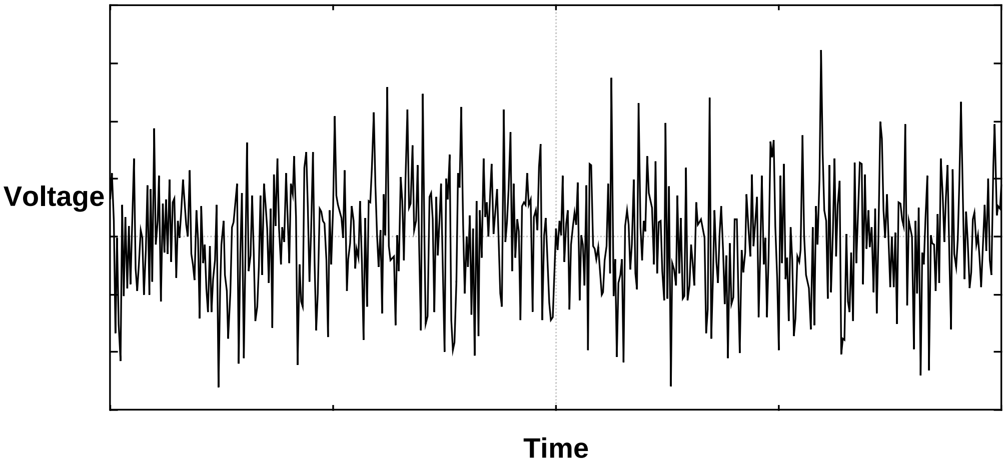

Figure 9.1 A typical noise voltage waveform which might be due to thermal noise.

A somewhat different type of noise is present in systems which store or transmit *analog* signals in *digital* form, such as CD players, and even your ordinary telephone system. As shown in the diagram below, an analog signal can be approximated by a series of discrete voltage steps in time or *quantised*, rather than being smooth (as it would have been when it originated in, for example, a microphone). It is actually quite reasonable to regard this staircase-like waveform as being the same as the original signal, but with the addition of a noise-like component (i.e. the "steps") due to quantisation, and this *quantisation noise* may in most cases be treated like other forms of background noise.

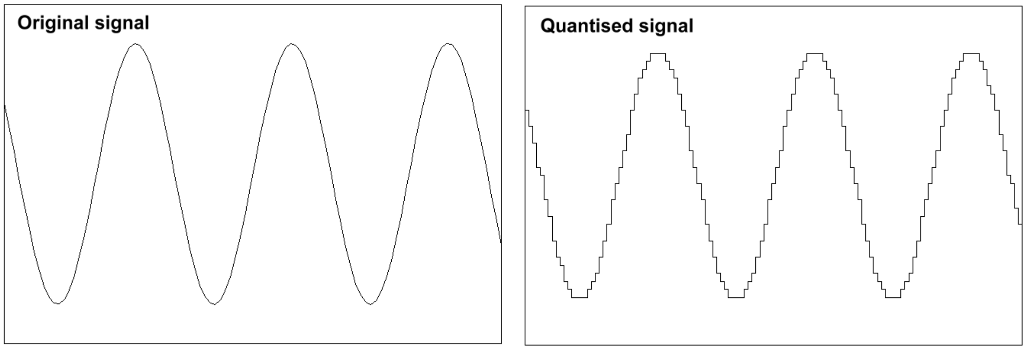

Figure 9.2 A quantised signal appears to be a "noisy" version of the original

Aside: *What is meant by the terms “analog” and “digital”?*

This question will arise again in a later chapter, when we look at digital circuits and signals. Fundamentally, an *analog* signal has a continuous range of possible values (for example, a particular voltage might lie anywhere between -20 volts and +20 volts). On the other hand, a *digital* signal can only have a certain limited number of values (for example, this might be -20, -10, 0, +10, +20 volts). When an analog quantity is approximated by the “closest” digital value that a system can provide, it is said to be *quantised*.

Signal-to-noise Ratio

All signals will, in practice, be corrupted by noise to some degree; what we are often interested in is: by how much, and how important is this corruption? The answer to the second question depends on exactly what we want to do with the signal, but usually it’s the **ratio** of the signal to the noise that’s important. As for the first question, we can usually make a measurement and express the result in a standard way.

The *signal-to-noise ratio* (often abbreviated to *S/N ratio* or *SNR*) of a signal is given by

$$\text{S/N ratio} = \frac{\text{signal amplitude}}{\text{noise amplitude}}$$

and is usually expressed in decibels, so that if the amplitudes are voltages or currents, then

$$\text{S/N ratio (in dB)} = 20\log_{10}\left(\frac{\text{signal amplitude}}{\text{noise amplitude}}\right)$$

where all the amplitudes are usually measured as *rms* values.

The diagram below illustrates a sine wave signal with noise added. Here the signal and noise amplitudes are about 10V and 1V rms respectively, so that the resulting S/N ratio is about 10, or 20 dB

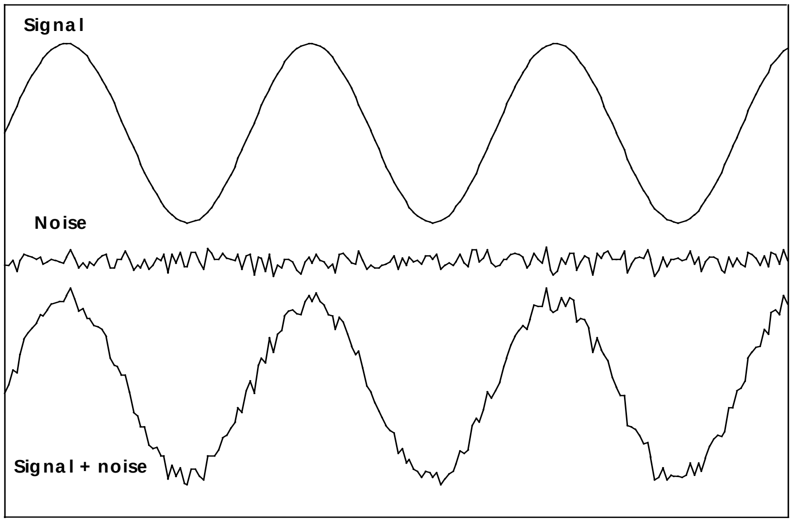

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Figure 9.3 Noise added to a sine wave signal. In this case the resulting S/N ratio is about 10 (20 dB).

Example 9.1: What is the S/N ratio in dB of the signal received by a radio receiver if the voltage at the input of the radio is 1 mV rms and the noise contributed by the receiver is 1 μV rms? (Assume that the receiver is the only source of noise).

Answer: S/N ratio (in dB) = $20 \log_{10}(1\text{mV} \ / \ 1\mu\text{V}) = 60$ dB

Example 9.2: KAOS places a hidden microphone in a room to eavesdrop on a conversation. In the middle of a cocktail party, the unwanted noise level is determined by the background conversation noise. This produces an output voltage of 150 mV. The voice of agent 86 standing nearby is picked up at a level of about 1 volt. What is the S/N ratio in dB?

Answer: S/N ratio (in dB) = $20 \log_{10}(1000 \text{ mV} \ / \ 150 \text{ mV}) = 16.5$ dB

Dynamic Range

A closely related term (and sometimes confused with S/N ratio, although slightly different) is the *dynamic range* of a signal or of a system carrying a signal. Like S/N ratio, the dynamic range is also usually expressed in decibels. It is defined (often somewhat loosely) in the following way:

For a signal:

$$\text{dynamic range} = \frac{\text{largest signal amplitude}}{\text{smallest signal amplitude}},$$

that is, a measure of the ratio of “loudest” to “softest”.

For a system:

$$\text{dynamic range} = \frac{\text{largest possible signal amplitude}}{\text{smallest detectable signal amplitude}},$$

where the amplitude of the largest possible signal is usually taken to be that of a sine wave just large enough so that *clipping* (or at least significant distortion) occurs, while often the smallest detectable signal amplitude is taken to be equal to the amplitude of the noise.

For a *digital* system, where voltages are represented by numbers, the dynamic range can be roughly defined as the ratio of the largest possible voltage step which can be represented to that of the smallest step. This ratio depends on the *number of bits* used to represent each voltage (16 bits are used in standard CDs, for example). For a system using n bits the result is:

dynamic range $\cong 2^n$, or
dynamic range **in dB** $\cong 6 \times n$ dB,

Example 9.3: A microphone with inbuilt amplifier, as used in a tape recorder, has an output noise level in a very quiet room (that is, with no signal) of about 30μV rms. The maximum output level is about 300mV rms before severe distortion occurs. What dynamic range does this represent?

Answer: The dynamic range is (300mV / 30μV) = 10,000 in voltage.

Expressed in decibels, this is $20 \log_{10}(10{,}000) = 80$ dB.

Example 9.4: What would be the approximate dynamic range of a digital audio recording system which used 12 bits?

Answer: The dynamic range is $2^n = 2^{12} = 4096$ in voltage.

Expressed in decibels, this is $6 \times n = 72$ dB.

What typical values would we expect for the dynamic range of various systems? The table below shows some examples.

Signal or system	**Typical dynamic range**	**Lower limit set by**	**Upper limit set by**
VCR (vision) signal	40 dB	tape noise	tape magnetic saturation
Vinyl record	45 dB	surface noise	groove spacing
Cassette tape	50 dB	tape noise	tape magnetic saturation
Compact disc	>90 dB	quantisation process (16 bits)	
Human hearing	120 dB	random motion of air molecules hitting ear drum	pain and damage
Good audio amplifier	>120 dB	thermal noise in circuit	power supply voltage

Table 9.1 Typical dynamic ranges of some common systems

The table shows one reason why it is not possible to make close to perfect copies of your CDs on cassette tapes, whose dynamic range is much less than the original CD. If you arrange the recording level so that the maximum possible signal amplitude on both systems corresponds, the background tape noise will swamp soft sounds recorded on the CD; conversely, if you arrange it so that the noise level of both is comparable, the tape will be severely overloaded on loud passages.

Some additional points:

- Note the relationship between two particular quantities: S/N ratio is always a property of a particular **signal**, while the dynamic range of a **system** really indicates the **maximum possible** S/N ratio for a signal passing through that system. Very often manufacturers of audio or video equipment quote "S/N ratio" figures which, strictly speaking, refer to the dynamic range (that is, the best attainable S/N ratio).

- The dynamic range of a **signal** indicates how much the amplitude varies over time. A good example of this is the sound in TV commercials, which often (in line with advertising "best practice"..) only has a range of "very loud" to "extremely loud". We would say that this signal has a relatively small dynamic range. The same would be true of certain types of rock music, while classical orchestral music tends to have a large dynamic range. In fact, it is normal practice in sound broadcasting to deliberately process audio signals so that their dynamic range is reduced, since the dynamic range of radio broadcasting **systems** (particularly AM) is limited to some degree. This technique is referred to as *compression* (not to be confused with digital *data compression*, which will be explained in a later chapter).

Preface to Chapters 10 to 12
WIRED and WIRELESS SIGNAL TRANSMISSION

In these next few chapters we will look at some of the principles involved in sending signals between two locations. This is referred to as signal *transmission*, regardless of whatever exact techniques are used.

Wired Signal Transmission

So far we have dealt with electrical signals occurring in circuits where the various components are directly connected together. If we want to analyse a circuit, we might apply Ohm's or Kirchhoff's Laws or whatever happens to be most useful or appropriate in the situation. But what happens if part of a circuit is somewhere else?

Suppose we have a resistor 100 metres away connected by long leads in series with our main circuit. Well, everything stills works pretty much as if the resistor were nearby and if we say, change the current in the circuit, and hence through the distant resistor, the voltage across the resistor will change appropriately. We are in effect transmitting a signal (that is, a change in voltage or current) between our main circuit and a distant location. In this case we are doing it via a *wired* connection –that is, there is some sort of direct physical connection between our *transmitter* (the main circuit –where the signal originates) and the *receiver* (the resistor). They are, in fact, part of the same circuit, and at least two wires must be involved, to allow a return path for the transmitter current to flow.

You are likely to encounter examples of wired signal transmission every day. Any two systems which pass information by wires or *cables* (a general term which includes multiple wires, or basically anything more complex than a single wire) use this method. Some examples might be:

- A normal (not mobile) telephone connection.
- A connection between a CD player and audio amplifier.
- A connection between a TV antenna and TV set.
- A connection between a computer and mouse.
- A connection between a computer and a network.

The technique of wired transmission might seem rather trivial and obvious, in the sense that transmitter and receiver are just part of the same circuit. However, we will see shortly that a number of complications arise, particularly at greater distances and/or higher signal frequencies. For example, so far we have conveniently neglected to mention that electrical signals do not travel instantaneously from one part of a circuit to another, although by everyday standards it might seem so. The laws of physics ensure that there is always a certain delay involved in wired, and indeed, in all forms of signal transmission.

Wireless Signal Transmission

As you are aware, signals are transmitted between two locations without using wires all the time –otherwise we would not have daily satellite weather images, radio news on the hour, TV remote controls, remote car alarms, mobile phones going off in restaurants, The Simpsons, or even eye contact between you and your friends. All these systems or situations rely on *electromagnetic (EM) waves*, a term which includes what we commonly call radio waves, microwaves, infrared radiation, visible light, and more. In fact, all these seemingly different things are in fact the same type of wave, differing only in frequency (or, equivalently, wavelength). We will say more about their nature and properties in due course.

Recently there has been a lot of interest in wireless devices and networks for computing, so that many computers of the future may not need to be "plugged in" to get access to things like printers or the Internet. Although some such devices and systems already exist, the concept of truly "portable computing" will probably come to fruition in the next decade.

A kind of "in-between" method of signal transmission uses *optical fibre*. Although it might be thought of as a wired connection, it actually uses a "light pipe" for signal transmission, and has many advantages of both wired and wireless transmission. We will look briefly at this technology later.

Aside: What do the terms "wired" and "wireless" usually mean?

When radio was first developed a century ago, it was referred to as "wireless", and many people would still know what you meant if you referred to a "wireless set". In modern communications the term has come to mean quite literally "without wires", but usually implies the use of electromagnetic waves. (However, if the US defense department worked out how to communicate by spraying sub-atomic particles around, I guess it would have to be called "wireless", since there is no direct electrical connection.)

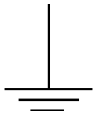
Chapter 10

SIGNAL TRANSMISSION BY CABLE

Now let’s consider some aspects of transmitting signals by means of wired connections. In most cases a "cable" is simply the name we give to the two or more wires that carry signals. I’m going to use the term a little more precisely here, to mean **just** two wires. In many cases, one of these wires is connected to *earth* (or *ground*). This wire can be considered to be the "return path" for the signal and the other wire is considered the "signal" wire (although of course the same current should flow in each).

****Aside:*** *What on earth is an earth?*

The term *earth*, or equivalently, *ground* simply means a **common (shared) connection point** in a circuit with respect to which we choose to measure all our voltages. Remember that voltage is always measured **between** two points in a circuit –we can't just measure the voltage at a single point. So in practice we usually measure between some chosen common point (which we call earth) and any other point of interest. That is, we can think of earth as being our voltage reference or "zero voltage" point. Historically, the name "earth" came about because a common connection in many cases was made literally through the earth (you can build a telegraph system with only one wire, using the earth as the return current path). The most common circuit symbol for an earth connection is shown at the left.



Shielding

Of course, it doesn't matter whether our two wires are really round or flat or some other shape, as long as they are relatively good conductors. In many cases, the wire which is connected to earth in a cable is constructed in the form of a woven wire mesh (or *braid*) or thin metallic foil surrounding, but insulated from, the other conductor by a tube of plastic material, as shown in the diagram below. The whole cable is then sheathed in an outer insulating jacket.

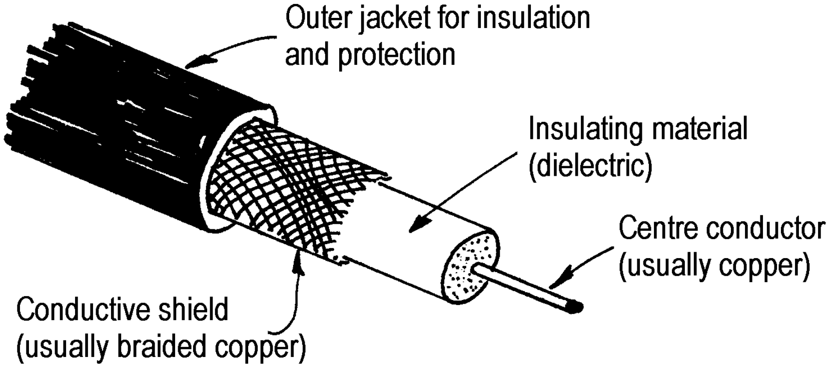


Figure 10.1 Cutaway view of a cable with coaxial construction.

You will find this sort of *coaxial* construction in, for example, the leads connecting CD players to amplifiers, or probably your TV antenna lead. One important role this type of arrangement is to provide *shielding* of the signal wire from any stray electric (and, to a lesser extent, magnetic) influences of things such as appliances, computers, house wiring and so on, which could cause interfering noise to be added to the signal. In extreme cases, a solid metal outer shield rather than a woven braid or wrapped foil is used to provide a very high degree of shielding, as well as physical rigidity. The unsightly pay TV cables you see festooned around suburbia have this sort of construction; even though they have a solid aluminium shield, they are still flexible enough for easy installation.

Cables have capacitance

Apart from shielding, it often doesn't really matter very much as to what sort of wires we use to send signals at relatively low frequencies (for example, in the audio range) and over short distances. There are some obvious exceptions, for example, like the need to ensure that the insulation on mains power cables is adequate for the voltage between conductors, and that cables are not so flimsy as to break, but what I'm really talking about here are the normal electrical properties of the cable. At high frequencies, or for long cable runs (these are just two sides of the same coin), it turns out that things can become both more messy and more interesting.

Whenever two wires are in close proximity (and remember we need a pair of wires to transmit our signal), there will always be a small amount of *capacitance* between them. A one-metre length of shielded cable will typically have a capacitance of 30 to 100 pF (picofarads) between its centre conductor and the outer shield. Since, for a short length of cable, this capacitance is reasonably small, its effect is often ignored at low frequencies. This is because it has a large *reactance* (which is how the capacitance will "show up" in the circuit), and won't have much effect on the open circuit between the wires[1].

However, cable capacitance cannot always be ignored, particularly at high audio frequencies and above. It can affect the operation of a system by combining with the output resistance of an amplifier or other device to form a *low-pass filter*, which may severely attenuate higher frequency components in a signal. Hence interconnecting leads on audio equipment are often kept reasonably short, or special amplifiers used to drive them.

**** Aside:*** *Filters.*

You briefly met the concept of electrical filters in an earlier chapter. Broadly speaking, these are circuits deliberately designed to have a lot more (or less) gain at some frequencies than others, so that certain ranges of frequencies can be effectively removed from a signal. Filters which allow low frequency signals to pass through unchanged, while blocking high frequency signals, are referred to as *low-pass* filters.

A simple form of low-pass filter consists of a resistor and capacitor, connected as shown below. Roughly speaking, this circuit has little effect on signals at frequencies below about $\omega_0 = 1/RC$, while above this frequency signals are increasingly attenuated as the frequency rises. ω_0 is referred to as the -3dB frequency, since it is the frequency at which the gain of the circuit has dropped by 3dB compared to its gain at dc.

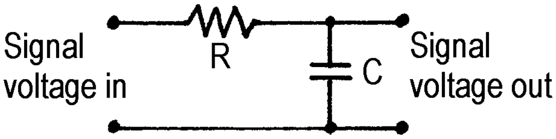


Figure 10.2 Circuit of a simple low-pass filter

Sometimes, the natural unavoidable properties of some circuit components connected together cause them to behave as a filter, even though this is not the intended main function of the circuit.

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[1] You will recall that recall that the reactance of a capacitor is equal to $1/(2\pi fC)$ ohms, where f is the frequency, and so will be large at low frequencies. This can be thought of as close to an open circuit, which corresponds to **infinite** resistance or reactance.

Cables have inductance too..

Similarly, **any** piece of wire actually has some *inductance* (you will remember that inductance is a property of "a coil of wire"). For short lengths of wire at low frequencies, we usually ignore it, just like the capacitance. Now let's just look at an *equivalent circuit* of the pair of wires in a cable if we include both the capacitance and inductance. It's actually something like the diagram below; the main idea I want to get across is that it's becoming fairly messy.

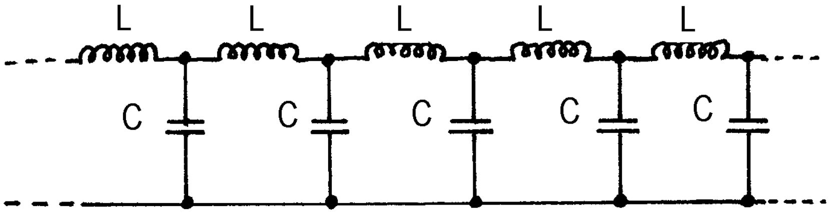

Figure 10.3 Simple equivalent circuit of a cable.

To make it more understandable, I have split up the cable inductance and capacitance into many separate little components labelled L and C; the overall effect is pretty much the same as for a continuous cable.

At this point you might imagine that trying to use a long length of cable for anything useful might be a nightmare! But it turns out that not all is lost...

Characteristic impedance of a cable

If we connect a signal generator to one end of a cable, the signal actually travels **as a wave** along the cable at a good fraction of the velocity of light. In situations where this becomes important it is common to refer to cables as behaving like *transmission lines*. If nothing is connected at the far end of the cable (that is, it is an *open-circuit*), the signal will actually be reflected back along the cable.[1]

However, a rather interesting thing happens. If a certain value of resistance is connected between the wires at the far end of the cable, there will be no reflection. All the power in the signal is turned into heat in the resistor. This special resistance value is called the *characteristic impedance* of the cable, and is usually denoted by the symbol Z_0 ("zed-nought").

---

[1] This is just like the echo of a sound wave off a distant wall, or the reflection of a water wave from the far end of the bathtub after you drop your rubber ducky in. Strangely enough, a very similar thing also happens if the far end is shorted-circuited rather than open-circuited.

Furthermore, as far as the generator is concerned, the near end of the cable behaves **as though it were simply a resistor, having resistance Z_0**, in spite of having some inductance and capacitance. Furthermore, this resistance value is the same **at any frequency**. The characteristic impedance Z_0 is fixed for any particular type of cable, and depends on the exact values of L and C per length of the cable.

The idea of connecting something across the end of a cable (whether it's the correct characteristic impedance or not) is referred to as *terminating* the cable. If a cable is terminated with a load of the same resistance as its characteristic impedance, it's said to be *matched.*

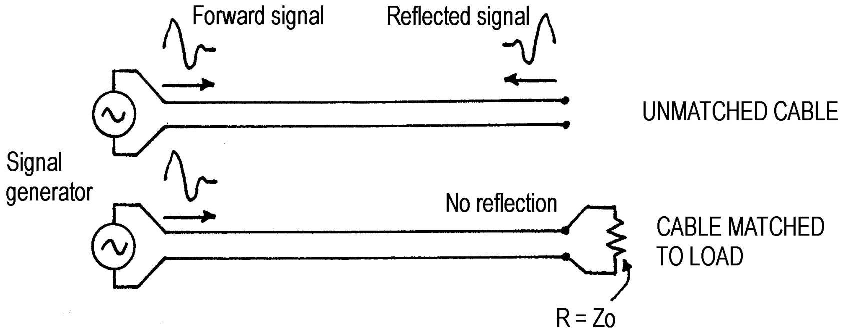

Figure 10.4 Terminating a cable with a resistance equal to its characteristic impedance eliminates signal reflections.

Cables are designed to have a range of characteristic impedances, but two common ones are 75Ω for video systems (for example, coaxial antenna cables or VCR leads) and 50Ω for many other radio-frequency systems. The "flat ribbon" cable occasionally used to connect TV antennas is of course also a transmission line, just like any pair of wires; its characteristic impedance is 300Ω. The antenna input connection of your TV set will be designed to look like a 75Ω or 300Ω resistor so that the antenna cable is correctly terminated.

The idea of using impedance matching, particularly with cables, is quite useful in practice. As well as cables, most radio-frequency amplifiers and other components (such as antennas) are designed to work with 50Ω or 75Ω generators and loads. These are then connected together with cables of the appropriate characteristic impedance.

There are several advantages to this "impedance matched" approach:

- As we have just seen, reflections along cables are minimised. Amongst other things, reflections can cause additional delayed versions of the signal to also be received, which can seriously affect the transmission of information.

- Maximum signal power is transferred to the load (since no signal is reflected). This can be very important for efficiency if you are a radio or TV broadcaster with a transmitter delivering 20 kW of power through a cable to an antenna
- The characteristic impedance is the same, regardless of the cable length. So is the impedance looking into the "near" end of a cable, and, ideally, it always looks just like a resistance. Hence, provided you terminate everything correctly, you can just connect all your bits and pieces together like plumbing components.

*** *Aside:*** An important part of microwave engineering concerns not only impedance-matched systems, but what happens when things aren't matched (said to be "mismatched"), and what to do about it. In this case a cable does **not** behave like a resistor, but as an inductor or capacitor, whose value depends on the frequency **and** the cable length.

*** *Aside:*** At **audio** frequencies, matching to eliminate reflections is, in general, not an issue, since the time taken for a signal to be reflected back is very short compared to the period of any frequency component in the signal. So, for example, a loudspeaker is not impedance-matched to an amplifier or the connecting cables. In fact, it is extremely difficult to do so.

Velocity factor

How fast a signal travels along a cable depends on the properties of the insulating material (or *dielectric*) between the two wires. The velocity is usually expressed as a fraction of the velocity of light, and is always less than one, so that

$$\text{Velocity factor} = \frac{\text{wave velocity along cable}}{\text{c}},$$

where c is the velocity of light $(3.00 \times 10^8 \text{ m/s})$

For the dielectric materials used in common cables (for example, polyethylene, air–polyethylene foam and Teflon) the velocity factor is typically in the range 0.66 to 0.85.

Example 10.1: A particular type of cable has a velocity factor of 0.70. With what velocity does the signal travel? How long would it take for the reflection of a pulse on a 200 metre length of cable which has been short-circuited at the far end?

Answer: Signal velocity = velocity factor × c
= $0.70 \times 3.00 \times 10^8$ m/s = 2.1×10^8 m/s
Total return trip distance for reflection = 2 × 200m = 400m
Time taken = distance /velocity
= 400m / (2.1×10^8) = 1.9×10^{-6} sec (1.9 μs)

Attenuation in cables

Our simple picture of a cable isn't quite complete. We have assumed that there is no *loss* in a cable –that is, that none of the signal power is converted to heat **in the cable itself**. To lose power in this way, there must be something in the cable that behaves like a resistor. Of course, the wires must have some resistance, which may be small, but not negligible if the cable is long enough. Worse still, at high frequencies, the apparent resistance increases due to a phenomenon called *skin effect*, where currents prefer to flow on the **surface** of conductors.

Without going into details, it turns out that the skin effect mechanism is usually the most important. This has the effect of making the cable more "lossy" at high frequencies. Note, however, that this does not affect the characteristic impedance. We usually measure the *loss* or *attenuation* of a length of cable in dB. It turns out that for most cables, (at frequencies still low enough so that the loss is dominated by skin effect) the attenuation in dB varies approximately as the square root of the signal frequency. A reasonable estimate for the attenuation per metre of cable at any frequency f is thus:

$$\text{Attenuation per metre} = \frac{A_{100}}{100} \cdot \sqrt{\frac{f}{f_0}}\ \text{dB}$$

where A_{100} (usually quoted in manufacturer's catalogs) is the attenuation per 100 metres at some reference frequency f_0. Note that, at any particular frequency, the loss in dB is just proportional to the cable length. This formula is adequate in most common situations where precise attenuation figures are not needed –for example, in calculating the loss of a long TV antenna cable.

As much higher frequencies, losses in the dielectric material between the two conductors of the cable can also be important. Often special "low-loss" cables are used –for example, to connect a TV transmitter to an antenna. These cables are often rather thick and avoid the use of solid dielectric materials. Much lower loss is obtained through the use of "foam" dielectrics or other materials which are largely air.

Example 10.2: (a) The Dick Smith catalog lists a particular type of TV antenna coaxial cable, with a quoted loss of 10.2 dB per 100m at 200 MHz. Assuming skin-effect losses only, estimate its attenuation per metre at 530 MHz.

Answer: Attenuation per 100m (A_0) at 200MHz (f_0) = 10.2 dB

$$\text{Attenuation per metre } = \frac{A_{100}}{100}\cdot\sqrt{\frac{f}{f_0}}\ \text{dB}$$

$$= \frac{10.2}{100}\cdot\sqrt{\frac{530}{200}} = 0.166\,\text{dB}/\text{m}$$

(b) You connect your TV antenna via a 20 metre length of this cable. The signal from SBS Channel 28 (near 530 MHz) is 1 mV, measured at the antenna. What voltage would you expect to measure at your TV set?

Answer: At 530 MHz, the cable loss is 0.166 dB / m. So the loss for 20 m of cable will be 20 × 0. 166 = 3.32 dB.

We use the dB formula for voltage (that is, ratio in dB = 20 $\log_{10}$ (V_1/V_2), where V_1 and V_2 are the voltages at the antenna and TV set). Note that we know that the voltage at the antenna must be higher, so there shouldn't be any confusion about which way round they go. So we have

$$20\log_{10}\left(\frac{\text{V at antenna}}{\text{V at TV set}}\right) = 3.32$$

We can rearrange this to give

$$\left(\frac{\text{V at antenna}}{\text{V at TV set}}\right) = 10^{\left(\frac{3.32}{20}\right)} = 1.47$$

which gives the voltage at the TV set to be 0.68 mV (680 μV)

(c) You are an engineer working for SBS TV (Channel 28, 530 MHz), and are installing a new transmitter and antenna. There is a long 80m cable run from the transmitter to the antenna, and normally you would use rather expensive super low-loss cable for this job. Unfortunately, your budget has been cut yet again by the government, and you decide to economise by using this same cable from Dick Smith. How much of your 30 kW transmitter power actually reaches the antenna?

Answer: The total cable loss at 530 MHz = 0.166 dB / m × 80m = 13.3 dB.

We can use the dB formula for power to give:

$$10\log_{10}\left(\frac{\text{power at transmitter}}{\text{power at antenna}}\right) = 13.3, \quad \text{and rearranging we have}$$

$$\left(\frac{\text{power at transmitter}}{\text{power at antenna}}\right) = 10^{\left(\frac{13.3}{10}\right)} = 21.4$$

This gives the power at the antenna to be about 30/21.4 = 1.4 kW. This is less than 5% of the power from the transmitter, so you have basically put together a highly effective cable heater!

*** Aside:** *Coaxial cable vs shielded cable –what's the difference?*

Strictly speaking, the term “coaxial” refers to the concentric arrangement of conductors in a cable, while “shielded” implies that the conductor(s) are surrounded by some sort of conducting sheet for the purposes of shielding.

What we usually call “shielded” cable is often coaxial in construction, but is not normally used as a transmission line. It is not designed to have a specific characteristic impedance, but often to have as low a capacitance as possible between the centre conductor and the shield. It tends to be used at audio frequencies (for example, for connecting a CD player to an amplifier).

So called “coaxial” cable (or “*coax*”) is usually deliberately designed for use as a transmission line at high frequencies, and is designed to have a specific characteristic impedance. It tends to be a bit larger and more robust than simple “shielded” cable. Often, however, it is used purely as shielded cable for test leads and so on, particularly as suitable connectors are readily available for common types of coax.
