16 A Short Introduction to Real Components

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Prerequisite knowledge required: Complex impedance (for the effects of parasitic components only)

16.1 Introduction

One of the most common causes of a circuit not working is that the wrong component has been used. (Just getting a resistor out of the drawer marked "10k resistors" doesn't guarantee that the resistor has a value anywhere near 10k: people can and do put resistors in the wrong drawers. Exactly the same thing happens with capacitors and inductors (and indeed anything else you may find in the lab cupboards).)

However, even if you do get the right nominal value of component, you might find that in an actual circuit it doesn't work quite as you expect, since real components don't behave exactly like the mathematically ideal resistors, capacitors, inductors and op-amps we usually study.

This note is designed to provide some guidance in how to quickly check that the component you've just picked out of the drawer actually is the right one for your circuit, and to provide some warning about when, and how, the performance of real components deviates from the ideal.

16.2 When is 100 = 10?

Answer #1: when it's printed on an electronic component. I should explain: there is a convention in putting numbers on components (whether it's printed using digits or using a colour code) that the last number is not a significant digit; it's called the multiplier, and it tells you how many zeros should be added to the end of the number represented by the other digits (in other words the power that 10 should be raised to before multiplying with the number represented by the other digits).

So "100" (or brown, black, black) when printed on a resistor, actually means:

$$10 \times 10^0 = 10 \times 1 = 10 \tag{16.1}$$

Similarly, "333" (orange, orange, orange) means 33,000 since:

$$33 \times 10^3 = 33 \times 1000 = 33000 \tag{16.2}$$

and "1164" (brown, brown, blue, yellow) means 1,160,000 since:

$$116 \times 10^4 = 116 \times 10000 = 1160000 \tag{16.3}$$

You might have noticed that if you've got a resistor less than 10 ohms, then there's a problem with this scheme. If you're using colour codes then there's a solution: gold as a multiplier means 0.1 and silver means 0.01. However if you're using numbers, then you have to do something else, and the usual solution is to use an 'R' where the decimal point should be for a resistor, or 'p' for a capacitor, or 'n' for an inductor.

So, for example a capacitor with "5p6" written on it would be a 5.6 pF capacitor, and a resistor with "R33" on it would be a 0.33 ohm resistor.

16.2.1 The Colour Code

You probably noticed some references to a colour code in the previous section. Instead of printing the numbers themselves, a series of colours is widely used in labelling electronic components; you'll come across this in particular with through-hole resistors[1]. Each digit has a colour associated with it (note that I've included the tolerances in this figure for completeness; I'll write more about tolerances in the next section):

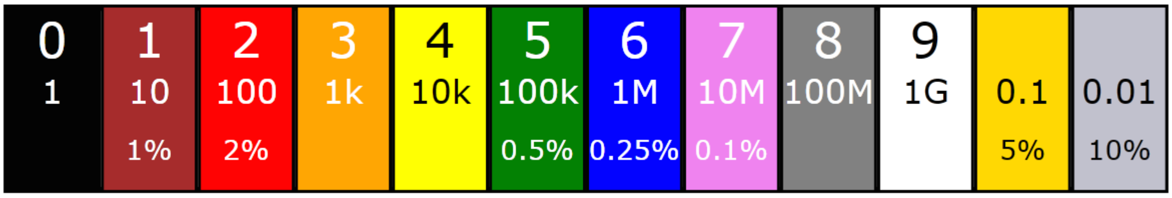

Figure 16.1 The electronic colour code

Table 1 Table of the colour codes

Colour	As a digit	As a multiplier	As a tolerance
Black	0	x 1	
Brown	1	x 10	1 %
Red	2	x 100	2 %
Orange	3	x 10^3	
Yellow	4	x 10^4	
Green	5	x 10^5	0.5 %
Blue	6	x 10^6	0.25 %
Violet	7	x 10^7	0.1 %
Grey	8	x 10^8	
White	9	x 10^9	
Gold		x 0.1	5 %
Silver		x 0.01	10 %

Note that the numbers from 2 through 7 are in rainbow order; white (the sum of all colours) is the biggest digit (9) and black (the absence of all light) is zero. The others you just have to learn.

You'll often find the colour code system used on through-hole resistors, (more rarely) on capacitors and (very rarely) on inductors. If used on resistors, there is usually another colour band as well, once which indicates the tolerance of the resistor: how close the actual resistance is likely to be to the specified.

So for example, a resistor with coloured bands yellow-violet-red-brown would be a 4k7 resistor, since the third band (red) is the multiplier band, and:

$$47 \times 10^2 = 47 \times 100 = 4700 \qquad (16.4)$$

The final band (the brown one) indicates a tolerance of 1%.

[1] Through-hole resistors are resistors with leads which go through holes in the printed circuit boards used to build circuits. (As opposed to surface-mount resistors, which don't have leads and sit on the top of circuit boards.)

Surface-mount resistors are usually labelled using digits, which are usually[2] the first two significant figures of the value and the multiplier.

16.2.2 When is 100 = 10 (again)?

Answer #2: never. I'll need to explain again. Components are never the value that they claim to be. There's no way that you can manufacture a resistor to have an exact value (in other words a 10 ohm resistor is never 10.0000000000000000…. ohms and a 10 pF capacitor is never 10.0000000000000…. pF), and even if you could, as soon as the temperature changed the resistance/capacitance would change as well (all real components have a temperature coefficient which specifies how much their value changes with temperature).

So, if a resistor marked "100" isn't exactly ten ohms, how close to ten ohms will it be? The answer depends on the component tolerance. All components have a tolerance, and this is also indicated by a number or colour in many cases (see the chart above). This tolerance band is the last band on a four- or five-colour band resistor.

For example: a 1k resistor with a 1% tolerance band could have a value anywhere between 990 ohms and 1,010 ohms. The resistors in the shelves in the lab are almost all 1% tolerance resistors (so the tolerance band is brown).

For surface mount resistors (which don't use the colour code, they just print the numbers) there isn't a tolerance band, and you usually have to look up the tolerance in the datasheet.

16.3 Equivalent networks and parasitics

We've come across the principle of equivalent networks before: the idea is to find a simpler network that behaves exactly (or almost exactly) like a more complex network of components. This is the idea behind the Thévenin and Norton networks (in which any number of linear elements in a two terminal network can be represented by a single source and single impedance), and the principle of replacing a network of series and parallel-connected resistors or capacitors with one component.

In a sense, the idea of using equivalent networks to represent real components is the reverse: rather than replacing a network of multiple components with just one or two components (reducing the complexity of the circuit), the task here is to try and find a network of several ideal components elements which behaves in the same way as one real component.

Why replace one component with several, thus making a network more complex? Because by doing so we can represent the behaviour of a real component in terms of the basic circuit elements (inductance, resistance and capacitance) which we know how to handle, and which can readily be analysed and simulated.

For example, all real wires have some inductance (since even a short straight wire creates a magnetic field around it when current flows through it, and any change in this magnetic field induces a potential difference in the wire). Also any node in a circuit (in fact anywhere that charge can be)

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[2] There is another way to label surface-mount resistors: a rather confusing thing known as the EIA-96 marking scheme, which uses a letter to indicate the multiplier. If you see a surface-mount resistor with a letter (other than an 'R') on it, this will be why. You'll then have to look up the value in a table (search on-line for "EIA-96").

will have some capacitance linking it to every other node in the circuit, since a build-up of charge at one place in the circuit will tend to repel other charges elsewhere in the circuit.

We can add the effects of these *parasitic* capacitance and inductance elements into circuit analysis by using a suitable equivalent network in place of the ideal passive component.

16.4 Resistors

There are two main types of resistor that we'll be using in the labs: thin-film through-hole resistors and surface-mount resistors. Through-hole resistors are designed to be mounted through holes in the circuit board, surface-mount resistors are designed to be placed on the surface of the circuit board[3].

Figure 16.2 Surface-mount resistor (taken from http://www.resistorguide.com/fixed-resistor/)

Surface mount resistors (in fact all surface-mount components) tend to perform closer to the ideal than their larger through-hole variants. This has a lot to do with their smaller size and the lack of leads and their inductance. (Any wire, even a straight wire, will have some inductance.)

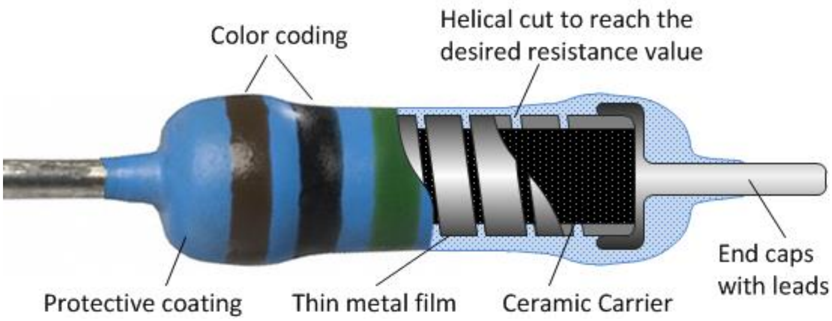

Figure 16.3 Thin film resistor (taken from http://www.resistorguide.com/metal-film-resistor/)

Through-hole resistors, however, may show some unexpected behaviour, particularly at very high frequencies. They will in real life have some inductance associated with the wire emerging from each end, and some capacitance due to the small gaps between the loops of the metal film due to the helical cut. For a well-designed resistor, the effects of this added capacitance and inductance will be small, however at very high frequencies they can have a noticeable effect.

We can model the performance of these components at high frequencies using the idea of an equivalent network and include the effects of the capacitor and inductor in one of two ways:

[3] The clue is in the name.

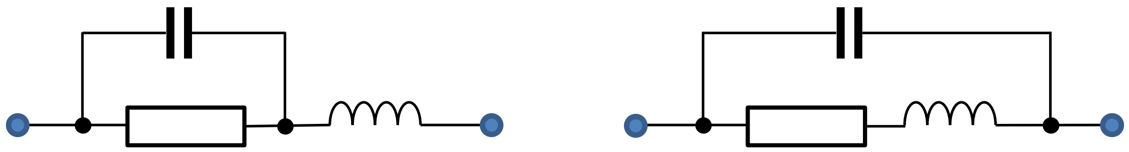

Figure 16.4 Possible equivalent networks for thin-film resistor

Neither of these equivalent networks will represent the actual performance of the resistor exactly; they are both approximations. Which one gives the best approximation will in general depend on which range of frequencies you are most interested in. This raises an important point:

- The best equivalent circuit to use is usually dependent on the frequency range of interest

Here, with most capacitance between the helical cuts and most inductance due to the leads extended straight out from the component body, the first of these equivalent circuits is likely to be slightly preferred for most of our investigations.

The only other type of resistor you may come across in the labs is a power resistor, designed to be able to handle a lot of heat. These resistors are large, and have tags on either end to which wires can be soldered. (These resistors are not usually mounted on printed circuit boards because they get too hot, and the very thin tracks on a typical circuit board just can't handle the currents that these resistors are designed to accept. Instead, they are bolted to heatsinks to help dissipate the heat.)

Figure 16.5 Wirewound power resistor (taken from http://www.resistorguide.com/wirewound-resistor/)

Apart from the effects of the parasitic capacitance and inductance, the other important differences between ideal resistors and real resistors (apart from their tolerance) are the effects of the temperature coefficient and the effects of ageing.

Resistors dissipate heat, which means that in operation they get warm, and this temperature rise results in a change in the value of the resistance. In most cases this is not significant, as the temperature coefficients of typical metal film resistors is around 10 parts per million (ppm) per degree Centigrade, which means that even if the resistor heats up by 100 ^{0}C the resistance would only increase by a factor of 0.1%.

More significant can be ageing effects: a slow change in the value of the resistance over time. This effect can be due to moisture getting into the resistor, and can be reduced to negligible levels by careful design and manufacture of the epoxy coating around the resistor.

16.4.1 The effect of resistor parasitics

Modern metal film resistors (such as used in the lab) have very low parasitic values, often less than 0.05 pF for the capacitor and 10 nH for the inductor (these are typical values for through-hole resistors).

These parasitics have very little effect at low frequencies, but can have a measureable effect at higher frequencies:

Table 2 Effect of parasitic components in a through-hole resistor

Frequency	Impedance of 10 nH parasitic inductor	Impedance of 0.05 pF parasitic capacitor
10 kHz	0.63 mΩ	320 MΩ
100 kHz	6.3 mΩ	32 MΩ
1 MHz	63 mΩ	3 MΩ
10 MHz	630 mΩ	300 kΩ

From these considerations, you can determine a suitable frequency range for the resistors. For example, if you are interested in frequencies up to 1 MHz, and want the parasitic effects to be less than 1% of the value of the resistor, then these results suggest you should use resistors with values between 6R3 and 30 k. (The lower limit comes from the effect of the series inductor, the higher limit from the effect of the parallel capacitor.)

It should be noted that surface-mount resistors (which are smaller and don't have leads) have much lower parasitic series inductance and lower parallel capacitance and are therefore behave much closer to ideal resistors at higher frequencies.

16.5 Capacitors

Capacitors are formed by separating one conducting surface from another conducting surface. The area of the surfaces, the distance they are apart and the dielectric constant of the material between them dictate the size and properties of the capacitor.

The trick to making a capacitor with a large value for its physical size is to find a way to pack a large surface area of conductor into a small space, separate them by a very small distance, and fill the gap with a dielectric with a very high relative permittivity.

There are a lot of different types of capacitors using a wide variety of dielectric materials, and we'll be using a few of them in the labs. They can broadly be divided into the following categories:

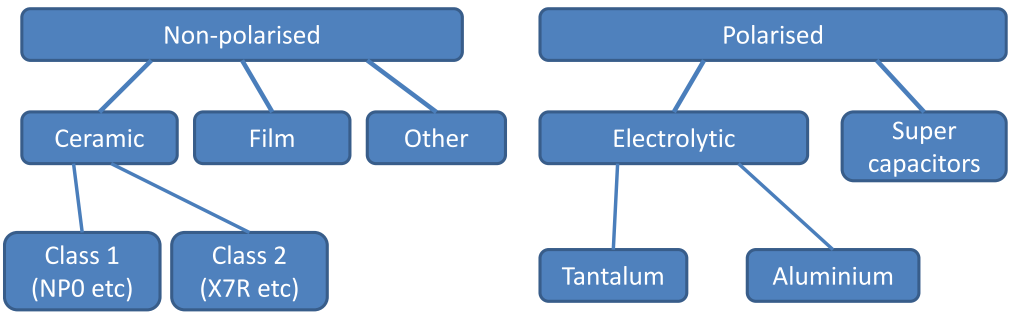

Figure 16.6 The major categories of capacitors

(Polarised capacitors have a positive terminal and a negative terminal and will only work as capacitors provided the positive terminal is at a higher voltage than the negative terminal. Non-polarised capacitors can be used either way around.)

The way capacitors indicate their values depends on what type of capacitor they are: some larger capacitors have enough room on their bodies to write out the value in full including the units, others assume you know what the units are (likely to be pF for non-polarised capacitors and µF for polarised capacitors are the most common), others use the colour codes.

One way to tell them apart: non-polarised capacitors will usually have two leads the same length; polarised capacitors will usually have their legs different lengths (the positive leg is the longer one).

Figure 16.7 A selection of non-polarised capacitors

Smaller surface-mount ceramic capacitors tend not to have anything written on them at all, but most through-hole ceramic capacitors tend to be labelled with the value using the standard scheme but using pF as the unit, with an additional digit representing the tolerance[4]: M is ±20%, K is ±10%. So for example, a capacitor labelled “472K” would have a nominal value of 4.7 nF, since:

$$47 \times 10^2 = 47 \times 100 = 4{,}700 \text{ pF} = 4.7 \text{ nF} \tag{16.5}$$

with a tolerance of 10%, which means it could have a value anywhere between 4.23 nF and 5.17 nF.

Larger polarised capacitors tend to be different, and just write the value on the body of the component. After all, it’s easier to read, and the bodies of these capacitors are large enough to do this.

16.5.1 Ceramic and film non-polarised capacitors

The type of dielectric used between the plates of the capacitor determines many of its properties, most notably the temperature dependence. Non-polarised ceramic dielectrics are known by a set of standardised three-character names. For example, “NP0” implies a very low temperature coefficient (around ±30 ppm/C), but they are more expensive, and physically larger than the equivalent value of a capacitor with an “X7R” dielectric (which can have a temperature coefficient of over ±800 ppm/C). (There are lots of other types of dielectrics; I’ve chosen these two common ones as examples only.)

Whether the temperature coefficient is a problem or not depends on the application. For some circuits (for example filter or timing circuits), it’s important for the value of the capacitance to be

[4] There are others (for example F = ±1%, G = ±2%, J = ±5% and the asymmetric Z +80/-20 %), but you’re unlikely to come across these in this module.

stable with temperature; in other applications (for example smoothing power supplies) the exact value of the capacitance is not as critical to the operation of the circuit.

Film capacitors are not based on ceramic dielectrics, but are constructed from thin layers of dielectric material with electrodes on both sides. Just about any insulator can be used for the film, and capacitors have been made using a wide variety of plastic and other materials (including air, glass and mica). These types of capacitors can have values that are very stable with temperature, and can tolerate higher voltages across the terminals than ceramic capacitors.

16.5.2 Tantalum and electrolytic polarised capacitors

Polarised capacitors only work if their positive terminal is at a higher voltage than their negative terminal, so they are not suitable for all situations, but they can provide very large values of capacitance at a much lower cost than ceramic or film capacitors. There are two common types of polarised capacitor; the first of these types is the tantalum capacitor:

Figure 16.8 A tantalum capacitor

Both the value (in µF) and the maximum working voltage of these capacitors is printed on them. In some cases it's not clear which is which, however if only one number is in the E6 series (as is the case here), it's obvious: this is a 2.2 µF capacitor with a maximum working voltage of 25 V.

The other common type of polarised capacitor is the aluminium electrolytic capacitor.

Figure 16.9 An aluminium electrolytic capacitor

These often have the entire value (including the units) printed on the case. (Figure 16.9 shows a 4700 µF capacitor).

Both of these capacitors obey the convention that the longer lead is the positive terminal, although for some reason it's usually the positive terminal that is indicated on the body of the tantalum capacitors (with the '+' symbol), whereas it's the negative terminal that's indicated on the body of the electrolytic capacitors (with a grey stripe including the '-' symbol on one side of the body).

16.5.3 Non-ideal capacitors

Equivalent networks can also be produced for capacitors. A typical capacitor equivalent circuit is shown below:

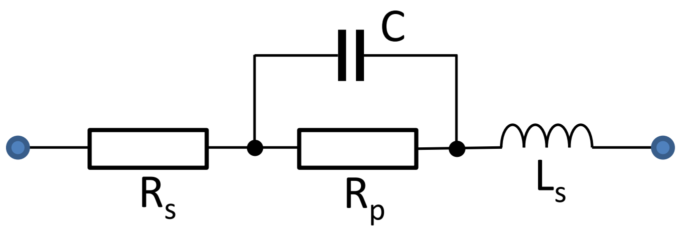

Figure 16.10 A general equivalent network for a capacitor

This time there are two parasitic resistors: a very small resistance in series with the capacitance, and a very large resistance in parallel with the capacitance.

The parallel resistance arises from two physical effects: the real resistance of the dielectric material (which in most modern capacitors is enormous and can usually be neglected), and an apparent resistance due to the effect of energy being lost when the charges move to form the dipoles in the dielectric (this is frequency dependent, as energy is lost only when the charges are moving). This is the most important effect at low frequencies.

At high frequencies the impedance of the capacitor in the network dominates the parallel resistance, and it's now the combination of the small series resistor and the inductor that become the most significant impairments to ideal operation. Together, these form what's known as the *effective series resistance* (ESR) of the capacitor.

This is often specified in terms of a *dissipation factor* (DF), which is defined as the ratio of the real part of the complex impedance of the component to the magnitude of the imaginary part. In cases where the parallel resistance Rp can be neglected, this is equal to:

$$DF = \frac{R_S}{\left| \frac{1}{\omega C} - \omega L_S \right|} \tag{16.6}$$

and it's a function of frequency. Values of around 0.1% are common for typical operating frequencies: real capacitors often have performance that closely approximates ideal components for a useful range of frequencies.

At very high frequencies, the effect of the series inductance becomes important. Again neglecting the effect of Rp, the impedance of the capacitor can be written as:

$$Z = R_S + \frac{1}{j\omega C} + j\omega L_S \tag{16.7}$$

and this has a minimum value where the effect of the capacitance and the parasitic inductance cancel each other out. This happens at the *self-resonant frequency*, which is given by:

$$\omega_0 = \frac{1}{\sqrt{LC}} \tag{16.8}$$

At this frequency, the impedance of the capacitance and the series inductance cancel out, and all that is left is the series resistance Rs. Above this frequency, the impedance of the parasitic inductance is larger than the impedance of the capacitance, and the component starts to behave as an inductor (the impedance has a positive imaginary component).

A plot of the total impedance of a typical capacitor (normalised to its value at 1 MHz) therefore tends to look something like this:

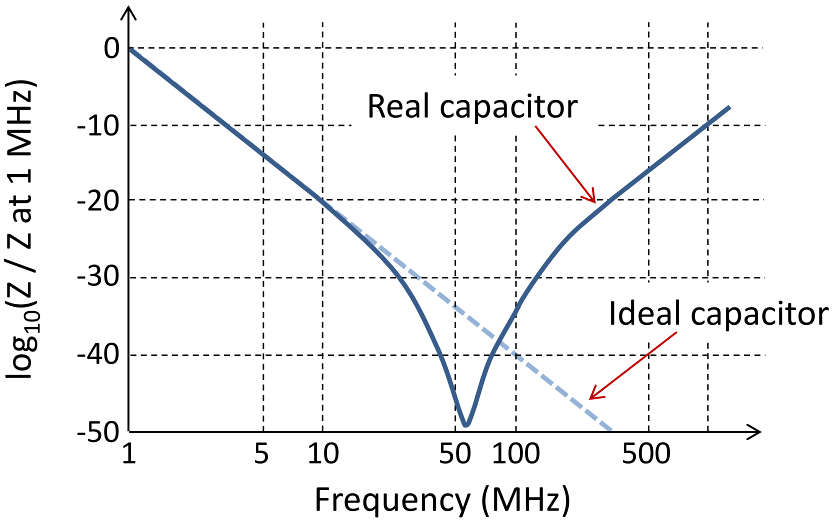

Figure 16.11 Impedance of a real capacitor against frequency

Note that the effect of the inductance can actually reduce the impedance of the capacitor at certain frequencies around the resonant frequency.

16.6 Inductors

Inductors are formed by taking a long wire, and wrapping it many times around a central ferromagnetic core (usually made of iron). To keep the size of the component small, the wire has to be very thin, and a long length of thin wire has an appreciable resistance. This is one reason why most real inductors don't behave much like an ideal inductor: to predict the expected behaviour of a circuit including a real inductor, the added series resistance of the wire has to be taken into account.

There can also be a capacitance between the windings of the coil, and this produces a small parasitic parallel capacitance. A general equivalent network for an inductor is shown in Figure 16.12 below:

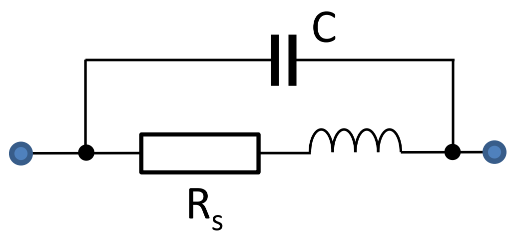

Figure 16.12 A general equivalent network for an inductor

Typical values for the inductors in the lab suggest that the series resistance R_s can be several tens of ohms.

Inductor data sheets will often specify the series resistance R_s in terms a Q value (or quality factor) for the inductor itself. For inductors, the Q value is defined as[5]:

$$Q = \frac{\text{reactive impedance}}{\text{real resistance}} \qquad (16.9)$$

and it's specified at a typical operating frequency for the inductor. The typical operating frequency is usually well below the frequency at which the capacitance has an effect, so the Q value can be expressed in terms of the equivalent component model as:

$$Q = \frac{|j\omega L|}{R_s} \qquad (16.10)$$

The presence of a parasitic capacitor indicates that the impedance of the component has a maximum value at some frequency: at very high frequencies the impedance of the real component will be very low due to the parasitic capacitor, at very low frequencies the impedance of the real component will be almost entirely determined by the resistor. In-between there is a peak value in the impedance; this is known as the *self-resonant frequency*, and occurs around the frequency where the impedance of the ideal inductor in the equivalent network has the same magnitude as the impedance of the parasitic capacitor.

The self-resonant frequency can be thought of as the maximum frequency that the component behaves like an inductor: above the self-resonant frequency, the component behaves more like a capacitor than an inductor, with the overall impedance having a negative imaginary component.

For example, consider the Vishay IM-10-22 3300 uH inductor. The datasheet for this component[6] specifies the minimum Q-value as 70 (as measured at 250 kHz), and the self-resonant frequency as 1.6 MHz. From these values we can determine values for the circuit elements in the equivalent network model:

[5] Note this is the inverse of the damping factor described above in the capacitors section.

[6] http://www.vishay.com/docs/34035/im10.pdf

$$R_s = \frac{j\omega L}{Q} = \frac{2\pi \times 250k \times 3300 \times 10^{-6}}{70} = 74 \text{ ohms} \tag{16.11}$$

$$\left|\frac{1}{j\omega C}\right| = |j\omega L| \text{ at the self-resonant frequency } \omega_0$$
$$C = \frac{1}{\omega_0^2 L} = \frac{1}{\left(2\pi \times 1.6 \times 10^6\right)^2 \times 3300 \times 10^{-6}} = 3 \text{ pF} \tag{16.12}$$

although note that the resistance will in general be a function of frequency and will tend to increase as the frequency increases[7] (the resistance of this component at DC is also specified in the datasheet, at just 38 ohms).

16.6.1 Non-linear effects

Another very important point about inductors is that they are non-linear. The relationship between the magnetic field in the core and the current flowing through the coil of wire is not a linear one, due to the non-linear magnetisation field induced in the (usually) iron core.

The resultant effect on circuit behaviour is that the inductance of an inductor can appear to be a function of the amplitude of the current flowing through the component. Real inductors often specify a rated current in their datasheets; typically this is the value of current at which the inductance drops to 90% of its value at low currents.

(This is another reason why engineers try to minimise the number of inductors in any design: they are difficult to design with (as well as being expensive). If a reactive component is required, it's almost always better to use a capacitor if at all possible.)

16.7 Diodes

At low frequencies, the most important parasitic component in a diode is the series resistance, largely due to the semiconductor material on either side of the p-n junction. This explains why most diodes don't obey the Shockley equation:

$$I = I_0\left(\exp\left(\frac{eV}{nkT}\right) - 1\right) \tag{16.13}$$

where e is the charge on an electron (1.6×10^{-19} C), k is Boltzmann's constant (1.38×10^{-23} J/K) and T is the absolute temperature in Kelvins.

For example, the following figure (Figure 16.13) is adapted from the datasheet of the popular 1N4148 silicon small-signal diode.

Since the forward voltage is above 0.4 V for all of this curve, the term $\exp(eV / nkT)$ is much greater than one for the entire visible curve on this graph:

[7] For those interested, this tendency for the resistance to increase with frequency is known as the *skin effect*. It's outside the scope of this module, but you'll come across it later in your degree programmes.

$$\exp\left(\frac{eV}{nkT}\right) = \exp\left(\frac{0.4}{0.05}\right) = \exp(8) = 2980 \tag{16.14}$$

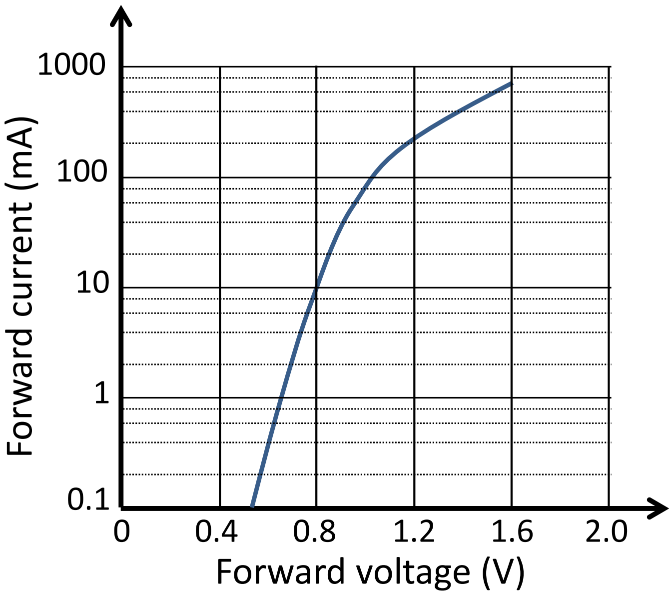

Figure 16.13 I-V characteristic of a real diode

therefore to a very good approximation, Shockley's equation becomes:

$$I = I_0 \exp\left(\frac{eV}{nkT}\right) \tag{16.15}$$

which for the case of a typical 1N4148 (with n = 2 and I_0= 3 nA), gives (when voltage is plotted against the log of the current):

$$\ln(I) = \ln(I_0) + \frac{eV}{nkT} = \ln\left(3\times10^{-9}\right) + \frac{V}{0.05} = -19.62 + 20V \tag{16.16}$$

and this is the equation of a straight line, which the curve from the data sheet clearly isn't.

What's going on here is the effect of the series resistance in the diode. If you include this in the calculation, the relationship between the current and the voltage across the diode becomes:

$$I = I_0 \exp\left(\frac{e\left(V - Ir_s\right)}{nkT}\right) \tag{16.17}$$

since the voltage across the ideal diode is the voltage across the entire equivalent network minus the voltage across the parasitic series resistance, which Ohm's law gives as the product of the current and series resistance.

An equivalent circuit for the diode at low frequencies therefore might look like this:

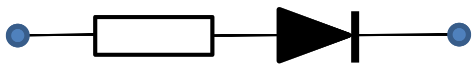

Figure 16.14 Low-frequency equivalent network for a real diode

The current-against-voltage (I-V) plot is shown again below, but this time with two theoretical curves added: an ideal diode with an ideality factor of 2.0 and a saturation current of 3 nA, and an equivalent network consisting of the same ideal diode, but in series with a resistor of 1.1 ohms:

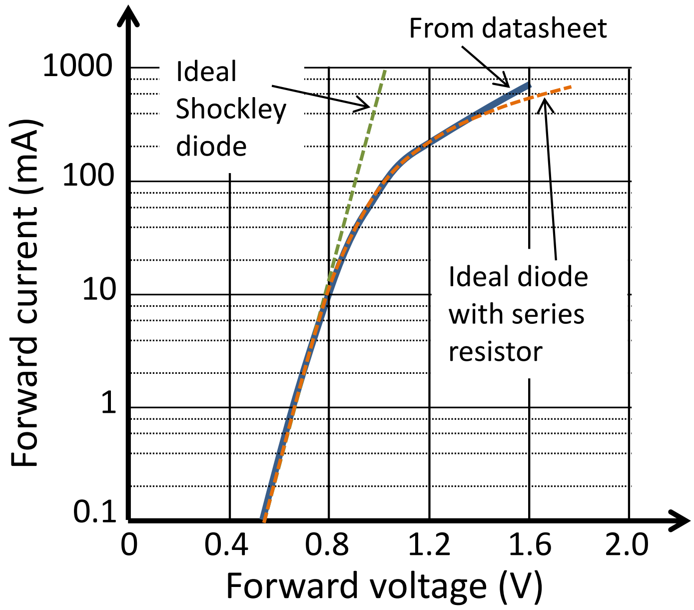

Figure 16.15 Diode characteristic with theoretical models

As you see, the equivalent network gives a much more accurate prediction for the diode behaviour at larger currents. For a small-signal diode like the 1N4148, this equivalent network is accurate enough for any applications that this diode might be used for (at least at low frequencies).

At higher frequencies, typical diode equivalent networks also contain a capacitor (there is a capacitance associated with a p-n junction) which has a value dependent on the voltage across the diode. This fact can be useful: there are special types of diodes (known as *varactors* or *varicaps*) which are designed to have large capacitances so that when reverse-biased they operate in circuits as voltage-controllable capacitors (that is, a capacitor whose value is a function of the reverse-bias voltage across the diode).

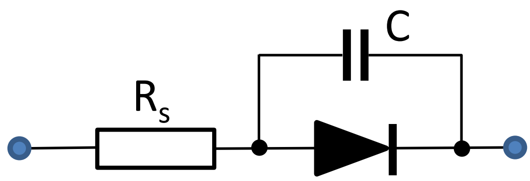

Figure 16.16 Equivalent network for real diodes

(It's worth noting at this point that the full diode model used in the industry-standard SPICE analogue simulation program has fourteen different parameters which allow detailed modelling of how the capacitance changes as a function of the voltage across the diode, amongst other effects.)

16.8 Integrated circuits

There's a lot of room on many integrated circuits, so as well as writing the name of the component, manufacturers often include the data of manufacture, the batch number, their own logo, etc. There's no standard between manufactures for the format of this individual information, you have to look at the individual manufacturer's data sheets.

However two things that are standard, and are very useful to know, are that:

- Where the pins appear around the edge of a component, the pins are numbered anti-clockwise around the body.
- A small circular indent on the body of the component indicates pin one.

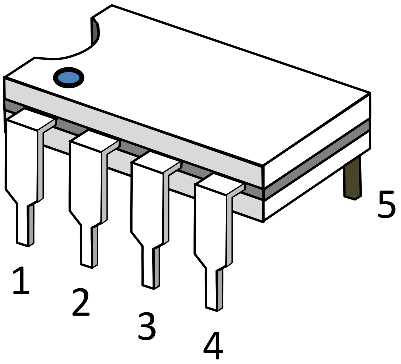

Figure 16.17 8-pin DIL pin positions - note location of pin 5

Integrated circuits have lots of functions, and lots of different ways in which they don't quite do what you hope they will. You just have to read the datasheets very carefully, and also read any application notes you can find on the manufacturer's website.

16.9 Summary: the most important things to know

- The resistor colour code, including the tolerance colours for 1%, 2% and 5%.
- Real passive component are often analysed and simulated using equivalent network models, the equivalent networks being made up from ideal components.
- At high frequencies, small resistors have larger impedance than expected due to the parasitic series inductance
- At high frequencies, large resistors have smaller resistance than expected due to the parasitic parallel capacitance
- The dissipation factor of a capacitor is the ratio of the real part of its complex impedance to the imaginary part. It is a function of frequency. An idea capacitor has a dissipation factor of zero.
- The Q-value of an inductor is the ratio of the imaginary part of its complex impedance to the real part. It is a function of frequency. An ideal inductor has an infinite Q-value.
- Diodes have a small series resistance, and a capacitance which decreases with increasing reverse voltage.
- Integrated circuit pins are numbered anticlockwise.