Online Radio & Electronics Course

Reading 3

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BASIC ELECTRICITY - PART 3

MORE ON RESISTANCE

As discussed briefly in Basic Electricity Part II, resistance is the opposition to current flow in any circuit. Resistance is measured in Ohms and the symbol for resistance is Ω though for equations (we will be using them more soon) the letter 'R' is often used.

Copper and silver are very good conductors of electric current. When the same emf (voltage) is applied across an iron wire of equivalent size, only about one-sixth as much current flows. Iron may be considered a fair conductor.

When the same voltage (emf) is applied across a length of rubber or glass, no electron drift results. These materials are insulators. Insulators are used between conductors when it is desired to prevent electric current from flowing between them. To be more precise, in a normal 'electric' circuit the current flow is negligible through an insulator.

Silver is one of the better conductors, and glass is one of the best insulators. Between these two extremes are found many materials of intermediate conducting ability. While such materials can be catalogued as to their conducting ability, it is more usual to think of them by their resisting ability. Glass (when cold) completely resists the flow of current. Iron resists much less. Silver has the least resistance to current flow.

The resistance a wire or other conducting material will offer to current depends on four physical factors:

1. The type of material from which it is made (silver, iron, etc.).
2. The length (the longer, the more the resistance).
3. Cross-sectional area of the conductor (the more area, the more molecules with free electrons, and the less resistance).
4. Temperature (the warmer, the more resistance, except for carbon and other semiconductor materials).

A piece of silver wire of given dimensions will have less resistance than an iron wire of the same dimensions. It is reasonable to assume that if a 1 metre piece of wire has a 1 ohm resistance, then 2 metres of the same wire will have 2 ohms of resistance.

On the other hand, if a 1 metre piece of wire has 1 ohm of resistance then two pieces of this wire placed side by side will offer twice the cross-sectional area, will conduct current twice as well, and therefore will have half as much resistance.

The basic formula for calculating the resistance of a wire is:

$$R = \rho L/A$$

Where:

R = resistance in Ohms.
ρ = resistivity of the material in ohms per metre cube.
L = length in metres.
A = cross sectional area of the wire in square metres.

ρ, is a Greek letter spelt 'rho' and pronounced as in 'row'

RESISTIVITY ρ

Since the resistance of a wire (or any other material) depends on its shape, we must have a standard shape to compare the conducting properties of different materials. This standard is a cube measuring 1 metre on each side. A pretty big cube! The resistance measured between opposite faces of the cube is called the resistivity.

Resistivity should not be confused with resistance. The resistivity of a material is the resistance measured for a standard size cube of that material. If you look at the table below you will see for example that the resistivity of copper is 1.76×10^{-8} . The part of this number shown as 10^{-8} is called the exponent and the 'minus 8' means that the decimal point must be moved 8 places to the left. If we take 1.76 and move the decimal point 8 places to the left we get:

0.000 000 017 6 Ohms per metre cube (can you see why shorthand is a lot easier?)

Now this is a very low resistance indeed. It is the resistance that would be measured across the opposite faces of a cubic metre of solid copper. Resistivity is not resistance. Resistivity is a measure of the resistance of material of a standard size to allow us to **compare** how well that material conducts or resists current compared to other materials.

Resistivity of Metals and Alloys at 20 degrees C.

Material	Resistivity (Ohms per metre cube)
Silver	1.62×10^{-8}
Copper	1.76×10^{-8}
Aluminium	2.83×10^{-8}
Gold	2.44×10^{-8}
Brass	3.9×10^{-8}
Iron	9.4×10^{-8}
Nickel	7.24×10^{-8}
Tungsten	5.48×10^{-8}
Manganin	45×10^{-8}
Nichrome	108×10^{-8}

The most common conducting material used in radio is, of course, copper, for it is a good conductor and relatively cheap. You can see in the table that aluminium is not as good a conductor as copper. However, aluminium is used for conductors more than any other material because of its light weight. In overhead power line distribution, weight is a very important consideration, so aluminium is the conductor of choice. In

radio and communications, antennas are made of aluminium, again because of the light weight.

CALCULATING THE RESISTANCE OF A WIRE.

A 100 metre length of copper wire is used to wind the primary of a transformer and the wire has a diameter of 0.5 millimetres. What is the resistance of the winding?

Solution:

We need to use the equation $R = \rho L/A$

Since the wire is copper we look at the Resistivity table and get a ρ of 1.76×10^{-8} for copper. The length (L) = 100 metres. We need to calculated 'A' (the cross sectional area) from the equation for the area of a circle.

$A = \Pi d^2/4$

Where:

Π = Another Greek letter, the mathematical constant Pi, approximated by 22/7
d = diameter of the circle (wire).

$A = 22/7 \times (0.5 \times 10^{-3})^2 / 4$
$A = 3.142 \times 0.00000025 / 4$
$A = 0.000000196375$ square metres

$R = \rho L/A$
$R = 1.76 \times 10^{-8} \times 100 / 0.000000196375$
$R = 8.96$ ohms

You will not have to use this equation in either the NAOCP or AOCCP theory exam. However, you must fully understand what the equation tells us, so let's look at it again.

$R = \rho L/A$ ◄ what does this really say?

We shall look at the numerator and the denominator on the right hand side separately.

$R=\rho L$

This means that resistance is directly proportional to the resistivity and to the length. As either ρ or length changes so does R. If ρ or length increases by say a factor of 2 then so does R. In other words, doubling the length of a wire doubles its resistance. If we increase the length by 3.25 times the resistance is increased 3.25 times. So, from the equation we say R is directly proportional to length and resistivity.

The cross sectional area is in the denominator of the equation on the right hand side. Ignoring the numerator for the moment, we can rewrite this relationship as:

$R = 1/A$

This means that resistance is inversely proportional to the cross sectional area, A. If the cross sectional area of a wire were to be doubled then its resistance would be halved. This would be the same as twisting two wires together and using them as one. If the cross sectional area of a wire was increased by a factor of say 4.5 times, then the resistance would be R/4.5 of what it originally was.

We have avoided bringing temperature into our calculations. The resistance of metals increases with temperature - we will discuss this further later.

In the real world, conductors are not round. Even wire is not truly round. Copper circuit board track is definitely not round. In these cases we work with the cross sectional area given by the manufacturer. For exam purposes you do not need to use the equation given, however, I emphasise again, you do need to know what the equation says about the resistance of a wire.

Resistance is directly proportional to the length and resistivity and inversely proportional to the cross sectional area.

THE METRIC SYSTEM

Scientific measurements are more and more being given in the metric system. It is a multiple-of-10. The basic prefixes of metric units of measurement are:

Atto (a)	=	quintillionth of	=	10^{-18} times
Femto (f)	=	quadrillionth of	=	10^{-15} times
Pico (p)	=	trillionth of	=	10^{-12} times
Nano (n)	=	billionth of	=	10^{-9} times
Micro (u)	=	millionth of	=	10^{-6} times
Milli (m)	=	thousandth of	=	10^{-3} times
Centi (c)	=	hundredth of	=	10^{-2} times
Deci (d)	=	tenth of	=	10^{-1} times
unity	=	1	=	1
Deka (da)	=	ten times	=	10 times
Heclo (h)	=	hundred times	=	10^{2} times
Kilo (k)	=	thousand times	=	10^{3} times
Mega (M)	=	million times	=	10^{6} times
Giga (G)	=	billion times	=	10^{9} times
Tera (T)	=	trillion times	=	10^{12} times

The common prefixes use in radio and electronics that you need to learn are highlighted in green (and also underlined). You will need to memorise all of these.

Volts, amperes, ohms, etc. may use metric-based prefixes. Some examples of the use of these prefixes are:

1 kV = 1000 volts.
1 mV = one thousandth of a volt.
10M Ω = 10 million ohms.
56mΩ = 56 thousandths of an ohm.
25mA = 25 thousandths of an ampere.
65uA = 65 millionths of an ampere.

CONVERTING FROM ONE PREFIX TO ANOTHER

Out of all the exam questions I have seen, and thousands that I have marked, more marks are lost than any other on questions like the following.

How do you convert Megahertz to Kilohertz? – and other such conversions.

Hertz is the UNIT. Mega and Kilo are prefixes of the unit.

Let's try the one above.
Megahertz is 10^6 – 10^6 means 1,000,000 or one million.
Kilohertz is 10^3 – 10^3 means 1,000 or one thousand.

Megahertz is a larger unit than kilohertz. How much larger is a megahertz than a kilohertz? How many times will one thousand divide into one million?

It takes 1,000 kilohertz to make one megahertz. A megahertz is 1000 times BIGGER than a kilohertz, so to convert megahertz to kilohertz we must MULTIPLY megahertz by 1000.

144 MHz is the same as 144,000 Kilohertz.

If you were asked to do it the other way round, that is, convert kilohertz to megahertz you would DIVIDE by 1000.

100 KHz is 0.1 MHz.

I think this looks all too easy to some, and for this reason it is done too quickly and very often the wrong answer is picked in the exam and 2 marks are lost all too easily.

Let's do another.

How do you convert microfarads to picofarads?

Please do it step by step, not what you immediately think it should be, unless you are very confident.

This would be my reasoning.

Micro = 1/1,000,000 or one millionth.
Pico = 1/1,000,000,000,000 or one millionth of a millionth.

This means that picofarads are one million times SMALLER than microfarads.

So to convert microfarads to picofarads you would MULTIPLY by 1,000,000.

Example – convert 0.001 microfarads to picofarads.

If we multiply 0.001 by 1,000,000 we get 1000 picofarads.

The easiest way to multiply by 1,000,000 is to move the decimal point 6 places to the right. Can you see that moving the decimal point in 0.001 six places to the right gives you 1000? Do it on a piece of paper – it's the way I do it. Simply place you pen on the decimal point in

0.001 and draw 6 ‘hoops’ moving to the right. Then add “zeros” to the ‘hoops’ that have nothing in them.

Like this:

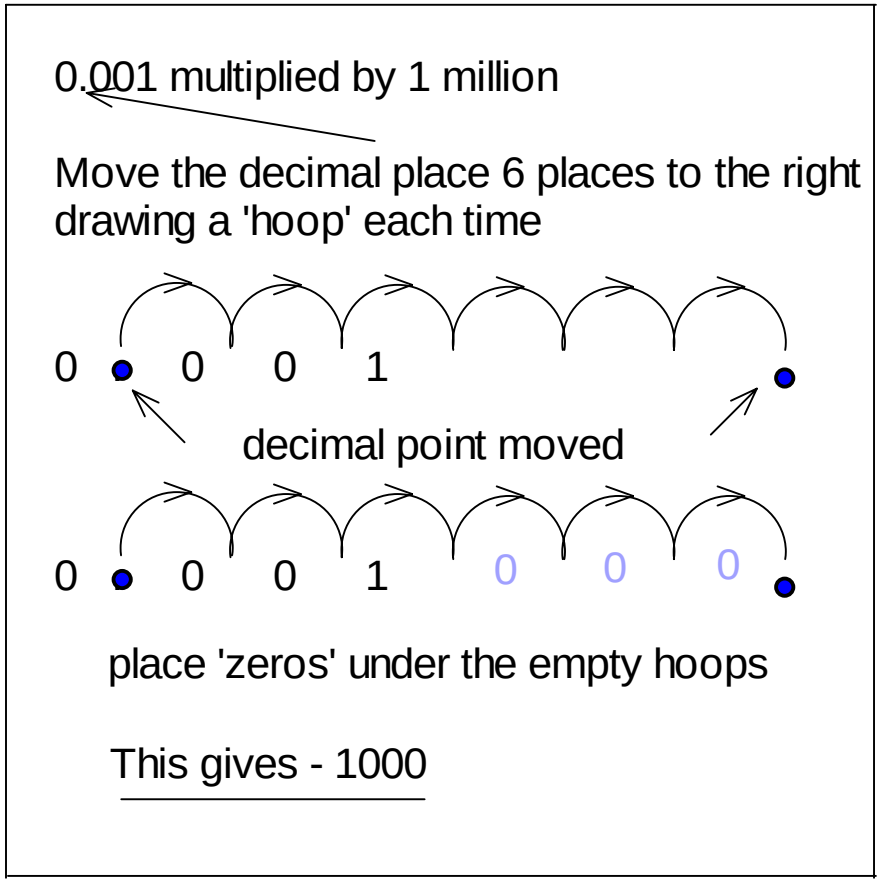

Figure 11.

This may seem like a silly way of doing it but it is a *safe way*. If you had to divide by 1 million (converting picofarads to microfarads), use the same method only move the decimal point 6 places to the *left.*

You can use pen and paper in the exam. Using this method you can convert from any prefix to any prefix. Do not try and memorise the conversions, but do memorise what each prefix means, then work out how to convert one to the other using the techniques described above.

SYMBOLS IN TEXT

Since the assignments are done using plain text you cannot show superscripts, subscripts and symbols. Actually many email programs do allow this but you should avoid using symbols as when your email is received the symbols could be stripped out.

This is the method I use (but you can use your own as long as it is clear).

For example, show:

10^{6} (10 to the power 6) as 10^6
10^{-6} (10 to the power *minus* 6) as 10^-6

Use the '^' which is a 'shifted 6' to indicate that what follows is a superscript.

For symbols you can type the symbol name in brackets. Take the formula for resistance of a conductor that we used earlier in this reading.

R = ρL/A

The Greek letter ρ can be typed as (rho):

R = (rho)L/A

If you have to type the Greek letter Π in a formula you can just type (Pi).

THE RESISTOR COLOUR CODE

Resistors are very small electronic components. Too small to write the resistors value on, so instead, each resistor has colour coded bands which tell you its value and tolerance. The tolerance is the percentage of error, about which the resistor may vary from its coded value.

Resistors are manufactured in what are called *preferred values*. Usually you will require a certain value of resistance in ohms and normally you will choose a resistance with the closest preferred value. If you want an exact resistance that does not match any preferred value, then you may have to make up a resistor especially for the job, or more commonly, you will use a variable resistance and adjust it using an ohmmeter.

There are only so many numerical values in a decade, i.e. from 0-10, or 0-100, 0-1,000, etc. Simple resistors only have 12 values in a decade e.g. 1.0, 1.2, 1.5, 1.8, 2.2, 2.7, 3.3, 3.9, 4.7, 5.6, 6.8, 8.2. This is called the E12 series

A newer series called E24 has 24 standard values and closer tolerances.

E12 Series	E24 Series	
10	10	33
12	11	36
15	12	39
18	13	43
22	15	47
27	16	51
33	18	56
39	20	62
47	22	68
56	24	72
68	27	82
82	30	91

Resistors can have either 4 or 5 coloured bands. With each type the last band is the tolerance. Five band resistors simply have room for three significant figures even though the E24 series only really needs two bands. Most of the time these resistors are 1 or 2% tolerance (within +/- 1 or +/- 2% of stated resistance). This will be either a brown or red band, respectively, at one end of the resistor, separated from the other bands. The value of the resistor starts at the other end.

The colour code, which you must commit to memory, is:

Black	= 0	Green	= 5
Brown	= 1	Blue	= 6
Red	= 2	Violet	= 7
Orange	= 3	Grey	= 8
Yellow	= 4	White	= 9

The tolerance band of a resistor is coded:

Gold	= 5%	Silver	= 10%
Brown	= 1%	Red	= 2%

Note: on the course web site you can download a colour chart of the resistor colour code including instructions on how to use it.

The tolerance band is always a band on the end and separated slightly from the other bands.

The second last band is the multiplier for both 4 and 5 colour banded resistors.

Example 1:

A resistor has 4 coloured bands. From left to right the bands are coloured:

Yellow, Violet, Yellow and Gold

The first significant number is: 4.
The second significant digit is: 7.
The third band is the multiplier, in this case 4, and means add four zeros.
So we get 470000 ohms or 470kΩ.
The tolerance is (gold) +/- 5%.
So the final result is 470kΩ +/-5%.

Example 2:

A resistor has 5 coloured bands. From right to left the bands are coloured:

Green, Blue, Black, Red, Brown

The first significant digit is: 5.
The second significant digit is: 6.
The third significant digit is: 0.
The multiplier in the fourth band is 2 (add two more zeros).
So we get 56000 ohms or 56KΩ.
The tolerance band is 1, therefore 1% tolerance.
So the final result is 56KΩ +/- 1%

The fourth band on a five-banded resistor can be Gold or Silver. Gold means the multiplier is 0.1 and Silver means 0.01. To multiply by 0.1 move the decimal place one place to the left. To multiply by 0.01 move the decimal place two places to the left.

Note: Currently only the four band resistors are tested in the exam.

CONDUCTANCE

There is no need for you to be concerned about the term 'conductance'. I mention it only for information and you will occasionally see the term. You will not see the term in your exam.

For some (not myself) it is more convenient to work in terms of the ease with which a current can be made to flow, rather than the opposition to current flow (resistance). Conductance is merely the reciprocal of resistance. The symbol for conductance is 'G' and G=1/R. Conductance is measured in siemens 'S', formerly the 'mho'.

The term 1/R is simply resistance divided into 1 giving the conductance in siemens. Taking any quantity 'x' and dividing that quantity into 1, is called the reciprocal of the quantity - this you will need to remember.

RESISTORS

Below is pictured some of the types and sizes that resistors are packaged in. They are all just resistors. Resistors can be made to vary, these are called rheostats, potentiometers, or just plain variable resistors.

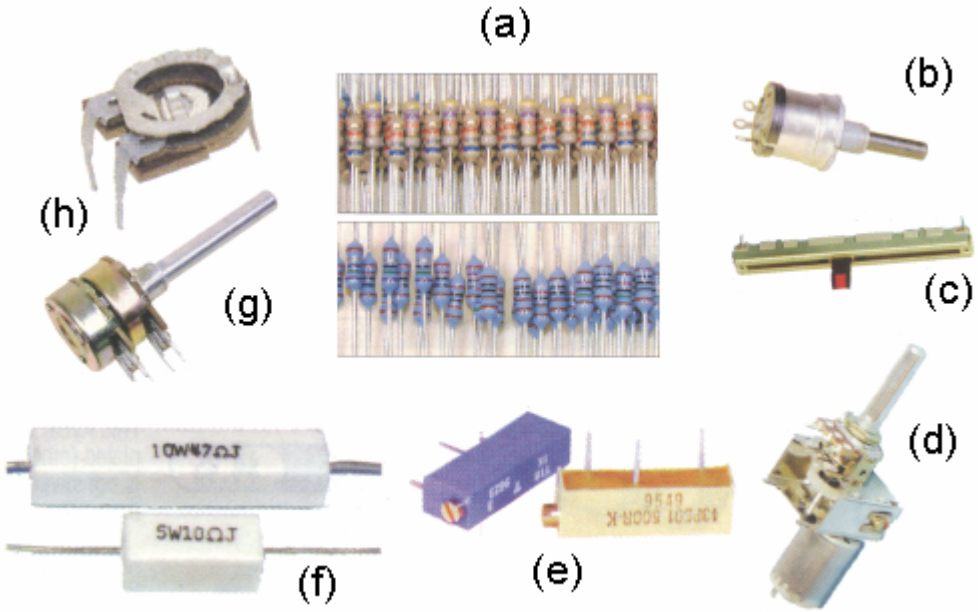

Figure 12.

The resistors in figure 12 are not shown to scale.

(a) fixed ¼ and ½ watt resistors.
(b) a variable resistor – potentiometer.
(c) a variable 'slider' resistor.
(d) a variable motorised resistor.
(e) multi-turn circuit board mounted variable resistor.
(f) high wattage wire wound resistors.
(g) two potentiometers on the one shaft.
(h) a circuit board mounted variable resistor – trim pot.

The only reason that resistors are made large is so they can dissipate (give off to their surroundings) heat. I only add this because a physically large resistor does not mean a large resistance. The large resistor at the bottom of the picture may only be a few ohms, and the tiny one in the centre could be 1MΩ. Large physical resistors will often not use the colour code and have their value marked on them in Ohms.

SCHEMATIC SYMBOL - RESISTOR

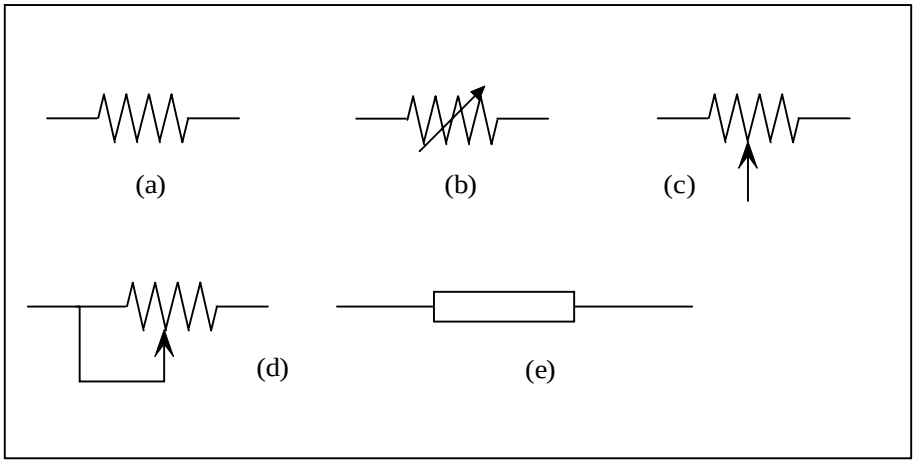

Figure 13.

Figure 13 shows the most common methods of representing a resistor in a circuit. The various types are:

(a) Fixed resistor.
(b) Variable resistor.
(c) This type of variable resistor is called a potentiometer (to be discussed).
(d) Rheostat - essentially the same as (b).
(e) An alternate symbol, though unpopular, at least in Australia.

End of Reading 3.
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