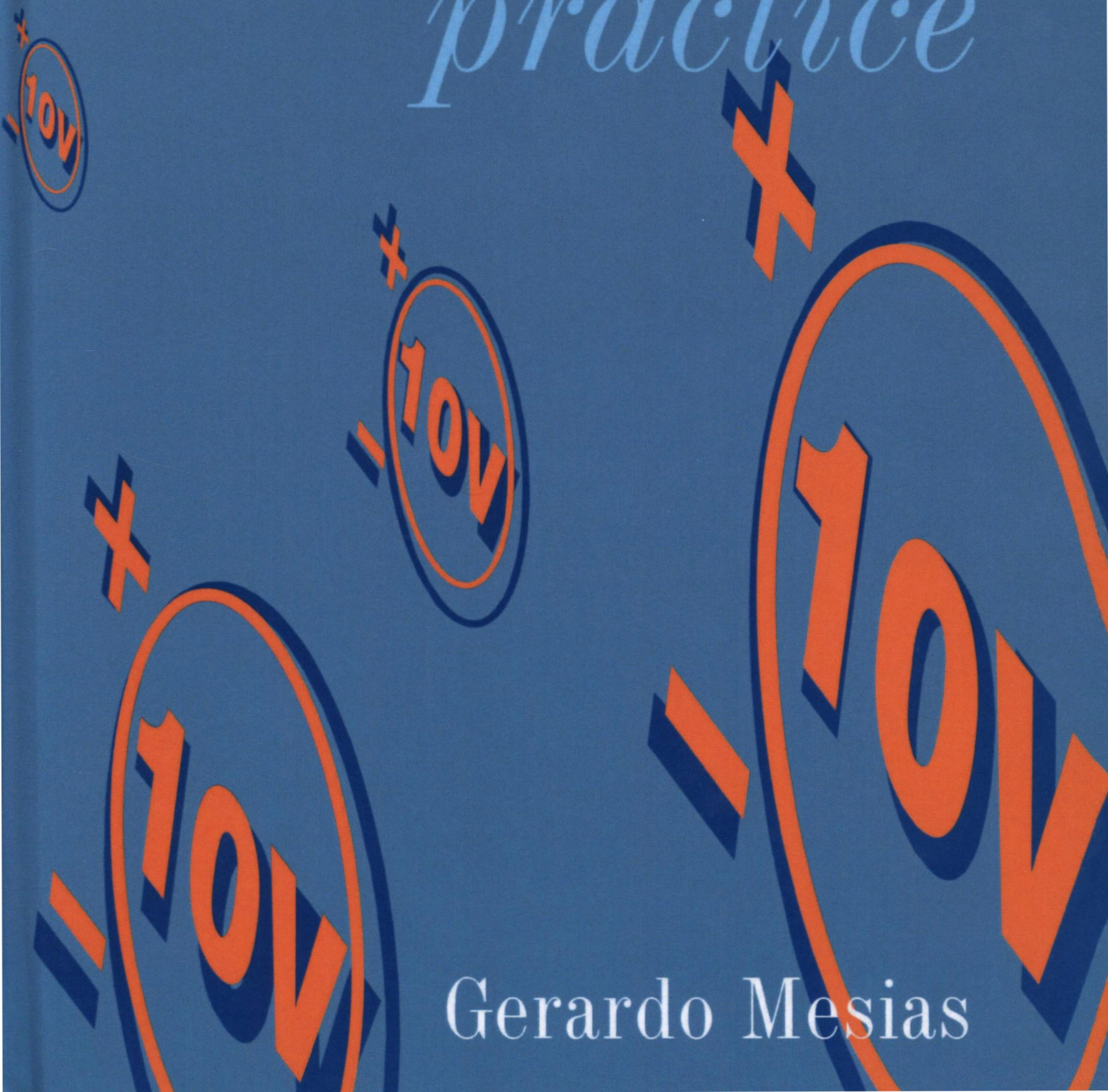
# Electronics
## *theory & practice*




Gerardo Mesias

**ELECTRONICS THEORY AND PRACTICE** is for students tackling analogue electronics on BEng and HNC/D courses. Many beginners find this a difficult topic: they will find here an orderly and straightforward way of learning and understanding the theory, and practising its application in circuits that will really work.

The basic theorems and laws are presented in a first chapter of revision, and subsequent chapters cover biasing, load lines, transistor modelling, current gain, voltage gain, cascaded systems, Bode plots, capacitors, high frequency, op-amps and bandwidth gain.

Supporting each part of the explanation are carefully graded worked problems (over 350 in all), and the whole is generously illustrated with 700+ diagrams showing how circuits work, and how circuits can be represented by equations.

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# Electronics Theory and Practice

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# Electronics Theory and Practice

# Preface

This book has been written to help you learn how to solve problems in electronics. Whether studying for BEng, HND or Graduate Diploma, you need to be able to cope with assignments and face examinations with confidence.

The basis of this confidence is practice in tackling problems. In solving a problem in electronics you are trying to express the circuit in mathematical terms: you are building a mathematical model of the circuit. The problems in this book, which are the result of long experience of students' needs in tutorial and remedial work, show how this is done.

All the problems are supplied with answers and complete worked solutions. This is useful because the answer obtained varies according to the method followed and the approximations made: two different results, such as 6.94 V and 7.06 V, may both be acceptable answers to a problem. Some simpler problems can be solved in a number of different ways. This can be a way of checking your result – by comparing the results by different methods. You should always arrive at the same result unless approximations have been made somewhere along the line. If you have gone wrong, you can check against the solution given in the book: try to identify exactly where you went wrong and how you can put it right.

The first chapter covers all the main laws and theorems needed to solve the problems in the following chapters. Each chapter starts with a concise explanation of the theory, which is followed by graded problems, starting with simple examples and progressing to the more complicated problems. The chapters are self-contained, and can be tackled independently in any order, referring to the first chapter as required for the basic theorems.

This book is intended for your own study. Once you are familiar with it you will find the way of using it that suits you best: in mastering the fundamental theorems and the different electronics topics, and in preparing for your examinations.

To
Camilo,
Thomas Oliver,
Ana-Claudia and
Gaston

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# Contents

# 1

# Fundamental theorems

## Ohm's law

Ohm's law is given by

$$V = IR$$

The voltage in a passive element is given by the product of the current multiplied by the resistance.

We can also easily deduce that:

$$I = \frac{V}{R} \qquad R = \frac{V}{I}$$

Some people prefer to use the magic triangle. This is of unknown origin, but is apparently widely used in secondary education. The magic triangle can be seen in Figure 1.1. In order to find $V$ in the triangle, you cover $V$ and you are left with $IR$. If you want to select another value, you cover the one you want and get the answer in the uncovered part.

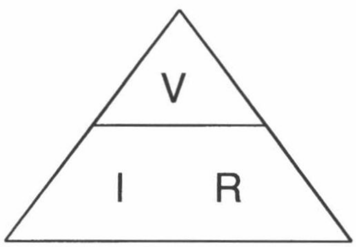


*Figure 1.1*

There are two points that need to be made at this stage, about Ohm's law. First, in Ohm's law the three elements of the formula, $V$ , $I$ and $R$ must be related, i.e., the current must be going through the resistor and the voltage will appear as a consequence of that current across the resistor. Remember that the voltage refers to the difference in voltage between two points. If a point is said to have 12 V, we imply that there are 12 V from that point to a reference point. The reference point is usually ground, at 0 V. If the reference point is other than ground, the value is clearly stated.

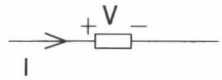


*Figure 1.2*

Secondly, it is important to realise from the very beginning, that the voltage will have a polarity, depending on the direction of the current that goes through the resistor. The relationship is shown in Figure 1.2. The side of the resistor where the current goes in is the positive side of the voltage. The side where the current goes out is the negative side of the voltage.

Another point that we would like to make is that Ohm's law does not apply to a voltage source, nor to a current source. By definition, a 12 V source will provide any current at 12 V. We can have 12 V and zero current or 12 V and 10 A, but we would not try to find a resistor in this case. Similarly for a current source. The current source will produce a current at any voltage. It is important to take this into account when solving problems with current and voltage sources.

## Kirchhoff's current law (KCL)

This law refers to the currents in a junction or node. It is illustrated in Figure 1.3. The algebraic sum of the currents going into a node is equal to zero. Currents going in are positive and those going out of the node are negative.

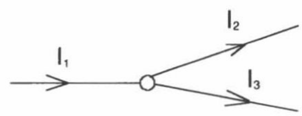


*Figure 1.3*

Another easier way to understand is to say the sum of the currents going in are equal to the sum of the currents going out of the node:

$$\Sigma I_{in} = \Sigma I_{out}$$

## Kirchhoff's voltage law (KVL)

The sum of the voltages around a closed loop are equal to zero. Another way of saying the same thing, that is perhaps easier to understand is: the sum of the voltage sources is equal to the voltage drops around a closed loop. This can be seen in Figure 1.4.

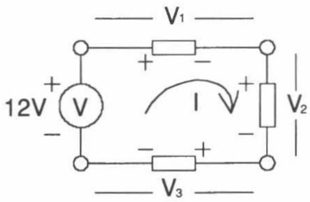


*Figure 1.4*

The equations are:

For Kirchhoff's law:

$$-12V + V_1 + V_2 + V_3 = 0$$

For the second alternative:

$$12V = V_1 + V_2 + V_3$$

**PROBLEM 1.1 KIRCHHOFF**

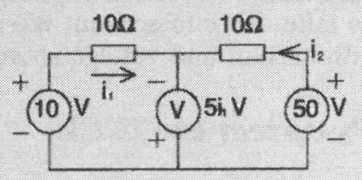


*Figure 1.5*

The two-mesh circuit has a current-dependent voltage source $V$. The polarities are as indicated. Find the value of $i_2$.

**Answer:** $i_2 = 6$ A

The sum of the voltages is equal to the sum of the voltage drops in the left mesh.

$$10 + 5i_1 = 10i_1 \quad (1)$$

Similarly, in the second loop

$$50 + 5i_1 = 10i_2 \quad (2)$$

From equation (1)

$$10 = 5i_1$$

$$i_1 = 2 \text{ A}$$

Replacing this value in equation (2)

$$50 + 5i_1 = 10i_2$$

$$50 + 10 = 10i_2$$

$$i_2 = 6 \text{ A}$$

**PROBLEM 1.2 KIRCHHOFF**

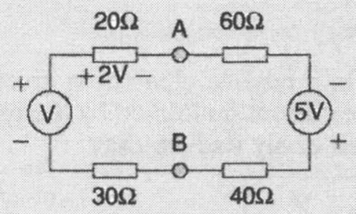


*Figure 1.6*

Find the value of $V$ and $V_{AB}$.

**Answer:** 10 V and 5 V

There is only one current and to produce 2 V in the 20 Ω resistor it must be

$$i = \frac{2}{20} = 0.1 \text{ A}$$

From KVL

$$V + 5 = iR_T$$
$$= i(20 + 30 + 40 + 60)$$
$$= 0.1 \times 150 = 15$$
$$V = 10 \text{ V}$$
$$V_{AB} = V - i(20 + 30)$$
$$= 10 - 0.1(50)$$
$$= 10 - 5 = 5 \text{ V}$$

Also

$$V_{AB} = -5 + i(60 + 40)$$
$$= -5 + 0.1(100)$$
$$= -5 + 10 = 5 \text{ V}$$
$$= 10 - 5 = 5 \text{ V}$$

**PROBLEM 1.3 KIRCHHOFF**

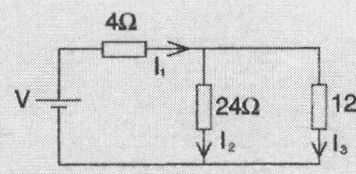


*Figure 1.7*

Calculate $I_1$, $I_2$ and $V$ if $I_3 = 2$ A.

> Answer: $I_1 = 3$ A, $I_2 = 1$ A and $V = 36$ V

On the 12 Ω branch we can apply Ohm's law

$$V = IR = 2 \times 12 = 24 \text{ V}$$

The 24 Ω branch has the same voltage as the 12 Ω branch. We apply Ohm's law again

$$I_2 = \frac{V}{R} = \frac{24}{24} = 1\text{A}$$

According to KCL

$$I_1 = I_2 + I_3$$
$$= 1 + 2 = 3 \text{ A}$$

$V$ is given, according to KVL, by

$$V = 24 + I_1R = 24 + 3 \times 4$$
$$= 24 + 12 = 36 \text{ V}$$

**PROBLEM 1.4 KIRCHHOFF**

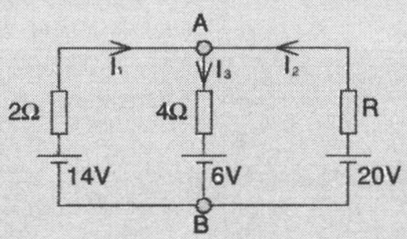


*Figure 1.8*

Find the value of $I_1$, $I_2$ and $R$, if $I_3 = 1.5$ A.

> Answer: $I_1 = 1$ A, $I_2 = 0.5$ A, $R = 16$ Ω

$$V_{AB} = 6 + I_3R = 6 + 1.5 \times 4 = 12 \text{ V}$$

On the left branch

$$V_{AB} = 14 - 2I_1$$
$$12 = 14 - 2I_1$$
$$-2 = -2I_1$$
$$I_1 = 1 \text{ A}$$

On the right branch

$$V_{AB} = 20 - I_2R$$

Note the sign of the voltages, given by the rule of polarity. $I_2$ can be found from KCL

$$I_2 = I_3 - I_1$$
$$= 1.5 - 1 = 0.5 \text{ A}$$
$$V_{AB} = 20 - I_2R$$
$$12 = 20 - 0.5R$$
$$0.5R = 8$$
$$R = 16 \text{ Ω}$$

**PROBLEM 1.5 KIRCHHOFF**

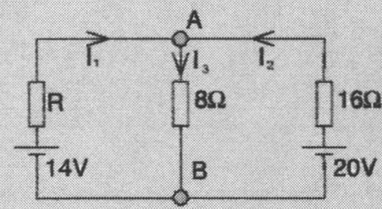


*Figure 1.9*

Find $I_1$, $I_3$ and $R$ if $I_2$ is equal to 0.5 A.

> Answer: $I_1 = 1$ A, $I_3 = 1.5$ A and $R = 2$ Ω

Following the sense of the currents shown, the polarity of the 16 Ω resistor will oppose the 20 V supply.

The voltage AB will be

$$V_{AB} = 20 - 16 \times 0.5 = 20 - 8 = 12 \text{ V}$$

Then

$$I_3 = \frac{V}{R} = \frac{12}{8} = 1.5\text{A}$$

From KCL

$$I_1 = I_3 - I_2 = 1.5 - 0.5 = 1 \text{ A}$$

$R$ produces a voltage drop of

$$V_{AB} = 14 - I_1R$$
$$12 = 14 - I_1R = 14 - R$$
$$R = 2 \text{ Ω}$$

**PROBLEM 1.6 KIRCHHOFF**

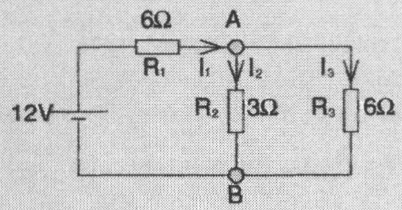


*Figure 1.10*

Find $I_1$, $I_2$ and $I_3$.

| Answer: 1.5 A, 1 A and 0.5 A |
|---|

Total resistance

$$R_T = R_1 + R_2 \| R_3$$

The parallel bar signifies that $R_2$ and $R_3$ are in parallel.

$$R_T = R_1 + \frac{R_2 R_3}{R_2 + R_3}$$

$$= 6 + \frac{6 \times 3}{6 + 3} = 8\Omega$$

Ohm's law

$$I_1 = \frac{V}{R_T} = \frac{12}{8} = 1.5\text{A}$$

Voltage AB

$$VA_{AB} = 12 - R_1 I_1 = 12 - 6 \times 1.5 = 3\text{V}$$

Ohm's law

$$I_2 = \frac{V_{AB}}{R_2} = \frac{3}{3} = 1\text{A}$$

$$I_3 = \frac{V_{AB}}{6} = \frac{3}{6} = 0.5\text{A}$$

Check

$$I_2 + I_3 = I_1$$

$$1 + 0.5 = 1.5$$

**PROBLEM 1.7 KIRCHHOFF**

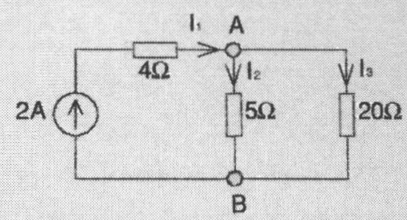


*Figure 1.11*

Find $I_1$, $I_2$ and $I_3$.

| Answer: 2 A, 1.6 A and 0.4 A |
|---|

$I_1$ = 2 A, as this is the same as the current source.

$$V_{AB} = 5I_2 = 20I_3$$

Therefore

$$I_2 = \frac{20}{5} I_3 = 4I_3$$

KCL

$$I_1 = I_2 + I_3$$

$$2 = I_2 + I_3$$

$$2 = 4I_3 + I_3$$

$$2 = 5I_3 \qquad I_3 = \frac{2}{5} = 0.4\text{A}$$

Now the value of $I_2$

$$2 = I_2 + 0.4$$

$$I_2 = 2 - 0.4 = 1.6\text{A}$$

**PROBLEM 1.8 KIRCHHOFF**

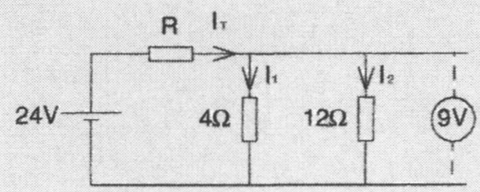


*Figure 1.12*

Find the value of $R$.

| Answer: $R = 5\Omega$ |
|---|

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