MODULE TITLE : DIGITAL & ANALOGUE DEVICES & CIRCUITS

TOPIC TITLE : INTRODUCTION

LESSON 1 : ELECTRONIC TECHNOLOGY

DADC - 1 - 1

Published by Teesside University Open Learning (Engineering)
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INTRODUCTION

The main thrust of this module is in the analysis and synthesis of electronic circuits, digital and analogue. Before we can investigate semiconductor based devices, it is worthwhile trying to define what 'electronics' is ... and also what it is not! In this introductory lesson we shall define some terms commonly used and misused. The lesson also provides a set of symbols for common electronic devices. Finally, the lesson provides some practical background material on the non-semiconductor devices that we should be familiar with. It is not essential to remember it all; just remember where to find it!

YOUR AIMS

At the end of this lesson, you should:

- have a better appreciation of the scope and range of basic electronic components
- understand some of the practical limitations of devices.

STUDY ADVICE

This is a rather long lesson covering a wide varity of themes. We reiterate, it is not intended that you master all of its contents on the first pass. Rather, you should familiarise yourself with its contents so that you can use the lesson as a source of reference to be dipped back into as you proceed to work through the module.

ELECTRONICS: A DEFINITION

These days, electronic circuits and devices are found in virtually every environment, machine and piece of equipment. They are used for sensing, measurement, signal processing, data storage, control and protection.

Can you think of any domestic appliance which does not contain electronic devices?

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Kettles, bar fires and fans are possible candidates, but even these may have electronic controls, indicator lamps or protective cut-outs.

The electronic revolution is of fairly recent date, fuelled by the development of the semiconductor diode and transistor in the late 1940s. It is clear that this process is far from complete. Progress in the design of integrated circuits is such that devices with 100 million transistors in them will soon be available. The speed and processing power of modern computers show little sign of reaching a limit.

It is not easy to differentiate between an electrical component and an electronic one.

What would be your definition?

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All the definitions which come readily to mind are imperfect. If we say that electronic components are miniature devices, where does that leave high- power transistors? Or if we say they have no moving parts, then is a miniature switch in a radio an electronic component or not? It also seems unreasonable to restrict electronics to semiconductor devices. What about resistors, or even the poor old valve? So a precise definition is perhaps impossible, but we do have a general notion that electronic circuits involve small static elements in assemblies containing semiconductor devices.

If you were to open up a transistor radio, you would see a bewildering array of components mounted on or near a printed circuit board (PCB).

List eight different component types you might find.

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Resistors, capacitors, diodes, transistors, potentiometers, an aerial, inductor, switches, light emitting diodes (LED), integrated circuits (IC), speaker.

In many cases, it is far from obvious what a particular component is, never mind what function it performs. This lesson is an attempt to introduce you to the practicalities of some non-semiconductor components, their function, availability, identification and limitations. Subsequent lessons will deal with the analysis of individual semiconductor devices and the design of more complex circuits.

CLASSIFICATION OF ELECTRONICS

FIGURE 1 gives a rough picture of the interrelationships of some of the common terms of electronics.

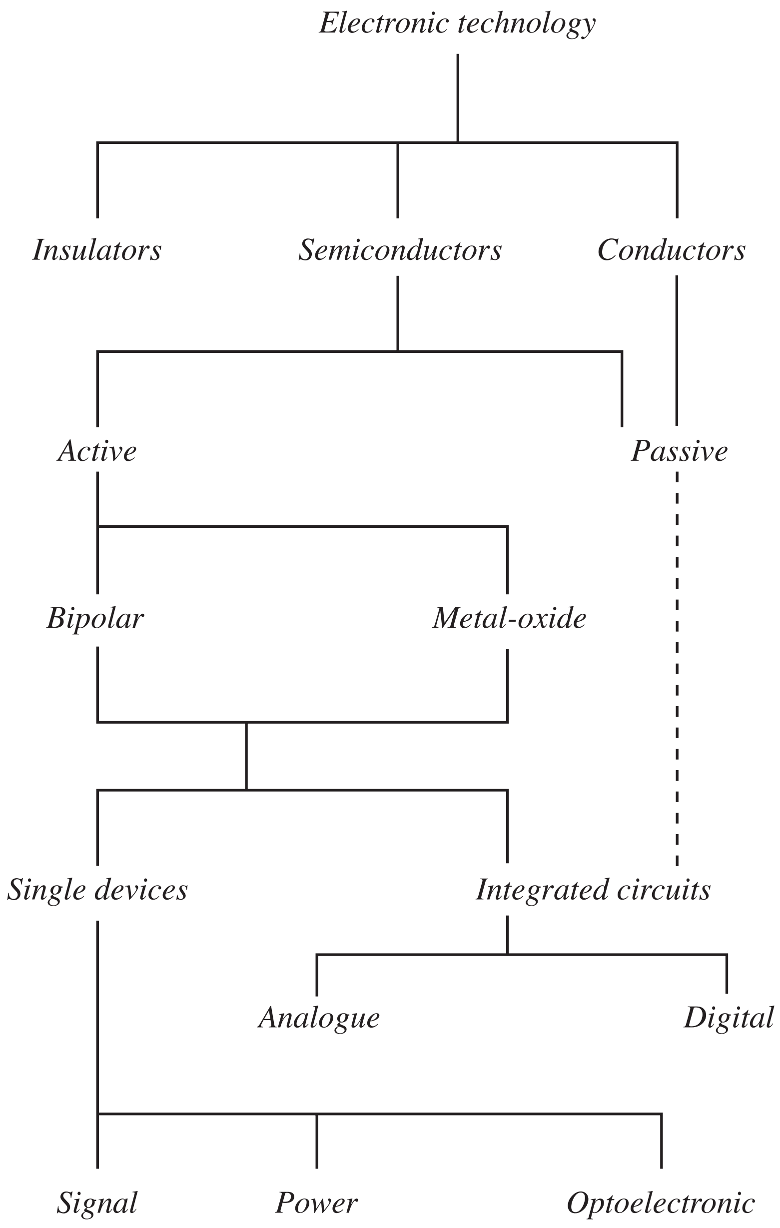

FIG. 1

We now define the terms used in this figure.

CONDUCTORS – INSULATORS – SEMICONDUCTORS

Conductors are usually metals, e.g. copper, aluminium or silver, which have a low electrical resistance at normal temperatures.

Insulators are materials which have very high resistances at normal temperatures, e.g. glass, paper or pure water.

Semiconductors are materials like silicon, germanium or gallium arsenide, which have conduction properties somewhere between conductors and insulators. Pure semiconductors are of little interest, but when doped with impurities, they form components which have fascinating and useful properties.

ACTIVE – PASSIVE

Active devices are those which can amplify signals. The obvious example is the transistor, but there are many other related devices. When we talk about amplification, there is the temptation to think we will get something for nothing, because what we get out is greater than what we put in. This is a vain hope! What active devices do is draw power from a supply and convert it to an amplified version of the input. Any attempts to make an amplifier work without a power supply are doomed to failure.

Passive devices are all the rest! For example: resistors, capacitors, diodes, inductors, lamps, etc. Note that capacitors and inductors, although passive, can store energy!

Is a relay active or passive?

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A relay is active, since its low power coil circuit can control high power.

SINGLE DEVICES – INTEGRATED CIRCUITS

A single device is an obvious concept. An integrated circuit (IC), or chip, is one which contains many devices; these may be all of one type or a complete mixture. An integrated circuit may be designed for essentially one function, e.g. a memory, or it may have a flexible structure designed to fulfil many applications.

Most integrated circuits these days essentially contain active devices. Integrated circuits can be classified roughly in the following way, although these categories are not rigid or precise.

SSI	Small Scale Integration	Up to 100 transistors e.g. an amplifier, or a quad 2-input gate
MSI	Medium Scale Integration	100-1000 transistors e.g. an analog-to-digital converter
LSI	Large Scale Integration	10^3 to 10^4 transistors e.g. small memories
VLSI	Very Large Scale Integration	10^4 to 10^6 transistors e.g. microprocessors, large memories
WSI	Wafer Scale Integration	10^6 to 10^8 transistors e.g. semiconductor data storage

Why do we want greater integration?

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Several reasons:

- Greater reliability with fewer separate devices.
- Lower cost per active device.
- Lower costs of interconnecting and interfacing.
- Potentially higher speeds, since distances are reduced.
- Greater static memory capacity.

ANALOGUE – DIGITAL

There are two ways of dealing with signals. An analogue signal is one that can take any value continuously between defined limits; e.g. an audio amplifier puts out an analogue signal to a speaker and a meter with a pointer is an analogue device.

A digital signal is one which can have only discrete values, e.g. the numbers 0, 1, 2, 3, 4 are discrete. If we just consider two discrete numbers, 0 and 1, we call this **binary digital** arithmetic. This is very convenient because it is easy to define two conditions in a transistor switch, one corresponding to an ON condition and the other to the OFF situation. Binary digital electronics could in principle be implemented by relays with 0 and 1 corresponding to de-energized and energized respectively. However, transistors are smaller, faster, cheaper, consume less power and have no mechanical parts, so there is really no contest.

The two binary numbers, 1 and 0, can also represent the two philosophical concepts TRUE and FALSE. So **binary digital electronic** circuits can also perform logic operations.

Engineers tend to use the words **digital**, **binary** and **logic** more or less interchangeably, but it is important to realize that they are talking about the same thing.

In general, is the world analogue or digital? And is greater accuracy obtainable with analogue or digital systems?

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Microscopically the world appears to be discrete, but in the world which we can measure, the signals are mostly analogue in nature. For example, our measurements of temperature and pressure are analogue.

Digital systems have the greater potential for high accuracy. Since they have only 1 or 0 values, they do not suffer the stability problems of analogue systems, which may be affected by many environmental factors. Ideally, digital systems give you a definite value.

BIPOLAR & METAL-OXIDE SEMICONDUCTORS

Two technologies dominate the semiconductor transistor industry. Bipolar transistors rely for their operation on forming junctions between n–type and p–type semiconductors. Hence the acronym BJT, which stands for Bipolar Junction Transistor.

Metal-oxide semiconductor (MOS) transistors, on the other hand, are controlled via an insulating layer of metal oxide.

In general, BJT technology is faster, but the devices consume more power and the individual transistors are larger, which is important in integrated circuits. The small size of MOS devices and their low power losses make them very attractive in memory applications and battery powered circuits.
These days, a further development of MOS devices called CMOS (Complementary MOS) is highly popular.

INDIVIDUAL ELECTRONIC DEVICE FAMILIES

Signal Devices are concerned with amplification. These form by far the largest group of semiconductors. Individual transistors and diodes are designed for a vast range of applications.

Power Electronics is the technology of semiconductors which can handle large currents (1 A to 5000 A) and voltages (to 5000 V). Devices include power versions of diodes, BJTs and MOS transistors, as well as more complex semiconductors such as **thyristors** and **triacs**.

Optoelectronics is the technology of that family of solid state devices which emit, react to, or detect light, usually in the visible spectrum. **Light-emitting diodes** (LED) and **liquid crystal displays** (LCD) are the two most important technologies.

The following symbols (see FIGURES 2, 3, 4, 5 and 6) are based on British Standard BS 3939, which is the same as the European IEC 617. These symbols will be used consistently throughout this module and it is recommended that you also try to adhere to this standard.

Basic

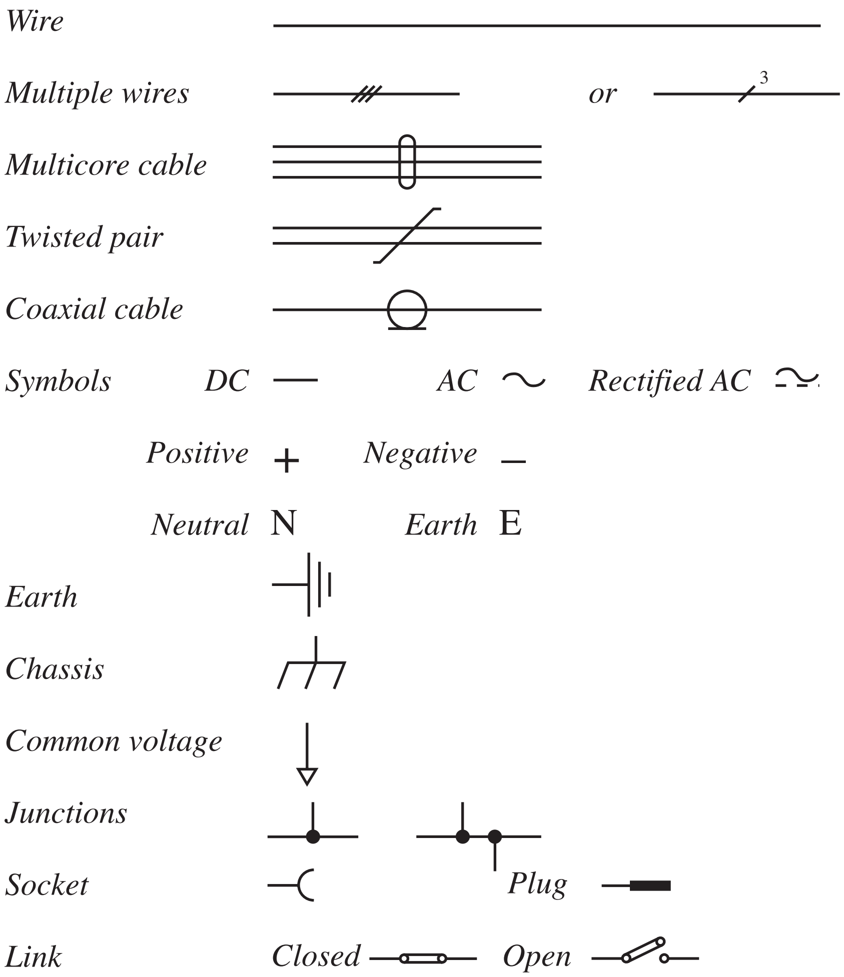

FIG. 2

Passive Components

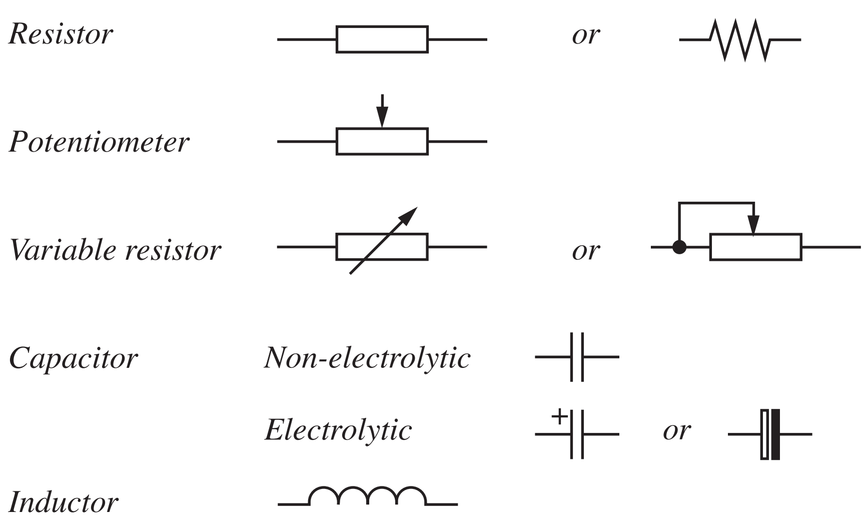

FIG. 3

Semiconductors

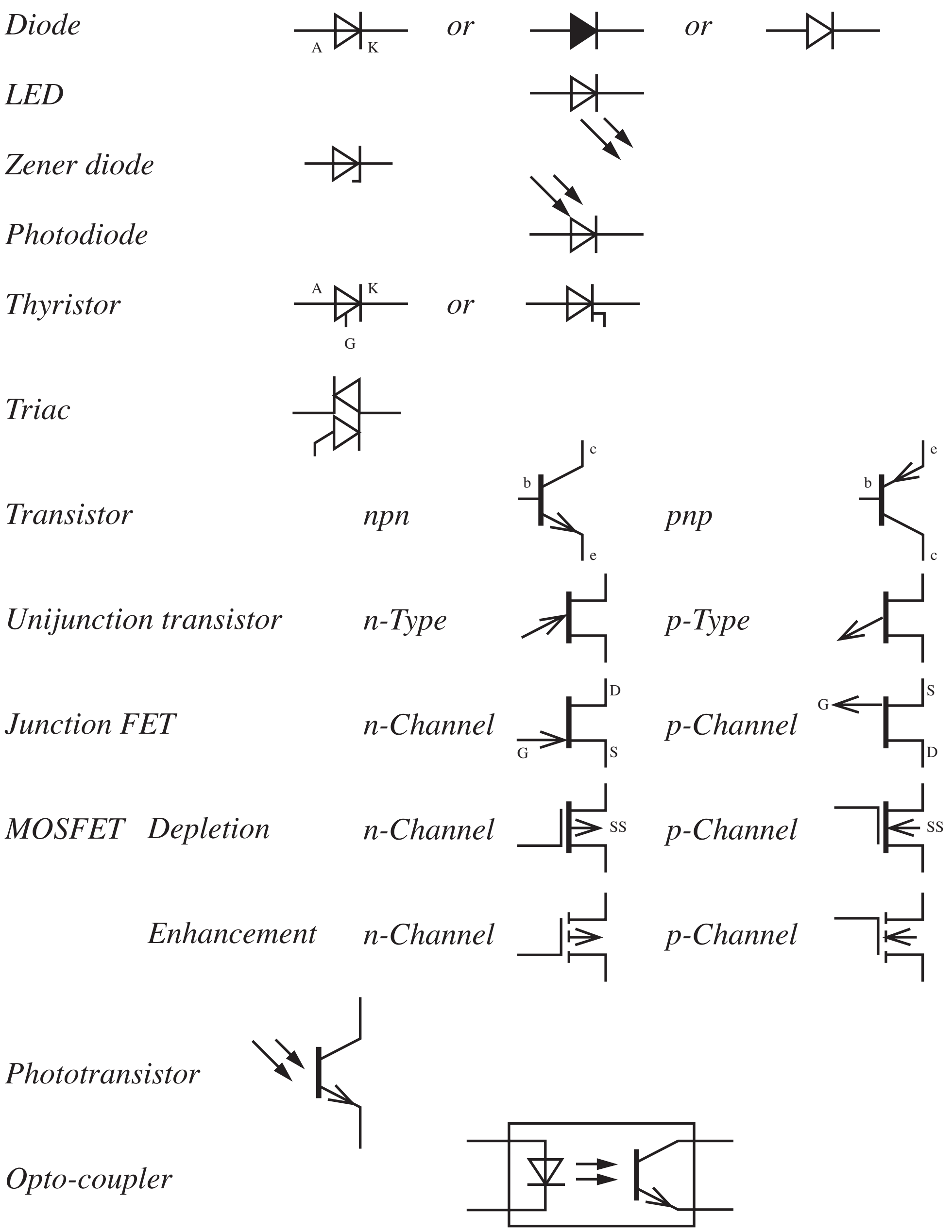

FIG. 4

Miscellaneous

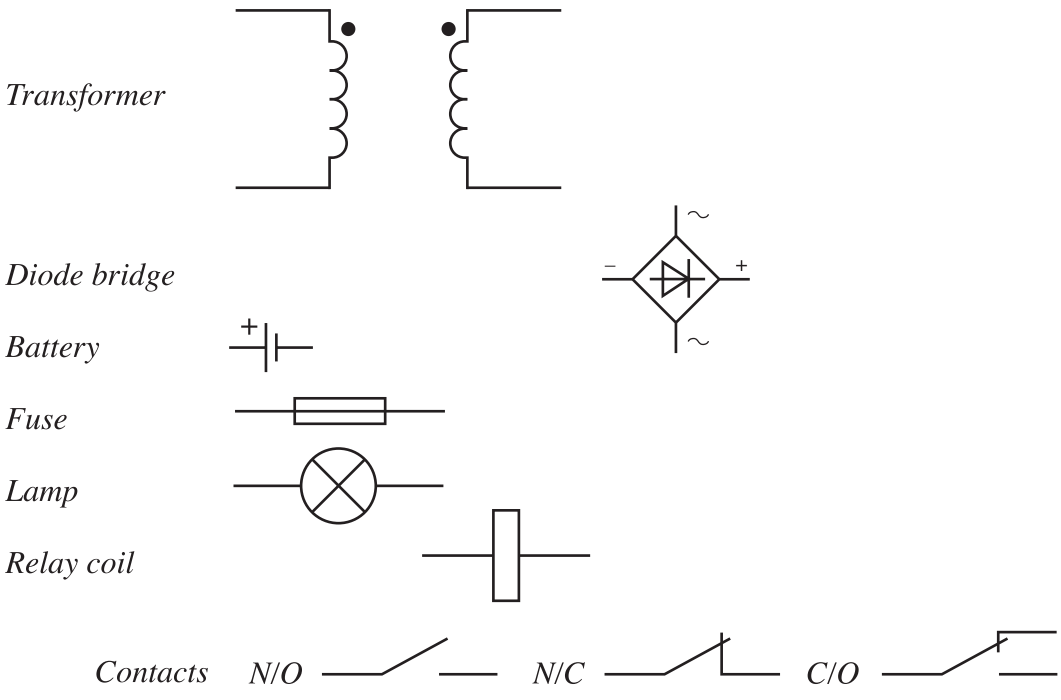

FIG. 5

Integrated Circuits

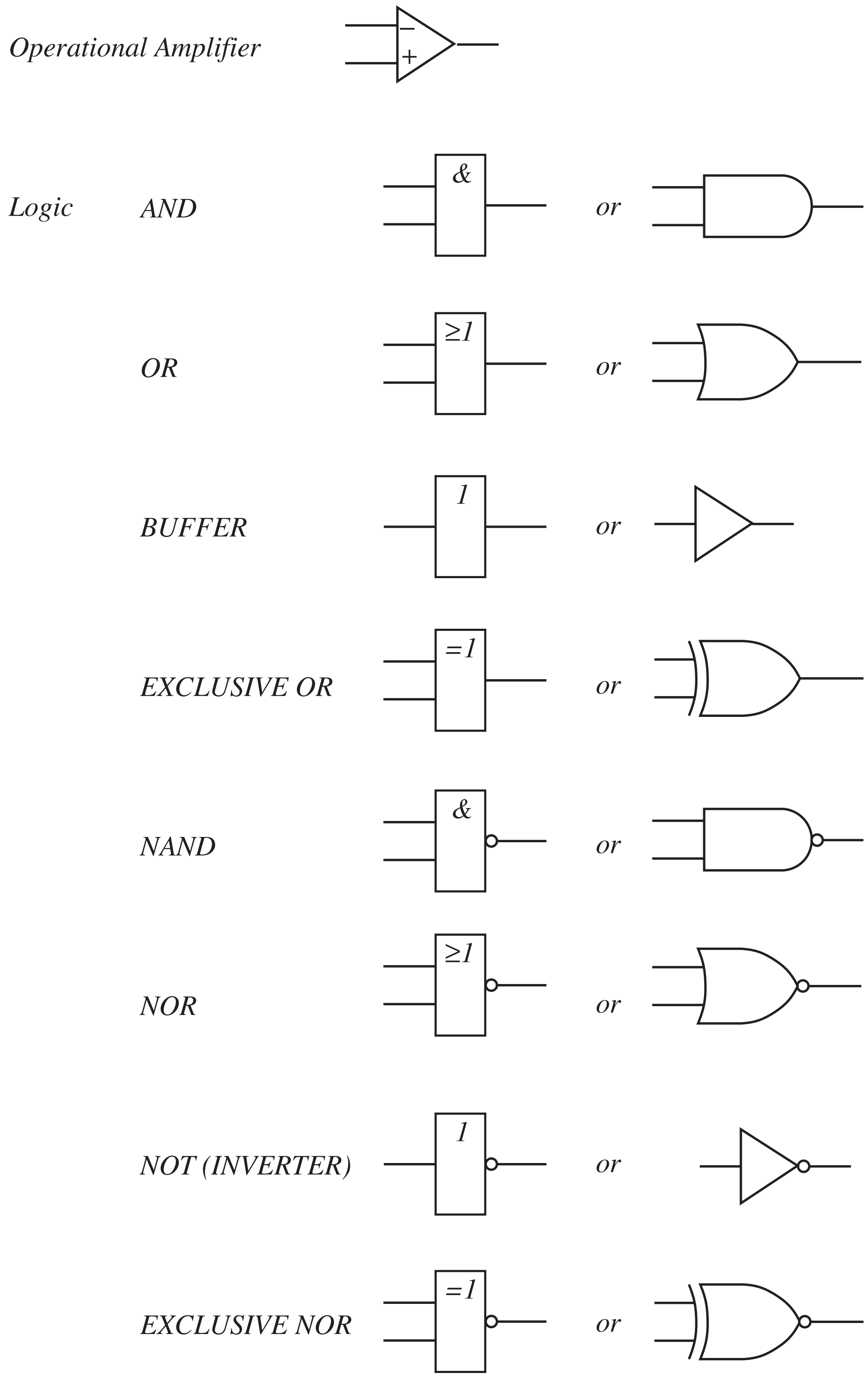

FIG. 6

A REVIEW OF NON-SEMICONDUCTOR DEVICES

This section will give a basic practical guide to a selection of common components. The information is readily available in catalogues like RS, Farnell or Maplin. Remember, in real life, an application may need much more detailed specification; for that, we need the manufacturer's data sheets!

RESISTORS

Operation

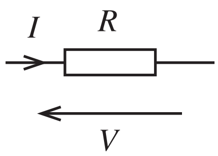

FIG. 7

A resistor is a passive, linear component in which $V = RI$.

The **power**, P, dissipated in a resistor appears as heat and is given by the relationship below.

$$P = RI^2 \text{ or } P = \frac{V^2}{R} \text{ (watts)}$$

I and V may be either pure d.c. values or a.c. (rms) values.

The unit of resistance is the **ohm** (Ω).

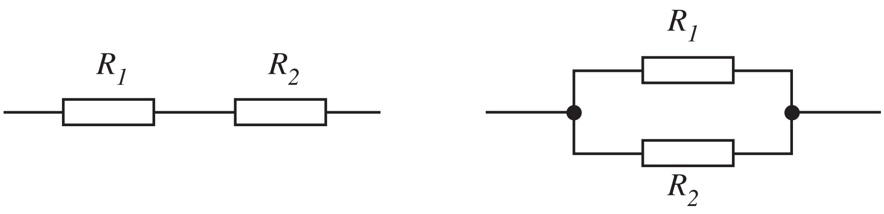

FIG. 8

Resistors connected in series add their resistances.

$$R_S = R_1 + R_2$$

Resistors connected in parallel have a combined resistance RP given by the following relationship.

$$R_P = \frac{R_1 R_2}{R_1 + R_2} \quad \text{or} \quad \frac{1}{R_P} = \frac{1}{R_1} + \frac{1}{R_2}$$

Parameters

The 3 parameters to specify when choosing a resistor are resistance, tolerance and power rating.

Resistors are available only in certain values. A popular range is the E12, which has 12 values per decade of resistance. The series is as follows.

10, 12, 15, 18, 22, 27, 33, 39, 47, 56, 68, 82.

Resistors are available from milliohms (mΩ) to megohms (MΩ), but popular and easily available values go from 1 Ω to 10 MΩ.

Resistances are often defined by colour coding. Three bands of colours are used.

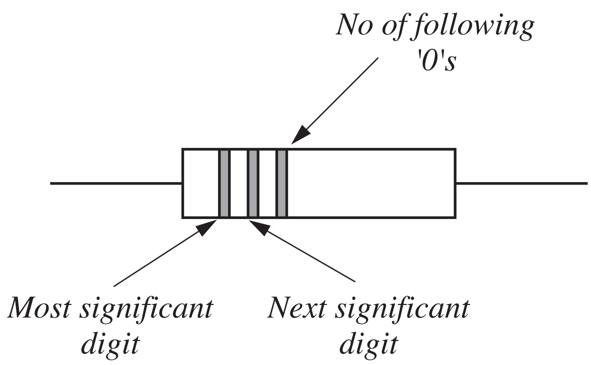

FIG. 9

The colour code is:

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

For example, green, blue, orange bands would signify 56 000 Ω or 56 kΩ.

(i) What would red, mauve, green be?

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(ii) How would 33 Ω be shown?

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(i) 2.7 MΩ.

(ii) Orange, orange, black.

To obtain non-standard resistance values, connect standard values in series or parallel.

Resistor tolerance is expressed as a percentage. Tolerances of ±10%, ±5%, ±2%, ±1% are readily available. For example, a 56 kΩ ±2% resistor would have an acutal resistance value in the range 54 880 Ω to 57 120 Ω.

What range of resistance could a 470 Ω + 10% resistor have?

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423 to 517 Ω.

A further colour band on resistors is used to specify tolerance.

±10%	:	Silver
±5%	:	Gold
±2%	:	Red
±1%	:	Brown

Power ratings of resistors vary from 1/8 watt to 100 watts or more. Power ratings must not be exceeded and indeed, to ensure a reasonable lifetime, the maximum operating power should be typically no more than 50% of the published rating.

Resistor Types

The following table gives a summary of commonly available resistor types.

TYPE	*MAX POWER (watts)*	*RANGE*	*TOL %*	*Temperature Coefficient (ppm/°C)*	*APPLICATION*
Precision Wirewound	*1*	*10 Ω – 100 kΩ*	*0.1*	*10*	*High stability Low noise*
Precision Metal Film	*1/8*	*10 Ω – 1 MΩ*	*0.1*	*15*	*High stability Low noise*
Metal Film	*1/4*	*0.1 Ω – 1 MΩ*	*1*	*50*	*General purpose*
Carbon Film	*1/2*	*10 Ω– 10 MΩ*	*5*	*– 500*	*Low cost*
Cermet Film	*1/2*	*– 100 MΩ*	*5*	*300*	*High value*
Power Wirewound	*300*	*0.1 Ω – 10 kΩ*	*5*	*– 250*	*High power*
Surface Mount	*1/4*	*1 Ω – 10 MΩ*	*2*	*200*	*Low inductance*
Thick-Film	*1/4*	*10 Ω – 100 kΩ*	*2*	*250*	*Multiple resistors per package*

Practical Considerations

The main problem with resistors occurs if they are operating near their maximum power rating. Their surface temperature can become very high (in some cases 200°C or more) so that, although the resistors may be within their rating, they may be heating up adjacent components. Furthermore, the maximum power rating may only apply where there is a free flow of air over the body of the resistor, and in some cases only where the resistor is mounted on a heatsink. Be careful where you put it!

Imperfections

What imperfections do you think resistors might have?

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Resistors are cheap, reliable, stable components, but have the following limitations.

(1) Their values change slightly with temperature. Typical values might be ±100 parts per million per °C. To get better, you pay more.

(2) They have a breakdown voltage, typically 250 – 500 volts for small resistors.

(3) Resistors constructed by winding a coil of wire round a former may have appreciable inductance.

POTENTIOMETERS & VARIABLE RESISTORS

Operation

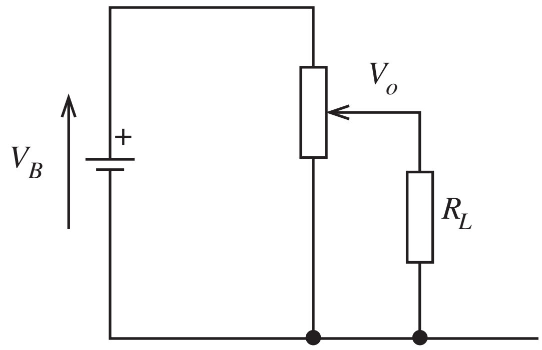

FIG. 10(a)

Many designs require (a) adjustable controls (e.g. volume control for a radio) or (b) some means of fine tuning a signal.

A potentiometer is merely a resistor to which a third connection has been made by an adjustable sliding contact. If the potentiometer is connected as shown to a supply then, as the control is moved from one end to the other, the voltage V_o can be varied continuously from 0 to V_B. The only limitation is that the load on the potentiometer, represented by R_L, should preferably have a much higher resistance than the potentiometer itself.

If the potentiometer has the sliding contact connected to one end, then we have a variable resistor.

Parameters

The important parameters of a potentiometer are resistance, power rating and construction. Potentiometers are available in a wide resistance range (10 Ω to 1 MΩ), and power rating (1/4 watt to 100 watts or more).

The main choice to be made by the customer is in the style of construction. Miniature potentiometers, which are designed to be adjusted infrequently or perhaps only once, are available to be mounted on printed circuit boards. They can be single-turn or multi-turn.

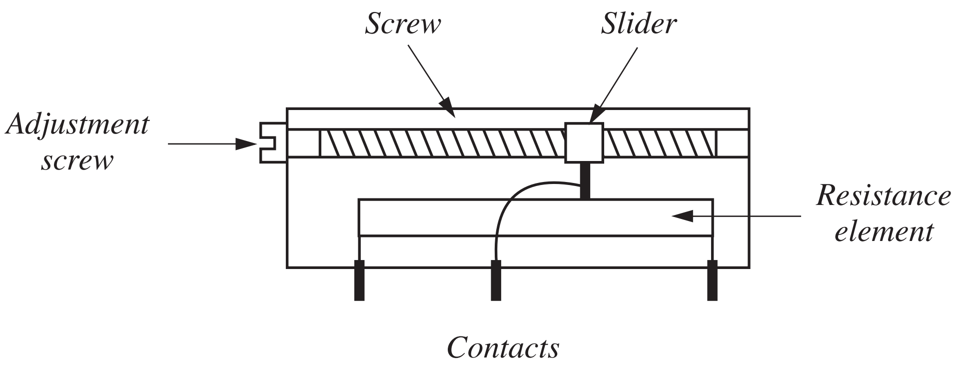

FIG. 10(b)

In a multi-turn potentiometer the sliding contact is moved along the resistance element by turning a screw, as in FIGURE 10(b). It may require 10 or 20 turns to go from end to end, but this gives fine control.

For potentiometers to be mounted on a panel for customer control, a more robust construction is required. Once again, potentiometers can be single-turn or multi-turn. Often, they are provided with calibrated (and sometimes lockable) dials.

Application

When using a variable resistor, the engineer must ensure that excessive current does not flow through any part of the component.

If the power rating is P and the maximum resistance is R, then the maximum permitted current is obtained from $P = RI^2$. The danger occurs when the variable resistance is set almost to zero. If conditions in the external circuit permit, the current may rise too high and burn out the wire.

CAPACITORS

Operation

$$I_C = C\frac{dV_C}{dt}$$

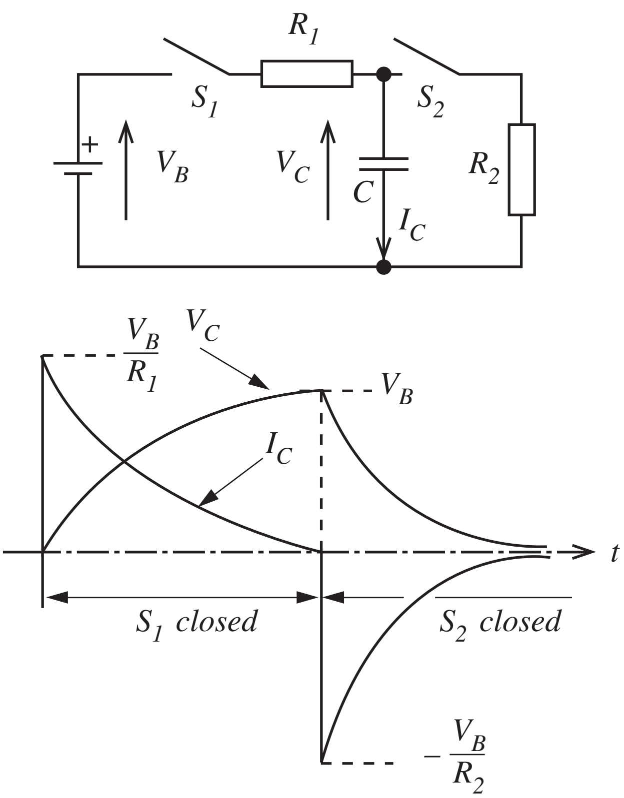

FIG. 11(a)

A capacitor is an electrical energy storage device, in essence a bit like a low power battery. When connected via a resistor R_1 and a switch S_1 to a d.c. supply, the capacitor charges up exponentially to the supply voltage, like a reservoir being topped up to the level of the input river. Once charged, it will stay in this state. If switch S_1 is opened and switch S_2 closed, the capacitor discharges via resistor R_2.

The unit of capacitance is the **farad** (F). The energy stored in a capacitor of capacitance C is given by $\frac{1}{2} CV^2$.

The **time constant** associated with the charge operation is defined by R_1C, which has the units of seconds if R_1 is in ohms and C in farads. The exponential has virtually reached its final value after about $4 \times R_1C$ seconds. Similarly, the discharge time constant is given by R_2C (seconds).

When fed with a sinusoidal voltage of frequency f_s Hz (= Hertz), the capacitor appears as an impedance of $\frac{1}{2\pi f_s C}$ (ohms). In other words, the impedance is high at low frequencies and low at high frequencies!

No power is lost in an ideal capacitor.

Parameters

The important parameters of a capacitor are capacitance, polarity, tolerance and voltage rating.

Capacitors tend to be available in standard ranges of values. The E12 range is popular. Capacitance values are sometimes colour coded, but are usually printed (often incomprehensibly) on the body of the device. Capacitors are available from about 10 picofarads (pF) to 100 000 microfarads (μF). Note that pico = 10^{-12} and micro = 10^{-6}.

FIG. 11(b)

Two different types of construction are manufactured; they are classified as electrolytic and non-electrolytic. The former are polarity sensitive, i.e. they can only be used one way round and cannot be used in a.c. circuits. They tend to have high capacitance/volume ratios and are typically used for power supply smoothing. Non-electrolytic capacitors can be used either way round. Electrolytic capacitors are normally marked to indicate how they should be connected.

Capacitor tolerance is typically ±10% or ±5% for non-electrolytic capacitors; for electrolytic capacitors, the tolerance is often rather wider, e.g. +50% to –10%. The reason for this is that, for smoothing applications, we usually want a guaranteed minimum capacitance, but we do not mind a lot extra!

Capacitor voltages are crucial. Always choose a capacitor with a safety margin on voltage (typically 25%). This allows for voltage surges. For capacitors connected in a.c. circuits, make sure that the rms voltage rating is not exceeded. Normally, the a.c. rating of a capacitor is much less than the d.c. voltage rating. It is best to choose capacitors designed for a.c. operation in such applications.

Capacitor Types

As with resistors, capacitors are available with a range of properties, defined essentially by the dielectric material. These are summarized in the following table.

DIELECTRIC	*RANGE*	*MAX DC VOLTAGE*	*POLAR*	*TOL. %*	*APPLICATIONS*
Mica	*– 0.1 µF*	*2 kV*	*No*	*1*	*Stable, HF*
Aluminium Electrolytic	*1µF – 1000 µF*	*500 V*	*Yes*	*20*	*Smoothing, low stability, short life*
Computer Grade A1	*– 0.2 F*	*500 V*	*Yes*	*– 10 to + 50*	*High µF, long life*
Tantalum Electrolytic	*1µF – 1000 µF*	*50 V*	*Yes*	*20*	*Small size, high µF*
Ceramic	*– 1 µF*	*1 kV*	*No*	*10*	*Good HF*
Polystyrene	*– 10 nF*	*630 V*	*No*	*2*	*Low value, close%*
Polyester	*100 pF – 10 µF*	*500 V*	*No*	*10*	*General purpose*
Polycarbonate	*100 pF – 10 µF*	*500 V*	*No*	*5*	*General purpose*
Polypropylene	*100 pF – 10 µF*	*1.5 kV*	*No*	*20*	*General purpose*

Practical Operation

Never connect in an electrolytic capacitor the wrong way round.

Always provide a discharge path for a capacitor in a high voltage circuit (50 volts or more). Otherwise, when the power supply is switched off, the charge may remain for a long time and may give a dangerous shock to a maintenance engineer. A high value resistance connected in parallel with the capacitor is recommended.

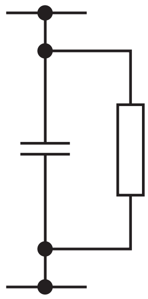

FIG. 11(c)

While capacitances in parallel add, capacitances connected in series give a combined capacitance C_s given by the following expression.

$$C_s = \frac{C_1 C_2}{C_1 + C_2}$$

Can you think of any problem that might occur if you connect capacitors in series?

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If the supply is d.c., how can you ensure that the capacitors will share voltage? You cannot; it depends on the relative leakage currents of the two capacitors. Usually, in this situation one must insert parallel resistors to define a sharing leakage current. See FIGURE 12.

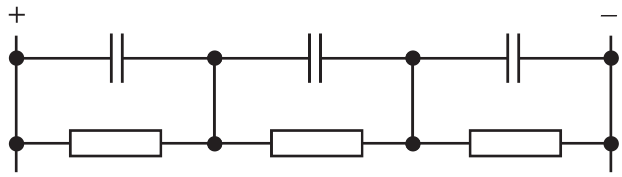


FIG. 12

Applications

Capacitors are commonly used in:

- smoothing power supplies
- decoupling between circuits
- timing circuits and waveform generators
- filtering of noisy or unwanted signals
- forming tuned circuits.

Imperfections

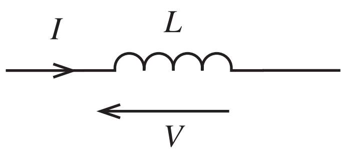
Capacitors are imperfect in that:

- capacitance varies with temperature
- some capacitors tend not to have stable capacitances with time
- some capacitors have appreciable inductance in their leads which degrades their high frequency performance

- capacitors, especially electrolytics, have internal leakage discharge paths, which means they gradually lose charge.

INDUCTORS

Operation



$$V = L\frac{dI}{dt}$$

FIG. 13(a)

An inductor is a coil of wire around which a magnetic field is created when a current flows through it. The magnetic field opposes any increase or decrease of current. Energy is stored in the magnetic field; so the inductor, like the capacitor, is an electrical energy storage device. The capacitor stores energy by virtue of the **voltage** across it; the inductor stores energy because of the **current** flowing in it.

The unit of inductance is the **henry** (H).

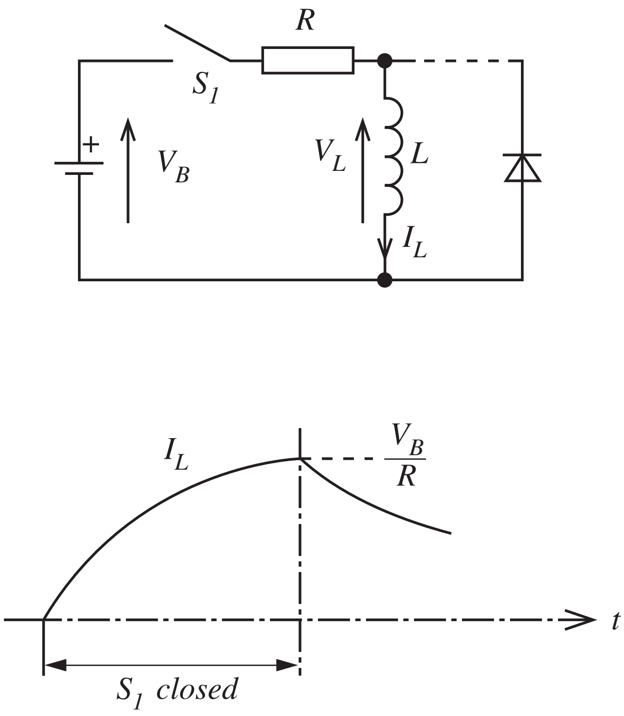


FIG. 13(b)

When connected to a DC supply, the current I builds up exponentially with a time constant of L/R (seconds). At the same rate, the voltage across the inductor falls to zero, and the maximum current flow is $\frac{V_B}{R}$ (amps).

One of the problems of inductors is that, if the switch S_1 is suddenly opened to reduce the current to zero, a very large voltage appears across the inductor (perhaps 2–3000 volts).

This voltage also appears across the switch; so, in the process of opening the switch, an arc (spark) is formed while the inductor energy is discharged. Whilst this is probably more scary than dangerous, it also puts stress on both the wiring insulation and the switch contacts, which may ultimately burn out.

To overcome this problem, a discharge path is usually provided for the inductor, as shown in FIGURE 13(b). The discharge path can be a diode in d.c. circuits, an RC network, or a non-linear resistor. When the switch is opened, the current *I* continues to flow round via the discharge path.

The energy stored in an inductor is $\frac{1}{2}LI^2$.

When connected to an a.c. supply of frequency f, the inductor has an impedance of $2\pi fL$ (ohms).

Parameters

The important parameters for an inductor are its inductance and current rating. The latter determines the size of the wire in the coil. Inductors are relatively bulky and heavy components and tend not to be available ex-stock as standard items. Often, kits are supplied to customers who may wind their own coils; alternatively, coils are constructed to a customer's order. Designing an inductor is quite difficult.

Inductors can be designed with inductances of a few microhenrys (mH) up to several henrys (H).

Construction

Inductors may be either air-cored or iron-cored. The wire is wound on a former. Air-cored inductors are stable and inductance is more or less constant as current and frequency are varied. On the other hand, air-cored inductors tend to have small values of inductance.

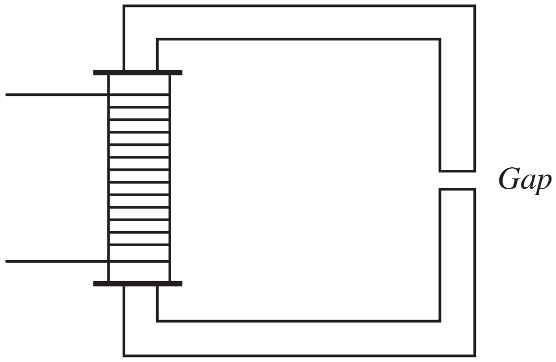


FIG. 13(c)

By putting a core of magnetic material (like iron) through the coil, inductance can be greatly increased. Then the properties of the magnetic material tend to dominate. Unfortunately, unless there is a gap in the core, or the current in the coil is periodically reversed, the magnetic material will saturate. If the current is switched off, part of the magnetic field remains. This property is called hysteresis.

Applications

Because of their relative bulk, electronic engineers tend to avoid inductors! Inductors commonly find applications in:

- smoothing flow of current.
- preventing current from rising too quickly in power semiconductor installations.
- power line filtering in combination with capacitors.
- high frequency oscillator circuits.

TRANSFORMERS

Operation

A transformer is a device for changing a.c. voltages and for providing electrical isolation. Power transformers are used to step up voltage at power stations to levels suitable for transmission lines (400 kV) and step them down again in stages to the ordinary house distribution voltage (230 V).

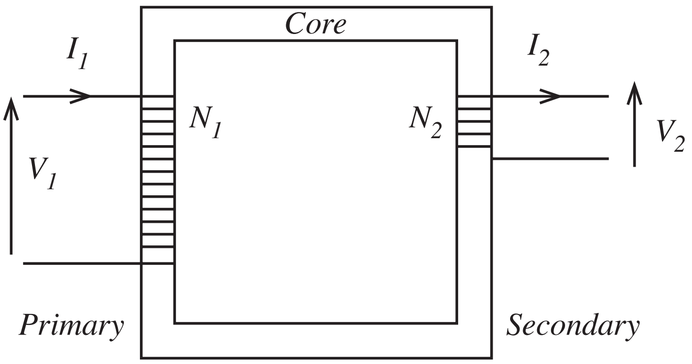


FIG. 14(a)

A voltage V_1 is applied to coil 1; this induces a magnetic field into the core, which is coupled to the second coil 2. The magnetic field causes a voltage V_2 to be induced in the second winding. In a perfect transformer, the voltage ratio depends only on the turns ratio:

$$\frac{V_1}{V_2} = \frac{N_1}{N_2}$$

If no power is lost in the transformer, then the following equation holds.

$$\text{Input power} = \text{Output power}$$

$$V_1 I_1 = V_2 I_2$$

$$\frac{V_1}{V_2} = \frac{I_2}{I_1} = \frac{N_1}{N_2}$$

This means that in a step-down transformer, the primary voltage is high and the primary current is low, whilst the secondary voltage is low and the current high.

Construction

The physical size of transformers is determined by two considerations.

(i) The size of wire or conductor needed to carry the required currents. (As a guide for copper wire/cable, a current density of 3 amps/mm^2 of cross-section is usual).

(ii) The relationships given in FIGURE 14(b) below.

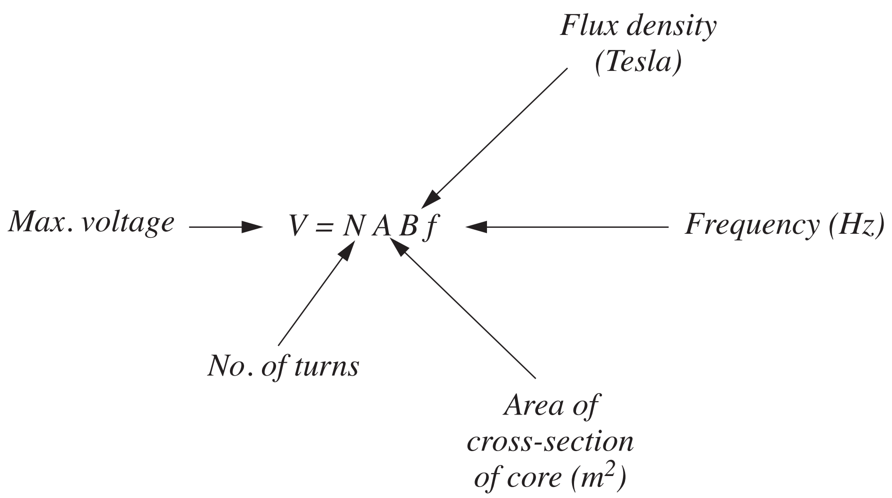


FIG. 14(b)

So, in order to be able to get the required voltage, the parameters N, A and B must be chosen for a given frequency.

Transformers are constructed similarly to inductors, i.e. coils are wound on formers and then fitted around magnetic cores. The assembly is then clamped together. Often the transformer is vacuum varnished to prevent the ingress of moisture.

Like all components, the transformer is imperfect; the wire has finite resistance so that heat is generated and there is also heat lost in the magnetic core material. Transformers can therefore get hot. Also, there is some flux leakage between primary and secondary winding; perfect coupling is not possible. The result of this is the loss of output voltage when a load is taken. The effect of voltage loss as load current rises is called **regulation**. Typically, output voltage falls by 2 – 5% when rated load current is taken.

Parameters

In specifying a transformer, we must define the following parameters.

Primary voltage (rms)
Secondary voltage (rms)
Frequency
Power handling capacity (usually expressed as VA).

Standard transformers are available, mostly small ones up to 1000 VA, designed for use with electronic equipment, which have 230 V primary and a range of low voltage secondaries (e.g. 10 V, 15 V, 20 V, etc).

Larger transformers have to be custom built.

Limitations & Applications

A transformer can only operate on an a.c. waveform. The voltage wave-form can be of any shape so long as the area of one half-cycle is lower than the maximum for the transformer and is balanced by the area of the second half-cycle. We are not restricted to sine waves, but we cannot use d.c. If d.c. is applied to a transformer winding, the transformer quickly saturates and the current rises dramatically, limited only by wiring resistance. (See Inductors).

SELF-ASSESSMENT QUESTIONS

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1. Relays have three advantages over transistors in implementing logic circuits. Can you suggest what they might be?

2. (a) What resistance is represented by the following colour codes?

   (i) Red-red-brown
   (ii) Green-blue-green
   (iii) Yellow-mauve-orange

   (b) What is the colour code for the following resistance values?

   (i) 10 Ω
   (ii) 12 kΩ
   (iii) 390 kΩ.

3. Tabulate the E12 resistor values between 10 Ω and 1000 Ω inclusive. Also tabulate the inverse of these values, i.e. from 0.1 Ω^{-1} to 0.001 Ω^{-1}. Now, using these tables, find the closest match to the four non-standard resistances listed below using:

   (a) two series resistors
   and (b) two parallel resistors.

   e.g. 20 Ω can be obtained exactly by two series 10 Ω resistances or by a 22 Ω and a 220 Ω resistance connected in parallel.

   (i) 138 Ω
   (ii) 50 Ω
   (iii) 95 Ω
   (iv) 23 Ω.

4. In FIGURE 15 what is the range of output voltage controlled by the two potentiometers/variable resistors? What should the rating of the potentiometer/variable resistor be in each case?

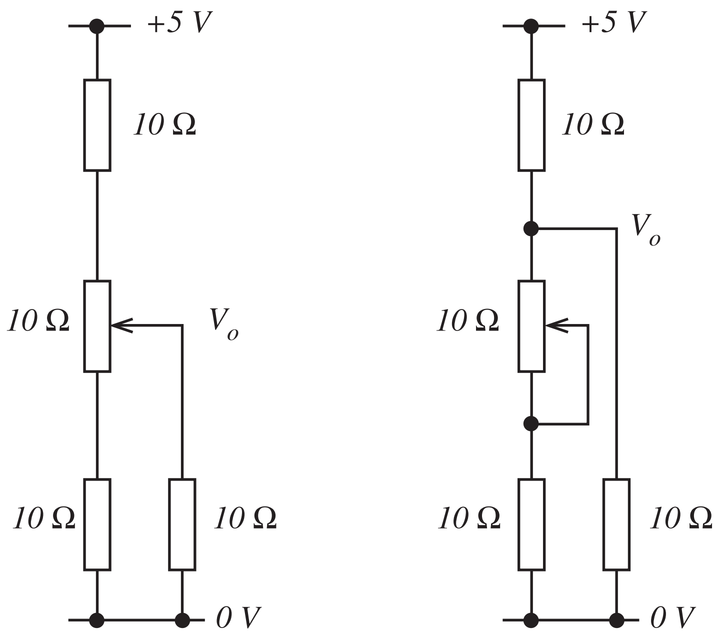

FIG. 15

5. Many power supply networks have smoothing capacitor arrangements, as shown below in FIGURE 16, where C_1 is a large electrolytic capacitor and C_2 is a small non-electrolytic capacitor. Why should we need C_2?

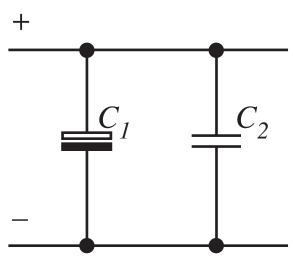

FIG. 16

6. The discharge of a capacitor is given by $v_c(t) = V_{c0}e^{-t/RC}$, where V_{c0} is the initial voltage and R is the resistance of a parallel connected resistor. A 2.2 µF capacitor is normally charged to 1000 V. For safety reasons, it must be discharged to no more than 10 V in 10 seconds when the supply is switched off. What should R be? Choose a standard value. What should its power rating be?

7. A current transformer is one in which the number of primary turns, N_1, is 1. If $N_2 = 100$ and the maximum I_1 is 50 A, what is the maximum I_2? If the VA rating is 10 VA, what is the maximum load resistance that we can use? If this resistance is increased what happens?

8. The wave-form of FIGURE 17 below is fed to a transformer. In order to ensure that the transformer does not saturate, what is the relationship between V_a, V_b, T_1 and T_2?

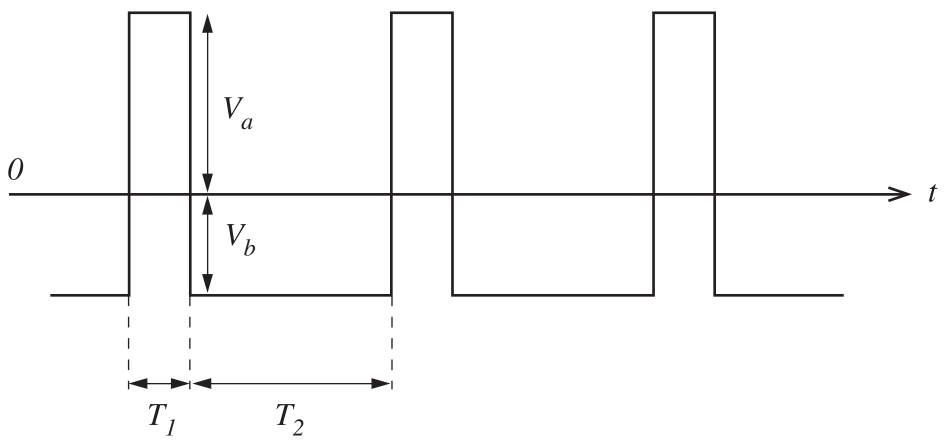

FIG. 17

ANSWERS TO SELF-ASSESSMENT QUESTIONS

1. Relay contacts have very low closed resistance and effective infinite open resistance.

   Relays are not susceptible to interference.

   There is electrical isolation between coil and contact circuits.

   Nevertheless, these are small advantages compared with the advantages of transistors.

2. (a) (i) 220 Ω
   (ii) 5.6 MΩ
   (iii) 47 kΩ

   (b) (i) Brown-black-black
   (ii) Brown-red-orange
   (iii) Orange-white-yellow

3.

Ω	10	12	15	18	22	27	33	39	47	56	68	82	
Ω^{-1} (× 10^3)	100	83.3	66.7	55.6	45.4	37.0	30.3	25.6	21.3	17.9	14.7	12.2	
Ω	100	120	150	180	220	270	330	390	470	560	680	820	1000
Ω^{-1} (× 10^3)	10	8.33	6.67	5.56	4.54	3.70	3.03	2.56	2.13	1.79	1.47	1.22	1.00

(i) 138 Ω (a) Series 120 + 18 or 82 + 56 both give exactly 138 Ω.

(b) $138^{-1} \times 10^3 = 7.25$; the closest is 5.56 + 1.79, which is 180 Ω in parallel with 560 Ω.

(ii) 50 Ω (a) Series 22 + 27 = 49, or 18 + 33 = 51 are the best.

(b) Two 100 Ω in parallel gives 50 Ω exactly.

(iii) 95 Ω (a) Series 68 + 27 or 56 + 39 both give 95 Ω exactly.

(b) $95^{-1} \times 10^3 = 10.5$; the closest is $8.33 + 2.13$, which is 120 Ω in parallel with 470 Ω.

(iv) 23 Ω (a) Series 12 + 12, 12 + 10 is best or, if we cheat, 22 + 1 gives an exact result!

(b) $23^{-1} \times 10^3 = 43.5$ which is well matched by $25.6 + 17.9$, that is 39 Ω in parallel with 56 Ω.

4. In circuit (a), if the potentiometer wiper is set to the top of the track, then the combined resistance of the circuit between V_o and 0 V is 10 Ω in parallel with (10 Ω + 10 Ω), which is 6.67 Ω.

Now, treating the circuit as a voltage divider, we obtain the value of V_o.

$$V_o = \frac{6.67}{6.67 + 10} \times 5 = 2\,\text{V}$$

Taking the wiper to the lowest end of the track, the resistance between V_o and ground is now 10 Ω in parallel with 10 Ω, which is 5 Ω. The value for V_o is now calculated as follows.

$$V_o = \frac{5}{5 + 20} \times 5 = 1\,\text{V}$$

Consider the current, Ip, flowing through the potentiometer.

In the first case, $I_p = \frac{2}{20} = 0.1\text{ A}$

In the second case, $I_p = \frac{(5 - 1)}{20} = 0.2\text{ A}$

So the rating of the potentiometer should be greater than $10 \times 0.2^2 = 0.4\text{ W}$.

In circuit (b), if the resistance is fully included, we have the same situation as in circuit (a), i.e. $V_o = 2\text{ V}$.

If the resistance is set to 0 Ω, then V_o is calculated as follows.

$$V_o = \frac{5}{5 + 10} \times 5 = 1.67\text{ V}$$

In the first case, the current in the variable resistor is the same as for the potentiometer, that is 0.1 A.

In the second case, the current does not in theory go through the material of the variable resistance but, in practice, as the variable resistance is adjusted close to 0 Ω, there will be a current through a bit of the resistance. The limiting case is defined by $I = \frac{1.67}{10} = 0.167\text{ A}$.

Hence, the minimum power rating of the variable resistor can be calculated.

$$10 \times 0.167^2 = 0.28\text{ W}$$

5. Electrolytic capacitors tend to have appreciable inductive and resistive terminals and leads, so they are not good for filtering high frequency noise. A small mF non-electrolytic capacitor reduces the high frequency noise.

6. Put values into the equation below.

$$v_c(t) = V_{c0}e^{-t/RC}$$

$$10 = 1000\exp\left(\frac{-10}{\left[R \times 2.2 \times 10^{-6}\right]}\right)$$

Rearrange to isolate the exponential term.

$$\frac{1000}{10} = \exp\left(\frac{10}{\left[R \times 2.2 \times 10^{-6}\right]}\right)$$

Take the natural logarithm of both sides.

$$4.605 = \frac{10}{\left[R \times 2.2 \times 10^{-6}\right]}$$

Rearrange to give the value of R.

$$R = \frac{10}{4.605 \times 2.2 \times 10^{-6}}$$

$$= 0.987\,\text{M}\Omega$$

A 1 MΩ resistor would be close enough. Its dissipation when there is 1000 V in the circuit is $\frac{1000^2}{10^6} = 1$ W. A rating of 1.5 W would be appropriate.

7. Since

$$\frac{I_1}{I_2} = \frac{N_2}{N_1}$$

$$I_2 = I_1 \frac{N_1}{N_2}$$

$$= 50 \times \frac{1}{100}$$

$$= 0.5\text{ A}$$

If the VA rating is 10, then the maximum voltage

$$= \frac{10}{0.5} = 20\text{ V}$$

Hence, the maximum secondary resistance is

$$R_s = \frac{20}{0.5} = 40\,\Omega$$

If this is exceeded, the current transformer will saturate and the output voltage will collapse to almost zero. This is because any transformer can only support so much voltage-second integral on each winding

$$\left(\text{defined by } V = NABf \text{ or } NAB = \frac{V}{f}\right).$$

8. To avoid saturation, the area of the wave-form above 0 V must equal the area of the wave-form below 0 V in one cycle. So $V_a T_1 = V_b T_2$.

SUMMARY

This lesson has hopefully refreshed some of your ideas about electronics, and made you think a little more about the range, application, availability and limitations of some of the common non-semiconductor components.

Remember that although you may have come across all of these components before, in many cases they were in ideal form, with unrealistic values. The challenge of electronics is not just to analyse simple circuits, but to design your own, using the tools that subsequent lessons will develop.