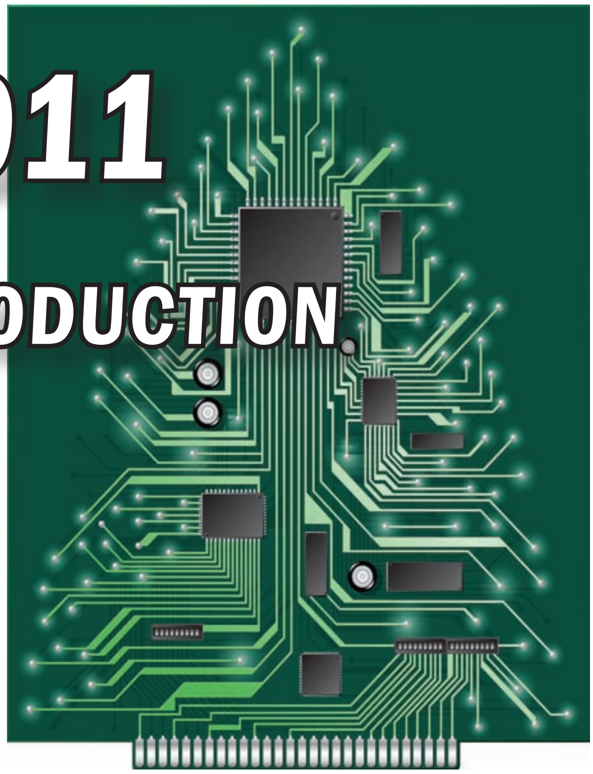
TEACH-IN 2011



A BROAD-BASED INTRODUCTION TO ELECTRONICS

Part 1: Introduction to signals in electronic circuits and systems

By Mike and Richard Tooley

Our Teach-In series is designed to provide you with a broad-based introduction to electronics. We have attempted to provide coverage of three of the most important electronics units that are currently studied in many schools and colleges in the UK. These include Edexcel BTEC Level 2 awards, as well as electronics units of the new Diploma in Engineering (also at Level 2). The series will also provide the more experienced reader with an opportunity to 'brush up' on specific topics with which he or she may be less familiar.

Each part of our Teach-In series is organised under five main headings: *Learn*, *Check*, *Build*, *Investigate* and *Amaze*. Learn will teach you the theory, Check will help you to check your understanding, and Build will give you an opportunity to build and test simple electronic circuits. Investigate will provide you with a challenge which will allow you to further extend your learning, and finally, Amaze will show you the 'wow factor'!

WE BEGIN this new *Teach-In 2011* series by introducing the signals used to convey information in electronic circuits, and the units that we use to measure the quantities in electronic circuits. We conclude this part by looking at some simple electronic circuits that you can build and test using Circuit Wizard software (see pages 54 and 71).

Signals in electronic circuits and systems

This first part of our Teach-In series will provide you with an introduction to the signals that convey *information* in electronic circuits. We will also introduce you to some of the units that are used when measuring electrical quantities, such as current, voltage and frequency. You will learn about the difference between analogue and digital signals and how to recognise signals from the shape of their waveforms.

Being able to 'read' and interpret a circuit diagram or 'schematic' is an essential skill required of every electronic technician and engineer. Many different parts and devices are used in electronic circuits, and it is important that you should be able to recognise them, both from the symbols that we use to represent them in theoretical circuit diagrams and also from their physical appearance.

Learn

Signals and signal conversion

In all forms of communication signals are used to convey information. The signals that we use in everyday life can take many forms, including flashing lights, shouting, waving our hands, shaking our heads and others forms of 'body language'. In fact, life would be very difficult without signals – think about driving a car or motorbike in heavy traffic! In this section we will look at how signals are used in electronics, how they can be converted from one form to another, and how they are measured.

In electronics, signals can take many forms including changes in voltage levels, pulses of current, and sequences of binary coded digits or *bits*. Signals that vary continuously in level are referred to as ***analogue*** signals, while those that use discrete (ie fixed) levels are referred to as ***digital*** signals. Some typical analogue and digital signals are shown in Fig.1.1. Notice how the digital signal exists only as a series of discrete voltage levels, while the analogue signal varies continuously from one voltage level to another.

Signals can also be quite easily converted from one form to another. For example, the signal from the stage microphone at a live radio broadcast will be an analogue signal at the point at which the original sound is produced (ie on stage). After appropriate processing (which might involve amplification and/or removal of noise and other unwanted sounds) it might then be converted to a digital signal for radio transmission, and then converted back to an analogue signal before being amplified and sent to the loudspeaker at the point of reception.

A device that converts an analogue signal to digital format is called an *analogue-to-digital converter* (**ADC**), while one that converts a digital signal to analogue is referred to as a *digital-to-analogue converter* (**DAC**). An electronic system that uses both analogue and digital signals is shown in Fig.1.2.

Electronic units

A number of units are commonly used in electronics, so we shall start by introducing some of them. Later, we will be put these units to use when we solve some simple circuit problems, but since it's important to get to know these units and also to be able to recognise their abbreviations and symbols we have summarised them in Table 1.1.

Please note!

Frequency and bit rate are very similar. They both indicate the speed at which a signal is transmitted, but bit rate is used for digital signals while frequency is used with analogue signals.

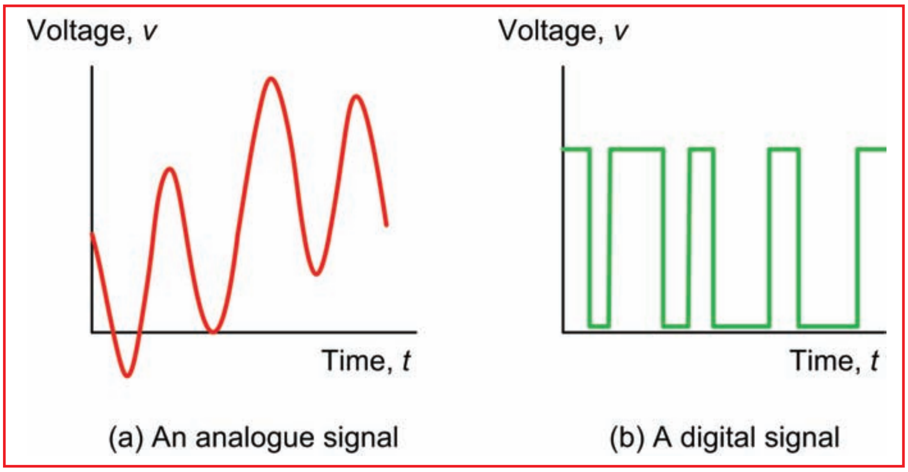


Fig.1.1. Typical analogue and digital signals

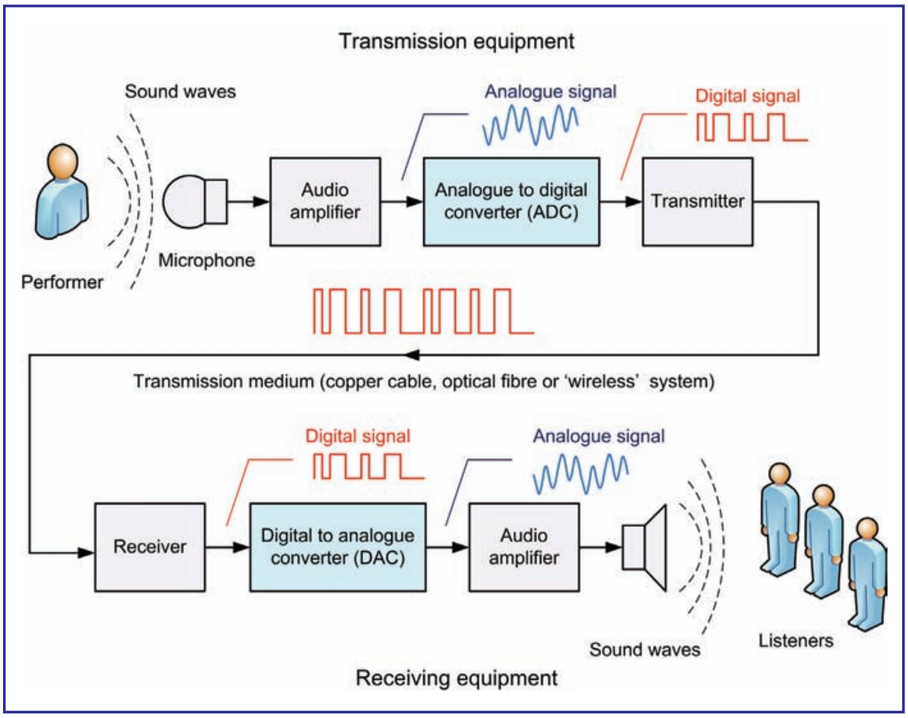


Fig.1.2. An electronic system that uses both analogue and digital signals

Table.1.1: Some electrical quantities and units of measurement

Parameter	***Unit***	***Abbreviation***	***Notes***
Electric potential	Volt	V	A potential of 1V (one Volt) appears between two points when a current of 1A (one Amp) flows in a circuit having a resistance of 1Ω (one Ohm). Note that electric potential is also sometimes referred to as electromotive force (EMF) or potential difference (pd)
Electric current	Ampere (or amp)	A	A current of 1A flows in an electrical conductor when electric charge is being transported at the rate of 1 Coulomb per second
Electric power	Watt	W	Power is the rate of using energy. A power of 1W (one Watt) corresponds to 1 Joule of energy being used every second
Electrical resistance	Ohm	Ω	An electric circuit has a resistance of 1Ω when a pd (see above) of 1V is dropped across it when a current of 1A is flowing in it
Frequency	Hertz	Hz	A signal has a frequency of 1Hz (one Hertz) if one complete cycle of the signal occurs in a time interval of 1s (one second)
Bit rate	Bits per second	bps	A signal has a bit rate of 1 bit per second if one complete binary digit is transmitted in a time interval of 1s

Please note!

To avoid confusion between the symbols and the abbreviations that we use for units, the former are normally displayed in italic font. For example, a capital letter V is used as both the abbreviation for voltage and for its unit symbol (the Volt). When used as a symbol in a formula it is conventionally shown in italic as *V* and when used as shorthand for volts it is shown in normal (non-italic) font as 'V'.

Multiples and sub-multiples

Unfortunately, because the numbers can be very large or very small, many of the electronic units can be cumbersome for everyday use. For example, the voltage present at the antenna of a mobile phone could be as little as one ten-millionth of a volt, or 0.0000001V. Conversely, the resistance seen at the input of an audio amplifier stage could be more than one hundred-thousand ohms, or 100,000Ω.

To make life a lot easier we use a standard range of multiples and sub-multiples. These use a prefix letter in order to add a multiplier to the quoted value, as shown in Table 1.2.

Please note!

Exponent notation is often useful when performing calculations using very large or very small numbers. You can use exponent notation by pressing the exponent (E) or engineering (ENG) button on your calculator.

Converting to/from multiples and sub-multiples

Converting to and from multiples and sub-multiples is actually quite easy, as the following examples show:

Example 1

Convert 7,240Hz to kHz. To do this you just need to move the decimal point *three* places to the *left*. This is the same as dividing by 1,000 (because there are 1,000Hz in 1kHz).

Moving the decimal point three places to the left tells us that 7,240Hz = 7.240kHz = 7.24kHz.

Example 2

Convert 2,200,000Ω to MΩ. To do this you need to move the decimal point *six* places to the *left*. This is the same as dividing by 1,000,000 (because there are 1,000,000Ω in 1MΩ).

Moving the decimal point six places to the left tells us that 2,200,000Ω = 2.2MΩ.

Example 3

Convert 0.625V to mV. To do this you need to move the decimal point *three* places to the *right*. This is the same as multiplying by 1,000 (because there are 1,000mV in 1V).

Moving the decimal point three places to the right tells us that 0.625V = 625mV.

Example 4

Convert 14,400kbps to Mbps. To do this you need to move the decimal point *three* places to the *left*. This is the same as dividing by 1,000 (because there are 1,000kbps in 1Mbps).

Moving the decimal point three places to the left tells us that 14,400kbps =14.4Mbps.

Please note!

Multiplying by 1,000 is equivalent to moving the decimal point three places to the right, while dividing by 1,000 is equivalent to moving the decimal point three places to the left. Similarly, multiplying by 1,000,000 is equivalent to moving the decimal point six places to the right, while dividing by 1,000,000 is equivalent to moving the decimal point six places to the left.

Waveforms and waveform measurement

A graph showing the variation of voltage or current present in a circuit

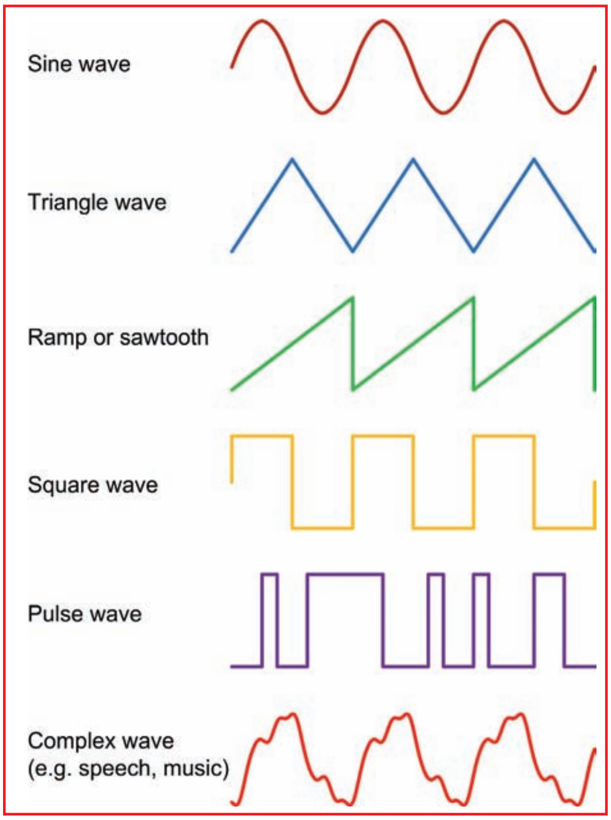


Fig.1.3. Some common waveforms

Table.1.2: Some common multiples and sub-multiples

Multiple	*Exponent notation*	*Prefix*	*Abbreviation*	*Example*
×1,000,000,000	$\times10^{9}$	Giga	G	1.2GHz (1,200 million Hertz)
×1,000,000	$\times10^{6}$	Mega	M	2.2MΩ (2.2 million Ohms)
×1,000	$\times10^{3}$	Kilo	k	4kbs (4,000 bits per second)
×1	$\times10^{0}$	None	none	220Ω (220 Ohms)
×0.001	$\times10^{-3}$	Milli	m	45mV (0.045 Volts)
×0.000,001	$\times10^{-6}$	Micro	*μ*	33μA (0.000033 Amps)
×0.000,000,001	$\times10^{-9}$	Nano	n	450nW (0.00000045 Watts)

is known as a ***waveform***. Waveforms show us how voltage or current signals vary with time. There are many common types of waveform encountered in electronic circuits, including *sine* (or sinusoidal), *square*, *triangle*, *ramp* or *sawtooth* (which may be either positive or negative going), and *pulse*.

Complex waveforms, like speech and music, usually comprise many different signal components at different frequencies. Pulse waveforms are often categorised as either repetitive or non-repetitive (the former comprises a pattern of pulses that repeats regularly, while the latter comprises pulses which each constitute a unique event). Some common waveforms are shown in Fig.1.3.

Frequency

The frequency of a repetitive waveform is the number of cycles of the waveform which occur in unit time (ie one second). Frequency is expressed in Hertz (Hz), and a frequency of 1Hz is equivalent to one cycle per second. Hence, if a voltage has a frequency of 50Hz, 50 cycles of it will occur in every second.

Periodic time

The periodic time (or period) of a waveform is the time taken for one complete cycle of the wave (see Fig.1. 4). The relationship between periodic time and frequency is thus:

$t = 1 / f$ or $f = 1 / t$

where t is the periodic time (in s) and f is the frequency (in Hz).

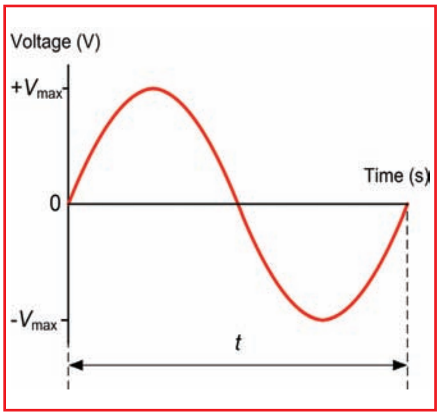


Fig.1.4. One cycle of a sinewave voltage showing its periodic time

Example 5

A waveform has a frequency of 50Hz. What is the periodic time of the waveform?

Here we must use the relationship $t = 1 / f$, where f = 50Hz.

Hence, $t = 1 / 50 = 0.02$s (or 20ms)

Example 6

A waveform has a periodic time of 4ms. What is its frequency?

Here we must use the relationship $f = 1 / t$, where t = 4ms or 0.004s.

Hence, $f = 1 / 0.004 = 250$Hz.

Amplitude

The amplitude (or *peak value*) of a waveform is a measure of the extent of its voltage or current excursion from the resting value (usually zero). The *peak-to-peak* value for a wave, which is symmetrical about its resting value, is twice its peak value (see Fig.1.5). These units are usually more convenient to use when taking measurements from a waveform display.

Pulse waveforms

When describing rectangular and pulse waveforms we use a different set of parameters (see Fig. 1.6). These include:

On time, t_{on}

This is the time for which the pulse is present at its maximum amplitude. This is sometimes referred to as the '*mark time*'.

Note that when a pulse is not perfectly rectangular (ie, when it takes some time to change from one level to the other), we define the off time as the time for which the pulse amplitude remains above 50% of its maximum value.

Off time, t_{OFF}

This is the time for which the pulse is not present (ie, zero voltage or current). This is sometimes referred to as the '*space time*'.

Note that, when a pulse is not perfectly rectangular (and takes some time to change from one level to another), we define the off time as the time for which the pulse amplitude falls below 50% of its maximum value.

Pulse period, t

This is the time for one complete cycle of a repetitive pulse waveform. The periodic time is thus equal to the sum of the on and off times (but once again, note that this is only valid if the pulse train is repetitive and is meaningless if the pulses occur at random intervals).

When a pulse train is not perfectly rectangular, the pulse period is measured at the 50% amplitude points.

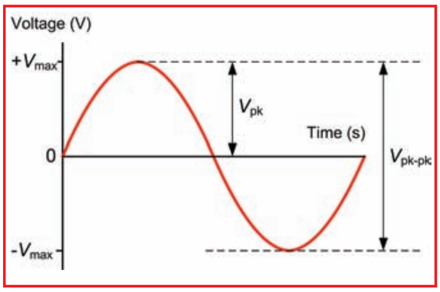


Fig.1.5. One cycle of a sinewave voltage showing its peak and peak-to-peak values

Pulse repetition frequency, prf

The pulse repetition frequency (prf) is the reciprocal of the pulse period. Hence:

$prf = 1 / t = 1 / (t_{ON} + t_{OFF})$

Mark to space ratio

The mark to space ratio of a pulse wave is simply the ratio of the on to off times. Hence:

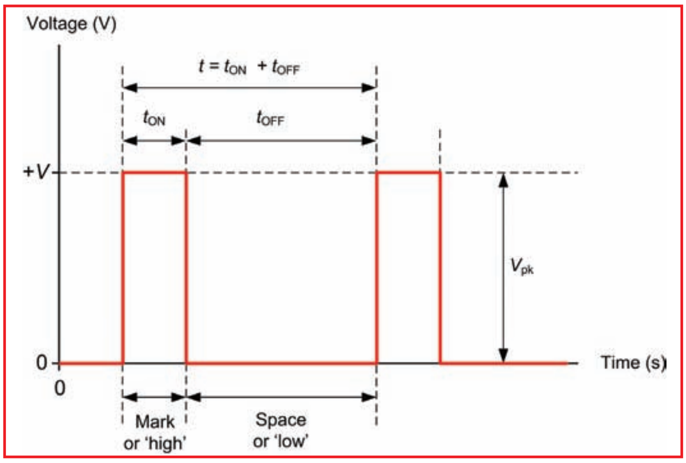


Fig.1.6. A pulse waveform showing 'on' and 'off' times

Mark to space ratio = $t_{ON} : t_{OFF}$

Note that, for a perfect square wave the mark to space ratio will be 1:1, because $t_{ON} = t_{OFF}$

Duty cycle

The duty cycle of a pulse wave is the ratio of the on time to the on plus off time (and is usually expressed as a percentage). Hence:

Duty cycle $= t_{ON} \;/\; (t_{ON} + t_{OFF}) \times 100\% \;=\; t_{ON} \;/\; t \times 100\%$

For a perfect square wave, the duty cycle will be 50%.

Cells, batteries and power supplies

Cells and batteries provide the power for a wide range of portable and hand-held electronic equipment. There are two basic types of cell: *primary* and *secondary*.

Primary cells produce electrical energy at the expense of the chemicals from which they are made and once these chemicals are used up, no more electricity can be obtained from the cell. An example of a primary cell is an ordinary 1.5V AA alkaline battery.

In secondary cells, the chemical action is reversible. This means that the chemical energy is converted into electrical energy when the cell is discharged, whereas electrical energy is converted into chemical energy when the cell is being charged. An example of a secondary cell is a 1.2V AA nickel cadmium (NiCad) battery.

In order to produce a battery, individual cells are usually connected in series with one another, as shown in Fig.1.9. The voltage produced by a battery with n cells will be *n* times the voltage of one individual cell (assuming that all of the cells are identical). Furthermore, each cell in the battery will supply the same current.

Series connected cells are often used to form batteries. For example, the popular PP3, PP6 and PP9 batteries are made from six 'layered' 1.5V primary alkaline cells, which are effectively connected in series. A 12V car battery, on the other hand, uses six 2V lead-acid secondary cells connected in series.

Where an electronic circuit derives its power from an AC mains supply, we sometimes show the supply as a box with two terminals (one marked positive and one marked negative). Treating the power supply as a separate unit helps keep the circuit simple. If the power supply fails we can simply replace the entire unit in much the same way as we would replace a set of exhausted batteries.

Fig.1.7. Some typical cells and batteries used in electronic equipment

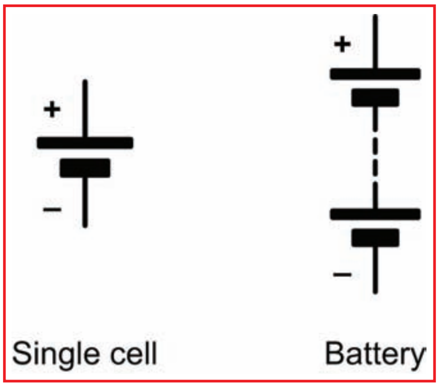


Fig.1.8. Symbols for cells and batteries

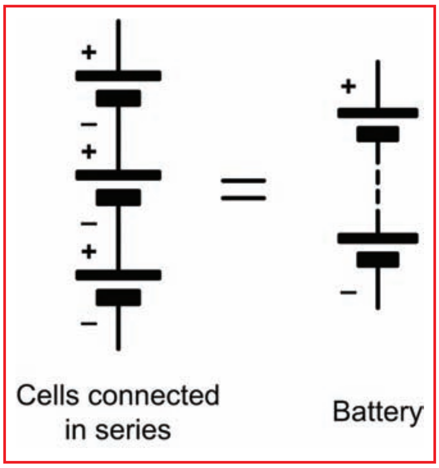


Fig.1.9. Series arrangement of cells

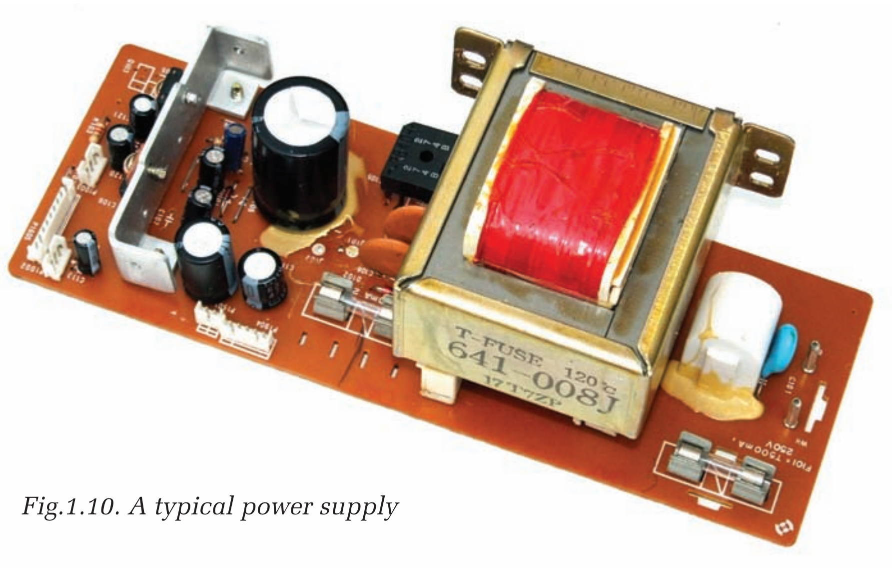


Fig.1.10. A typical power supply

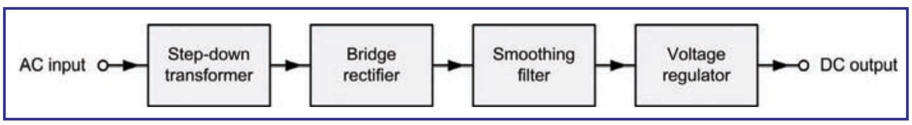


Fig.1.11. A block schematic representation of the power supply in Fig.1.10

A typical power supply which has an AC mains input and DC output is shown in Fig.1.10. Fig.1.11 shows how we can represent the power supply using a simple *block schematic diagram*. Note that we have not shown any switches, fuses or indicators in this diagram!

Please note!

We refer to the output voltage produced by a battery or a power supply as an electromotive force (EMF). Electromotive force is measured in volts, V. In contrast, we refer to the voltage drop across an electronic component (such as a resistor or capacitor) as a potential difference (pd). Potential difference is also measured in volts (V).

The best way to distinguish between EMF and pd is to remember that EMF is the 'cause' and pd is the 'effect'.

Check – How do you think you are doing?

Short answer questions

1.1. Explain the difference between analogue and digital signals.

1.2. List the units used for each of the following electrical quantities:

(a) current

(b) potential

(c) power

(d) resistance

(e) frequency

(f) bit rate.

1.3. Explain what is meant by each of the following abbreviations:

(a) mV

(b) kHz

(c) µA

(d) MHz

(e) kΩ

(f) nW

(d) kbps.

1.4. An amplifier requires an input signal of 0.055V. Express this in mV.

1.5. An ADC operates at a bit rate of 125kbps. Express this in Mbps.

1.6. A current of 75μA flows in a resistor. Express this in mA.

1.7. A radio signal has a frequency of 0.465MHz. Express this in kHz.

1.8. A portable CD player uses a battery which has four 1.5V cells connected in series. What EMF does this battery supply?

1.9. Explain the difference between EMF and pd.

1.10. Explain the difference between primary cells and secondary cells.

Long answer questions

1.11. Fig.1.12 below shows an electronic system that uses both analogue and digital signals. Take a careful look at the diagram and see if you can understand how it works before answering the following questions:

(a) Explain the purpose of the system

(b) At which points (A, B, C etc.) do the signals exist in digital form and at which points do they exist in analogue form?

(c) What form do the signals have when they are present in the wireless (radio) link?

(d) Can you suggest any advantages and/or disadvantages of the system?

1.12. Fig1.13 shows a waveform diagram.

(a) What type of waveform is shown?

(b) What is the amplitude of the waveform?

(c) What is the period of the waveform?

(d) What is the repetition frequency of the waveform?

(e) What is the mark-to-space ratio of the waveform?

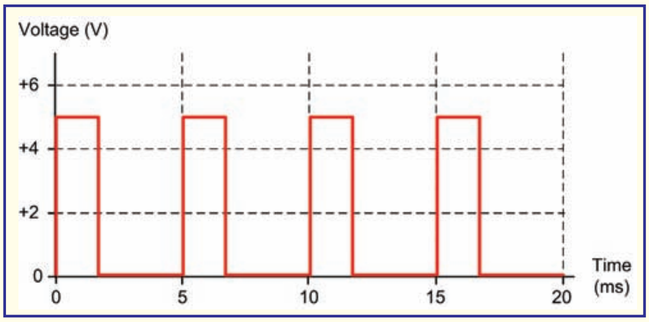


Fig.1.13. See Question 1.12

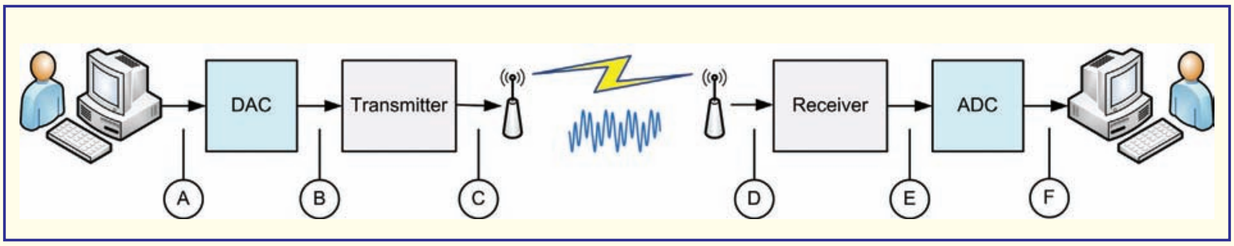


Fig.1.12. See Question 1.11

Build – The Circuit Wizard way

ONE of the problems with electronics is simply the amount of kit that you need to get started. Even a basic starter set-up could run in to hundreds of pounds; soldering iron, hand tools, circuit board, wires, leads, components, test equipment – it all adds up! Therefore, the 'Build' section of our Teach-In series is going to focus around using Circuit Wizard, a really great piece of circuit simulation software that runs on your Windows PC.

In this way, you'll have access to literally thousands of components, a full range of 'virtual test equipment' along with real-time simulation and tools to help you actually visualise the operation of your circuits. There's also the ability to build breadboard circuits and convert your circuits into a printed circuit board (PCB) design that can then be manufactured. We really feel that it's the ideal way to get started with electronics, so much so that, with the next issue of *EPE*, we will give away a *free* CD-ROM containing a 'demo' version of the Circuit Wizard.

Simulation

Students of electronics are often confused by the fact that you can't actually see what's going on inside a circuit. In a mechanical machine it's easy to see things moving and working, but we have none of these visual clues when working on an electronic circuit.

Computer simulation neatly overcomes this problem by providing a visual representation of what's going on under the surface. This might include the flow of current in wires, the voltage at various points in a circuit, or the charge present in a capacitor.

In industry, the use of software for simulation, design and manufacture of electronic products is the norm. Indeed, being able to make effective use of software tools is now a key skill for any aspiring electronic engineer or hobbyist.

A standard licence for Circuit Wizard costs around £60 and can be purchased from the editorial office of EPE – see the UK shop on our website (**www.epemag.com**). Further information can be found on the New Wave Concepts website; **www.new-wave-concepts.com**. The developer also offers an evaluation copy of the software that will operate for 30 days, although it does have some limitations applied, such as only being able to simulate the included sample circuits and no ability to save your creations, this is the software that will be *free* with *EPE* next month. However, if you're serious about electronics and want to follow our series, then a copy of Circuit Wizard is a really sound investment.

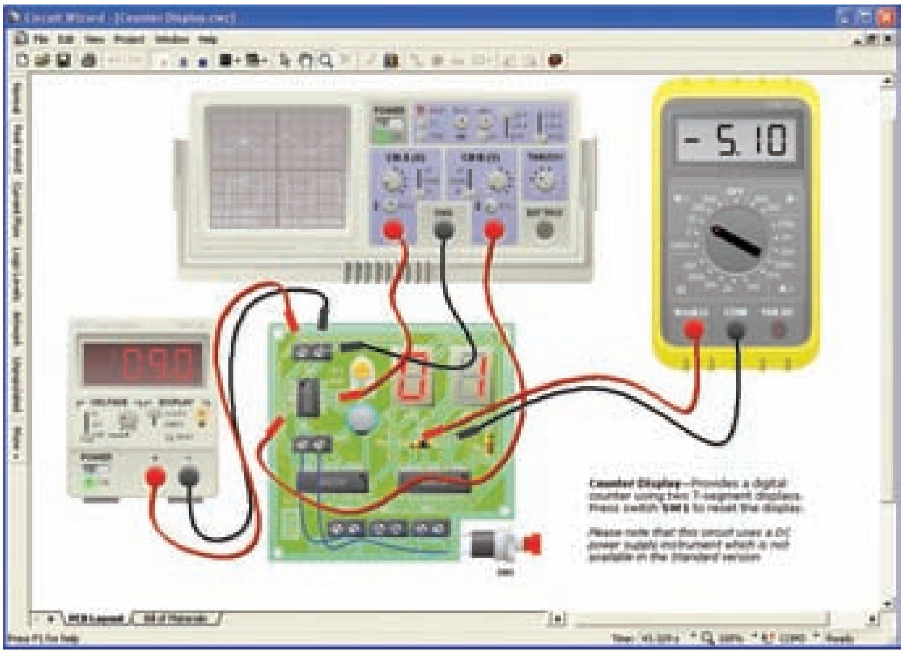


Fig.1.14. Circuit Wizard screenshot showing the use of 'virtual instruments'

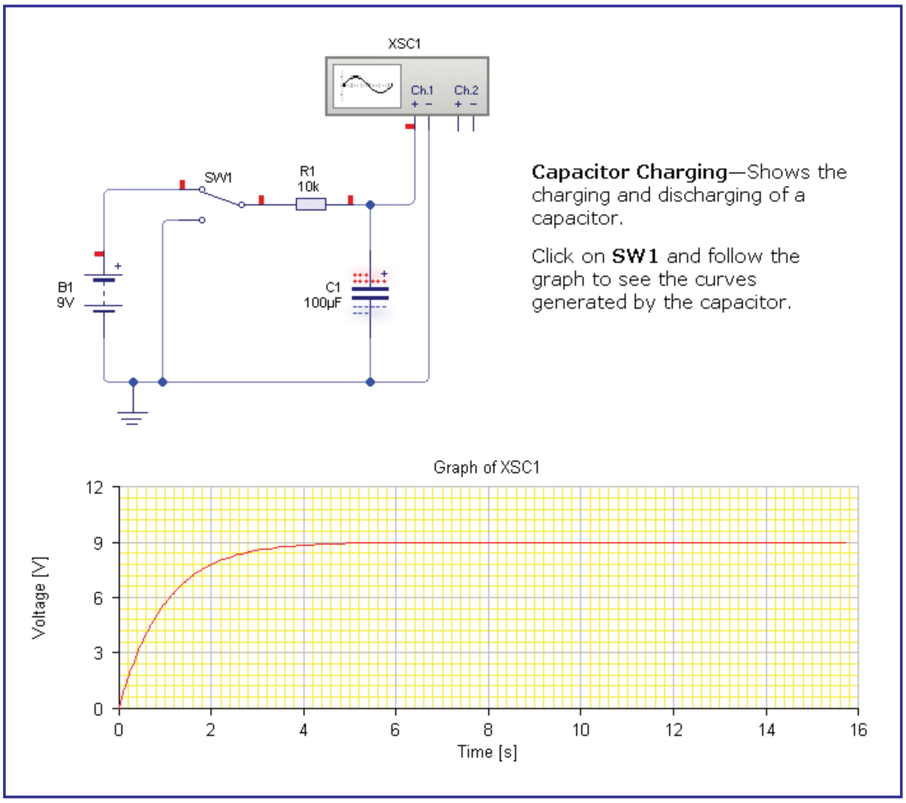


Fig.1.15. A capacitor charging circuit showing charge building up on the plates, voltage levels and a graphical plot of voltage against time

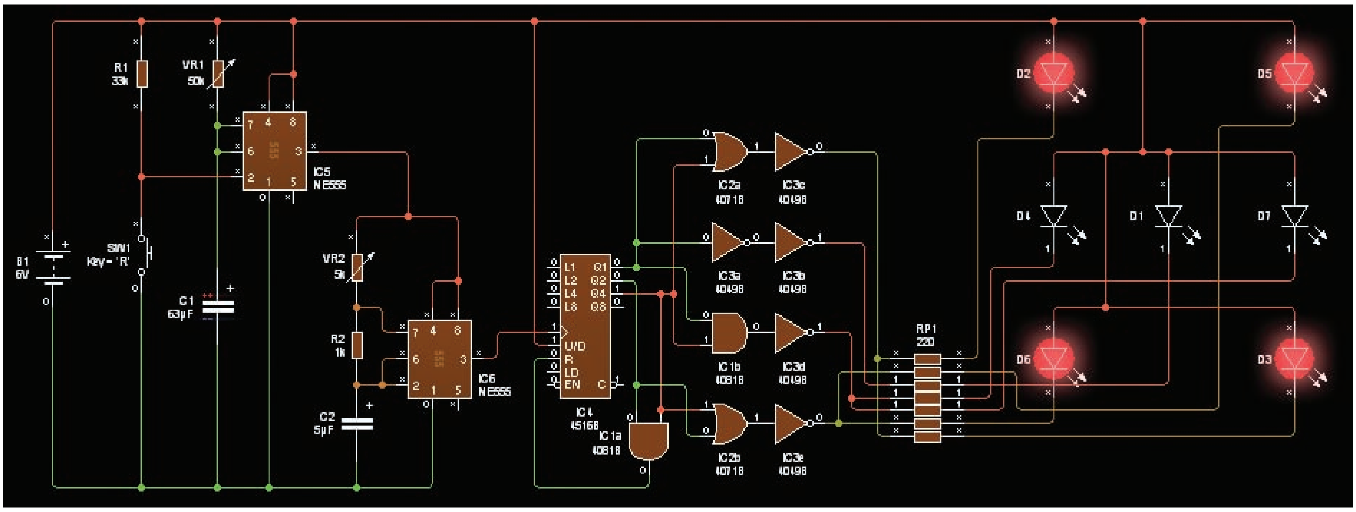


Fig.1.16 A logic-based electronic dice in 'logic view' showing digital signal levels at each point in the circuit

In this instalment, we're going to look at installing and getting started with Circuit Wizard. In future months we will be using the software to investigate the theory and circuits that you will meet in 'Learn'. We'll also develop electronic devices and use Circuit Wizard to design and produce PCBs so that you can make the real thing!

Installation

Installation of Circuit Wizard is very straightforward, and it's a surprisingly small installation for what is such a powerful piece of software. Our install process took no more than quarter of an hour from start to finish. During the installation process you'll be asked to enter a licence key which will be supplied with your install disc.

When you run Circuit Wizard for the first time you will be asked to obtain a release code, which can be done over the 'phone or via the developer's website where the release code is then subsequently e-mailed to you. This needs to be done within a 60-day window or the software will cease to load.

First looks

The user interface is both clean and intuitive. The main white drawing area fills most of the screen, with the standard Windows menus and toolbar across the top. A tabbed pane on the right-hand side of the screen presents a 'Getting Started' menu, where you can access various samples/tutorials and gain help.

Clicking the 'Gallery' tab exposes an extensive library of components and test equipment. Tabs on the far left of the screen allow you to see your circuit in various different 'views'. These are designed to help you see what's actually going on in your circuits by colouring and/or animating the circuit diagram to show voltages/currents.

This is a really nifty feature, allowing you to actually see electronics in action. There are a number of preset views or you can create your own to suit. Along the bottom of the screen a row of tabs allows you to change between different pages of your design.

'Drawing' is where you would actually enter and simulate a circuit, 'PCB Layout' is where you would produce a PCB design (as well as working with virtual test equipment and breadboards). Finally, 'Bill of Materials' generates an inventory/costing of the components used in your circuit.

Finding your way around

By far the best way to get started with Circuit Wizard is to follow the guided tour screen videos and experiment with the sample circuits provided. All of these are directly accessible from the 'Getting Started' page in the right-hand pane (click on

Fig.1.17. Circuit Wizard's Gallery of components and test equipment

The Circuit Wizard way

the 'Assistant' tab if the circuit gallery view is shown).

The screen videos explain the basic operation of the software but lack sound, with only written descriptions appearing on the screen; this does make for slow progress. If you're a confident computer user you may want to just jump straight in and explore over fifty sample circuits that are included and get to know the software hands-on.

Fig.1.18. Circuit Wizard provides a good selection of starter materials

The sample circuits are split by complexity into three folders; simple, basic and advanced. Each of these is then further divided into sub-categories, which really showcase the extensive features of the software. The sample circuits are excellent and contain instructions on how to test out the circuit – they're also really educational, so you might even learn something about electronics as you discover the software too!

In next month's instalment, we'll be showing you how to enter and test some simple circuits that will be underpinned by the theory covered in our 'Learn' section. Until then, you might like to get yourself a copy of Circuit Wizard and have a play! If you're really keen to get stuck in, check out our *Teach-In 2011* website at **www.tooley.co.uk/teach-in**, where you can download some further examples.

Fig.1.19. A typical bench oscilloscope

Investigate

WAVEFORMS are usually displayed using an instrument called an oscilloscope. You will learn more about this instrument later in the series. Oscilloscopes can be standalone test instruments (see Fig.1.19) or they can be virtual instruments that use a PC's in-built signal processing capabilities (eg, the analogue-to-digital converter in a PC sound card).

Fig.1.20 shows a typical virtual instrument display obtained by using a soundcard oscilloscope program. The program receives its data from the computer's sound card with a sampling rate of 44.1kHz and a resolution of 16-bits. The data source can be selected by the PC's own sound card controls (eg, microphone, line input or wave). The frequency range of the instrument depends on the performance of the computer's sound card, but is typically accurate over the range 20Hz to 20kHz.

The oscilloscope also contains a simple signal generator producing sine, square, triangle and sawtooth waveforms in the frequency range from 0 to 20kHz. These signals are available at the speaker output of the sound card.

Take a careful look at Fig. 1.20 and use it to answer the following questions:

(a) What type of waveform is shown?

(b) What total time interval is displayed on the screen: (Hint: look at the horizontal scale)

(c) What settings are used for the vertical and horizontal scales on the oscilloscope display?

(d) What is the greatest positive voltage present in the waveform sample?

(e) What is the greatest negative voltage present in the waveform sample?

(f) What is the overall peak-peak voltage of the waveform?

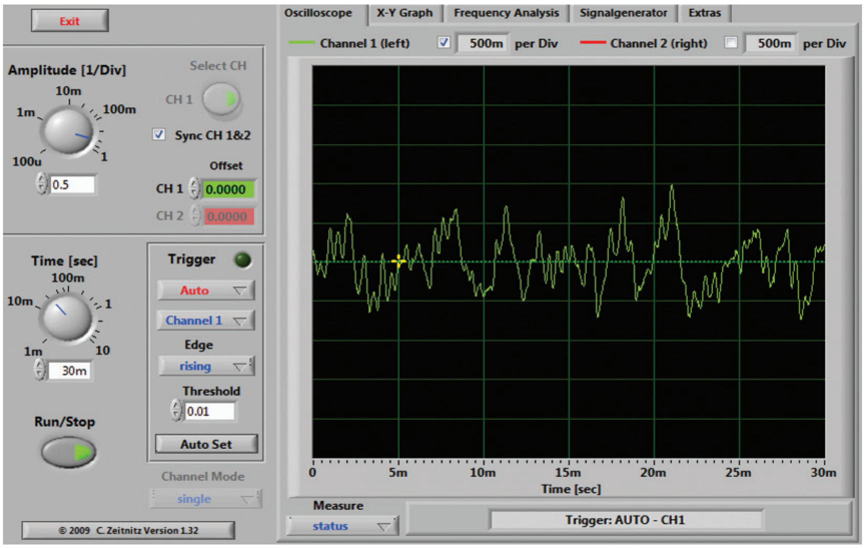


Fig.1.20 See the Investigate questions

Answers to Questions

1.1. Analogue signals vary continuously in voltage and current whilst digital signals can only exist in discrete levels of voltage or current.

1.22. (a) Ampere, (b) Volt, (c) Watt, (d) Ohm, (e) Hertz, (f) bits per second.

1.3. (a) millivolt, (b) kilohertz, (c) microamp, (d) megahertz, (e) kilohm, (f) nanowatt, (g) kilobits per second.

1.4. 55mV

1.5. 0.125Mbps

1.6. 0.075mA

1.7. 465kHz

1.8. 6V

1.9. EMF is used to describe the output voltage produced by a battery or power supply. Potential difference is used to describe the voltage drop that appears across a component such as a resistor or capacitor.

1.10. Primary cells produce electrical energy from a non-reversible chemical reaction and must be disposed of when exhausted. Secondary cells make use of a reversible chemical reaction and can be recharged and used again.

1.11. (a) Wireless data link between computer systems, (b) A digital; B analogue; C analogue; D analogue; E analogue; F digital, (c) Sinewave radio frequency with superimposed (modulated) signal information, (d) Disadvantages: lack of security compared with systems linked by cable, may suffer from interference to/from other nearby wireless systems; Advantages: simple to install, does not need permanent cabling.

1.12. (a) pulse wave, (b) 5V, (c) 5ms, (d) 200Hz, (e) 1:2

Amaze

Download a copy of the Soundcard Oscilloscope software and investigate the operation of the program using some typical signals applied to the microphone or auxiliary inputs of a PC. The software is available from Christian Zeitnitz's website: **http://www.zeitnitz.de/Christian/scope_en**

Next month

In next month's *Teach-In 2011* we shall be looking at resistors and capacitors. Examples of these two passive components are found in almost every electronic circuit. Furthermore, when used together, these two components form the basis of a wide range of electronic timing and delay circuits.

We shall be investigating the behaviour of these circuits using Circuit Wizard.

For more information, links and other resources please check out our Teach-In website at:

www.tooley.co.uk/teach-in