Electronics for Model Railways

Chapter 26

Using test equipment

By Davy Dick

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In memory of Margaret

Contents

Using test equipment

You build a module … You apply the power … It doesn't work … What's wrong?

Where do you start?
What do you need?
What can you do?

Firstly, don't panic! You are certainly not alone. No-one gets every project to work first time. However, we can minimise the risk by having a logical approach to fault-finding and testing.

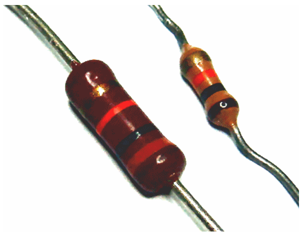
This chapter can't cover all possible faults for all kits and home-built projects found in magazines or on the Internet.. Some use ICs or PICs, some don't; some are supplied as kits with carefully selected components, others are supplied as circuit boards with members sourcing their own components; some need computer software, some don't.

This chapter should provide useful pointers, looking at the most common problems users encounter. It also looks at some equipment that should help you test your modules.

Let's start with the good news … **Its not always us**

If a module won't work, it might not be our fault, as there are other possible factors, such as:

- Faulty components. Rare, but does happen.
- Incorrect instructions. Happens occasionally; watch out for updates and amendments.
- Ambiguous instructions. The author knows what is meant but has taken too much for granted.
- Ambiguous components. Chip with markings rubbed off or difficult to determine. One of these resistors has a red band while the other has an orange band- which is which?
- Bugs in the software



Now the bad news.... **Its usually us**
Not as bad as it sounds, as in the great majority of cases the problem can be identified with a visual inspection (aided by a decent magnifier).

Getting started

Many modellers initially make little distinction between construction and testing. They build their kits and are keen to see if they work. While understandable, it is best to take the time to carry out simple checks before plugging in the chips and switching on the power. Although there are a variety of approaches, one of the best is:

"Fault-finding starts <u>before</u> you insert the PICs and/or ICs"

This is for two reasons:

- Faults that might damage your components can be detected before they destroy your circuits. For example, its best to spot that you've mistakenly use a 15v regulator instead of a 5v regulator, or connected a 12v supply to a 5v connection – before your PICs or ICs are fried.
- Checking for shorts or breaks in a circuit and resistance values are not complicated by the internal resistances between pins on PICs and/or ICs, giving 'wrong' readings.

Once all the checks listed below are completed satisfactorily, any transistors can be soldered on to the PCB and ICs and/or PICs can be inserted into their holders

Keep an open mind

It's easy to jump to the conclusion that the chip must be faulty, or the program is wrong – only to find that you have soldered a component the wrong way round or forgot to wire an essential link on a board. Rule nothing out; start with the premise that anything and everything is possible. The chip or component might be faulty (it has happened, although rarely) or the program may have errors (this has happened too) but the vast majority of mistakes are caused by the constructor. Fortunately, most problems are easily detected and corrected.

Knowing the symptoms

"It doesn't work" is a first observation but it pays to use all your senses to fully appreciate the problem. Can you:

- See: Screen contents, error messages, motion, lights, even smoke!
- Hear: Points operating, motors spinning, warning beeps.
- Feel: Vibration from rotating parts, temperature of chips.
- Smell: Components overheating, dust, odour from spillages.

In addition, you can deduce:

- Times: Start-up times, shutdown times, delays in running tasks.
- Sequences: Noting the order of events (e.g. does the computer application hang before or after a particular device is used).
- Differences: Noting the performance comparisons between two identical modules running the same application or connected to the same system.

If you ask for help, others will probably ask you to describe the symptoms and saying *"it doesn't work"* is not really an answer.

Visual checks

Let's start with the obvious; the problems we can spot just by looking. Don't skip over this section, assuming that you built the project correctly and the fault must be somewhere else. After all, if you build the project correctly, there is a good chance that it would work.

Most faults can be found solely through visual inspection

Here are some self-checks to try.

Are all the components fitted to the board?

Compare your board to the layout in the printed instructions or the circuit diagram. A quick first check is to look at the diagram and note the component quantities. If, for example, the resistors are numbered from R1 to R8 and the capacitors are numbered from C1 to C7, there should be 8 resistors and 7 capacitors on your project board.

Are all components the correct values?

For example, have you swapped a 10k and a 100k resistor? If you are unsure of the coding system for resistors, you can find them on many websites, such as:

www.csgnetwork.com/resistcolcalc.html

To identify capacitor values from their markings:

www.csgnetwork.com/capcccalc.html
www.csgnetwork.com/capcodeinfo.html

Are all components wired the correct way round?

More on this later.

Are all wire links and/or jumper links in place, where they are included?

These are easily overlooked. Bear in mind that some are optional links while others are essential; read the instructions.

Are all components soldered to the PCB pads?

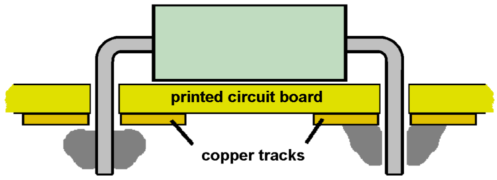
Are there any components whose wires protrude through the holes in the circuit board but have not been soldered to the track pads of the PCB?

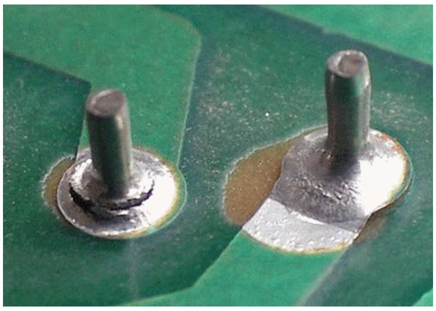
Are there any dry joints?

Poorly soldered joints are a major source of problems. They prevent circuits from working, or cause them to function badly or intermittently.

The wire leads on the components and the copper pads on the printed circuit board should be clean and bright (free from any oxidisation) prior to soldering. The wire should be in full contact with the pad; the solder should not be used to bridge a gap.

This illustration shows the effects of dirty or oxidised joints. On the left, the solder has formed a blob on the component lead but has not made a connection with the copper pad. On the right, the solder has formed a mound on the pad but has not made a connection with the component lead.





Consider the image on the left.

It shows that the left-most pin is not making a solid connection to the track pad. The solder had adhered to the component wire but not to the pad.

Poor connections are also formed when a component is disturbed before the molten solder has been allowed to fully harden (e.g. by prematurely cutting the excess wire from a component). These are visible as the solder surface is not smooth but crystalline. Both of these image show disturbed joints

Most dry and disturbed joints are easy to spot on visual inspections. In some other cases, jiggling a component results in one end moving or even lifting from the PCB.

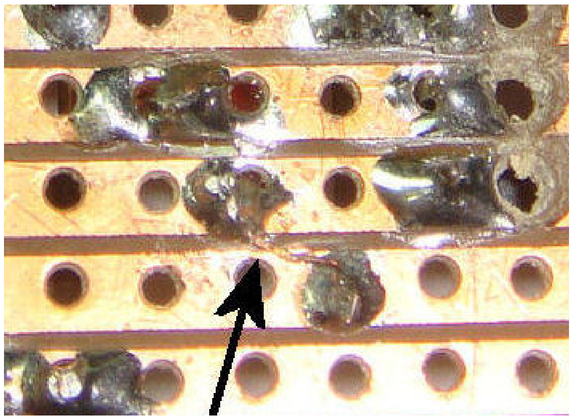
You could also use a multimeter to confirm whether there is any break or unwanted resistance across a joint.

A suspect joint can be remade by removing as much of the solder from the joint as possible. If required, the component lead or track pad should be cleaned, before applying fresh solder. The soldering iron tip should be cleaned and wetted (a small amount of solder on the tip to aid the heating of the joint). Never apply the solder to the soldering iron tip and then transfer it to the joint. That way, the flux that was designed to protect the joint from oxidisation during soldering is burnt off prior to the solder touching the joint. Instead, apply the heat to the joint surface and apply the solder to the heated surface.

Are there any unwanted shorts between the tracks of the PCB?

This is another very common problem and is usually caused by:

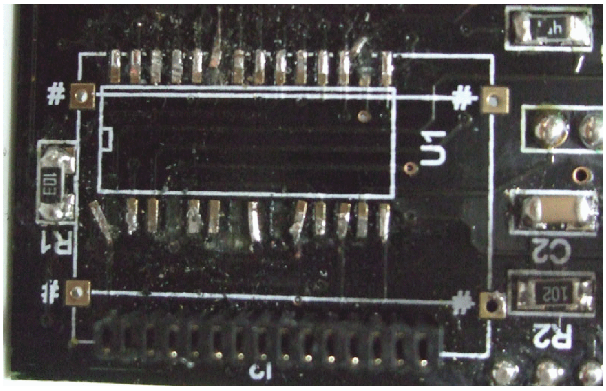
- Applying excessive solder to a joint to the point that the blob flows across to a neighbouring copper track on the circuit board.
- A fine stray wisp of wire (see image).



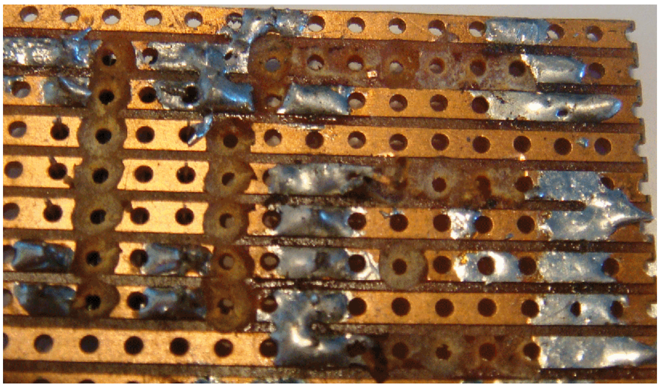
Use of a magnifier is helpful here, even if you have good eyesight. An eyeglass magnifier or an illuminated magnifier on a stand is a worthwhile investment if you plan to construct a number of projects.

Are all the PCB tracks solid?

If you etch your own boards, 'holes' in tracks from over-exposure/over-etching a thin copper track and can lead to minute breaks in the track, or tracks that split when a board is flexed when screwed down.

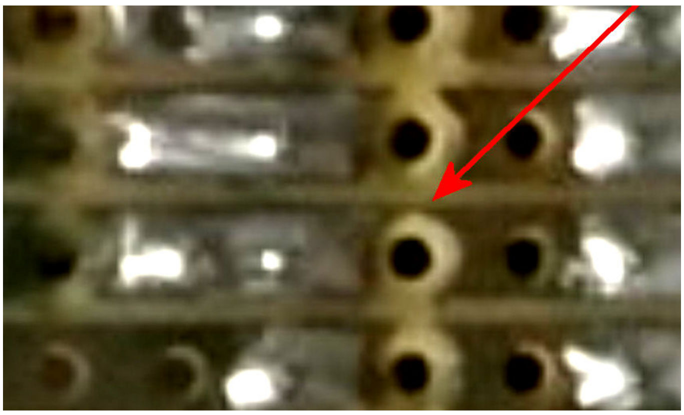


Similar problems can be caused by overheating a connection during soldering, to the stage where the copper track separates from the board. The floating thin copper track is vulnerable to cracking and breaking. Here is an extreme example, where the excessive heat has lifted and broken many of the board's pads.



In this image, excessive heat has resulted in whole section of copper track becoming detached from the stripboard.

Not to mentions the multiples blobs of solder bridging across adjacent tracks.



In this image, you can just see that the cut in the track has not been completely cleared.

There is still a tiny sliver of copper remaining; enough to cause shorts and all kinds of problems.

Do you have a loupe or a strong magnifier?

Are switches set correctly?
Applies to modules where DIP switches are used for configuring its settings.

Are all ICs correctly fitted?
Check that all ICs are pressed fully home into their holders.
Check that none of the IC's pins have been bent under instead of being inserted into the IC holder.

Are all module connections sound?
The module board may check out OK, but what about the connections to attached components – e.g. potentiometers, switches, buttons, lights, plugs, sockets, etc.

Are heat sinks fitted?
Heat sinks are commonly used on components that might overheat due to high current handling. These include voltage regulators, power transistors and some dropper resistors. These can easily be overlooked as they are not mentioned on some schematic diagrams or even in the assembly instructions.

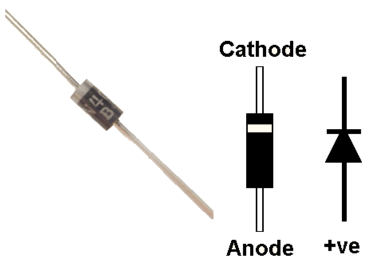
Polarities

The next step is checking that the components are fitted to the board “the right way round”. Resistors and smaller value capacitors can be fitted either way round but higher value capacitors and all semiconductors have polarities that have to observed. Fitting a semiconductor component in reverse stops the module from working correctly, and may destroy the component.

Here, as a reminder, are details of the polarities of commonly-used components.

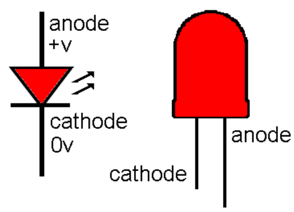
Diode

The band round a diode denotes the cathode and this is shown compared to its symbol on a schematic diagram.
Fitting a diode in reverse may not destroy it, depending on how it is used in a circuit, but may destroy another component by allowing excessive current to flow. For example, it is common to connect a diode across a relay that is being switched by a transistor. Fitted the correct way round, it prevents back emf (high reverse voltages caused by the collapsing magnetic field in the relay coil) from destroying the transistor. However, if fitted the wrong way round, it effectively puts the full supply voltage across the transistor. With no load to limit it, the current through the transistor will rise from tens of milliamps to hundreds of milliamps. Not only will the relay fail to operate, but the circuits components may be damaged by the excess current flow.

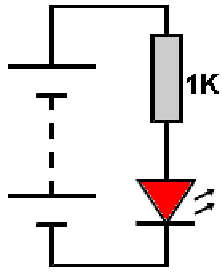


LED

The LED symbol, as shown on a wiring schematic, is displayed on the left, while the drawing on the right shows that the longest lead a LED is commonly the anode.
If you have LED with its leads cut (e.g. been removed from a board), you can't use this identification but you can use other methods.

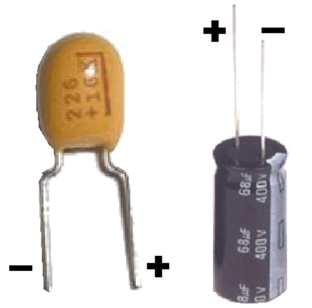


In some round LEDs, there is a flat edge on the LED bezel and this is always next to the cathode. If you don't have a flat edge, look inside the LED; the cathode is usually, but not always, the larger electrode.
If all else fails, just connect a 1k resistor to the positive terminal of a power supply (from about 5V to 12V) and a wire to the negative terminal. The LED will illuminate when the LED's anode is connected to the resistor.



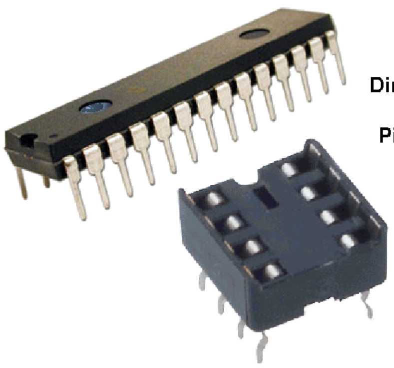
High-value capacitors

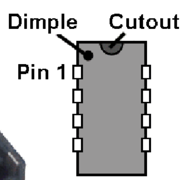
Electrolytic and tantalum are 'polarised' – they have to connected the correct way round or they risk being destroyed.
The polarities are marked on their bodies; the examples show a + symbol on one leg of a tantalum capacitor and a negative symbol on a black stripe on an electrolytic capacitor.



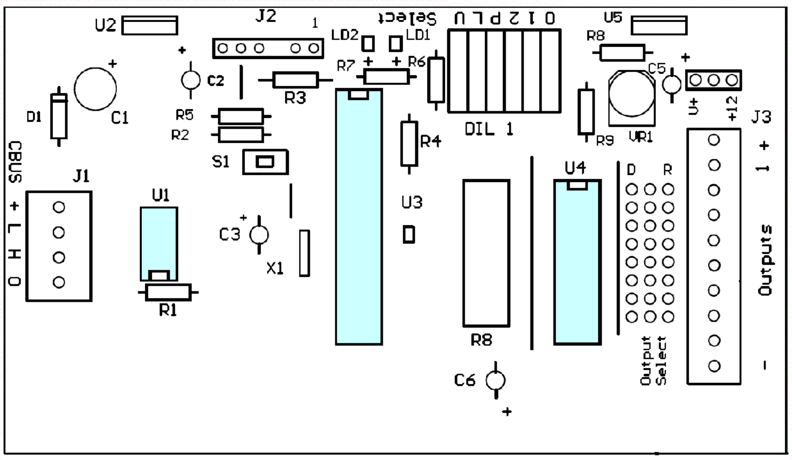
ICs and PICs

At one end of the body there is an arc cut into the moulding and often a 'dimple on the body. These indicate where the pin numbering begins and ends, with pin 1 of the chip being next to the dimple, to the left of the arc.
Most I.C. holders have similar markings to indicate the 'top' and should be soldered to the PCB the right way round. Then, when the chip is due for insertion, it is pushed into the holder with the orientation markings aligned.





Here is the outline of a typical printed circuit board. The silkscreen print on the surface shows indents. They indicate where the dimple of the chip should sit.



I/O pins

Many modules use a ribbon cable or multiple wires to connect it to external components, or to another module. The wires could be soldered directly to the module circuit board but is is more convenient to use plugs and sockets, as they allow easy removal and refitting.
The pins may be plain or may be the 'Molex' type that have a plastic body that ensures that the plug can only be inserted one way round. This prevents, for example, a power plug being inserted in reverse. Of course, this assumes that you have correctly wired the plug in the first place.

Similarly, check that wires to the interconnect plugs have their wiring in the correct order and are plugged in with the correct orientation. Using ribbon cables or a colour coding system minimises wiring errors.

Ratings

Electronic components have ratings that denote their maximum operating conditions – e.g. the amount of current that a diode can pass, or the amount of power that a PIC output pin can handle, beyond which they are likely to be destroyed.
In some cases, their specifications list both a continuous rating and a maximum rating. For example, a 0.25W resistor could dissipate 0.5W for a limited time. On the other hand, an integrated circuit may be instantly destroyed if it is operated beyond its maximum rating.

If you are building a project, the wattage value of power (e.g. dropper) resistors is calculated by

$$P = V \times I \qquad \text{or} \qquad P = I^2 \times R \quad \text{or} \qquad P = V^2 / R$$

where P is the power value, V is the voltage across the resistor and R is the resistor value.
Consider a 10mA LED connected to a PIC pin via a 270 ohm resistor. The 5V from the PIC is reduced to 2.5V at the LED. The minimum wattage rating for the dropper resistor is only 2.5v x 0.01A = 0.025W. Now consider connecting a 6V 1 Amp relay to a 12v supply via a 6 ohm resistor. Dropping 6V at 1A would dissipate a full 6 Watts in the resistor, requiring a high wattage resistor mounted on a substantial heat sink and situated away from the module's other components.
As can be seen, a resistor's wattage rating has to cope with its maximum working conditions. In practice, a wattage rating higher than that calculated is used, to provide a margin of safety.

Linked to maximum wattages, transistors and ICs also have maximum operating temperature ratings, beyond which destruction is likely. Exceeding safe temperatures drastically reduces component life and can lead to 'thermal runaway' – increased temperature results in increased current flow, which leads to even greater temperatures, and so on, until the point of destruction is reached.
This can be avoided by ensuring that transistors and ICs:

- Are never run beyond their operating parameters.
- Are not close to, or touching, any heat sources.
- Are fitted with their own heat sinks where appropriate.

You can use components with higher ratings than those specified; it just means that their size may be larger. For example, you can use 1N4002 (2 Amp) diodes instead of 1N4001 (1 Amp) diodes, or a 2A power supply instead of a 1A supply. The exception is fuse ratings; never fit a fuse with a higher rating than recommended.
Don't use components that have lower ratings than specified – they were given the higher rating for a purpose.

Tolerances

A component's tolerance is the degree to which its value may vary from its stated value.
So, for example, a 100k resistor with a 10% tolerance may be found to be as low as 90k or as high as 110k. You can buy resistors and capacitors with very narrow tolerances but these are rarely required in our projects; they are most used where very accurate results are required, such in timing circuits or in measuring equipment.

Note
If you are building from a kit, all the tolerance and rating values have been selected and tested and should pose no problem to constructors.

External problems

Sometimes the problem is not in the module but in the way that the module is connected and/or used.

Are you using a suitable power supply?
Does it have the required voltage and the required current rating?
The power supply should provide a stable output, one whose voltage remains constant under a variety of current requirements. Cheaper power supplies are unregulated. This means that their voltage output without a load may be higher than its quoted output, while their voltage output may drop below their quoted output when they have to supply current.

Many modules fit voltage regulators and these expect to fed by a voltage that is over 2V greater than the required voltage. So, for example, feeding a 9v supply to a 5v regulator is OK, while feeding the same regulator with a 6v power supply will produce an output that is less than 5v – often low enough to reset a PIC or alter a circuit's switching levels

What is the effect of a lower supply voltage level than that given in a schematic?
In the best case, little or nothing. However, in many cases the module's performance suffers; amplifiers produce lower voltage swings, relays fail to operate, switching levels are not reached, and so on. If a module uses a PIC, its brownout level will be reached, causing the PIC to reset. Many PICs include a built-in Brown-Out Reset (BOR) feature that resets the PIC when its supply voltage drops below an acceptable level for correct operation.
Bear in mind that a PIC's supply voltage may only occasionally drop when it has to supply a burst of heavy current (e.g. when activating servo motors). This might explain how a module seems to misbehave intermittently.

What is the effect of a higher supply voltage level than that given in a schematic?
Firstly, there is the danger that semiconductor devices may be destroyed,
Then there are the problems of heat, component life and thermal runaway mentioned earlier.
Also, the triggering point for switching devices may be altered.

How can a power supply be tested?
The simplest way is to test the power supply when not connected to a circuit but with a dropper resistor across its terminals. The resistor value is chosen to draw the maximum current that the supply says it can provide. The value is determined by R= V/I, where V is declared voltage of the power supply and I is its declared current rating (bearing in mind that the nearest available value may have to used).
For example, if a module requires 100mA, a 5v power supply can be tested by placing a 47 ohm 1W resistor across it output leads. The current should be 5/47 = approx 106mA and a satisfactory power supply's voltage should still be 5V.

Any other power supply problems?
SMPS (switched-mode power supply) supplies often only provide their stipulated output voltages when a sufficient current is drawn from the supply. If the minimum load current is not drawn (e.g. when testing the supply before connecting it to a module) the supply regulation does not function properly.

In the case of PC power supplies, a source of high-wattage that is readily available from discarded computers and often found at car boot sales, the supply simply cuts off it there is no load.
Test a stand-alone SMPS supply by connecting a 100 ohm resistor across the terminals before taking a voltage reading.
A word of caution. The power dissipation in the resistor = 12 x 12 / 100 = 1.2W
If testing a laptop 18v supply, P = 18 x 18 /100 = 3.24W.
So, beware of the considerable heat from the resistor. Handle with care; watch your fingers!

Some users have a variable supply when building a module on the workbench. Some of these supplies may initially output a higher than the desired voltage, until regulation takes over. This poses the possibility of blowing semiconductors and/or PICs.

In general, it is best to switch on a power supply before connecting it a module that has no power regulator fitted. Fully-built modules with 5v regulators fitted are safe, as the regulators prevent any initial voltage surges.

Are you using the correct software/firmware?
Some projects are "works in progress", continually being developed and improved, removing bugs and adding features.
There may be hardware changes (e.g. the selection of a better component or a different component value), firmware changes (e.g. a new version of the code to be used to program a PIC) or software (e.g. updated versions of control programs or test utilities).
Maybe a feature you think you ought to have is unavailable because you are using a previous version of the software or the PIC code. Check their websites and use the latest versions.
Also, some modules only work when their device driver software is installed (see their documentation).

Are you using the software correctly?
Make sure you understand how to use the software, how to set it up, what it is supposed to do, what steps you need to take (and in what order), and what any error messages may mean. Some software is pretty obvious (e.g. an on-screen throttle) while others benefit from reading the manual (e.g. JMRI) or an understanding of the background technology (e.g. CBUS traffic monitors or RS232/USB sniffers).

Do you have the correct COM port setting?
Some modules may be designed to plug straight into your computers USB port. Others may only have a serial port interface, in which case a serial to USB adaptors has to be used. In this case, the software is fooled into thinking it is communicating with a specific serial port given by its COM port number. The software will prompt for which port number to use. Providing the wrong port number will either result in the program not working, or the program producing an error message. This can be complicated by different computers allocating different COM port numbers to your device. So, for example, it may attach as COM5 on your desktop but as COM3 on your laptop – and as a different port number on your friend's computer.

Is there unwanted electromagnetic interference?
These fields are caused by all mains, radio frequency and oscillatory electrical circuits. They can act at a distance and can induce unwanted voltages in anything that contains a length or coil of wire.

Sources of magnetic fields include SMPS power supplies, thermostats (e.g. fridges, central heating), car ignition circuits, fluorescent lights, radio masts and amateur radio, mobile phones, cordless phones, wireless LANS, video senders, etc. In addition, model railway sources include electric motors, solenoids and DCC signals. Of course, railway tracks act as great aerials!
The spurious voltages can result in unwanted operating conditions in a module and can explain why a module works on the workbench but not on layout.
Some interference sources are obvious; the layout works OK on another SMPS power supply, the problems start when the fluorescent lights are switched on, or when a cordless/mobile phone is used, etc. Others are evident with a little observation; glitches coincide with the central heating switching off or when a particular servo or solenoid is activated. Some interference problems are solved at source (e.g. changing a fluorescent tube or starter, fitting a suppressor or replacing a thermostat). Other problems may be solved at layout level (e.g. re-routing cables, fitting additional RF bypass capacitors or filters, replacing a noisy servo).

Does your layout suffer thermal problems?
With many layouts sited in sheds, garages and lofts, they are subjected to extremes of temperature.

- Excessive heat, and changes in temperature, can cause a great many faults.
- Excessive heat, as explained earlier, can cause excessive currents in modules, and causes component lifetimes to be shortened. Extreme heat warps plastic, causes LCDs to lose their contrast, and causes mayhem with semiconductors.
- Temperature changes also produce problems. The differing thermal coefficients (the amount of expansion and contraction) of PCB track, wire and solder can loosen the solder bond of a module's connections over time.
- Temperature variations can also lead to 'thermal creep'. IC chips move a tiny fraction of a millimetre each time the module heats up and cools down and eventually 'creep' out of their sockets.
- Temperature variations also cause the layout's metal tracks to expand and contract and can lead to poor connections at track junctions.

The application of heat (by a hair dryer or similar) to an area of the module board will expand any metal and hopefully expose any poor or intermittent connection. Conversely, if the problem is already present, the application of a freeze spray (available from electronic component suppliers) to selected areas will cool the area and hopefully restore normal operations, thereby showing up the problem connection.

Do you have static problems?
Static electricity discharge is really a construction issue but it might also explain a 'faulty' IC. Static energy is most commonly generated when humidity is low and we walk across a carpet, wear nylon clothing, rub against certain materials and furnishings, etc. The static charge remains on the body remains it gradually bleeds away – or we touch an object that allows the static to be rapidly discharged as a spark. If that object is a module board and its components then there is a danger of damage, particularly to CMOS chips.
These dangers can be minimised by the avoidance of static build-up and proper handling of devices.
Attention can be paid to the working environment, by having an antistatic floor mat or

bench mat, applying antistatic agents to suspected materials, increasing the room's moisture level using a humidifier (or those little water containers than hang from your radiators), or even sometimes by opening the room's window.
Attention should also be paid to handling sensitive components, or boards on which they are mounted. Fully-populated boards should be held by their edges, avoid touching the components, the PCB tracks or the board's edge connections. Components that are sensitive to static damage should be kept in their packaging until they are about to be fitted to a module. The antistatic bags or conductive foam protect them until ready for use.
Lastly, make sure that you are not a carrier of static charge before handling sensitive components.
Some people rely on touching the radiator or a screw on a computer case, as both of these should be earthed. A more reliable technique is ground yourself with a conductive antistatic wrist strap.
These are readily available and consist of a wrist band that makes contact with your skin and connects to the ground via a 1 MegOhm resistor, and a length of wire with a crocodile clip on the end. This ensures that any high voltage charge is safely leaked away to ground. The resistor is fitted as a safety measure, to greatly limit the current should the croc clip accidentally come into contact with live mains.

Note

These measures won't repair a blown chip, but may stop you from also blowing the replacement chip.

Fault-finding equipment

If none of the above tests find the fault, test equipment can help you locate a fault.
Project designers employ a range of test and development tools. For most hobbyists, a simple multimeter is a good investment and a worthwhile tool that will be used again and again. They are available very cheaply and are accurate enough for most purposes.
A few other aids are also covered but lets start with the most commonly used tester.

The multimeter

As the name suggests, it is a meter that can make a range of measurements that help detect problems in components, in project boards and also in track wiring. It can expose problems not found by visual inspection.
Even the most basic model will measure:

- Resistance
- Voltage
- Current

Each of these will be available in a number of ranges, as this aids reading accuracy.
For example, the voltage ranges might include 0 to 200mV, 0 to 2V, 0 to 20V and 0 to 200V.
You choose the range that you expect best cover the voltage being read.

Not also, that the meter will have both AC and DC voltage and current ranges.
There are two types of multimeter:

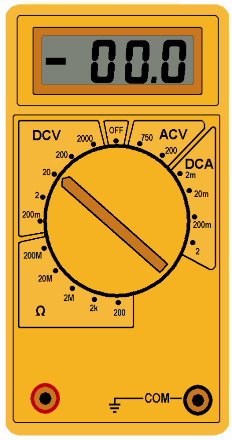
- The analogue meter, with a needle that moves across a calibrated scale.
- The digital meter, with the readings being read off a digital display.

They both have different benefits.

The digital readout provides a reading with no ambiguity, subject only to the tolerances of the meter's own electronics. If you are asking for help on a Forum, you can guarantee that you will asked for the voltage levels at various points on your circuit.
The analogue meter has advantages when reading varying levels. The digital meter takes readings periodically and presents them to the user. It is not easy to spot if there is a sudden quick dip in a value (e.g. a drop in voltage as a loco creates a momentary short going over a point). With an analogue meter, this would be readily detected as a quick dip in the meter reading. Just be careful with analogue meters as you can damage the needle if you try to read a high value with the range set to a low value; the needle will shoot up to the end of its range and could be bent. Always work from higher ranges downwards, if there is any doubt.

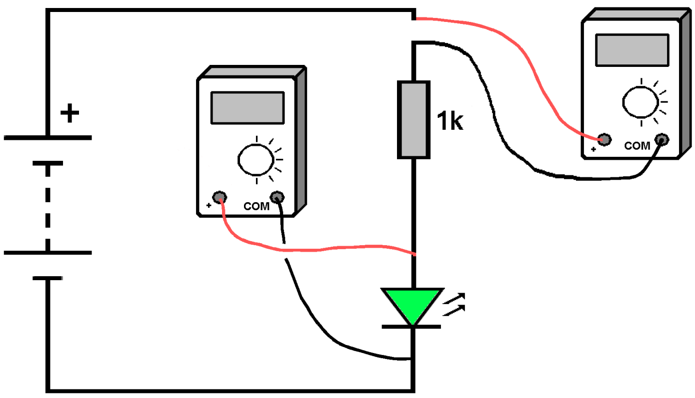
Apart from fault-finding on electronic modules, multimeters are used for a host of tests on model railways. For example, on trackwork, it can detect broken wires, shorts at points, poor (i.e. high resistance) connections. On locos, they can detect whether all wheel pickups are working and whether there are any problems with the motor. On controllers, they can detect whether there is the expected voltage output, whether a fuse has blown, etc.

The illustrations show typical multimeters. The sockets along the bottom are for plugging in test leads that are used to make the measurements. The black lead connects to the COM (Common) terminal and the red lead to the red terminal. The large knob chooses whether voltage, current or resistance is being measured, with each allowing a range of measurements.

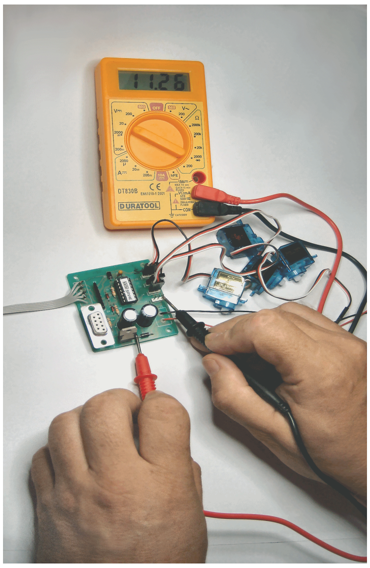


More expensive multimeters may also provide extra functions such as diode and transistor checking and capacitance measurements.
Some also include a continuity buzzer. This is useful when working in ill-lit situations or when working in awkward locations such as under your baseboard. Having an audible response allows you to concentrate on placing the meter's prods without also trying to look at a screen readout.

This simple circuit has a battery powering an LED. There is a dropper resistor in series with the LED to limit the current through the LED.
The illustration shows how to measure the voltage across the LED and also the current flowing through the LED.
Connecting the meter across the LED tells you what voltage the LED is working on. Connecting the meter in series with the LED tells you what current is flowing through the LED.



Measuring voltage

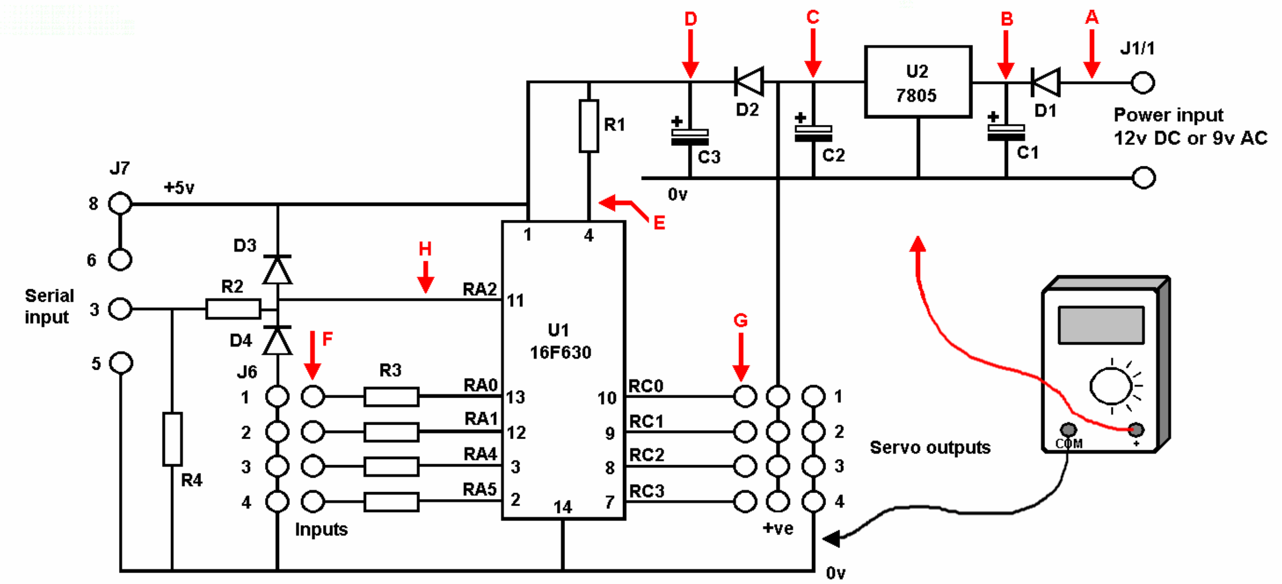


With these settings, the meter measures the voltage *across* a component, or *between* two particular points in a circuit.   So, for example, if you are told that there should be a 2v drop across a resistor, the leads are touched against each side of the resistor wires, or to the parts of the copper track to which the resistor is soldered. Bear in mind that one end of the resistor will be 2v higher than the other end (e.g. it may be 5v at one end and 3v at the other end).   The measurement is reading the *difference* between both ends.

In most cases, measurements are taken with respect to ground potential. So, if you are simply told that the reading at a point in the circuit should be 4v, it means with respect to ground. In these cases, the black lead is connected to ground, with the red lead touching the point to be read. In most other circuits, the ground potential is the common 0v point.

Example

Consider these possible voltage tests on a SERVO4 module.



Test point	Likely voltage reading	Purpose of test
A	12v DC or 9v AC	Confirms that the external power supply is working and is making a satisfactory connection to the module.
B	11.3v	Confirms that D1 is wired the correct way round and is working.
C	5v	Confirms that U2 is wired the correct way round and is working. Confirms that there is no abnormal load (e.g. a short circuit) across the regulator.
D	4.53v	Confirms that D2 is wired the correct way round and is working.
E	4.5v	Confirms that R1 is correctly connected.
F	Switches between 0v and 5v	Confirms that the incoming switching signal (e.g. from a switch on a control panel or from the output of another module such as a CBUS board) is working and is reaching the SERVO module input.
G	Between approx 0.17v and 0.33v	See notes
H		See notes

Notes

The difference in readings between A and B (and between C and D) is caused by the voltage drop across the diodes.
Test points G are the outputs from the PIC to the servos. If the PIC is working properly, it sends out a stream of pulses whose pulse width varies depending on the programmed servo rotation position. The voltmeter averages out the voltage pulses, producing an average voltage that is significantly lower than the supply voltage.
Test point H is the input to the PIC from the serial input socket and is only active when a PC is programming the servo module, otherwise the voltage reading is zero. A voltage reading at point H can confirm that the PC's serial port output is arriving at the PIC, proving that the computer, the serial cable and the servo setting program are all functioning. The voltage reading at point H should be approx 3v, dipping while the application's setting slider is moved.

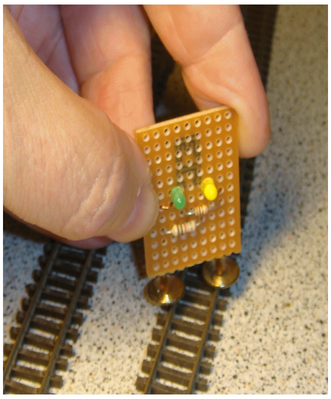
Ground / Earth / 0v

The above diagram measures readings against the 0v level.
You may find some magazines or articles refer to this as 'GND' or 'ETH' level, GND being the American term for ground and ETH being the UK term for earth. Strictly speaking these terms should only be used when that connection is taken to the actual physical ground (e.g. to a metal water pipe or a metal spike sunk into the ground. However, the term is sometimes used for 0v level. Most circuit diagrams refer to 0v.

Other voltage readings

Multimeters are useful for detecting voltage drops with long cable runs. If 12v is fed into a cable but only 10v arrives at the other end, the cable may be too thin or the drop may be caused by badly soldered joints, poor plug and socket connections, poor relay contacts, etc. The meter will expose the source of the problem.

DCC signals can be measured using the AC settings of a multimeter, with enough accuracy to determine the presence/non presence of the signal and an approximate reading of DCC signal level.



This image shows a quick and easy way to test for the presence of DCC at various points on the track.
Two studs are soldered to a piece of stripboard. Two LEDs (with their resistors) are wired in different directions across the studs. The tester is held against the rails. If one LED lights, you have power. If the other LED lights, you have power in the opposite direction. If both LEDs light, your track is receiving DCC power. The tester can be moved around to test various sections of track easily and is less fuss to use than a multimeter (e.g. it can be used one-handed).

Note

While multimeters are capable of testing mains voltage, beginners should never poke around inside mains power supplies, or any other device where live mains voltages are exposed.

Don't carry out high voltage tests, specially mains voltages, unless you are fully competent.
Mains voltages can be lethal.

Logic probe

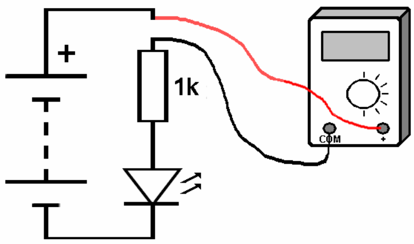
Many of the voltage readings you make will be analogue (e.g. The voltage might be any level between 0V and 12V).
However, when you work with digital modules, you only want to know if an input or output is high or low, usually 0V or +5V.
Examples uses of a logic probe are to:

- Check the supply pins of a chip. Is it getting both the +5v and the 0v?
- Check the output from a track detector – is it changing when a loco passes?
- Check the input to a circuit that is coming from a switch – is it going from +5v to 0v, or 0v to 5v, when the switch is operated?
- Check whether the inputs and outputs of digital modules are producing the expected results.

The internal circuits in lots of electronic modules work on 5v, even when the they are connected to a 12v or other voltage supply. This project is for a very useful tool that tells you whether a point in the circuit is at +5v or at 0v.
You could ask why not just use a multimeter? You could connect the -ve lead of your meter to the 0v line of your module. Then you could tap various parts of the circuit with the other lead. If you have +5v on that point, you will get a reading. But – and here is the catch – if you do not get a reading, it does not mean that you have 0v at that point. You might just have a broken wire that is not connected to anything. To check for connections to 0v, you would have to connect the meter's +ve lead to the 5v line and then test with the other lead's probe. You would have to reverse your meter connections every time you wanted to check for +5v or 0v.
That is where a logic tester is handy. It connects to the +5v and 0v of the module you are checking. Then you touch any point in the circuit. If +5v is on that point, a green LED lights up. If there is 0v at that point, the red LED lights up. All other voltages, or points not connected to anything, either keep the LEDs unlit or dimly lit.
The image shows a commercial logic probe but it is not too difficult to build your own.

Measuring current

With these settings, the meter is placed in *series* with the part of the circuit being measured, so that the normal circuit current also flows through the meter. This might necessitate breaking into the circuit, probably by unsoldering one end of a component and lifting that end clear of the board. The diagram shows a very basic test used to measure the current flowing through an LED.



Most often you will be checking the current drawn by an entire module. Here, the multimeter is placed in series with the power lead to the module. Again, observe polarity – i.e. the red lead to the more positive side of the circuit.
Most modules consume approximately 20mA to 60mA. This does not include the current drawn by any devices (e.g. motors, solenoids, servos, etc.) connected to the module. For example, a servo control module draws about 20mA but each individual servo could draw many hundreds of milliamps.
If no current is read make some basic checks (meter switched on/set to current range/wired

in correctly, power supply switched on) before checking the module's components.
If an excessive current is read, switch off immediately, before any components are destroyed. Then make the checks outlined earlier (e.g. shorts across tracks, wrong component values, components connected incorrectly, etc.).

Other uses for current readings are

Heatsink decisions

Read the voltage across and the current through a component (e.g. a voltage regulator or a dropper resistor), calculate the power dissipated in the component and select the heatsink necessary to handle it.

LED droppers

LEDs are rated to work at certain currents, with most rated at a maximum of around 25mA or 30mA. Low current LEDS can operate as low as 2mA and a 20W power LED works at over 1A. You can use an online calculator to determine the dropper resistor value. If you are not connected to the Internet, you can use the multimeter to check the resultant current from using a number of different series resistors (remember to use the highest value first).

Reading fluctuating values

Some circuit produce temporary changes in voltage/current, either intentionally or as the result of some problem. These cannot be accurately examined or measured with a digital multimeter, which is intended to read fixed values. If the value changes slowly, as in the case of gradually increasing current caused by overheating, then a digital meter can display the changes.
However, short duration spikes or voltage dips are unwanted and cause problems. For example, a burst of heavy current being drawn by a servo may drop the supply voltage and cause a PIC to reset. The duration of the voltage change may be too short to be detected by a digital multimeter. In many cases, such changes are observable on an analogue multimeter. Instead of a digital readout, they move a pointer across a marked scale. Hence many short-lasting changes are displayed as a flick of the pointer, where it would not be likely to be detected on a digital readout. Analogue multimeters are slightly more expensive than digital versions.
Rapidly changing values, such as DCC or CANBUS signals, can only be accurately examined with the use of an oscilloscope (an expensive piece of equipment and not required for general use – see later).

Measuring resistance

With these settings, the meter measures the resistance *across* a component, or *between* two particular points in a circuit.
Note that the readings must be made with the power switched off.
Like voltage readings, accurate measurements are simple when a component is tested before it is soldered to a PCB. Measurements of components once soldered are often complicated by other components that are on the board. In extreme cases, you may have to disconnect one end of the component from the PCB, to ensure that you are only reading the component on its own.
Also, remember to read the resistance with the meter's probe connected both ways round, to ensure against unexpected results (e.g. an initial suggestion of a short circuit might simply be that you are reading a diode or a transistor in its low resistance direction).

Typical problems detected by resistance measurement are:

Open circuit

No reading means no resistance to measure, indicating a break in the circuit (assuming you have switched on the meter, set it to the correct range and connected it across the correct points).

Short circuit

A very low resistance reading indicates a short inside the component or a short across the modules PCB tracks or connections. Of course, there are occasions when you hope to see a short circuit - when testing for the continuity of a stretch of wiring, or confirming that wires have been connected to the correct pins/connectors.

High resistance

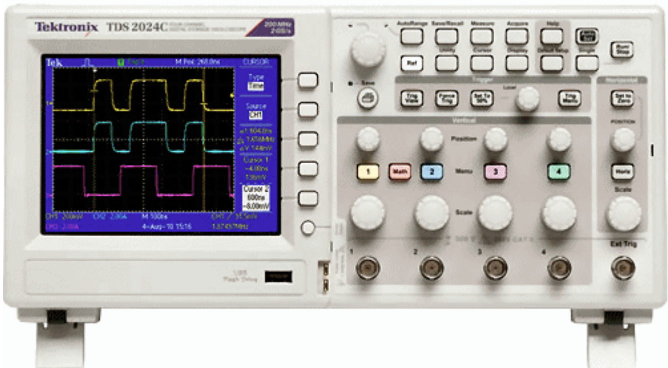
A higher reading than expected usually indicates a poor connection. Check for a dry joint in the soldering, or poor switch and relay contacts. It could also mean that the wrong value of component has been fitted.

Intermittent connection

Fluctuating readings indicate a connection that only makes proper contact intermittently. It may be caused by badly soldered joints, poor plug and socket connections, poor relay contacts, or even a wire that is broken inside the plastic outer sheath. As explained previously, an intermittent connection may only exhibit itself in times of extreme heat or cold.

Using an oscilloscope

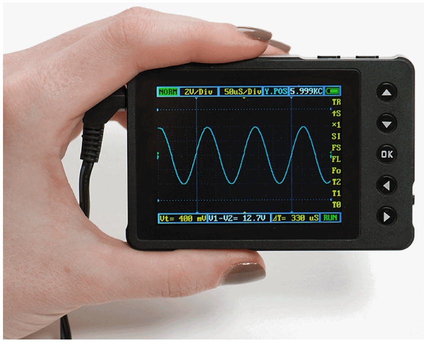
This is definitely not the first test tool that you will buy. In fact, you may never need or use one, although it is widely used by professional developers and service technicians.
In the hobby area, it is a valuable tool for examining signals where there is a suspected problem.



An oscilloscope creates a two-dimensional scaled graph on the screen showing how the signal voltage being monitored changes over time, as shown in this image. It can display both AC and pulsating DC waveforms.

Time is displayed along the X (horizontal) axis, from left to right, and the voltage level of the signal read at each point in time is shown on the Y (vertical) axis.
The display is usually calibrated in 10 horizontal divisions and 8 vertical divisions.

Oscilloscopes are very useful in examining and checking signals that are 'cyclic' – i.e. signals that repeats themselves. This can commonly be found in model railway electronics.
Examples are pulse width DC controllers, servos, DCC, CBUS, etc.
Older oscilloscopes used cathode ray tubes,similar to those used in old television sets.
Most models now use an LCD screen to display their readings.
The model shown above is a professional product and these can cost thousands of pounds.
They are really bench tools.



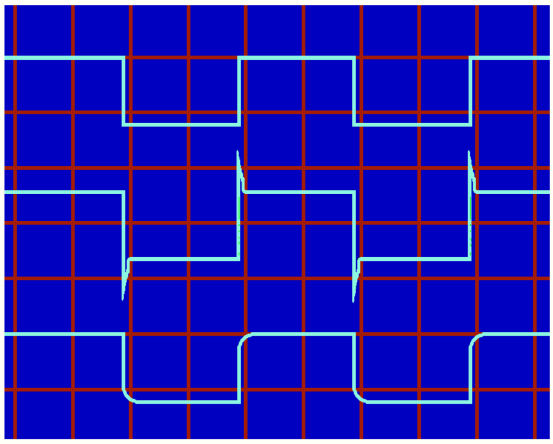
If you need to test on the move, you can buy a handheld version as shown.
Another approach is to place the electronics in a separate box and connect it to a PC or laptop. That allows the monitor to be used as a large display screen. It also reduces the cost considerably.

This image shows a PicoScope unit converting a laptop into a temporary oscilloscope.

One lead from the scope is connected to 0V and the probe is touched against the point in the circuit to be tested.

Likely tests using the oscilloscope include:

- The voltage level of the signal
- The frequency of a signal
- The repeat rate of pulses
- The time delay between events.
- Whether the signal is being distorted
- Whether the signal is suffering from interference or noise
- Whether the waveform is clean (a fast rise and fall time, no ringing)



The illustration shows a square wave output being examined.
The top display shows what a clean waveform should look like.
The middle display shows the effect of 'ringing', with the value overshooting as it rises and falls.
The bottom display shows that the waveform is being rounded off.
These imperfections would produce no visible effect on a simple pulse device such as a flashing LED on a vehicle.
However, on systems that rely on efficient communications, such as DCC and CBUS, these distortions can create a significant problem. The oscilloscope can be used to reveal any such signal problems.

Some signals are entirely cyclic, such as a servo's signal stream or the PWM output from a controller. The exact same waveform is constantly transmitted for any one setting. Change the setting (e.g. increase or decrease the controller's speed) and you get another constantly repeating waveform.

Other signals contain data and these contain 0s and 1s in particular patterns to encapsulate the information being sent. Since they don't contain continual repeating ons and offs, their data rate is measured in bps (bits per second) and its multiples (Kbps, Mbps).

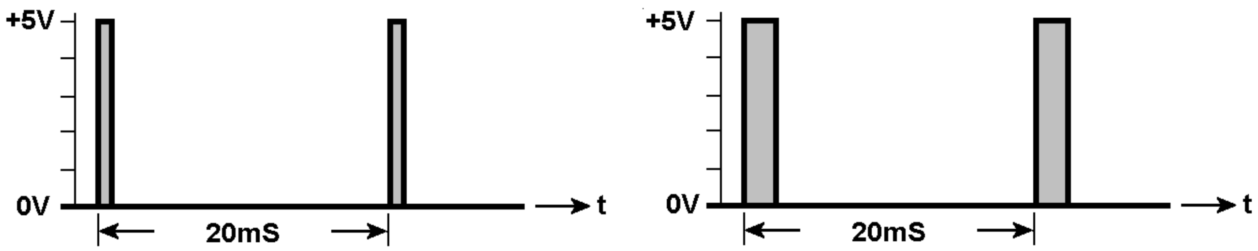
Some examples:

- Servo repeat rate is 50Hz
- PWM repeat rate can be as low as a few hundred Hz.
- DCC is approx 7KHz
- A computer's serial port operates at 115200 bps
- CBUS is 125kbps

The oscilloscope has to calibrate the X axis in units of time appropriate to the speeds being examined, otherwise you would not be able to adequately see the waveform.
The 'Horizontal Sweep' is the control that alters the speed at which the trace moves across the screen and is usually measured in seconds per division (s/div), milliseconds per division (ms/div), microseconds per division (s/div), or nanoseconds per division (ns/div).

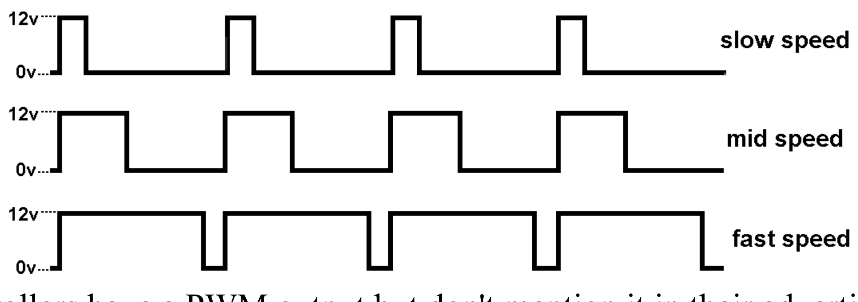
Example

The scope's horizontal scale has 10 divisions. Say you want to look at the signal being sent to a servo. The pulse is sent out every 20mS, so setting the sweep speed to 10mS/div would result in the display showing what happens over a 100mS time slot. This would let you see five servo pulses on the display.



If the sweep speed was set to 1mS/div, you would see 50 pulses on the display but the pulse widths would be so narrow that you would not be able to see the pulse width changing when the servo settings were altered. Its a matter of matching the sweep width to the signal being examined. Oscilloscopes typically handle waveforms from as low as 1Hz up to several MHz, or if you pay a lot more they can cover several hundred GHz.

The chapter on loco controllers explained how PWM (pulse width modulation) improves the running of your loco, specially at low speeds.
The repeat rate of the waveform may be a few hundred Hz but can be lower or even many KHz. The common feature is that the pulse width varies from being non-existent (the same as 0V) to being constantly high.



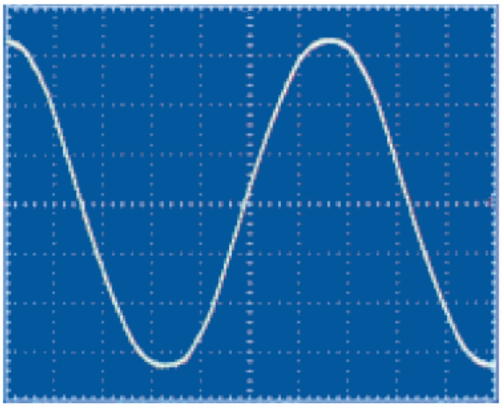
Some DC controllers have a PWM output but don't mention it in their advertisements. You can easily check with an oscilloscope by placing its leads across the controller output and adjusting the horizontal sweep until you see waveforms like those above.

Voltage levels

In the same way as you match the horizontal scale to the waveform, the vertical axis must also be set to have the waveform fill most of the vertical screen space. The vertical scale is measured in volts per division (V/div), millivolts per division (mV/div), etc.
If the signal being measured peaks at only 10mV, you wont see much if you have the vertical scale set to 1V/division. Similarly, if you try to view a 5V signal with the scale set to 10mV/div, the waveform shoots off the vertical edges of the screen and you won't see the waveform details, such as ringing and rounding.

AC readings

The above examples show pulsed DC signals being examined. The oscilloscope is also able to read AC waveforms, such as the output from a mains transformer (you can also read the mains itself if you are experienced enough and take safety precautions – if in any doubt, leave well alone!).



The illustration shows a typical display of an AC voltage. The horizontal line along the middle of the display indicates 0V and the waveform swings above and below this value as it alternates between positive and negative peaks.
In the UK and most of the world, the mains supply is at 50Hz (mostly around 230V), with the Americas and some other countries using 60Hz (mostly around 120V).
So, if the oscilloscope was set to 10mS/div, you would see two complete cycles of 50Hz AC on the display.
If the scope was set to 50V/div, we would mostly fill the screen vertically with a standard UK mains supply waveform (from the first chapter we noted that a 240V RMS is the same as 340V peak-to-peak which is what the scope will see).

Digital storage

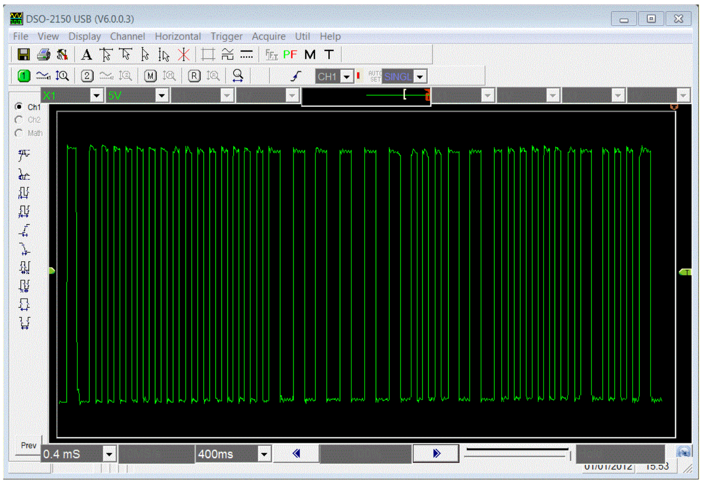
All the above waveforms were cyclic: you could rely on the pattern continually repeating itself. However, there are other signals that don't repeat so conveniently. For these, a *'digital storage oscilloscope'* is used. Instead of simply reading the input and displaying the results on the screen, a DSO saves the values of each sample it reads into memory This lets you view the results your convenience. The results can also be stored as a file or be printed out.

So, events that happen only once or only occasionally, known as *'transients'* can be detected where they would otherwise happen too quickly to be spotted. This is handy for detecting 'brown outs', sudden short drops in the supply voltage that may reset PICs or provide false triggering. You also check whether a change of output somewhere is unexpectedly triggering an unwanted input somewhere else.

DSOs are also used to examine digital signals that are not cyclic. These signals contain data that may be constantly changing. Examples are communication systems, DCC and CBUS.

The image shows the display of a DCC signal. Although the pattern looks random, the sequence of ONs and OFFs, contain the data that will be used by the DCC decoder.

It is possible to examine this waveform and determine the exact content of the message. It can also be used to check the integrity of the waveform, for example to see whether there is excessive ringing on the DCC bus.

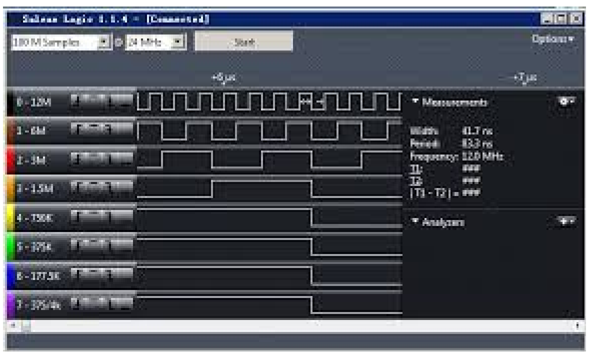


Logic analyser

Most oscilloscope have two separate independent inputs, allowing you to monitor two different signals at the same time. The more expensive models can handle four channels. As explained earlier, oscilloscopes can examine both analogue and DC pulsed inputs and so can display voltage levels, rise and fall times, noise, distortion, etc. However, with their limited number of inputs, they cannot readily be used where there are many different digital readings to be taken simultaneously and compared.

Developers, or those faultfinding on modules with multiple input and outputs, use a *'logic analyser'* to display the status of all the inputs/outputs on a single screen simultaneously. As the name suggests, it is not designed for looking at analogue signals. It captures and displays the logical state (i.e. either high of low) of digital signals.

It has the big advantage over oscilloscopes in that it can handle a large numbers of different signals, the exact number depending on how big your budget is. The most-powerful laboratory models can have a large display area and show up to hundreds of channels. The picture shows a *'Saleae'* analyser with 8 channel capability. It has 9 test hook clips, one for the common point and one for each point to be monitored. To reduce costs, it connects to your computer via USB and uses the computer and its large monitor.



Of course, you do not have to use all eight channels if you do not need them all.
This image shows eight different points on a circuit being monitored.
An analyser's display shows the sequence of events and the timing between events (e.g. whether the output from one part of the circuit triggered an input in another part of the circuit and, if so, if there was a delay).

Since you can look at many outputs lines in parallel, you can see the output from 8-bit or 16-bit buses, which is why this tool is popular with computer engineers.
Some models can look at a group of inputs and display their combined values in decimal or hex notation, or even in assembly code mnemonics.
Some models understand communications protocols such as RS232, I2C, SPI, CAN, etc.

Final observations

This chapter is not the definitive text on fault-finding. There are many variations, different approaches, and much that can be added from others' experiences. Remember, tests and their results will depend on the circuit being tested and your ability to use your equipment (you have read the manuals, haven't you?)

Hopefully, this chapter provides some useful tips for those starting off in the hobby and gives an overview of some test equipment.