There are two main types of Multimeter, Analogue (shown left) and Digital (shown right). Digital meters are very accurate but analogue meters can show a slowly changing reading more clearly.

Multimeters have many functions but all can measure Voltage, Current and Resistance.

When measuring unknown quantities, always set the meter to the highest range first and work your way down.

**Measuring Voltage**

Voltage readings are taken across the component you want to measure. Most readings will be taken with the negative lead connected to 0v of the circuit.

**Measuring Resistance or Continuity**

When measuring resistance you must disconnect any power and try to have one end of the component disconnected so that you get a true reading.

You can also test for continuity or breaks in a wire or copper track. Select a low resistance range on the meter and put the probes on either end of the item you want to test.

If the reading is 0.00 then there is continuity (closed circuit). If the display flashes a 1 then there is no continuity (open circuit).

**Measuring Current Flow**

When measuring current flow the meter is placed in series with the component so the meter becomes part of the circuit.
**CALCULATIONS**

**Resistor Colour Code**

The first two bands represent the first two digits. The third band is the multiplier. An easy way to think of this is that the colour represents the number of zeros.

The fourth band states the tolerance, (how accurate the resistor is):
- **Red** = 2 %
- **Gold** = 5 %
- **Silver** = 10 %

When gold is the third band then divide by 10
When silver is the third band then divide by 100

<table>
<thead>
<tr>
<th>Colour</th>
<th>1st</th>
<th>2nd</th>
<th>3rd band - no. of zeros</th>
</tr>
</thead>
<tbody>
<tr>
<td>Black</td>
<td>0</td>
<td>0</td>
<td>none</td>
</tr>
<tr>
<td>Brown</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Red</td>
<td>2</td>
<td>2</td>
<td>0 0</td>
</tr>
<tr>
<td>Orange</td>
<td>3</td>
<td>3</td>
<td>0 0 0</td>
</tr>
<tr>
<td>Yellow</td>
<td>4</td>
<td>4</td>
<td>0 0 0 0</td>
</tr>
<tr>
<td>Green</td>
<td>5</td>
<td>5</td>
<td>0 0 0 0 0</td>
</tr>
<tr>
<td>Blue</td>
<td>6</td>
<td>6</td>
<td>0 0 0 0 0 0</td>
</tr>
<tr>
<td>Violet</td>
<td>7</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>Grey</td>
<td>8</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>White</td>
<td>9</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td>Gold</td>
<td>0.</td>
<td></td>
<td>(divide by 10)</td>
</tr>
<tr>
<td>Silver</td>
<td>0.0</td>
<td></td>
<td>(divide by 100)</td>
</tr>
</tbody>
</table>

**Ohms Law**

The relationship between voltage, current and resistance is shown by Ohms Law:

\[
V = IR
\]

\[
I = \frac{V}{R} = \frac{9}{470} = 0.019A
\]

**Power Law**

The relationship between power, current and voltage is shown by the Power Law:

\[
P = IV
\]

\[
P = 12 \times 0.5 = 6 \text{ Watts}
\]

**Combining Components**

For two or more resistors in series

\[
R_1 + R_2 = R_1 + R_2
\]

For two resistors in parallel

\[
\frac{R_1 \times R_2}{R_1 + R_2}
\]

For three or more resistors in parallel

\[
\frac{1}{R_{TOT}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}
\]

For two or more capacitors in parallel

\[
C_1 + R_2 = C_1 + R_2
\]

For two capacitors in series

\[
C_1 \times C_2 = C_1 \times C_2
\]

For three or more capacitors in series

\[
\frac{1}{C_{TOT}} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}
\]
The standard Bipolar transistor can be used as a switch or an amplifier, depending on how you connect to it. There are two polarities of bipolar transistor, NPN and PNP.

Transistor Parameters
The diagram shows the basic current flow and voltages when a transistor is in use. These are called parameters.

- $V_{BE}$ - The voltage between the base and emitter
- $V_{CE}$ - The voltage between the collector and emitter. This is usually the maximum voltage the transistor can tolerate.
- $I_C$ - The amount of current flowing into the collector
- $I_B$ - The amount of current flowing into the base.
- $h_{FE}$ - The current gain of the transistor $= \frac{I_C}{I_B}$

NOTE: $V_{BE}$ must be 0.6v or more to turn on transistor.

Maunfacture and Packaging
Below is an extract from a manufacturers catalogue showing the details of various transistors. Notice how the more you buy of one transistor, the cheaper each transistor becomes. N.B. Power $= P_{TOT} = I_C \times V_{CE}$

<table>
<thead>
<tr>
<th>Transistor Number</th>
<th>Polarity</th>
<th>Case Style</th>
<th>$I_C$ (max)</th>
<th>$V_{CE}$</th>
<th>$h_{FE}$</th>
<th>Power</th>
<th>Application</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>BC107</td>
<td>NPN</td>
<td>TO18</td>
<td>100</td>
<td>45</td>
<td>110-450</td>
<td>300</td>
<td>Audio Driver</td>
<td>£0.24 £0.20 £0.18</td>
</tr>
<tr>
<td>BC108</td>
<td>NPN</td>
<td>TO18</td>
<td>100</td>
<td>20</td>
<td>110-800</td>
<td>300</td>
<td>General Purpose</td>
<td>£0.24 £0.20 £0.18</td>
</tr>
<tr>
<td>2N3904</td>
<td>NPN</td>
<td>TO92</td>
<td>200</td>
<td>40</td>
<td>100-300</td>
<td>350</td>
<td>Switching</td>
<td>£0.13 £0.10 £0.08</td>
</tr>
<tr>
<td>ZTX300</td>
<td>NPN</td>
<td>E-line</td>
<td>500</td>
<td>25</td>
<td>50-300</td>
<td>300</td>
<td>General Purpose</td>
<td>£0.17 £0.15 £0.12</td>
</tr>
<tr>
<td>2N3053</td>
<td>NPN</td>
<td>TO39</td>
<td>700</td>
<td>40</td>
<td>50-250</td>
<td>5000</td>
<td>General Purpose</td>
<td>£0.43 £0.33 £0.28</td>
</tr>
<tr>
<td>BFY51</td>
<td>NPN</td>
<td>TO39</td>
<td>1000</td>
<td>30</td>
<td>40 min.</td>
<td>800</td>
<td>General Purpose</td>
<td>£0.39 £0.31 £0.26</td>
</tr>
<tr>
<td>TIP31A</td>
<td>NPN</td>
<td>TO220</td>
<td>3000</td>
<td>60</td>
<td>25</td>
<td>40W</td>
<td>Audio Amp</td>
<td>£0.58 £0.51 £0.44</td>
</tr>
<tr>
<td>2N3055</td>
<td>NPN</td>
<td>TO3</td>
<td>15000</td>
<td>60</td>
<td>20 min.</td>
<td>115W</td>
<td>High Power Amp</td>
<td>£1.26 £0.96 £0.78</td>
</tr>
<tr>
<td>BC178</td>
<td>PNP</td>
<td>TO18</td>
<td>100</td>
<td>25</td>
<td>125-500</td>
<td>300</td>
<td>General Purpose</td>
<td>£0.28 £0.23 £0.17</td>
</tr>
<tr>
<td>BC559</td>
<td>PNP</td>
<td>TO92</td>
<td>100</td>
<td>30</td>
<td>240</td>
<td>500</td>
<td>Low noise amplifier</td>
<td>£0.10 £0.05 £0.04</td>
</tr>
<tr>
<td>ZTX500</td>
<td>PNP</td>
<td>E-line</td>
<td>500</td>
<td>25</td>
<td>50-300</td>
<td>300</td>
<td>General Purpose</td>
<td>£0.17 £0.13 £0.10</td>
</tr>
<tr>
<td>TIP122</td>
<td>PNP</td>
<td>TO220</td>
<td>5000</td>
<td>100</td>
<td>5000</td>
<td>65W</td>
<td>Hi-Power Darlington</td>
<td>£0.84 £0.60 £0.44</td>
</tr>
<tr>
<td>TIP127</td>
<td>PNP</td>
<td>TO220</td>
<td>10000</td>
<td>100</td>
<td>3000</td>
<td>125W</td>
<td>Hi-Power Darlington</td>
<td>£0.84 £0.60 £0.44</td>
</tr>
</tbody>
</table>

Case style
- TO18
- TO92
- E-line
- TO220
- TO39
- TO3

View from below
Tag denotes emitter
Logic gates are components used to make decisions in circuits. The inputs can be connected to various sensors, and circuits can be designed to operate when certain conditions are met. When using logic, we refer to +v as a ‘1’ and zero volts as a ‘0’. Each gate has its own rule it follows to produce an output.

Below is the most basic gate.

**BUF**

Rule: Output is on if input is on.

A circle on the output of the symbol will invert the output, but the action of the gate stays the same.

**NOT gate (INVERTER)**

Rule: Output is off if input is on.

**OR gate**

Rule: Output is on if A OR B are on

When a NOT gate is added to the output, the rule is the same but the output is the opposite - it is inverted.

**NOR gate**

Rule: Output is off if A OR B are on

**AND gate**

Rule: Output is on if A AND B are on

With a NOT gate added to the output, it becomes an

**NAND gate**

Rule: Output is off if A AND B are on

**EXCLUSIVE OR (XOR) gate**

Rule: Output is on if A OR B are on but not both

With a NOT gate added to the output, it becomes an

**EXCLUSIVE OR (XNOR) gate**

Rule: Output is off if A OR B are on but not both

All these gates can have 3, 4 and sometimes 8 or more inputs. The rules are exactly the same as for their 2 input version.

3 input NOR gate

Output is off if A OR B OR C are on

4 input AND gate

Logic gates can be combined to perform more complex tasks and decisions. A common example is a bistable latch using two NOR gates, also known as a Set/Reset (S/R) flip-flop.

Pressing Set makes Q go to 1 and remain in that state after the switch is released. Pressing Reset will make Q return to 0.
The Monostable

A monostable is a device that produces a single timed pulse that can control other devices, (mono meaning one). The input can be anything that produces an input from high to low. The output can provide about 50mA and can drive low current devices. A transistor driver is used to drive high current devices.

**INPUT**
This can be any low input trigger

**CONTROL**
The 555 monostable with timing components

**OUTPUT**
Any output device with or without driver.

A simple push-to-make switch with a pull-up resistor.

An RC circuit will produce a brief low pulse at power up.

The 555 timer can be connected as a monostable. The timing is set by R and C. The formula is $t = 1.1CR$

The output can supply enough current to drive an LED.

For a light bulb output, a transistor driver is needed.

The Astable

An astable is a device that continually produces pulses at a certain rate known as its frequency. The 555 can also be connected as an astable. R2 can be a variable resistor so the frequency can be adjusted.

The frequency is determined by the following formula:

$$f = \frac{1.44}{(R1+2R2)C}$$

The output can drive an low current devices. Again a transistor or Darlington pair must be used to drive higher current devices.

The output is known as a square wave with equal mark/space ratio.

A speaker can be connected through a capacitor to produce an audible tone.
Operational Amplifier

These devices have two inputs, inverting and non-inverting. The way they work is as follows.

The difference between the voltages at the two inputs is amplified to the output by about 10,000 times!

If VI is greater than VN then the output is negative.
If VI is less than VN then the output is positive.
If VI equals VN then the output is zero.

They usually use split power supplies, (+V, 0V, -V) but can also be used with a normal battery.

Voltage Dividers

A voltage divider is simply a way of connecting two resistances in series to produce a fraction of the input voltage. The output is at the junction of the two resistances and is determined by:

\[ V_{\text{out}} = V_{\text{in}} \times \frac{R_2}{R_1 + R_2} \]

TIP! If the two resistors are the same value, then the output will be exactly half the input.

SENSING CIRCUITS

Voltage Dividers

A voltage divider is simply a way of connecting two resistances in series to produce a fraction of the input voltage. The output is at the junction of the two resistances and is determined by:

\[ V_{\text{out}} = V_{\text{in}} \times \frac{R_2}{R_1 + R_2} \]

TIP! If the two resistors are the same value, then the output will be exactly half the input.

Sensing

One of the resistances can be replaced with a sensor that changes its resistance. When a change in condition happens, the output voltage changes. The other resistor can be replaced by a variable resistor giving the sensor circuit some adjustment. These components can be placed in either order to produce the opposite change in output.

This is the output from a light detector circuit. The output voltage is constantly changing and cannot be used to drive any output devices.

The output from the sensor can be connected to the base of a transistor as shown. When the input voltage rises above 0.6v, then the output is switched on.

Operational Amplifier

These devices have two inputs, inverting and non-inverting. The way they work is as follows.

The difference between the voltages at the two inputs is amplified to the output by about 10,000 times!
If VI is greater than VN then the output is negative.
If VI is less than VN then the output is positive.
If VI equals VN then the output is zero.

They usually use split power supplies, (+V, 0V, -V) but can also be used with a normal battery.

Here the operational amplifier has been used as a comparator. It compares between the input sensor voltage and a reference voltage from another voltage divider. The output switches a relay to operate a heater. When the heat rises the relay switches off until the temperature drops again, switching the heater back on. This is an example of sensor feedback.
**Relays**

A relay is a device that can activate a switch using an electro-magnet. This is useful when devices need to be isolated from the control circuitry. For example, a battery-controlled temperature sensor could activate the relay which switches on a 240v mains fan.

The most basic type has just two contacts (SPST) that connect when the relay is **energised**. The coil is connected to the battery circuit and draws around 150mA. Some contacts can have ratings up to 16 Amps for car accessories.

Some relays have 3 contacts, (SPDT). When the relay is at rest, the **common** and **normally-closed** contacts connect. When the relay is energised, the common contact is pushed against the **normally-open** contact, forming a new connection. The diagrams show a single pole relay, meaning one set of contacts. Relays with 2, (DPDT), 3 and 4 poles are readily available.

**Darlington Pair**

Generally transistors have either high power capability, or high gain, but not both. To overcome this, two transistors can be connected together as shown to form a Darlington pair. The first transistor has high gain, the second has high current capability. The final gain is the product of the two.

\[ \text{eg. } V_{BE} \text{ must be at least } 1.2\text{v to switch on both transistors. } V_{BE} = (2 \times 0.6v) \]

The current capability is that of T2. Best of both worlds!

**Thyristors**

Thyristors are a semi-conductor device that can switch on and latch output devices.

Once an input is sent to the gate, the thyristor conducts and latches on. The only way to switch off the output is either disconnect the power or short out the thyristor using a push switch. Some thyristors can switch up to 30 Amps.