An Introduction to Semiconductors

This year I'll be talking about semiconductors, starting with the different semiconductor materials and moving on to the different configurations that semiconductors can take. I won't be going to any great detail of the theory behind semiconductors or the manufacturing methods, it's far too complex for this talk. I was taught the theory many years ago at university but in the intervening years most of that knowledge has been mislaid! Also there have been many changes since the early 1970s. I'll also be demonstrating the characteristics of many of the devices using a simple curve tracer.

This year's talk will be split into two parts. In this part I'll concentrate on the different types of diodes and their characteristics and I'll cover transistors and ICs in the next part.

What is a Semiconductor?

A semiconductor material has a conductivity between that of a conductor, such as copper, and an insulator, such as glass. Unlike a metal the resistance of a semiconductor decreases with temperature and the conductivity can be changed by adding, or doping, controlled quantities of impurities.

The discovery of the semiconducting properties of materials actually pre-dates the thermionic valve as the rectifying properties of point contact diode had been observed as early as 1874[1].

Like the thermionic valve the first semiconductor device was the diode and one early use was as a detector in a crystal set. This was a point contact diode where a thin wire, known as a catswhisker, made contact with a semiconductor material, galena (lead sulphide). However it was necessary to move the point contact on the surface of the galena crystal to find the best rectifying point so perhaps not the most reliable device.

The crystal set remained popular throughout the early part of the century but as valve technology improved its use declined as valves could provide amplification which the semiconductors of the time could not.

One area where early semiconductors did find an application was in power supplies where the rectifying properties of some elements and metallic compounds were used for low voltage power supplies and battery chargers as an alternative to valve rectifiers. The main semiconductor materials used in these applications were selenium and copper oxide.

During the second World War there were many advances in electronics. As radar frequencies increased it was found that the performance of valves was not adequate for these higher frequencies but silicon diodes could be used, mainly as detectors and mixers, in the radar receivers.

After the war research continued into semiconductor devices and materials, resulting in the transistor and ultimately the integrated circuit. Over the years significant improvements in the materials and the manufacturing processes has resulted in the vast range of devices available today. I'll examine some of these devices in the next talk.

Many of the early devices used Selenium and Copper Oxide but these have been largely superceded by Germanium, Silicon and Gallium Arsenide.

Each of the materials in use today are refined to a very high purity level before controlled levels of impurities are added to create 'P' and 'N' type semiconductor material and single or multiple PN junctions depending on the device it's to be used in.

There are many types of diode available and those described in this talk are some of the more well known types.

Diodes and Rectifiers

Anode **Cathode**

+	**-**	**Current Flows**
-	**+**	**No Current Flows**

Figure 1 - Diode Conductivity

There are many different types of diode but they all have the basic property that current will flow in one direction but not when the polarity is reversed.

Like the thermionic diode there are two electrodes, the anode and cathode with a single PN junction. When the anode is more positive than the cathode current will flow and when the anode is negative with respect to the cathode no current will flow as shown in figure 1.

Diode Characteristics

Figure 2 shows the characteristics for a typical semiconductor diode. It can be split into three sections.

Starting with the forward section, this is where the anode is positive with respect to the cathode. As the applied voltage increases the current increases slowly until a specific voltage, V_d, is reached. The current then rises rapidly limited only by the circuit resistance.

When the applied voltage is reversed the current drops to virtually zero with only a small leakage current, I_s, flowing. This is the reverse section in figure 2.

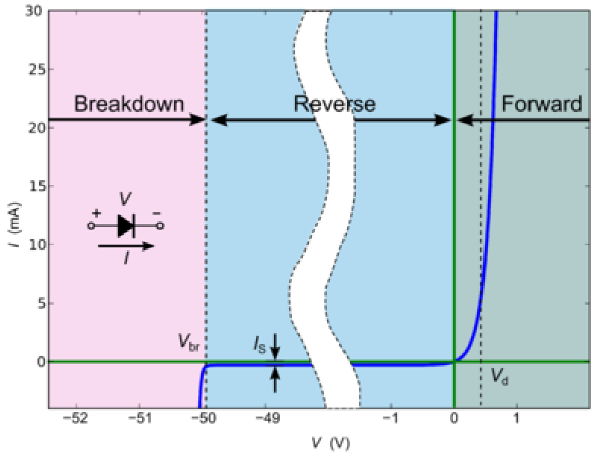


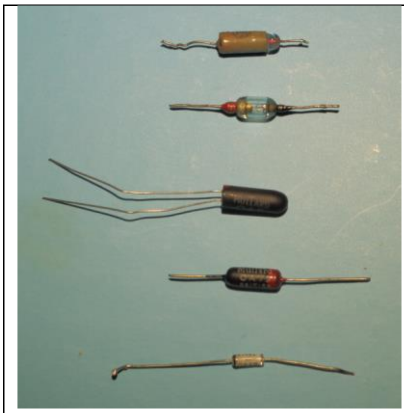
Figure 2 - Current vs Applied Voltage

As the reverse voltage increases there comes a point where the current increases rapidly, V_{br}. This is the point where the diode breaks down and if the current is not limited the diode will be destroyed.

The voltages V_d and V_{br} and the current I_s depend on the semiconductor material and the diode construction.

Typical signal diodes are shown in figures 3 and 4 with figure 3 showing germanium types and figure 4 showing a typical silicon zener diode and signal diode and two earlier metal diodes, the Westector and a selenium signal diode. The germanium diodes were typically used as detectors in AM, FM and TV receivers of the 50s and 60s and the Westector and selenium diodes were commonly used in the timebases of 50s TVs.

Most semiconductor diodes indicate the cathode connection with a coloured band. Note that the OA5 diode in figure 3, similar to the OC71 type of transistor, has its cathode marked with a red dot.



CG6E

GEX34

OA5

OA79

OA47

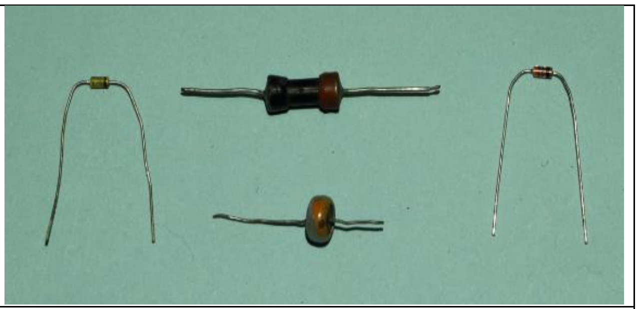


Figure 3 (Left) - Germanium Signal Diodes
Figure 4 (Above) – Westector, Selenium and Silicon Diodes

If you look at the data sheet for a diode one of the parameters is the Peak Inverse voltage (PIV). This is the maximum reverse voltage that the diode is guaranteed to withstand. In practice the actual PIV will vary due to variations in the manufacturing process and will usually be higher than the specified value but it is not recommended to operate a diode close to it specified PIV.

The data sheet will also specify the forward voltage drop (V_d) at different currents. This voltage can be used to identify the material used in a diode as a germanium diode has forward volt drop of typically around 0.3V with the equivalent for a silicon diode being typically around 0.6V.

Figures 5 to 10 show the measured characteristics of several of the signal diodes in figures 3 and 4 using a simple curve tracer. The X axis (CH2) is the applied voltage, upto -80V and +80V (left and right hand sides of the plot respectively) and the Y axis (CH1) is the diode current up to a maximum of 15mA. The individual plots show the X and Y values per division.

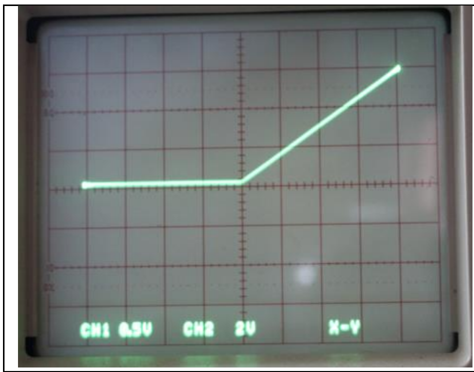


Figure 5 - OA5
(X 20V/div, Y 5mA/div)

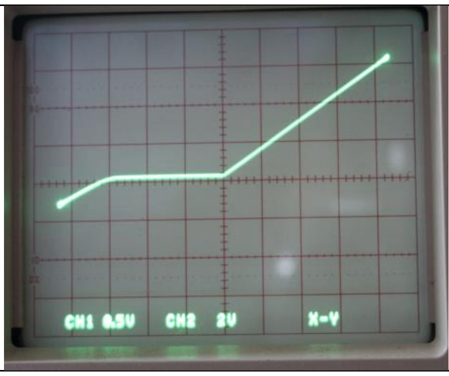


Figure 6 - OA47
(X 20V/div, Y 5mA/div)

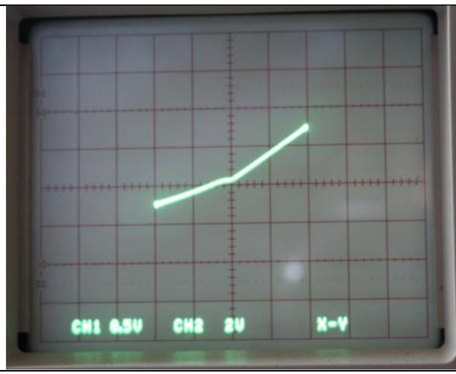


Figure 7 - CG6E
(X 5V/div, Y 1mA/div)

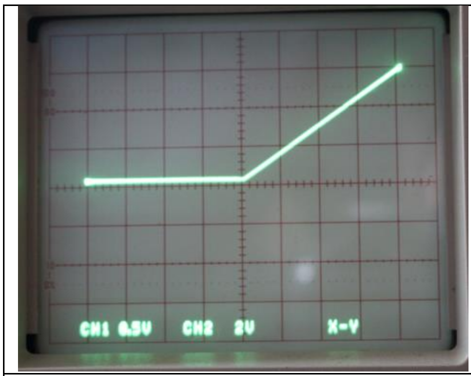


Figure 8 - 1N4148 Silicon Diode
(X 20V/div, Y 5mA/div)

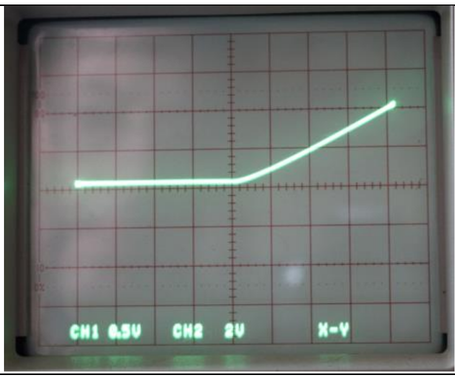


Figure 9 - Westector Diode
(X 20V/div, Y 5mA/div)

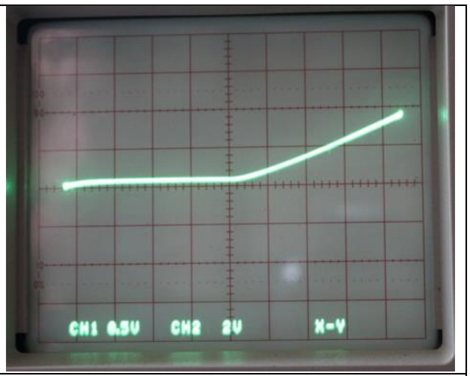


Figure 10 – Selenium Diode
(X 20V/div, Y 5mA/div)

The plots show that the breakdown voltage (PIV) for the OA5 is greater than 80V which is consistent with its specified 100V PIV from the OA5 datasheet. The OA47 has a measured PIV of 60V which is greater than its specified maximum of 25V. This, as mentioned earlier, is quite common but an OA47 should not be used in a circuit where it is subjected to a reverse voltage greater than 25v to ensure the circuits reliability. The CG6E diode has a measured PIV of approximately 2.5V so this is not the best diode in the world but would probably be OK for use in a crystal set. I have no datasheet for the CG6E so cannot comment on how it compares to its specified PIV.

The plot for the 1N4148 diode is comparable to the OA5 but has a higher Vd than any of the germanium diodes. The Westector has a measured PIV greater than 80V and the Selenium diode has a PIV of around 70V. Also note that the forward slope of the Westector and Selenium diodes is lower than any of the germanium diodes. This means that its forward resistance is higher than a germanium diode. If used as a rectifier the rectified dc voltage would be lower than a silicon or germanium diode for the same AC input voltage and load current.

Power Diode (Rectifiers)

The signal diodes we have seen usually have a maximum reverse breakdown voltage of around 100V and a maximum current rating of 50 to 100mA. Power diodes are designed for higher currents and higher voltages.

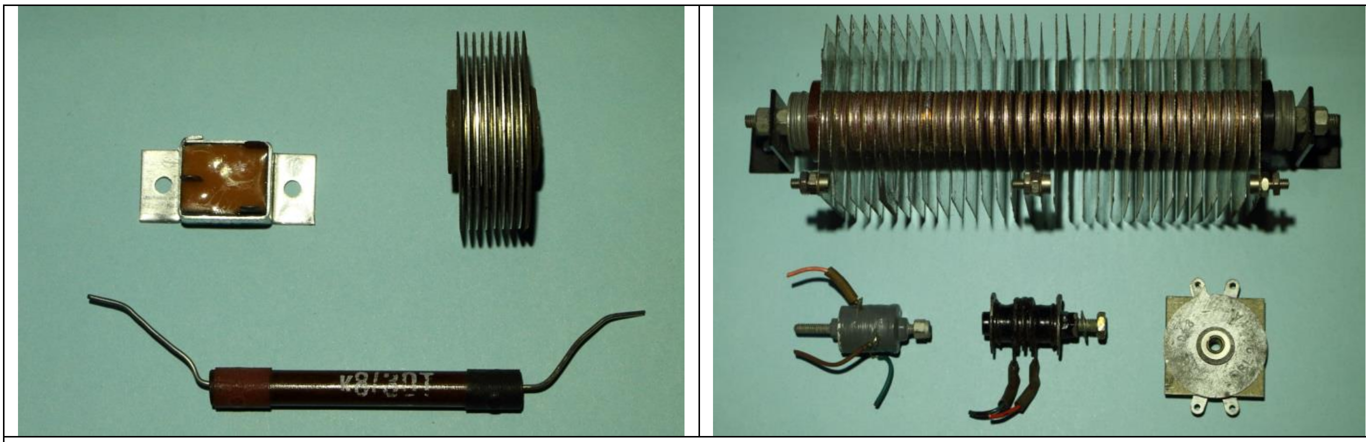


Figure 8 - Selenium and Metal Rectifiers

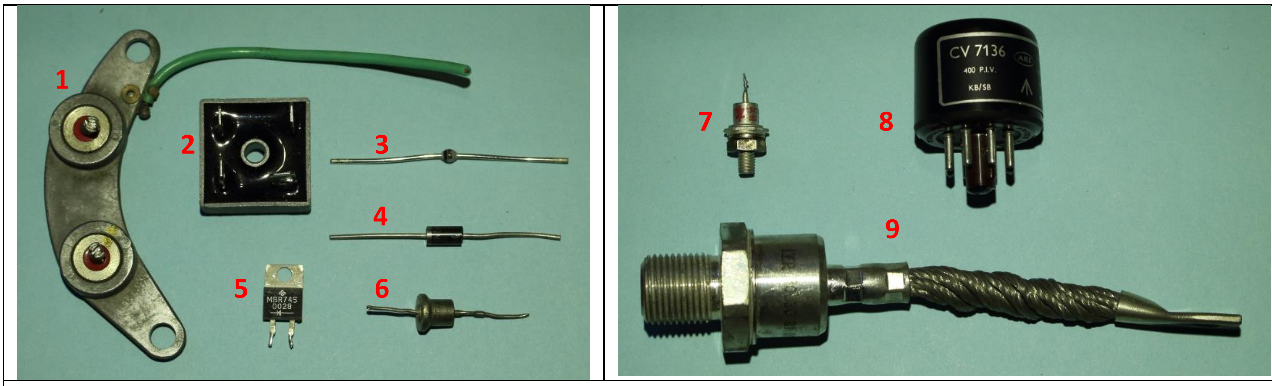


Figure 9 - Silicon Rectifiers

1) Alternator rectifier, 2) KBPC2504 (25A 400V bridge), 3) BYV28-600 (3.5A 600V ultra fast), 4) 1N5404 (3A 400V), 5) MBR 745 (7.5A 45V Schottky), 6) BY100 (450mA 800V), 7) 1S420 (10A 100V), 8) CV7136 (4 x 400V 700mA, 9) 70U30 (250A 300V)

Note that the 1S420 has the cathode connected to the case. It is also available as the 1S420R which has the anode connected to the case which can be beneficial when building bridge rectifiers.

A single selenium or metal diode has a relatively low breakdown voltage, typically around 20V, therefore to be usable for high voltage rectification several diodes have to be connected in series but this has the effect of increasing the forward voltage drop. In the case of higher current rectifiers fins are fitted to dissipate the heat generated.

When silicon rectifiers became available, an early one being the BY100, these soon replaced the selenium and metal rectifiers as they were smaller, dissipated less heat and had a lower forward voltage drop. Figure 9 shows several different types of silicon diodes. The higher current types are designed to be bolted to a heatsink as the dissipation can be significant even with a low forward volt drop.

When a silicon diode “switches” off, as it becomes reversed biased, there is a charge stored within the diode. This has to dissipate before the diode can completely switch off. When used in a conventional power supply this is not normally a problem but as switched mode power supplies became more common these diodes become less efficient so different diodes are required which have faster switch off times. These are normally known as fast or ultra fast rectifiers.

Switch mode power supplies are often used to supply high currents but the forward voltage drop for a silicon rectifier, typically 0.7V, can cause significant losses. One solution is to use a Schottky rectifier which has a metal/silicon junction rather than a silicon/silicon junction. These have a lower forward voltage drop of typically

0.45V. However Schottky diodes have a lower PIV than normal silicon rectifiers, normally between 30V to 100V which is adequate for most switch mode power supplies which are typically used to provide low voltages at high currents.

To provide higher currents rectifiers can be paralleled but care must be taken as the rectifiers must be the same type and preferably from the same batch to ensure the forward voltage drops are the same. If the volt drop is different between the rectifiers one will take more current than the others making it more prone to failure. Once it fails the others take more current causing them to fail.

One other effect in conventional power supplies is that when the rectifiers switch off they can cause RF interference. A small, suitably rated, capacitor across each diode can reduce the interference, alternatively a capacitor across the input of a bridge rectifier has a similar effect.

Rectifier Characteristics

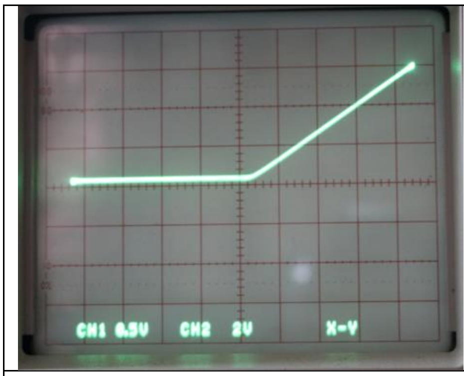


Figure 11 - CF2D Selenium rectifier (X 20V/div, Y 5mA/div)

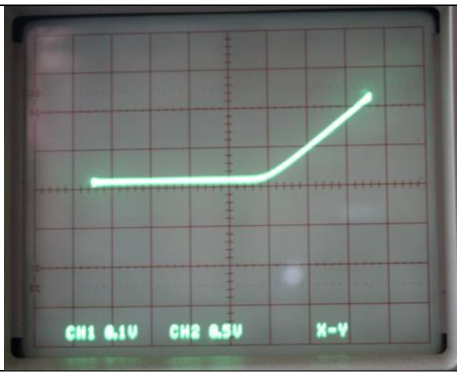


Figure 12 - CF2D Selenium rectifier (X 5V/div, Y 1mA/div)

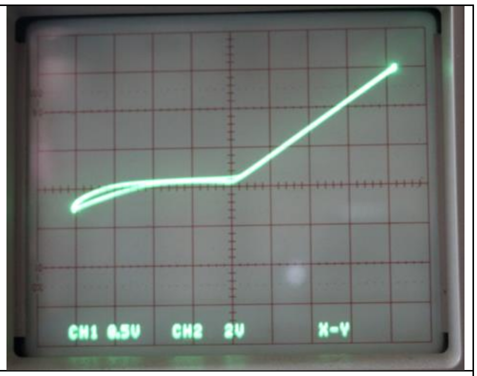


Figure 13 – Metal rectifier ((X 20V/div, Y 5mA/div)

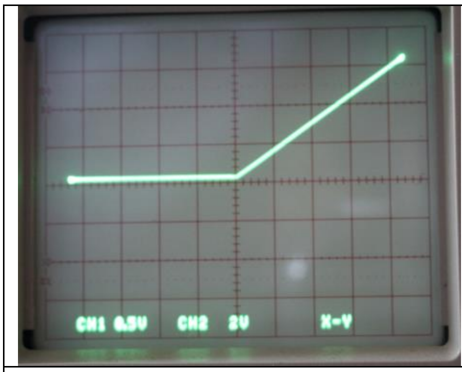


Figure 14 – BY100 Silicon Rectifier (X 20V/div, Y 5mA/div)

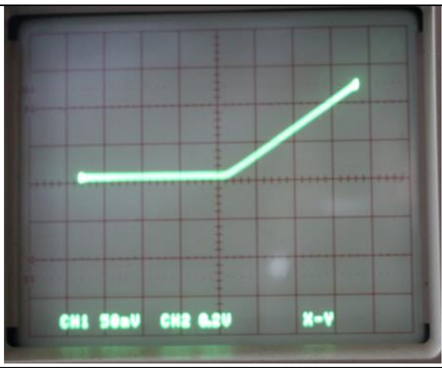


Figure 15 – BY100 Silicon Rectifier (X 2V/div, Y 0.5mA/div)

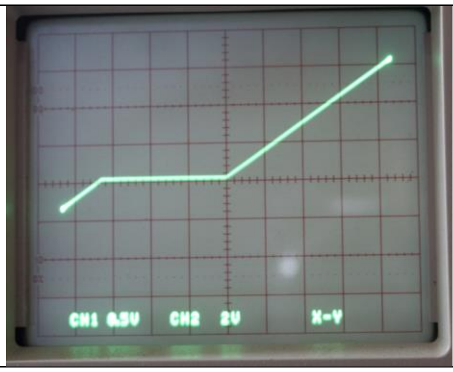


Figure 16 – MBR745 Schottky (X 20V/div, Y 5mA/div)

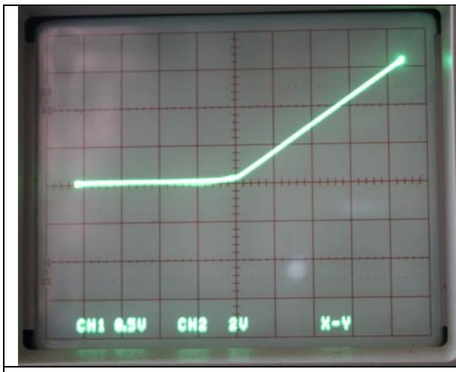


Figure 17 – Germanium Rectifier (X 20V/div, Y 5mA/div)

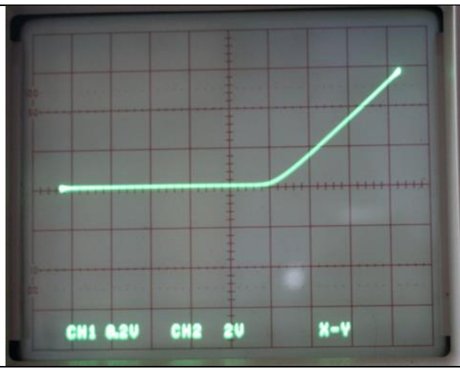


Figure 18 - K8/30T rectifier (X 20V/div, Y 5mA/div)

Figure 12 is a close up view of the CF2D Selenium rectifier in Figure 11 showing that it needs approximately 5V across the device before it starts conducting in the forward direction. The metal rectifier in figure 13 is the black rectifier shown in figure 8. This has a PIV of approximately 40V.

Figures 14 and 15 are the measured characteristics of the early BY100 silicon rectifier with figure 15 showing the forward volt drop of approximately 0.5V.

Figure 16 shows a Schottky rectifier with a measured PIV of just over 60V. This rectifier has a rated PIV of 45V.

The germanium rectifier in figure 17 looks similar to the other rectifiers but closer examination shows there is a small reverse current.

The K8/30T rectifier in figure 18 has a forward volt drop of approximately 20V. This because it is made from a large number of individual diode elements. Measurements made earlier indicate it has a PIV of around 1400V.

Checking Diodes and Rectifiers

A digital multimeter with a diode test function can be used to check diodes for their type and correct operation. Table 1 shows the typical voltages for the different types of diode or rectifier.

Table 1	
Diode Type	**Typical Voltage With DMM Diode Test**
Germanium	0.25V
Silicon	0.5V
Schottky	0.2V

Check the diode under test using both polarities of the test leads. 0V both ways indicates a short circuit diode and maximum voltage both ways indicates a possible open circuit diode but because the voltage available from a DMM diode test is usually limited to around 3V it is not possible to check selenium EHT rectifiers as their forward volt drop is greater than 3V.

Other Diodes

Zener Diode

All semiconductor diodes have a maximum reverse voltage rating above this voltage the diode will break down and the current will increase significantly.

In a Zener diode the reverse breakdown voltage is carefully controlled. This effect can be used to provide a reference voltage or to limit the voltage into an amplifier.

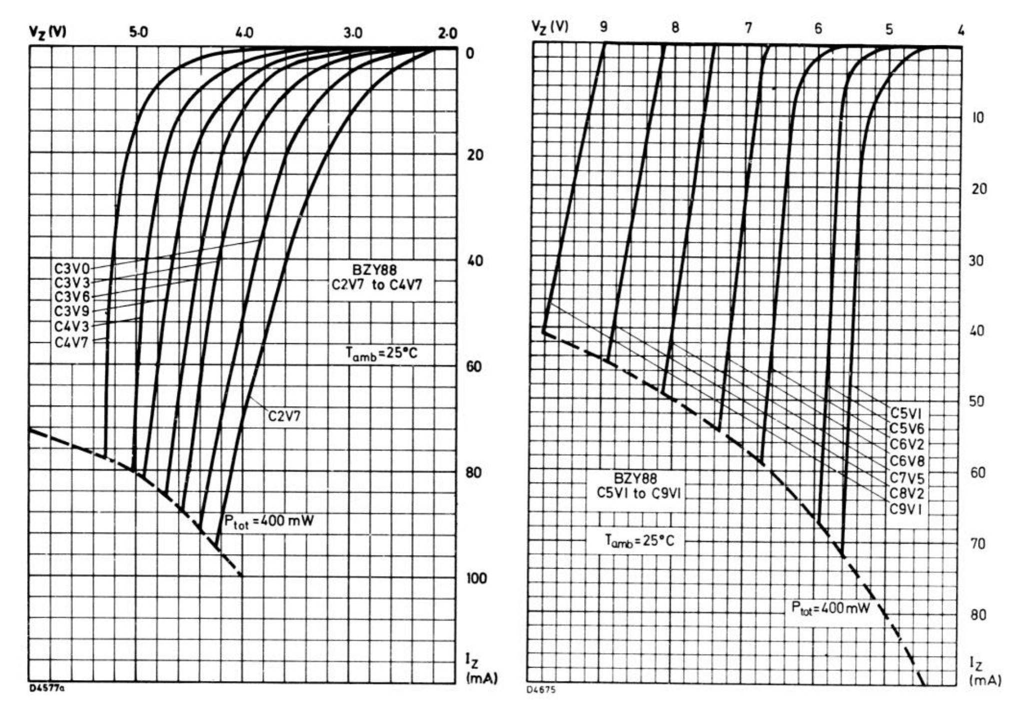


Figure 19 -Reverse breakdown characteristics for BZY88 series voltage reference diodes

You can see that the lower the breakdown voltage the less well defined is the breakdown voltage.

Strictly speaking only diodes with a breakdown voltage below 5.6V should be called Zener diodes as the breakdown mechanism above that voltage is Avalanche breakdown.

The breakdown voltage has a temperature coefficient i.e. as the temperature changes the breakdown voltage will change. Below around 5.6V the coefficient is negative, above 5.6V the coefficient is positive. Around 5.6V the temperature coefficient is around zero. This is why many power supplies use a 5.6V reference diode.

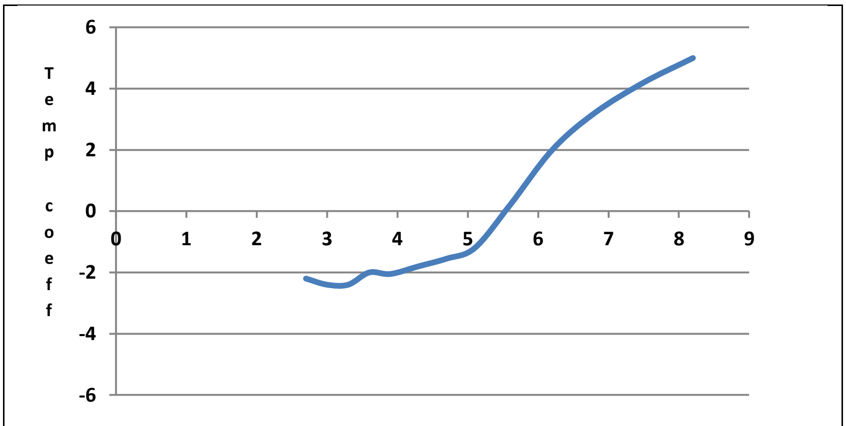


Figure 20 - Temperature coefficient vs breakdown voltage of the BZY88 at 5mA forward current

One application which can make use of the temperature coefficient is a battery charger for Sealed Lead Acid batteries. These require a constant voltage when being charged but the charging voltage is temperature dependant. The temperature coefficient of a 2.7V reference diode is virtually the same as the charging voltage temperature coefficient. Therefore using a regulator with a 2.7V reference diode as its reference will provide a charger whose voltage matches the batteries requirement.

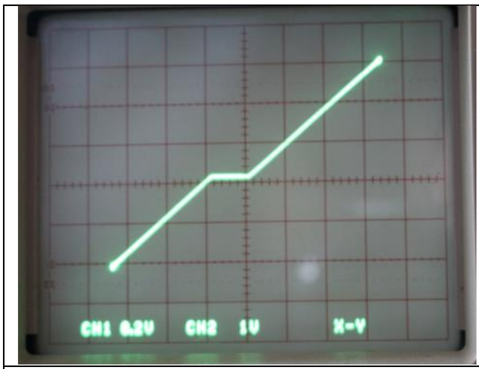


Figure 21 – 8.2V Zener diode (X 20V/div, Y 5mA/div)

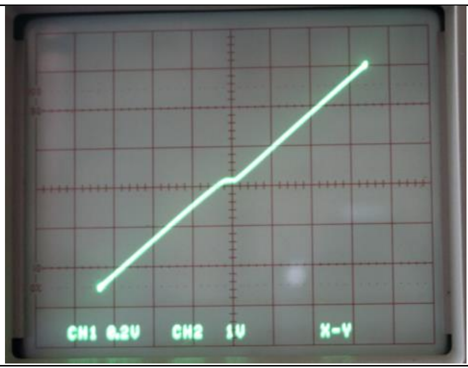


Figure 22 – 3.3V Zener diode (X 20V/div, Y 5mA/div)

Figures 21 and 22 show the characteristics for a couple of Zener diodes. In the forward direction they are like any other silicon diode but in the reverse direction they breakdown at a well defined voltage.

There is one application which requires a stable low temperature coefficient, low impedance source, this is for tuning TVs using a varicap voltage tuned tuner. For this a 33V supply is required. Using a Zener diode for this voltage would cause the significant tuning drift as a 33V Zener diode has a temperature coefficient of around 26mV/°C. You could use six 5.6V Zener diodes in series but, although this would have a low temperature coefficient, the source impedance would be high. So for this application a special voltage reference was developed, the TAA550. Strictly speaking this is an integrated circuit as it contains many active devices but because it's a two pin device and can be considered as a special type of Zener diode I've included it here rather than in the next talk on transistors and ICs.

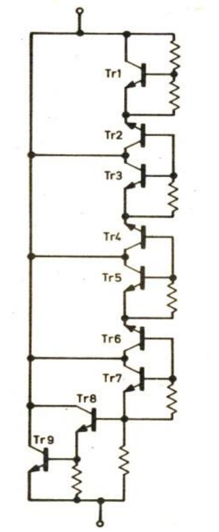


Figure 23 TAA550 circuit

The internal circuit is shown in figure 23. The circuit may look a bit strange as the transistors TR2, 4 & 6 appear to have reverse biased emitter base junctions. These three transistors along with TR3, 4 & 5 can be considered as a single Zener diode with TR1 acting as a Vbe multiplier to increase the "Zener" voltage and with TR8 & 9 as another Vbe multiplier the voltage across the device is increased to the required 33V. The temperature coefficients of the Vbe multipliers and the zeners cancel out to give a reference diode with a low temperature coefficient suitable for use with a varicap tuner.

Note:- A Vbe multiplier is a circuit where the collector emitter voltage of a transistor is a multiple of its base emitter, the multiple being the ratio of the resistors connected between the base and emitter and the base and collector. It is commonly used in audio amplifiers to stabilise the bias on the output transistors. For more information see https://en.wikipedia.org/wiki/Rubber_diode)

Varicap Diode

An N type semiconductor has an excess of electrons and a P type has a lack of electrons, normally called "holes". At a PN junction electrons diffuse into the P type material and "holes" diffuse into the N type material until equilibrium is achieved, forming a region called the depletion region which is equivalent to an insulator.

When the junction is forward biased this region is effectively reduced to zero allowing current to flow.

When the junction is reverse biased the depletion width increases, the width increasing as the reverse bias increases.

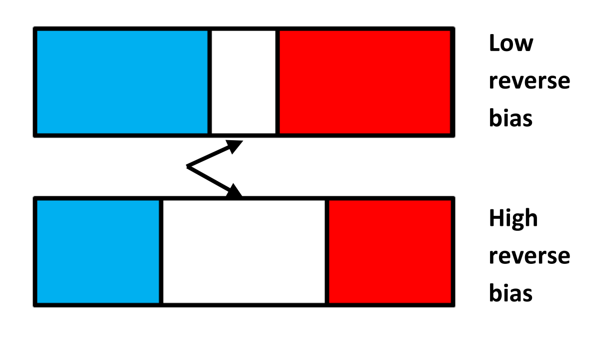


Figure 24 - Representation of depletion region under low and high reverse bias conditions

Now this can be thought of as an insulating region between two conductors, in other words a capacitor. As the reverse bias is increased the depletion layer width increases in proportion to the square root of the applied voltage. As capacitance is inversely proportional to the spacing of the "plates", the capacitance is inversely proportional to the applied voltage.

All diodes exhibit this phenomenon with a capacitance variation of a few 10s of pf but varicap diodes, or varactor diodes, are specially designed to exploit the effect and can have much greater capacitance variation than a standard diode.

The primary use for varicap diodes is in VHF radio and TV tuners where they are used to tune the local oscillator and the aerial circuits. They were also used in early, pre IC, colour decoders as part of the subcarrier oscillator to lock the oscillator to the incoming colour burst. These varicap diodes usually have capacitance range of 10pf to around 20pf but there are some varicap diodes with a capacitance variation in the 100s of pf region which can be used in MW and LW tuners. Some earlier mechanically tuned tuners used varicap diodes in the oscillator to provide AFC.

When used in an oscillator the bias voltage on the diode can be affected by the oscillator voltage which can cause distortion of the oscillator output but using two diodes in series can reduce this effect at the price of reducing the capacitance range.

PIN Diode

All the diodes we have seen so far have had a PN junction. We now come to diodes which do not have a conventional junction starting with the PIN diode.

The PIN diode is constructed with a layer of P type silicon and a layer of N type silicon surrounding a layer of pure silicon with no doping, an Intrinsic layer hence the PIN designation. The intrinsic layer is much wider than either of the doped layers.

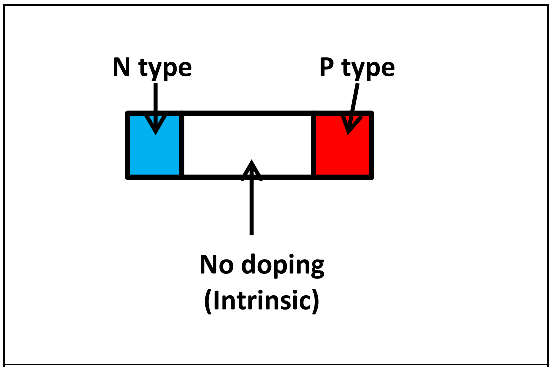


Figure 25 - PIN diode construction

When forward biased electrons and "holes" are injected into the intrinsic layer which, put simply, causes the forward resistance to be proportional to the forward current.

When reverse biased the diode acts like a capacitor in a similar manner to the varicap diode but because of the wide intrinsic layer the capacitance is very low. This means the PIN diode can be used to switch RF with very good isolation when "off". The on resistance can also be very close to the equivalent on resistance of a mechanical relay.

Another use is as a current controlled RF attenuator as used in some UHF TV tuners.

Tunnel Diode

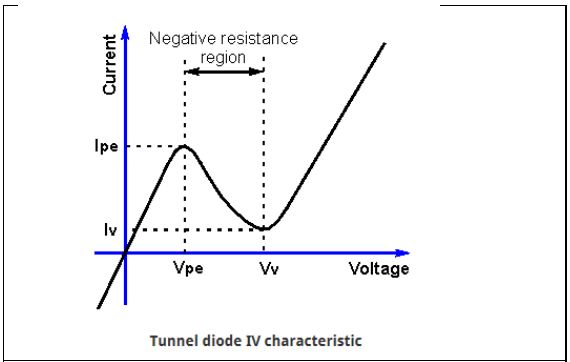


Figure 26 - Tunnel Diode characteristics

The tunnel diode was invented in August 1957 by Leo Esaki, Yuriko Kurose and Takashi Suzukiwhen they were working at Tokyo Tsushin Kogyo, now known as Sony. It comprises a heavily doped P-N junction, typically using germanium but other semiconductors can be used. This gives a characteristic with a zero reverse breakdown voltage but, due to a process called quantum tunnelling, the forward characteristic has a section where the current decreases as the forward voltage increases. This is the negative resistance section shown in figure 26.

This negative resistance can be used as an amplifier or oscillator well into the microwave region. However as it is a two terminal device the input and output are not isolated reducing its usefulness. Tunnel diodes were also used in the trigger circuits of some oscilloscopes.

They are fragile devices as too much forward current can destroy them.

Gunn Diode

Figure 27 - Gunn Diode Microwave Module

The Gunn diode was invented in 1962 by physicist J.B.Gunn. It is a negative resistance device which can be used to amplify or oscillate. Unlike other diodes which have both P and N doped regions, the Gunn diode comprises only N type semiconductor, typically Gallium Arsenide, with three differently doped regions. Because of the way the doping is applied it has a negative resistance region with a characteristic not unlike the tunnel diode.

By applying a voltage across the device to bias it into the negative resistance region it will oscillate. The frequency is dependent on the properties of the doping regions. The oscillation frequency is normally in the microwave region but can be tuned by adding a resonator such as a microwave cavity.

The major use of these devices is in microwave radar modules.

Light Emitting Diode (LED)

At the atomic level when a diode is forward biased the electrons are jumping between the energy levels within the semiconductor material. When they jump from a high level to a lower level, energy is released in the form of electromagnetic radiation. The difference between the energy levels determines the frequency of the radiation. With the right materials this radiation is in the form of light.

The original LEDs used Gallium Arsenide and emitted infra-red radiation at the “low frequency” end of the visible spectrum. Subsequent development produced visible LEDs with radiation at the red end of the spectrum. Changes to the semiconductor material produced first Yellow then Green LEDs in the early 1970s and finally in the 1990s Blue LEDs appeared. Over the years with changes to the materials and processes used the efficiency of the LEDs has improved meaning more light output for the same forward current or lower current for the same light output.

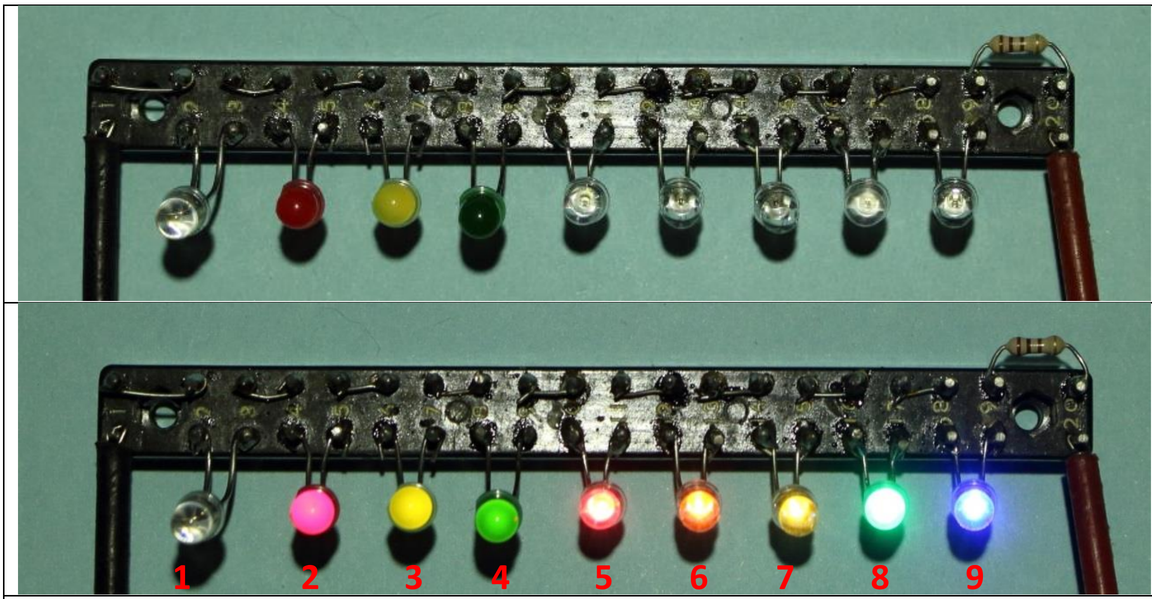


Figure 28 - LEDs ranging from Infra Red to Blue

Figure 28 shows various LEDs both off and on. The LEDS 1 to 4 on the left date from the 1970s/80s and LEDs 5 to 9, on the right, are more modern types dating from around 2010. The LEDs are in series with the current through them set to 10mA showing the higher brightness from the more recent LEDs.

The LED on the extreme left is an infra red LED and is not visible to our eyes. On most cameras it will show up but the camera I used to take the pictures has filtering to remove any IR radiation. Most digital cameras will show infra red radiation and this is one method of determining if an IR remote control is working. Simply point the control at either a digital camera or the camera on your phone. If you can see the LED lighting, up the remote control is working. Figure 29 shows the four left LEDs but taken on my phone camera. The IR LED on the far left shows up clearly.

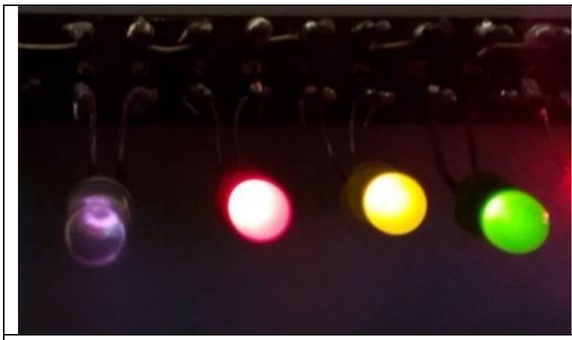


Figure 29 - The four left LEDs taken on a phone camera.

Figures 30 to 32 show the characteristics of two red LEDs. LED 1 in figure 30 has a reverse breakdown voltage of approximately 20V whereas LED 2 has a breakdown voltage of over 80V although LEDs are generally reckoned to have a PIV of around 5V. When used as indicators on an AC supply it is recommended to fit an inverse parallel diode across the LED.

Figure 32 is an expanded part of LED 2 characteristic, showing a forward voltage of approximately 1.8V.

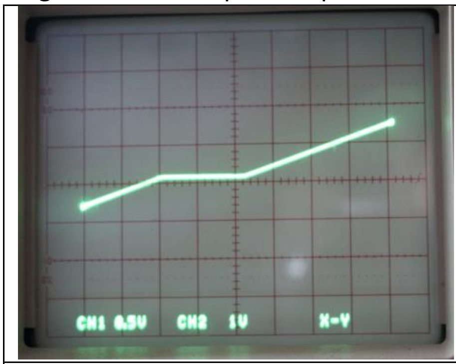


Figure 30 – Red LED (1) (X 10V/div, Y 5mA/div)

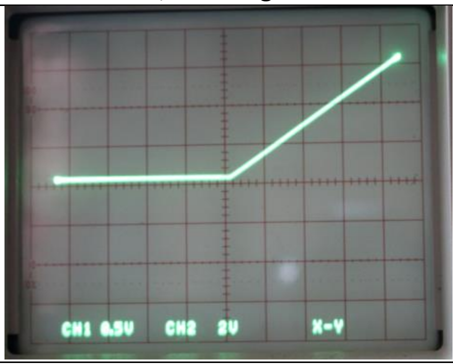


Figure 31 – Red LED (2) (X 20V/div, Y 5mA/div)

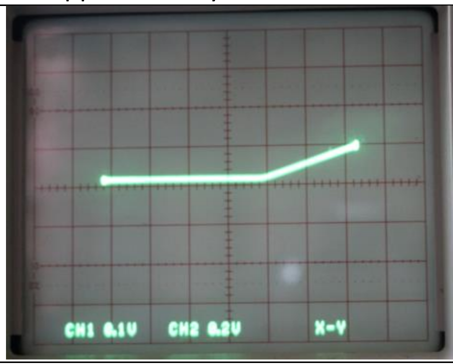


Figure 32 – Red LED (2) (X 2V/div, Y 1mA/div)

LED		Approximate Forward Voltage	
	Colour	**DMM**	**@10mA**
1	**Infra red**	1.15V	1.28V
2	**Red**	1.59V	1.90V
3	**Yellow**	1.73V	2.06V
4	**Green**	1.77V	2.07V
5	**Red**	1.68V	1.91V
6	**Orange**	1.71V	1.91V
7	**Yellow**	1.76V	1.94V
8	**Green**	>2.95V	3.33V
9	**Blue**	>2.95V	3.26V

Table 2 - LED Measured Voltages

The colour of the light emitted by an LED depends on the materials used and the construction. Many LEDs are encapsulated in a material of the same colour as the emitted light but not all are, so to determine the colour of an unknown LED the diode test function on a digital multimeter can be used to measure the forward voltage. Table 2 shows the voltages measured on a Fluke 79 DMM for the LEDs in figure 28. Also shown are the LED voltages measured on the demo unit at 10mA. When using a DMM there is often enough current available to dimly light up the LED giving visual indication of the colour but note that some green LEDs, especially early types can appear yellow at the very low currents available from a DMM.

You will notice that the measured forward voltages for LEDs 3 and 4 (Yellow and Green) are very similar because they are the same semiconductor material. Similarly the voltages for LEDs 5, 6 and 7 are very similar as they are the same semiconductor material. LEDs 8 and 9 have different forward voltages as they are different semiconductor materials.

The DMM measurements for LEDs 8 and 9 were over the maximum voltage on the DMM diode check setting. However the current available on the DMM was enough to light up the LEDs giving a visual indication of the colour.

The forward voltage is the value measured at a forward current of 10mA for typical LED samples. A more detailed list of materials and characteristics is in the Appendix.

White LEDs

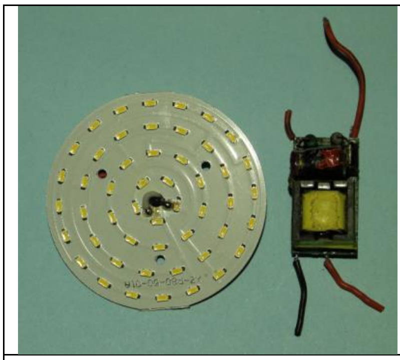


Figure 33 - LED Lamp plus Power Supply

Recent developments have produced White LEDs but these use a phosphor to convert light from a blue LED to a broad spectrum of light. This is very similar to the principles used on CRT screens. The efficiency and light output of these diodes has improved to the point where they are being used as replacements for incandescent lamps. Figure 33 shows the LED element and its power supply used in a typical LED light bulb. My experience has been that the LED elements will generally last the claimed lifetime but the weak point is the power supply.

White LEDs are also used in "LED" TVs which actually use LCD screens but are back lit by an array of white LEDs

A true LED TV uses OLEDs which use a layer of an organic compound which emits light in response to an electric current.

LED Displays

Once practical LEDs had been developed it was a short step to the seven segment and other displays, a selection of which are shown in figure 34. The most common type is the seven segment display which can show the numbers 0 to 9 and a limited number of letters, enough to show the hex characters 0 to F with a decimal point. Also shown is a 16 segment display which can show all the letters A – Z as well as the numbers. Some of the original seven segment displays had character which were only about 5mm high and used a magnifying bubble to increase the apparent size. Others had approximately 10mm high characters. As the optics and LED materials improved displays of up to 100mm became available.

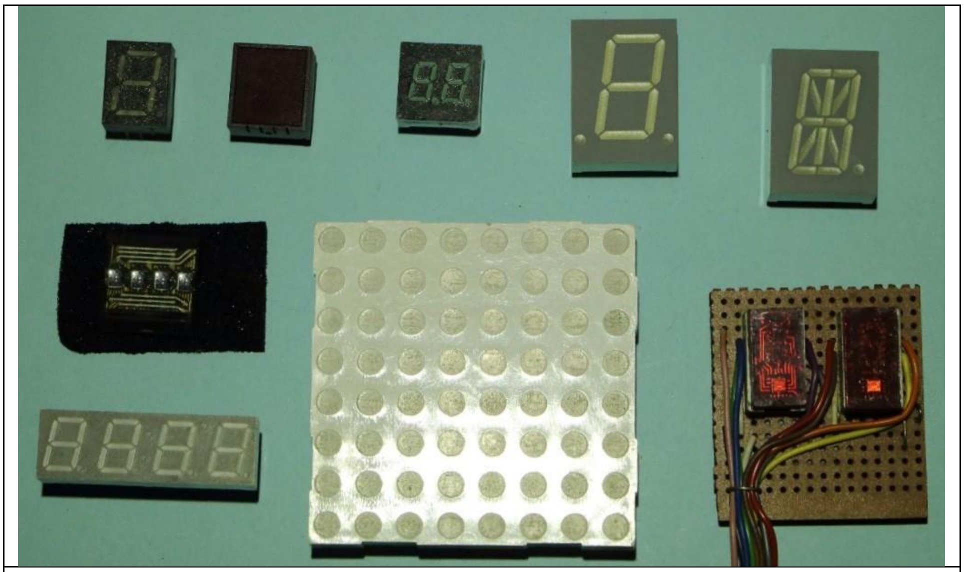


Figure 34 - A selection of LED displays

The display on the black antistatic foam and the two displays on the Veroboard have built in drivers and decoders allowing ASCII and BCD data respectively to be displayed. The ASCII display also illustrates the bubble magnifier used on many earlier displays.

The display in the centre is an array of 64 LEDs in an 8 x 8 matrix. This can be used to show simple graphics or with a large matrix of such displays, more complex graphics. One application is for a fire alarm display panel which, with a suitable semi-transparent cover can show the location of fire alarm sensors in a building, lighting up the appropriate one when an alarm is sounded.

Photo Diode

When light falls on a diode junction it causes a current to flow, effectively converting light into electricity. This is used to great effect in solar panels.

The Demo Unit, figure 35, has an IR LED driven by a 1kHz square wave from a 555 putting a current of approximately 10mA through the diode. A BPW41 photodiode, located 4cm away from the LED receives the light from the LED. The receiver can be operated in two configurations, without and with DC bias applied. Without bias the photo current flows into the scope input impedance. With the bias the current flows through the bias resistor. Figure 36 shows the received signal without bias on the diode, approximately 200mV pk-pk. Applying bias from a 12V supply via a 470kΩ resistor to a reverse biased photo diode the output voltage across the diode increases to approximately 6V pk-pk as shown in figure 37.

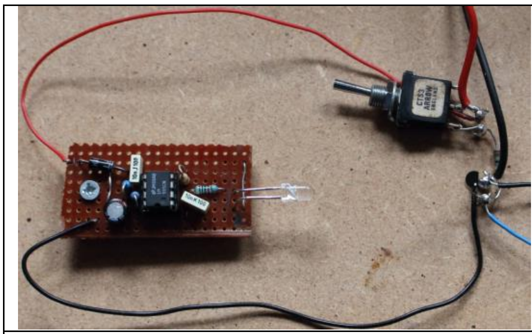


Figure 35 - IR Diode Demo Unit

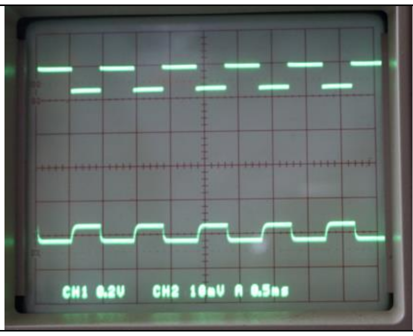


Figure 36 - Output Voltage From Bare Diode - 200mV Pk - Pk

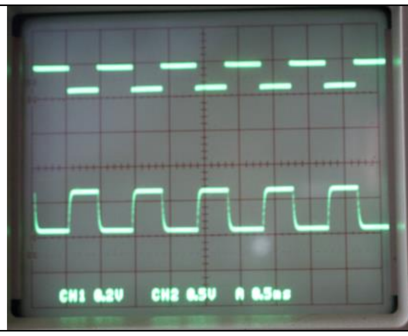


Figure 37 - Output With Reverse Bias Applied - 6V Pk –Pk.

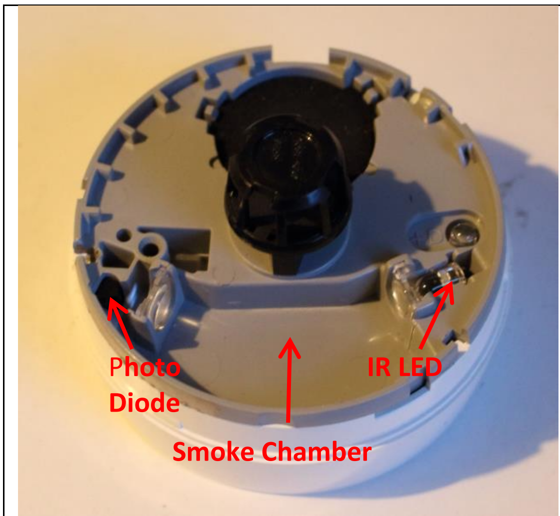


Figure 38 - Optical Smoke Sensor

Photo diodes are produced that can respond to visible light but the BPW41 diode used in the demo unit has an encapsulation that acts as an infra red filter to minimise any interference from visible light. This type of photo diode is used in IR remote control system and in optical smoke detectors and sensors.

Figure 38 shows a Gent smoke sensor, where the IR LED and Photo diode, a BPW41, are pointing into a chamber at an angle to each other. The IR LED is pulsed at regular intervals but because of the optical alignment very little IR light reaches the photo diode. When smoke enters the chamber the IR light is scattered by the smoke particles meaning more light reaches the photodiode, increasing its output. Once the output passes a specific level the alarm is triggered.

Other uses for photo diodes are in Infra red remote control systems and optical communication systems.

Diac

A diac is a bidirectional device two terminal that is “off” or open circuit until its breakdown voltage is reached. It will then remain conducting until the current through it drops below its “holding current”. One of its main uses is triggering triacs.

The characteristic, shown in figure 39, shows the Diac remaining no conductive until the voltage across it reaches just under 40V when it conducts. If you look carefully at the point at which it triggers you can see a “step”. But because the current from the curve tracer is relatively low the Diac does not fully conduct. Figure 41 shows the characteristic according to the data sheet.

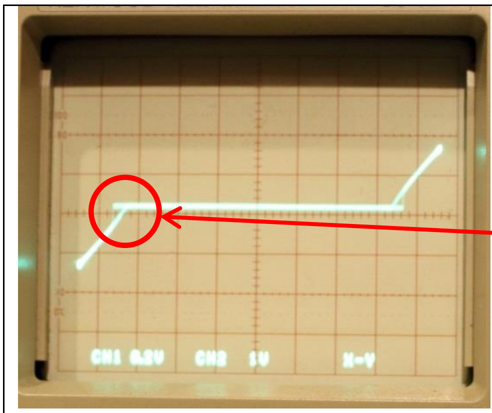


Figure 39 - Diac Characteristics

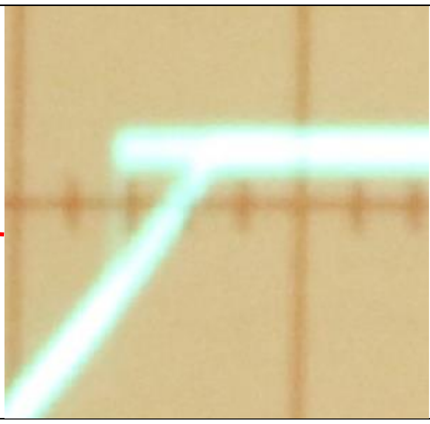


Figure 40 – Close up of turn on/off point

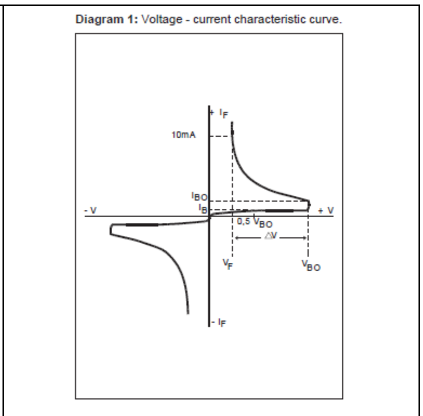


Figure 41 - The characteristic according to the data sheet

Appendix

1) **LED material and characteristics (Wikipedia)**(https://en.wikipedia.org/wiki/Light-emitting_diode)

Colour	Wavelength [nm]	Voltage Drop [ΔV]	Semiconductor Material
Infrared	$\lambda > 760$	$\Delta V < 1.63$	Gallium arsenide (GaAs) Aluminium gallium arsenide (AlGaAs)
Red	$610 < \lambda < 760$	$1.63 < \Delta V < 2.03$	Aluminium gallium arsenide (AlGaAs) Gallium arsenide phosphide (GaAsP) Aluminium gallium indium phosphide (AlGaInP) Gallium(III) phosphide (GaP)
Orange	$590 < \lambda < 610$	$2.03 < \Delta V < 2.10$	Gallium arsenide phosphide (GaAsP) Aluminium gallium indium phosphide (AlGaInP) Gallium(III) phosphide (GaP)
Yellow	$570 < \lambda < 590$	$2.10 < \Delta V < 2.18$	Gallium arsenide phosphide (GaAsP) Aluminium gallium indium phosphide (AlGaInP) Gallium(III) phosphide (GaP)
Green	$500 < \lambda < 570$	1.9[1] $< \Delta V < 4.0$	**Traditional green:** Gallium(III) phosphide (GaP) Aluminium gallium indium phosphide (AlGaInP) Aluminium gallium phosphide (AlGaP) **Pure green:** Indium gallium nitride (InGaN) / Gallium(III) nitride (GaN)
Blue	$450 < \lambda < 500$	$2.48 < \Delta V < 3.7$	Zinc selenide (ZnSe) Indium gallium nitride (InGaN) Silicon carbide (SiC) as substrate Silicon (Si) as substrate—under development
Violet	$400 < \lambda < 450$	$2.76 < \Delta V < 4.0$	Indium gallium nitride (InGaN)
Purple	Multiple types	$2.48 < \Delta V < 3.7$	Dual blue/red LEDs, blue with red phosphor, or white with purple plastic
Ultraviolet	$\lambda < 400$	$3 < \Delta V < 4.1$	Indium gallium nitride (InGaN) (385-400 nm) Diamond (235 nm) Boron nitride (215 nm) Aluminium nitride (AlN) (210 nm) Aluminium gallium nitride (AlGaN) Aluminium gallium indium nitride (AlGaInN)—down to 210 nm
Pink	Multiple types	$\Delta V \approx 3.3$	Blue with one or two phosphor layers, yellow with red, orange or pink phosphor added afterwards, white with pink plastic, or white phosphors with pink pigment or dye over top.
White	Broad spectrum	$2.8 < \Delta V < 4.2$	Cool / Pure White: Blue/UV diode with yellow phosphor Warm White: Blue diode with orange phosphor

2) **References**

[1] Radcom July 2017 P79