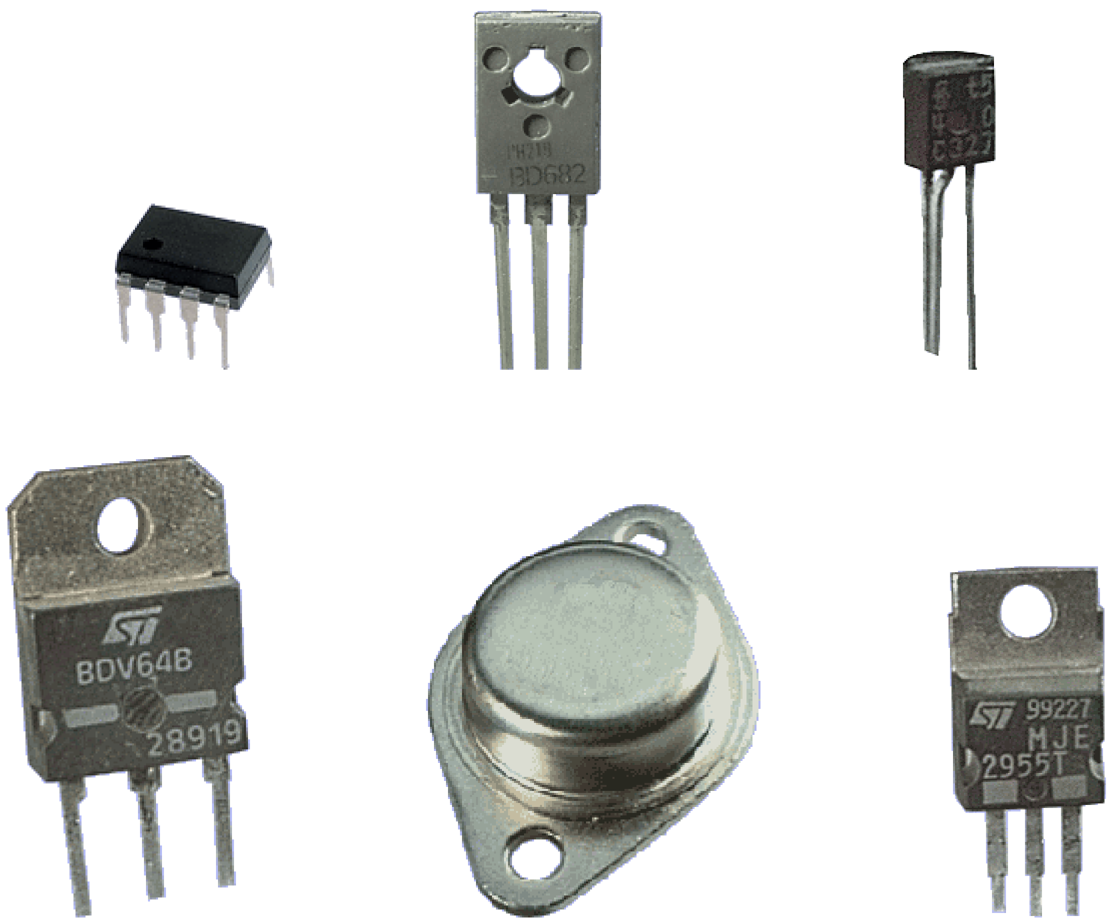
Diploma of Audio Production **Name________________**

Analogue Fundamentals (Audio Knowledge)

Introduction to Semiconductors and simple applications

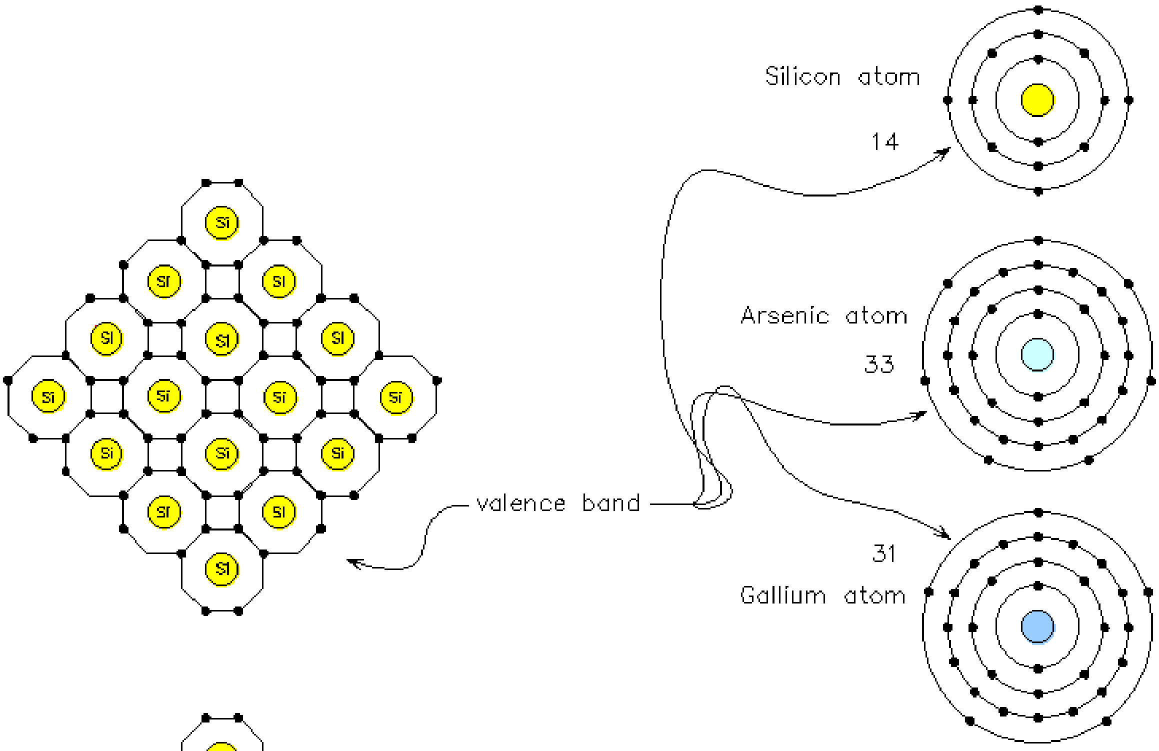
Module 13

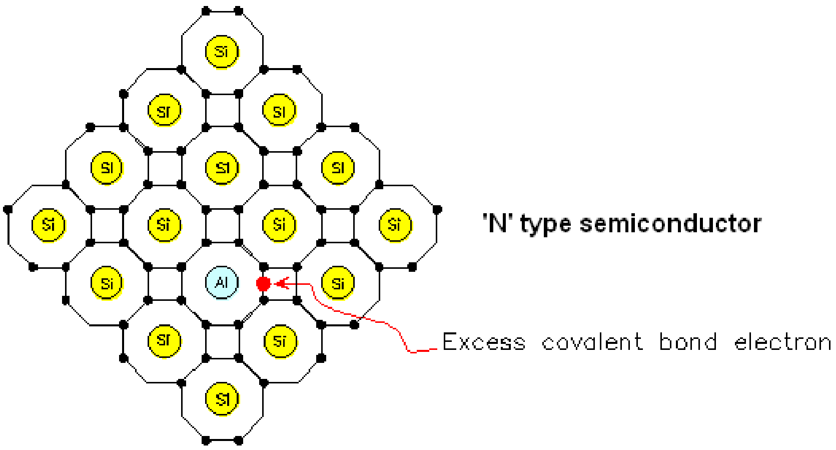
Topic 1: Semiconductors
Topic 2: The diode in operation
Topic 3: The transistor in operation
Topic 4: A basic analogue transistor amplifier circuit

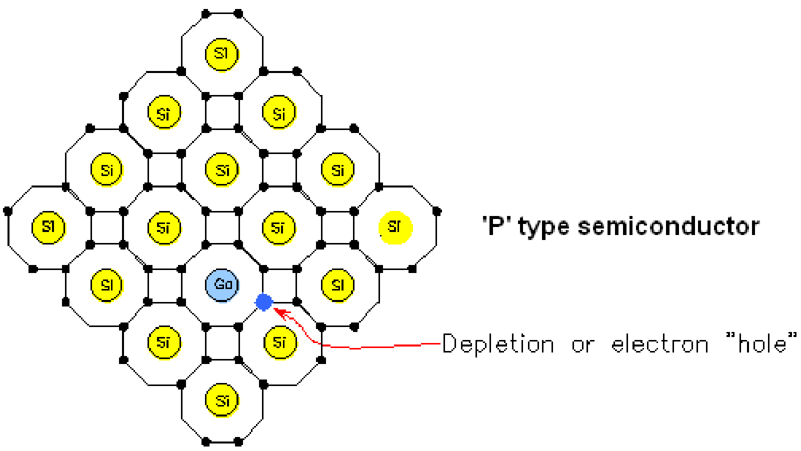


Topic 1: Semiconductors.

A Diode consists of two layers of semiconductor. So how do semiconductors work? By introducing a specific impurity into silicon (itself an insulator) such as Arsenic or Gallium, extra electrons or electron "holes" are created in the valence layer of the silicon atoms. See the diagram below:

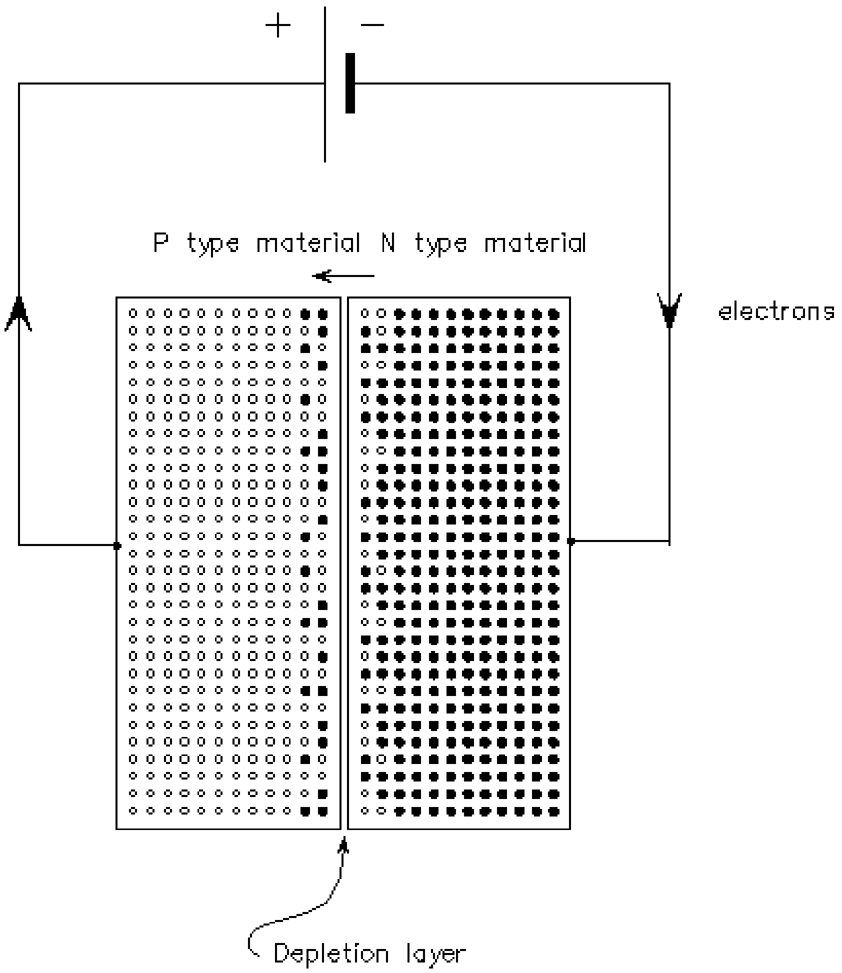


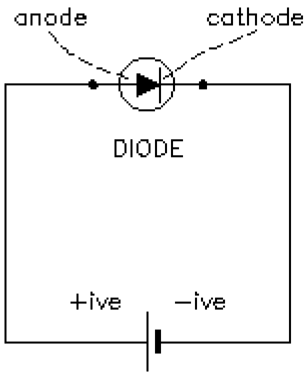




Topic 2: The diode in operation.

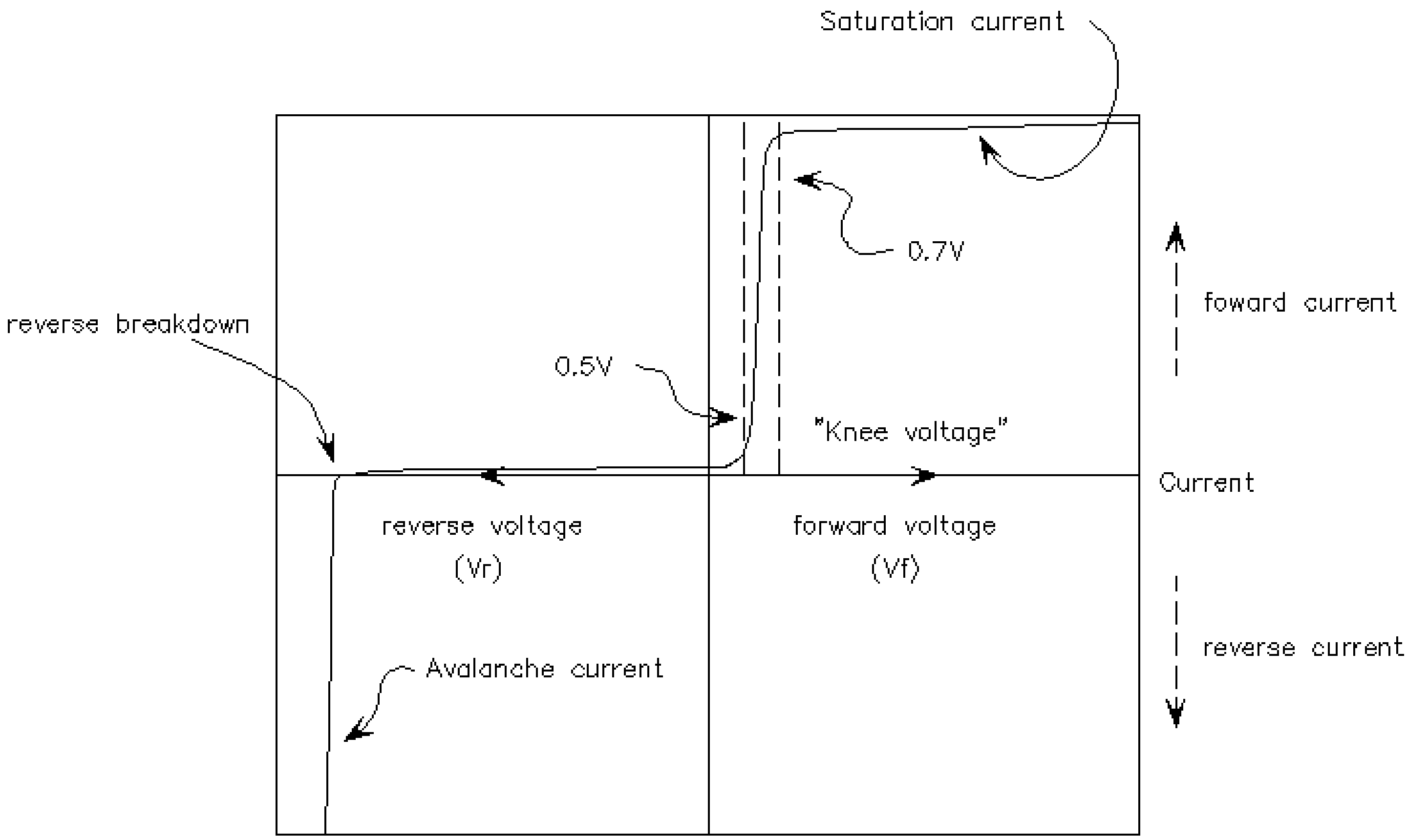
When layers of these semiconductors are combined in wafers, some of the extra electrons in the 'N' type material are attracted to the holes in the 'P' type, and migrate over resulting in a "depletion zone" in the junction.

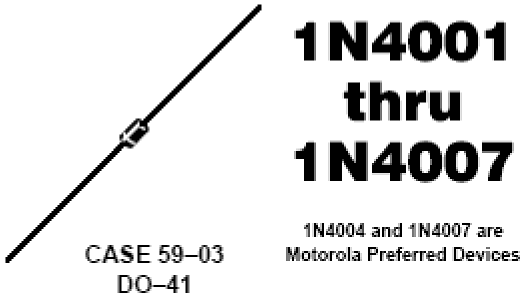




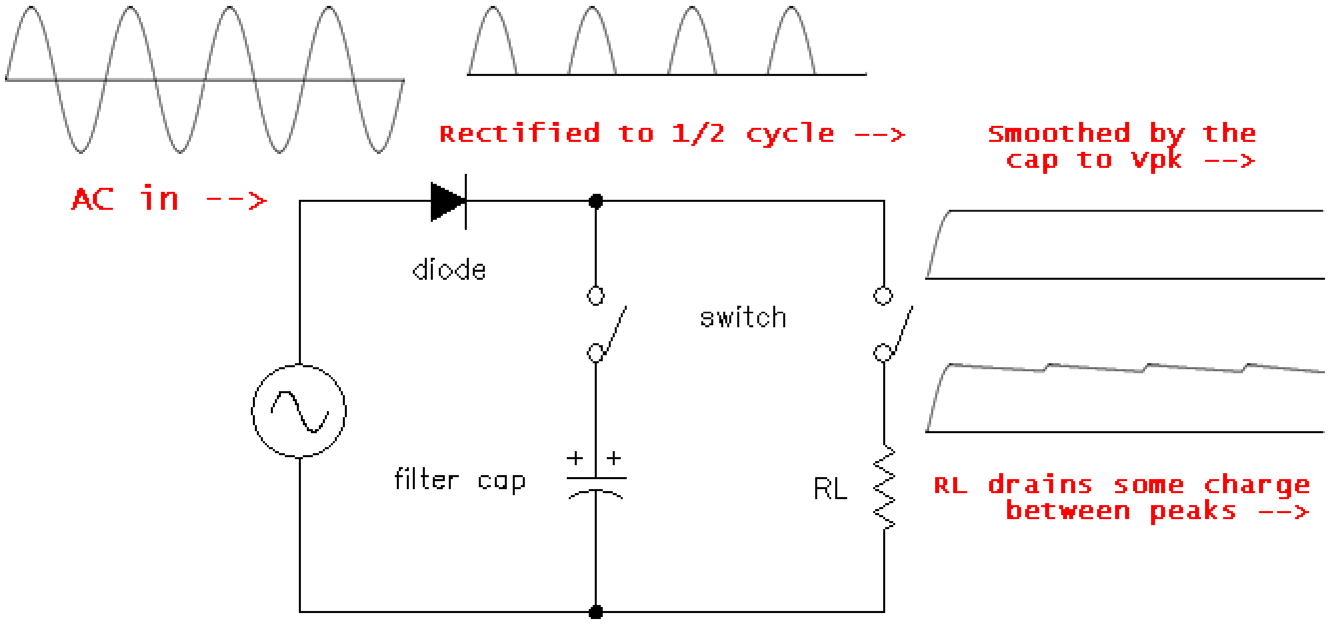
This gives the device an interesting property; namely that if a voltage is applied in the direction that the electrons are *already attracted to*, the junction will begin to conduct. If the battery is connected around the other way, the depletion zone recedes and the diode does not conduct unless the voltage is high enough to produce a breakdown in the junction, resulting in an 'avalanche current'. When the avalanche current occurs, the junction conducts much like a short circuit (often destroying the device!). When the junction conducts in the forward direction, it is said to be "forward biased". When the battery is reversed it is said to be "reverse biased". Once the device begins conducting (at a voltage called the 'knee voltage'), the voltage across the junction does not increase much (typically from 0.55 volts to 0.75volts), but the current increases a lot until a saturation point is reached where the particular device can no longer usefully increase forward current flow without damage.

See the graph below:





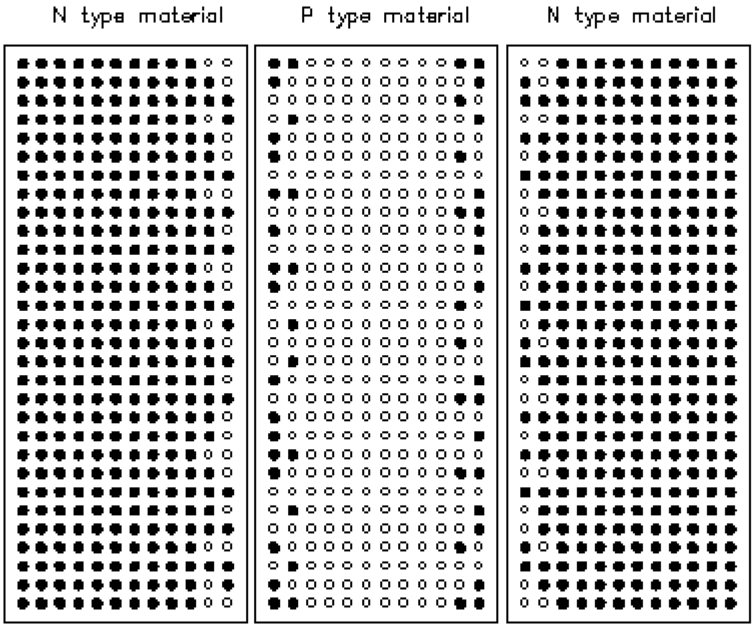
By using this characteristic of the diode, we can turn AC into DC. Below is a schematic of a “half wave” rectifier. When the AC passes through the diode in one direction, the AC viewed on a CRO looks like the 2nd display. When the capacitor is switched in, it charges up and smooths the ripple into a continuous DC voltage equal to the peak voltage of the ½ wave. When a load (R_L) is switched in however, some of the voltage stored in the capacitor is drained off and it has to charge up again on the next half wave.



Topic 3: The transistor in operation.

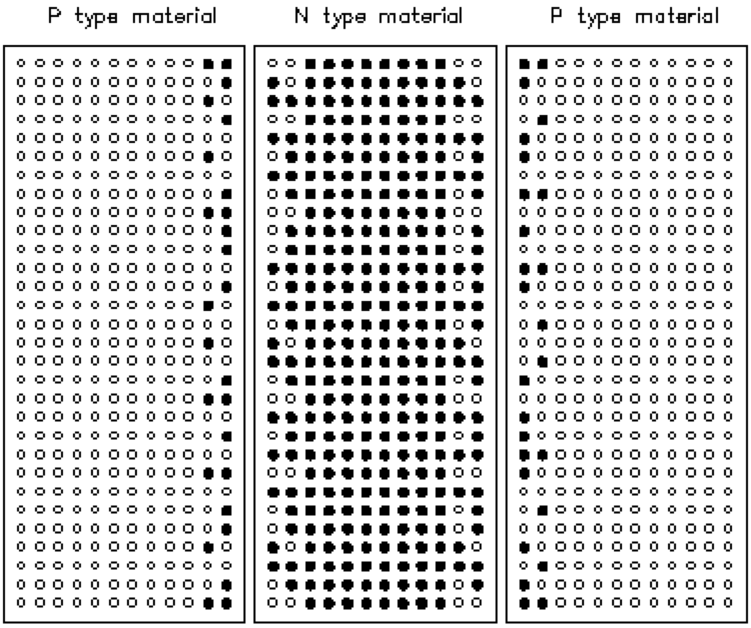
A transistor consists of three layers of semiconductor; either:

['N' type – 'P' type – 'N' type]

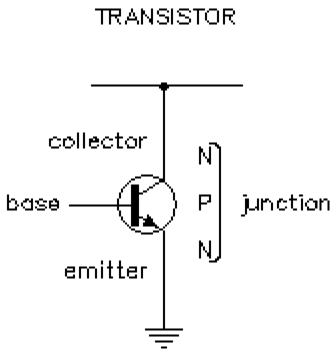


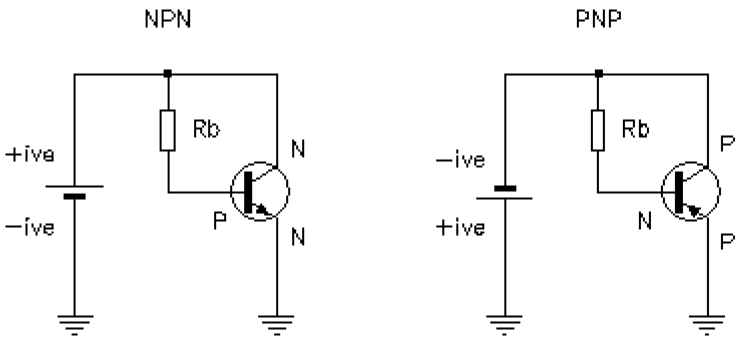
Or:

['P' type – 'N' type – 'P' type].

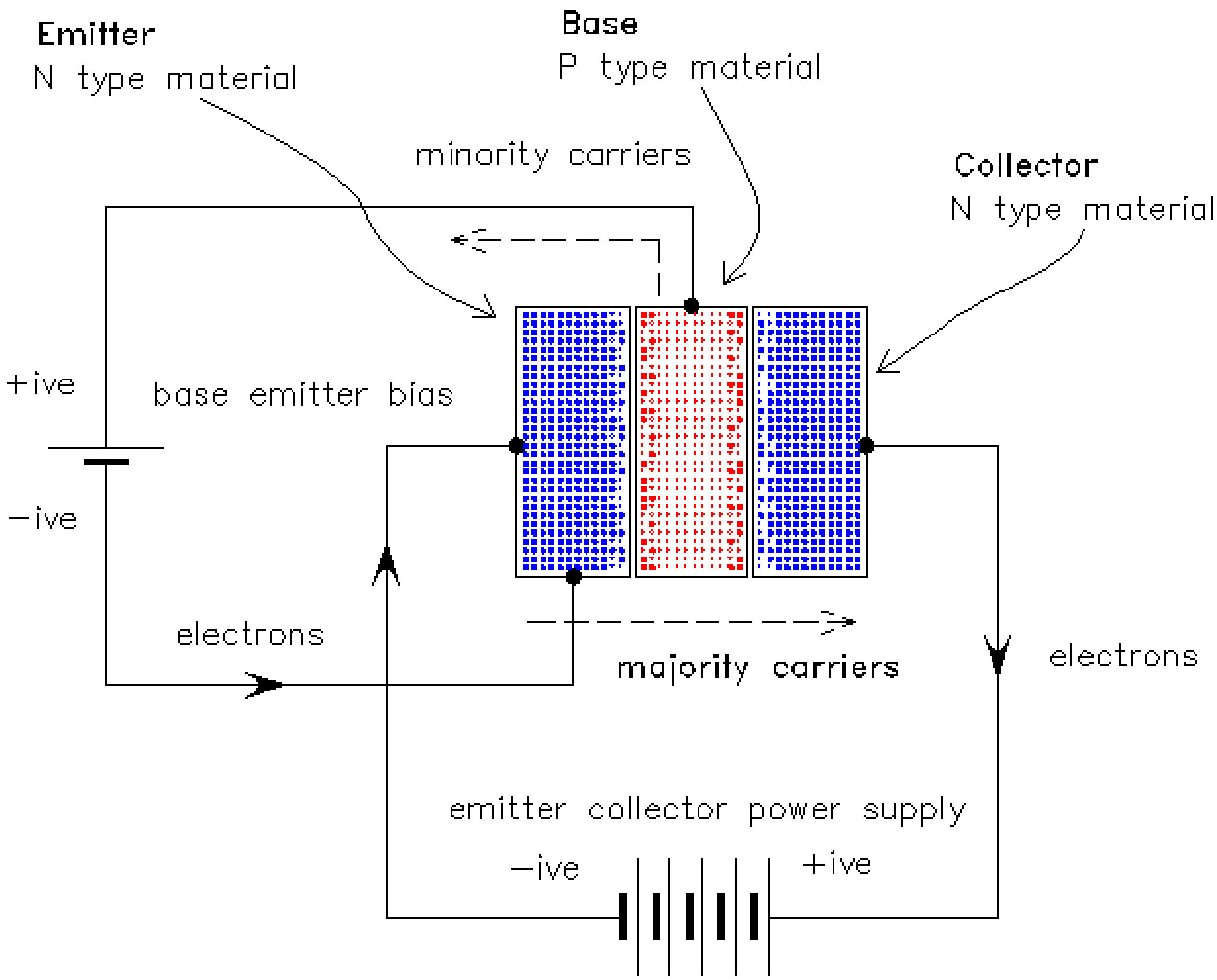


The 'NPN' & 'PNP' transistors are represented by the schematic symbols below:

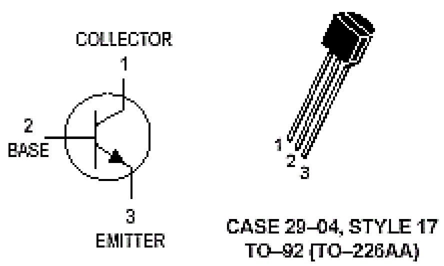




Transistors are similar to diodes when measured with a DMM. Each junction is like a diode. They have different uses however because they have the ability to ***amplify*** a current.

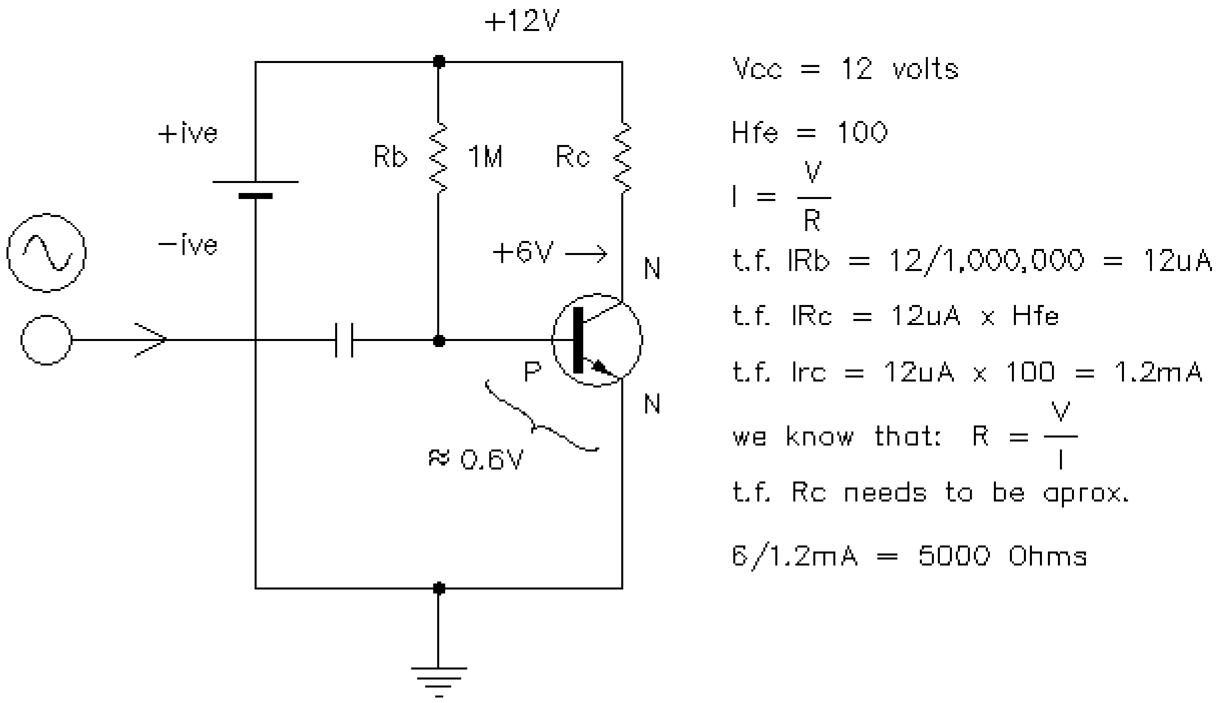


The above sketch shows an NPN transistor in operation. When a ‘bias voltage’ is applied to the base, which is the middle part of the transistor, a small current flows between the base & emitter which allows the emitter to conduct through to the collector. The small base current which flows through the emitter, (in the above diagrams; to ground), is amplified by a factor of between 30 and 400 times, depending on the characteristics of the transistor used! The amplification factor of the transistor is referred to as the **hFE** – the current gain (also sometimes called the ‘**β**’). This means that if we had 1 milliamp flowing through the base-emitter junction, and the hFE of the transistor was (say) 300, it will conduct up to (1 x 300) = 300mA through the collector – emitter.



Topic 4: A basic analogue transistor amplifier circuit

Now look at the diagram below; we have included a resistor in the collector circuit.

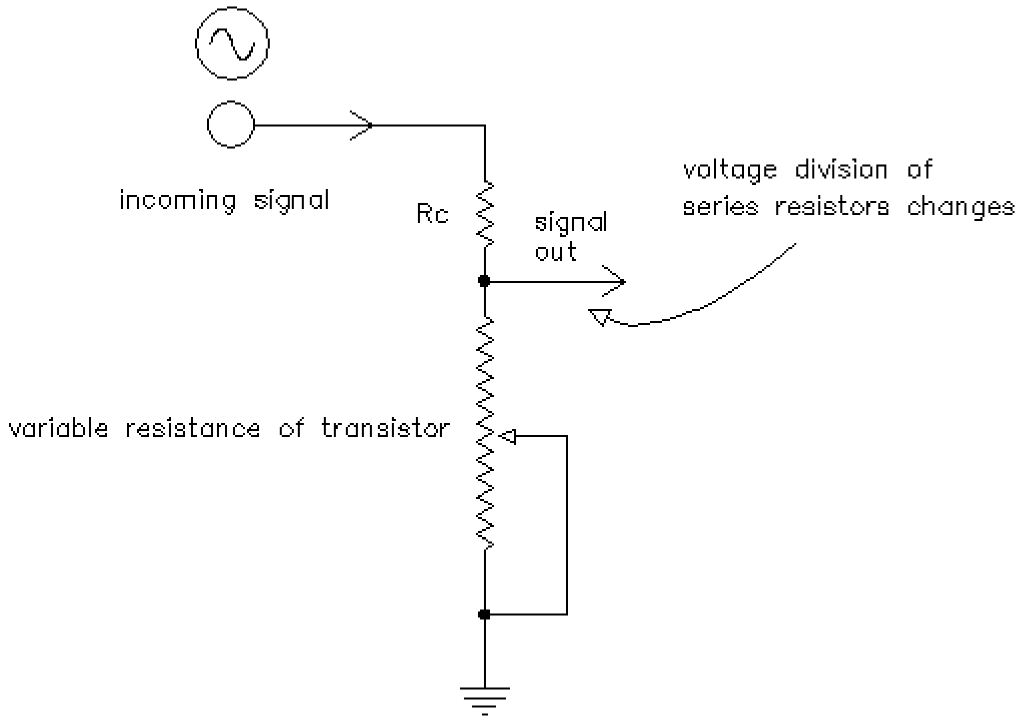


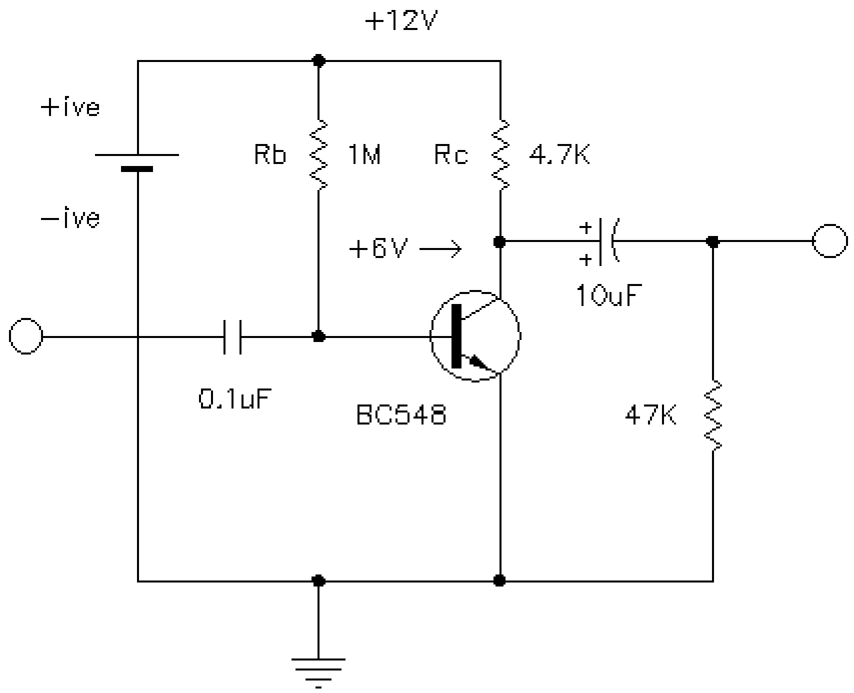
Supposing the transistor used in this little circuit has a typical current gain (hFE) of 100. If we make the base circuit conduct by forward biasing it with a 1 megohm (1,000,000) resistor to the +12V supply, we will get approximately **I = V/R** of 12µA flowing through the base/emitter circuit. (in this case we will ignore the V_{BE} voltage which will be about 0.6 volts (like a diode junction).

This will make our transistor conduct a current from the emitter to the collector based on the hFE of about (12µA x 100) = 1.2mA. Using the re-arranged Ohms Law of **R = V/I** we can then calculate the approximate value of the resistor needed to produce a voltage at the collector of 6V (½ Vcc), which works out to about 5000Ω. (It needs to be about half way of $\mathbf{V_{CC}}$ to be useful as an analogue amplifier – more on this later).

Because Ohms Law states that **V = IR**, and the current flowing through the base-emitter is amplified, the voltage over the collector resistor $\mathbf{R_C}$ is many times the voltage going into the base-emitter junction. We have thus created a very simple amplifier with quite a high voltage gain. This voltage gain is expressed as $\mathbf{A_V}$.

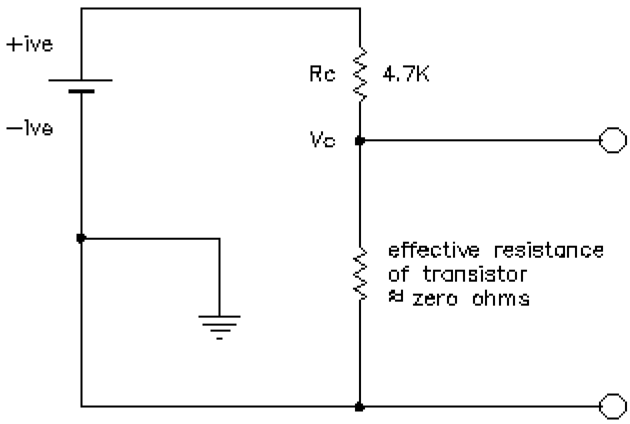
If we look at an equivalent circuit it would be this:





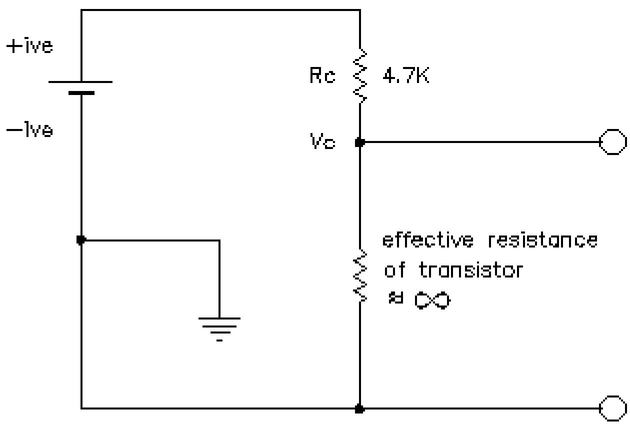
We can add a couple of bits to make this useful as an amplifier of AC signals: a small capacitor to the base for inputting signals (this isolates DC voltage from the input signal), and an electrolytic capacitor on the collector output to give us the AC signal. The extra resistor hanging off this capacitor is to discharge the residual DC from the cap charging up on turn on. Our little amp will have a voltage gain of more than 100 which is quite a lot, and would make a pretty good fuzz box, because it will reach maximum voltage 'swing' with little input. The value of the parts in this circuit is about $1.00.

In this circuit when the input signal is at the maximum positive point, it turns the transistor on to the maximum amount. This causes the emitter-collector to conduct to the maximum amount, and the current through R_C will be greatest. Knowing that **V = IR** we can see that the voltage drop over RC will be greatest at this point, and the 'equivalent circuit' will be this:

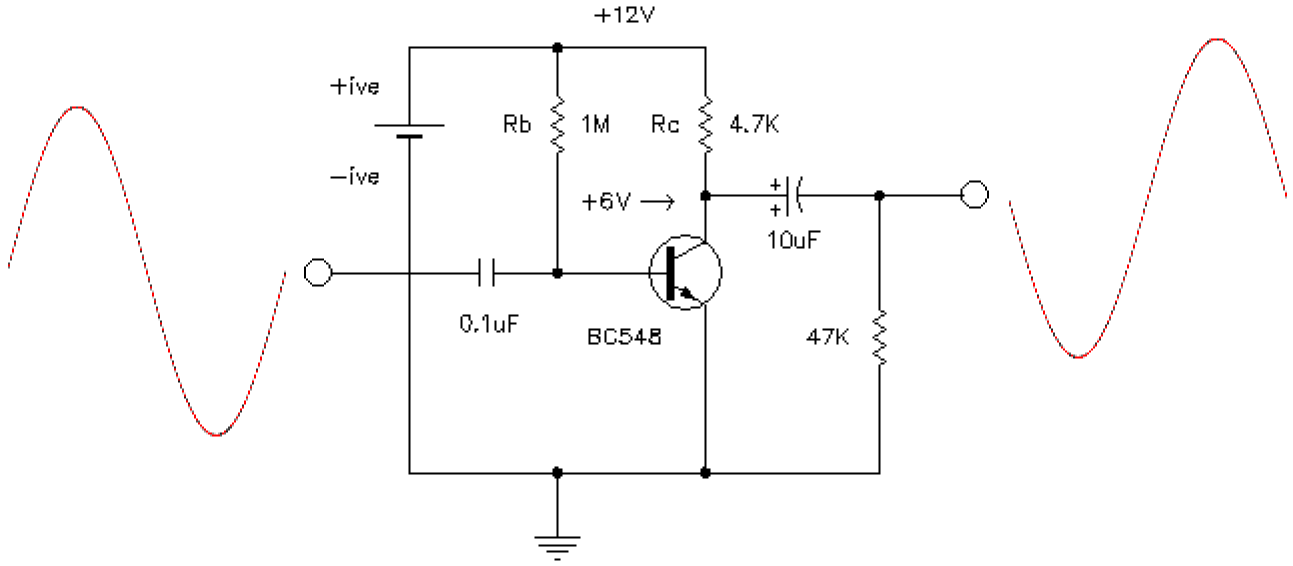


Using Ohms Law and the voltage divider effect, we can see that the voltage out will be at the minimum level. The transistor is acting like a very low ohm resistor.

When the input voltage is at the minimum, the transistor will be almost switched off; the transistor is acting like a very high ohm resistor and the equivalent circuit would be this:



Using Ohms Law and the voltage divider effect, we can see that the voltage out will be at the maximum level, because the bulk of the voltage will appear over the transistor. The transistor is acting like a very high ohm resistor. The transistor is in effect a "**transferable resistor**", and because of the voltage divider effect of series resistance, we can see that the signal coming out of this circuit will be the "opposite" of what comes in; i.e. it is 180º out of phase. When the instantaneous voltage of the input is at a maximum, the transistor is at the lowest resistance, and when the input is at the minimum instantaneous voltage, the transistor is at the highest resistance. This is known as an 'inverting' amplifier. Also, the analogue circuit is biased so that the voltage at the collector sits at roughly ½ of V_{CC} so that it can swing up and down without bottoming out or "clipping". This type of amp is called "Single Ended", and operates in "**Class A**" mode, and has a high "quiescent current" flowing all the time.



As amplifier circuits go this is a simplified example and would not be very stable with temperature and variations in transistors but it does work.

Next session we will look at more simple circuits using transistors.