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**The Transistor as a Switch**

When used as an AC signal amplifier, the transistors Base biasing voltage is applied so that it operates within its "**Active**" region and the linear part of the output characteristics curves are used. However, both the NPN & PNP type bipolar transistors can be made to operate as an "ON/OFF" type solid state switch for controlling high power devices such as motors, solenoids or lamps. If the circuit uses the **Transistor as a Switch**, then the biasing is arranged to operate in the output characteristics curves seen previously in the areas known as the "**Saturation**" and "**Cut-off**" regions as shown below.

**Transistor Curves**

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| Transistor Curves for Switching |

The pink shaded area at the bottom represents the "Cut-off" region. Here the operating conditions of the transistor are zero input base current (Ib), zero output collector current (Ic) and maximum collector voltage (Vce) which results in a large depletion layer and no current flows through the device. The transistor is switched "Fully-OFF". The lighter blue area to the left represents the "Saturation" region. Here the transistor will be biased so that the maximum amount of base current is applied, resulting in maximum collector current flow and minimum collector emitter voltage which results in the depletion layer being as small as possible and maximum current flows through the device. The transistor is switched "Fully-ON". Then we can summarize this as:

* 1. Cut-off Region - Both junctions are Reverse-biased, Base current is zero or very small resulting in zero Collector current flowing, the device is switched fully "OFF".
* 2. Saturation Region - Both junctions are Forward-biased, Base current is high enough to give a Collector-Emitter voltage of 0v resulting in maximum Collector current flowing, the device is switched fully "ON".

An example of an NPN Transistor as a switch being used to operate a relay is given below. With inductive loads such as relays or solenoids a flywheel diode is placed across the load to dissipate the back EMF generated by the inductive load when the transistor switches "OFF" and so protect the transistor from damage. If the load is of a very high current or voltage nature, such as motors, heaters etc, then the load current can be controlled via a suitable relay as shown.

**Transistor Switching Circuit**

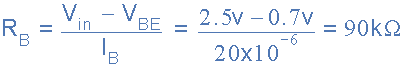
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| Transistor Switch |

The circuit resembles that of the **Common Emitter** circuit we looked at in the previous tutorials. The difference this time is that to operate the transistor as a switch the transistor needs to be turned either fully "OFF" (Cut-off) or fully "ON" (Saturated). An ideal transistor switch would have an infinite resistance when turned "OFF" resulting in zero current flow and zero resistance when turned "ON", resulting in maximum current flow. In practice when turned "OFF", small leakage currents flow through the transistor and when fully "ON" the device has a low resistance value causing a small saturation voltage (Vce) across it. In both the Cut-off and Saturation regions the power dissipated by the transistor is at its minimum.

To make the Base current flow, the Base input terminal must be made more positive than the Emitter by increasing it above the 0.7 volts needed for a silicon device. By varying the Base-Emitter voltage Vbe, the Base current is altered and which in turn controls the amount of Collector current flowing through the transistor as previously discussed. When maximum Collector current flows the transistor is said to be **Saturated**. The value of the Base resistor determines how much input voltage is required and corresponding Base current to switch the transistor fully "ON".

**Example No1.**

For example, using the transistor values from the previous tutorials of:   β = 200, Ic = 4mA and Ib = 20uA, find the value of the Base resistor (Rb) required to switch the load "ON" when the input terminal voltage exceeds 2.5v.



**Example No2.**

Again using the same values, find the minimum Base current required to turn the transistor fully "ON" (Saturated) for a load that requires 200mA of current.

Switch Example 2

Transistor switches are used for a wide variety of applications such as interfacing large current or high voltage devices like motors, relays or lamps to low voltage digital logic IC's or gates like AND Gates or OR Gates. Here, the output from a digital logic gate is only +5v but the device to be controlled may require a 12 or even 24 volts supply. Or the load such as a DC Motor may need to have its speed controlled using a series of pulses (Pulse Width Modulation) and transistor switches will allow us to do this faster and more easily than with conventional mechanical switches.

**Digital Logic Transistor Switch**

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| Digital Logic Transistor Switch |

The base resistor, Rb is required to limit the output current of the logic gate.

**Darlington Transistors**

Sometimes the DC current gain of the bipolar transistor is too low to directly switch the load current or voltage, so multiple switching transistors are used. Here, one small input transistor is used to switch "ON" or "OFF" a much larger current handling output transistor. To maximise the signal gain the two transistors are connected in a "Complementary Gain Compounding Configuration" or what is generally called a "**Darlington Configuration**" where the amplification factor is the product of the two individual transistors.

**Darlington Transistors** simply contain two individual bipolar NPN or PNP type transistors connected together so that the current gain of the first transistor is multiplied with that of the current gain of the second transistor to produce a device which acts like a single transistor with a very high current gain. The overall current gain Beta (β) or Hfe value of a Darlington device is the product of the two individual gains of the transistors and is given as:

Darlington Transistor Current Gain

So Darlington Transistors with very high β values and high Collector currents are possible compared to a single transistor. An example of the two basic types of Darlington transistor are given below.

**Darlington Transistor Configurations**

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| Darlington Transistor |

The above NPN Darlington transistor configuration shows the Collectors of the two transistors connected together with the Emitter of the first transistor connected to the Base of the second transistor therefore, the Emitter current of the first transistor becomes the Base current of the second transistor. The first or "input" transistor receives an input signal, amplifies it and uses it to drive the second or "output" transistors which amplifies it again resulting in a very high current gain. As well as its high increased current and voltage switching capabilities, another advantage of a Darlington transistor is in its high switching speeds making them ideal for use in Inverter circuits and DC motor or stepper motor control applications.

One difference to consider when using Darlington transistors over the conventional single bipolar transistor type is that the Base-Emitter input voltage Vbe needs to be higher at approx 1.4v for silicon devices, due to the series connection of the two PN junctions.

Then to summarise when using a **Transistor as a Switch**.

* Transistor switches can be used to switch and control lamps, relays or even motors.
* When using bipolar transistors as switches they must be fully "OFF" or fully "ON".
* Transistors that are fully "ON" are said to be in their **Saturation** region.
* Transistors that are fully "OFF" are said to be in their **Cut-off** region.
* In a transistor switch a small Base current controls a much larger Collector current.
* When using transistors to switch inductive relay loads a "Flywheel Diode" is required.
* When large currents or voltages need to be controlled, **Darlington Transistors** are used.

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