AS Systems & Control Study Notes

Part 4: Diodes, Transistors and Field Effect Transistors

Part 1 Learning Objectives

- Know the properties, function and applications of basic semiconductor devices:

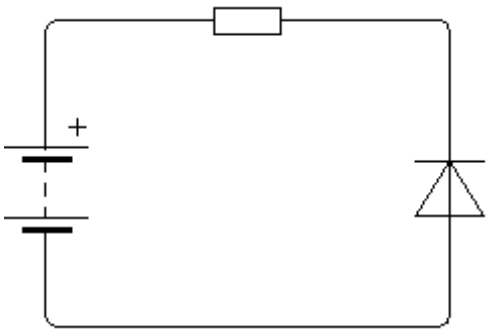
- Diodes
- Bipolar Transistors
- Field Effect Transistors (FETS)

Replica of the first transistor

Diodes

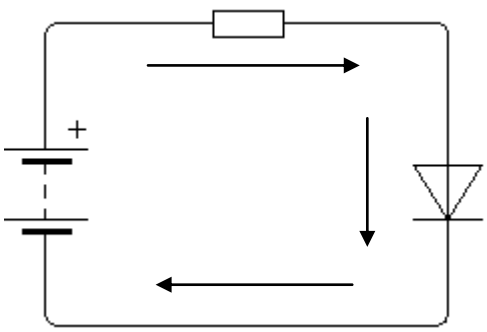
A diode is a component that allows current to flow in one direction only: from anode to cathode (anode = positive, cathode = negative.) It is analogous to a bicycle tire valve (it allows air in but not out.)

If the anode is made negative with respect to the cathode then **no current will flow** through the circuit. The diode is said to be **reverse biased:**



Reverse biased diode
No current flows through the resistor

If the anode is made positive with respect to the cathode then **current will flow** through the circuit. The diode is said to be **forward biased**.



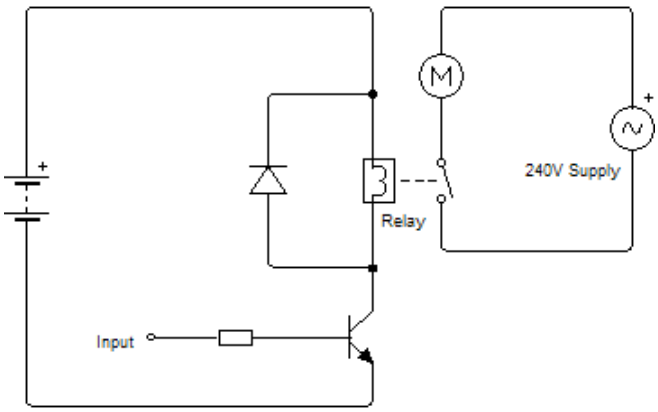
Forward biased diode
Current flows through the resistor

Diode application: Back EMF Suppression

Some components are known as inductive loads. Inductive loads are those that contain a coil of wire such as relays, solenoids and motors. Inductive loads rely on electromagnetism in their operation.

When the power to an inductive load is switched off the magnetic field around it collapses. This causes what is known as a "back EMF" (EMF = Electromotive Force) to be induced. This current flows in the opposite direction and has a much higher voltage than the supplied voltage. This high voltage can damage sensitive components such as transistors and integrated circuits.

A diode can be used to direct the reverse current back in to the coil preventing it from passing to the transistor. This situation is found in circuits that use a transistor to operate a relay:



A diode being used to protect a transistor from Back EMF

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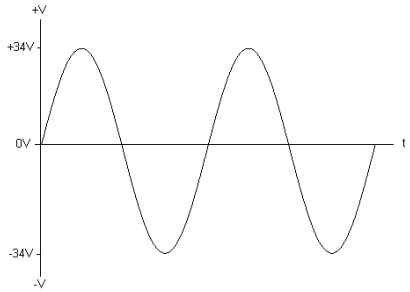
Diode Application: Rectification

There are two types of power supplies used in electronic systems:

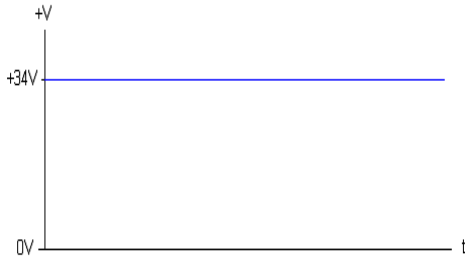
- Alternating Current (AC)
- Direct Current (DC)

An alternating current is one where the current flows in one direction for a period, and then in the other direction. A domestic mains socket is an example of an AC source:



An AC power source

Direct current power is where the current flows though the circuit in one direction only. A battery is an example of a DC source:



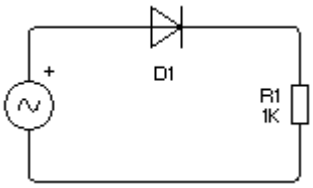
A DC power source

Rectification

Most electronic systems require a DC power source, televisions, radios and computers for example.

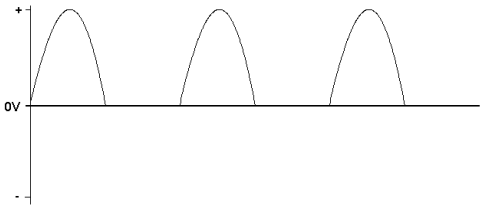
Unfortunately the mains electricity is an AC source and is therefore unsuitable for supplying these devices. A method is therefore required to convert AC into DC. This process is called Rectification.

Rectification: Half-wave rectification



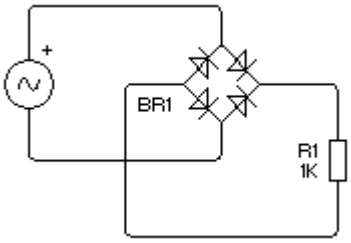
Half-wave rectifier circuit

The circuit above only allows current to flow in one direction and therefore only conducts when the AC is flowing forwards. This circuit is generally not suitable for supplying most electronic systems as it only produces a pulsing DC current every positive half-cycle:



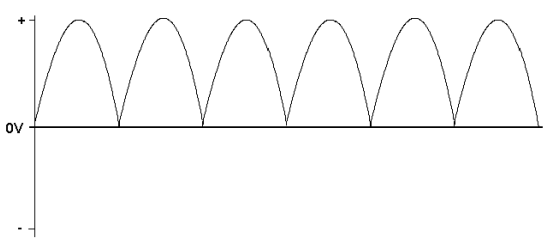
Voltage developed across the resistor

Rectification: Full-wave bridge rectifier



Full-wave bridge rectifier circuit

A circuit known as a Full-wave rectifier is a much more useful than the half-wave circuit. It produces pulses of current twice as often than the half-wave circuit because it directs the current to flow through the resistor for both half-cycles:



Voltage developed across the resistor

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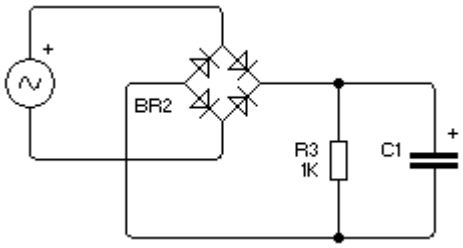
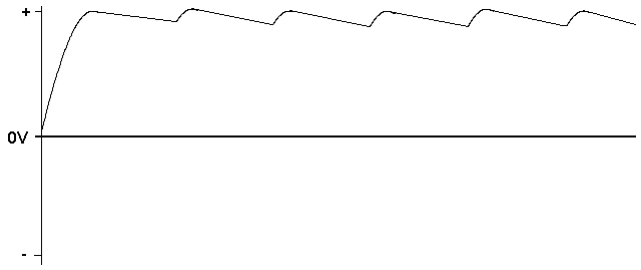
Full-wave rectification with smoothing



Full-wave rectifier with reservoir capacitor

As was observed with the previous circuit, pulses of current were produced rather than a continuous one. To solve this problem a capacitor is introduced which charges up during each pulse and releases it when the voltage starts to fall. This is called smoothing , the capacitor is often referred to as a reservoir capacitor. The voltage developed across the resistor will therefore look like this:



Voltage developed across the resistor (exaggerated for clarity)

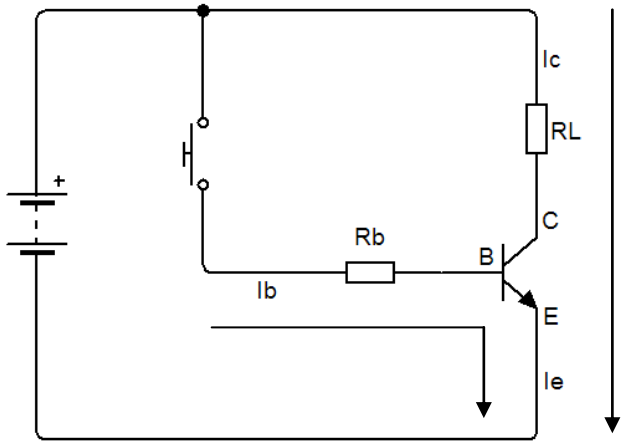
The pulses in the above graph have been exaggerated to show the operation of the circuit more clearly. The output of a rectifier is said to have ripple, meaning that an element of AC is superimposed on top of the DC. This ripple increases with heavier loads, but in practice however this can be reduced to a practical level by increasing the size of the capacitor or by using additional smoothing circuits such as filters.

Bipolar transistors

The transistor is the basic building block of the majority of electronic systems. It is a component with three leads:

- Base
- Collector
- Emitter

Put simply the current flowing from the **Collector** to the **Emitter** is controlled by the current flowing into the **Base.**



Simple transistor circuit

The current flowing from the collector (C) to the emitter (E) is much greater than the current flowing into the base (B.) Therefore the transistor is amplifying the base current. The amount a transistor amplifies the base current by is know as the hFE or gain. Different transistors have different gains. The operation of transistors can be explained using the following formulae:

Ic = Current flowing into the collector
Ie = Current flowing out of the emitter
Ib = Current flowing into the base
RL = Load resistor
Rb = Base current limiting resistor
Vbe =Base-Emitter voltage drop (approx 0.7V)
Vsupply = Voltage of the battery

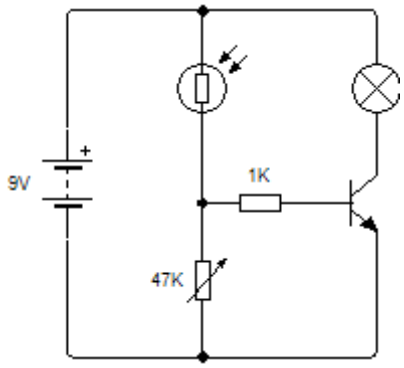
Ic = Ib x hFE

Ic = (Vsupply - Vbe ÷ Rb) x hFE

Also: Ie = Ic + Ib

Transistor application—Light sensitive switch

The circuit below show how an LDR and a transistor to switch a lamp on when light shines on the LDR.

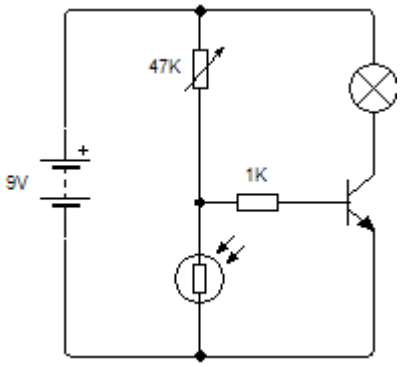


A light sensitive switch
(Lamp on when light)

The LDR and the variable resistor form a potential divider. The variable resistor is used to adjust the sensitivity of the circuit.

When it is dark the LDR has a very high resistance, the voltage on the base of the transistor is therefore small and the transistor will not switch on.

As the light level increases the resistance of the LDR drops causing the voltage on the base of the transistor to rise. Once the base of the transistor raises to about 0.7V then it will start to conduct. If the base voltage is sufficiently high then the transistor will switch on the lamp.

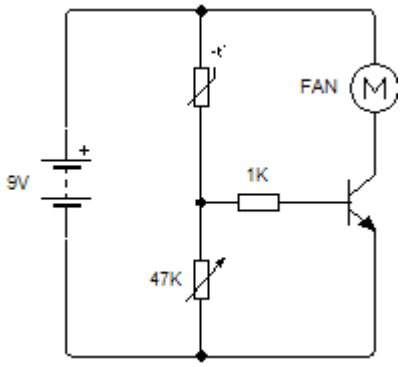


A light sensitive switch
(Lamp on when dark)

Transistor application-Cooling system

The circuit shown below could be used to cool a high power circuit should it start to overheat.

A laptop cooling system is a good example of this application. Laptop processors must be cooled to prevent them from overheating, this is usually achieved with the use of a heatsink and fan. Laptops however are battery powered and it is therefore necessary to limit power consumption to prolong the life of the battery. By fitting the processor with a thermistor, the fan can be switched on only when the processor is too hot, therefore saving power.



Cooling system

The circuit works in exactly the same way as the light senor circuit. In this case as the heats up its resistance falls. This causes the voltage applied to the base to increase. Once it has reached about 0.7V the transistor will start to switch on causing the fan blades to rotate.

Laptop cooling fan

Field Effect Transistors (MOSFETs)

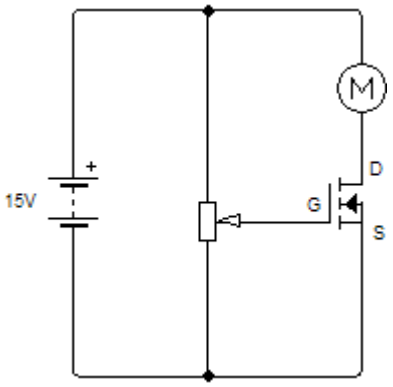
The bipolar transistor is a current operated device, that is the current flowing through the collector and emitter is controlled by the current flowing into the base.

Like the bipolar transistor a MOSFET is also an amplifier. The current flowing through a MOSFET however is controlled by the voltage applied to its Gate. A MOSFET has three leads:

- Gate
- Source
- Drain

The current flowing from the **Source** to the **Drain** is controlled by the voltage applied to the **Gate**.

The circuit shown below demonstrates how a MOSFET can be used to control the speed of a motor. The potentiometer is used to set the voltage that is applied to the gate. The larger the voltage on the gate the more current flows through the motor and hence the faster the motor runs.



Motor speed control circuit

Properties of MOSFETS

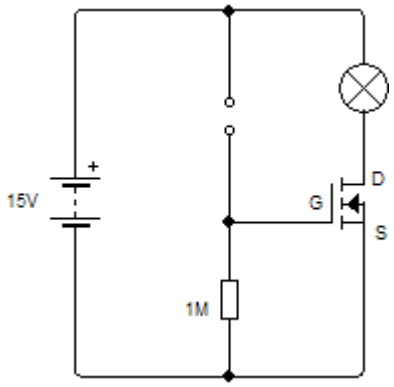
The input resistance of a FET is very high (in the order of MΩ) and therefore draws very little current from the circuit connected to its input. FETs are therefore very sensitive and can amplify very small signals. Some types of FETs are used to amplify radio signals because of this.

Bipolar transistors suffer from an effect known as "thermal runaway" that can damage the transistor, especially at high powers. FETs on the otherhand do not suffer from this effect and are much more robust at higher powers. MOSFETs are therefore often used when driving high powered output devices.

120W Stero MOSFET power amplifier

MOSFET application-touch activated switch

The circuit below shows how a simple touch activated light can be made. Normally the gate is connected to 0V and the transistor will therefore be switched off. Placing you finger over the two contacts will complete the potential divider circuit. Although the resistance of your finger is very high the transistor is so sensitive that the tiny voltage applied to its gate will switch on the lamp:



Touch activated switch