GCSE Electronics: Component 1

Unit 4: Switching circuits (page 1)

A transducer driver is required to interface a low power electronic circuit to output devices that require a large current.

In addition, there are cases where switching circuits are required to act as an interface between analogue sensors and digital sub-systems.

There are three different switching devices that have very different properties.

1. NPN Transistor

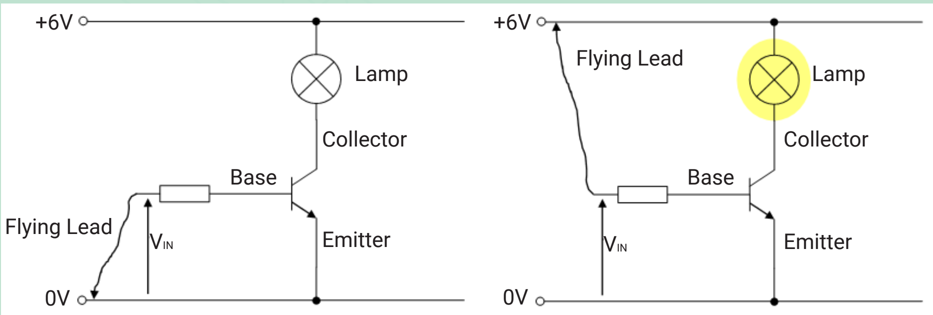
The transistor is a three-terminal device. Current can only flow in the collector circuit if a small current flows in the base circuit.

There are a couple of things to note about the way in which the transistor is connected:

i. the emitter terminal is connected directly to the 0V line

ii. a resistor has been added to the base terminal, this is to limit the current flowing in the base circuit as only a small current is needed to switch the transistor on

iii. the load (a lamp in this case) is connected into the collector circuit.



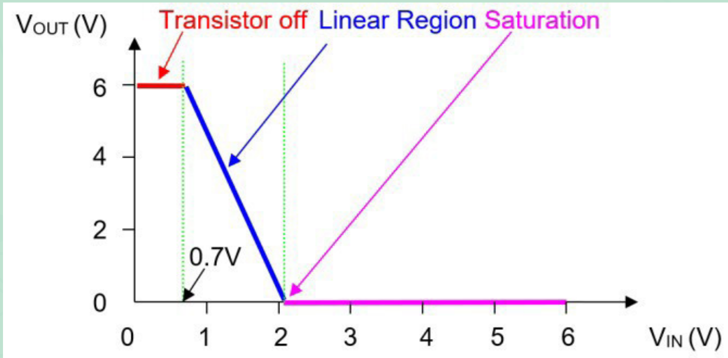
A ***small* base current** is used to control a **much *larger* current** in the collector circuit.

There are two basic rules we have to remember about the transistor:

i. if the voltage between the base and emitter, usually referred to as V_{IN} < 0.7V then the transistor will be **off**

ii. if the voltage between the base and emitter, usually referred to as V_{IN} > 0.7V then the transistor will be **on.**

To understand the operation of the transistor, it is necessary to study the switching action of the transistor in a little more detail.



There are **three** key parts to this graph, which is known as the transistor voltage transfer characteristic:

(i) **Off region**: This part of the characteristic when V_{IN} is between 0V and 0.7V. It shows when the transistor is completely switched off, no current flows through the base-emitter junction, no current flows through the collector and the voltage across the collector emitter junction of the transistor (V_{OUT}) is equal to the supply voltage.

(ii) **Linear region**: When the voltage V_{IN} increases above 0.7V, a base current starts to flow. The transistor behaves as a current amplifier and the base current causes a larger amplified current flow through the collector and load. As V_{IN} increases further, more current flows into the base and this allows a further increase in the collector-emitter current.

(iii) **Saturation:** As V_{IN} continues to increase, a point is reached where changes to V_{IN} no longer cause any change to V_{OUT} and we say that the transistor is saturated.

The saturation point is reached just before the voltage across the load reaches the full voltage of the power supply and the voltage across the collector-emitter junction of the transistor V_{OUT} is about 0.2V (i.e. nearly = 0V).

Note: We have referred to the voltage across the collector- emitter junction of the transistor as V_{OUT}. It is often referred to as V_{CE}.

Transistor switching circuit

When the transistor is being used as a switch, we operate in the cut-off and saturation regions of the characteristic, avoiding the linear region.

There are two reasons for avoiding the linear region when designing transistor switching circuits. Firstly, the output device will not work correctly because the full supply voltage does not appear across the load as V_{CE} will have a significant value. Secondly, because of this value of V_{CE} and the current flowing in the collector, power will be used up in the collector-emitter junction causing the transistor to overheat.

In this course, we will only be considering switching circuits. The following information will be important:

For V_{IN} < 0.7V: V_{BE} = V_{IN} and V_{CE} = Supply Voltage

For V_{IN} > 0.7V: V_{BE} = 0.7V and V_{CE} = 0V

Current Gain (h_{FE})

In order to design circuits for transistors, there is also an important formula that needs to be considered. This is the current gain formula for the transistor. We have mentioned several times that the transistor acts as a current amplifier. Each transistor has a current gain called 'h_{FE}' and this is defined by the following **current gain formula,** where I_C is the collector current and I_B is the base current.

$$h_{FE} = \frac{I_C}{I_B}$$

Different types of transistor have different h_{FE} values that can range from 10 to over 800 in value. As far as examination questions are concerned, you would not be expected to remember the different values of h_{FE}, you will either be told the h_{FE} value for the transistor, or you will be able to calculate it from values of I_B and I_C.

Note: The formula for current gain is only valid in the linear region but we stated earlier that we avoid the linear region when considering switching circuits. We get around this problem when designing switching circuits by assuming any calculations performed involving current gain is done at the point where the transistor switching action is just leaving the linear region and entering the saturation region. That is at the last possible moment the formula is still valid.

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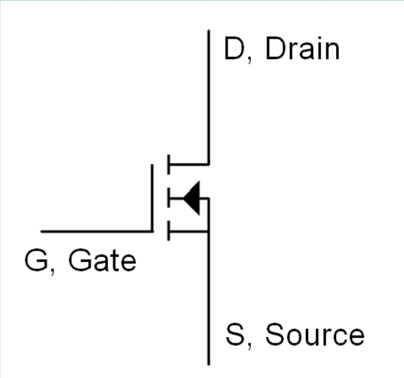
2. N-channel MOSFET

A different type of transistor is called a MOSFET. This stands for **m**etal **o**xide **s**emiconductor **f**ield **e**ffect **t**ransistor, which is a bit of a mouthful so we will simply refer to it as a MOSFET.

The symbol, and picture for an n-channel enhancement mode MOSFET is shown opposite.



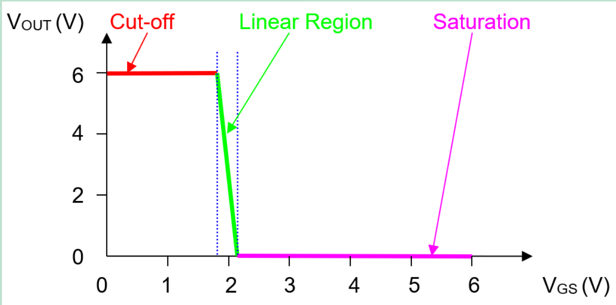
The leads for this type of transistor are labelled as: gate (G), drain (D) and source (S).

The **enhancement-mode MOSFET** has the property of being normally "OFF" when the gate bias voltage is equal to zero.

A drain current will only flow when a gate voltage (V_{GS}) is applied to the gate terminal. This positive voltage reduces the overall resistance of the device allowing current to flow between the drain (D) and source (S). Increasing this positive gate voltage will cause an increase in the drain current, I_D, through the channel. The MOSFET can also saturate when V_{GS} is increased sufficiently. When this occurs the resistance of the MOSFET reaches its lowest.

MOSFET operation

The transfer characteristic of the MOSFET is similar to that of the NPN transistor, with one major difference; the linear region is very small, making it very unlikely that the MOSFET will operate in this region, as shown below.



MOSFET switching circuit design calculations

The only formula we need to design MOSFET circuits is the formula that relates the drain current ID to the input voltage V_{GS}. The symbol g_M represents the transconductance of a MOSFET.

Transconductance is the electrical characteristic relating the current through the output of a device to the voltage across the input of a device and is measured in Siemens (S). The formula is:

$$I_D = g_M(V_{GS} - 3)$$

This formula can be arranged to give:

$$g_M = \frac{I_D}{V_{GS} - 3} \quad \text{and} \quad V_{GS} = \frac{I_D}{g_M} + 3$$

Enhancement-mode MOSFET's make excellent electronics switches due to their low "ON" resistance, extremely high "OFF" resistance and extremely high input resistance. This input resistance is so high the gate current is negligible and can assumed to be **zero.**

This is a major advantage over transistors.

Enhancement-mode Power MOSFET's have zero gate current and can be driven directly by input sub-systems such as logic gates that can only provide a very small current.

When used with sensing sub-systems they do not load the sensing sub-system.

Power MOSFETs can handle very large currents with some able to provide currents of 100A or more.

Selecting a suitable Power MOSFET

There are two key points to consider:

i) The maximum drain current required for your load.

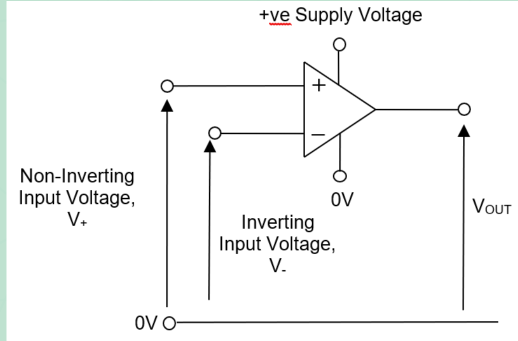
ii) The cost in relation to the maximum drain current available.

3. Voltage Comparators

In the previous two options, we have concentrated on the ability of transistors and MOSFETs to produce a large output current from a small input current or voltage.

Sometimes the signal connected to these electronic switches takes much longer to increase and this can lead to problems with the transistor or MOSFET not fully switching on, causing them to overheat.

The voltage comparator is contained in an integrated circuit (IC) and is usually supplied in plastic dual in line (DIL) packages containing one or more comparators.



A comparator has two power supply terminals, two inputs and an output and shown on the diagram above.

The operation of the comparator is such that it amplifies any difference between the two input voltages by a very large amount, causing the output to be at one of the extremes of the power supply connected to it. This means that the output voltage will be either high or low and can only fall into one of the following categories.

Case 1: If V+ > V- then V_{OUT} will be at the positive saturation voltage.

Case 2: If V+ < V- then V_{OUT} will be at 0V.

A difference of just a few microvolts between the two inputs is enough to cause the output to swing rapidly from one state to another. The rapid transition makes the voltage comparator an ideal device to use with circuits employing slow response sensors like LDRs and thermistors. It converts an analogue input signal into a digital output signal.

Note: Ideally the two output voltages of a comparator should either be the positive supply voltage or 0V. In practice, positive saturation is usually one or two volts less than the positive supply and can be up to a few hundred millivolts greater than 0V.

Example of a temperature sensing system