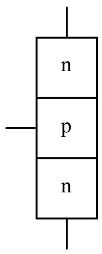
Nicholas Hender
VCE Physics Unit 3

Area Of Study 2, Electronics And Photonics, Study Notes 2

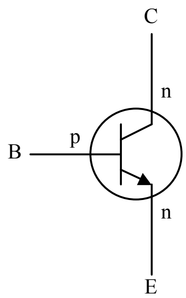
Transistors

The **B**ipolar **J**unction **T**ransistor (or BJT) is the kind considered in this study. The specific kind of BJT being considered is the **npn** transistor, so called because it's constructed from three layers of semiconducting materials, the outside layers being **n-type** semiconductors, and the middle layer a **p-type** semiconductor. The npn BJT can therefore be thought of as two PN diodes arranged back-to-back (with the "P"s in the middle).

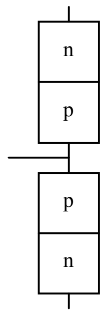
A transistor has three "legs" that connect it to a circuit. The outside legs, connecting to the n-type materials are called the **collector**, **C**, and the **emitter**, **E**. The middle leg, connecting to the p-type material is called the **base**, **B**.



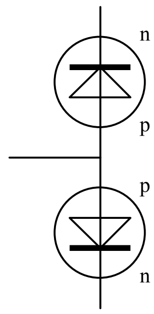
An npn BJT as n and p type semiconducting materials.



An npn BJT as a circuit symbol, with the **B**ase, **C**ollector and **E**mitter labelled.

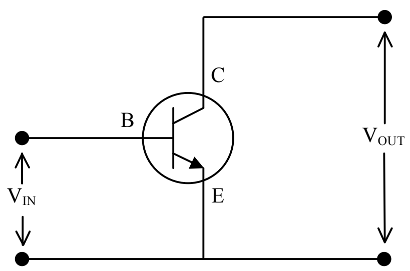


Two diodes "back-to-back" as n and p type semiconducting materials.



Two diodes "back-to-back" as circuit symbols.

Most basically, a transistor joins two circuits. One circuit runs through B and E of the transistor. The other circuit runs through C and E. Considering the two circuits as one, current through B and E can be thought of as **input** to the circuit, and current through C and E can be thought of as **output** from the circuit.



When connected with a power supply, the above is what's known as a **C**ommon **E**mitter (**CE**) circuit

What the transistor does:

- C to B acts as a reverse biased diode, which works as current controlled resistor, according to the particular transistor's "characteristic curve".
- B to E acts as a forward biased diode.
- The more voltage supplied across C and E, the more the current and the less the resistance. (A voltage supply is not shown in the above diagram for the purpose of simplicity).
- An AC signal is usually the input across B and E.
- The AC signal input across B and E is output across C and E, but with higher current and increased voltage, and hence more power.

The transistor therefore forms the basis of an **amplifier**.

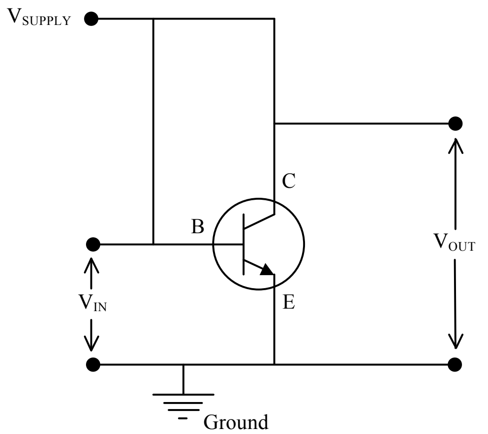
Example:

A "transducer" is a device that converts energy from one form to another. A microphone transduces sound energy into electrical energy, and could be used as the AC input across B and E. A loudspeaker transduces electrical energy into sound energy, and could be used as the output across C and E. Sound going into the microphone comes out of the loudspeaker amplified (louder).

Amplifiers From Transistors

Power supply

For B to have enough voltage to “switch on” and allow current to pass (as B to E acts as a diode), a certain amount of DC voltage must be supplied. DC voltage must also be supplied for increased current from C to E. In diagrams of complex circuits, power supply is represented most simply by a positive “rail” across the top of the circuit, and a negative or “ground” “rail” across the bottom of the circuit. This avoids needing to show the path by which each component is given power, because the components are simply connected to power at their closest point to the supply rails. It also lessens confusion between the power supply and the input and output signals.

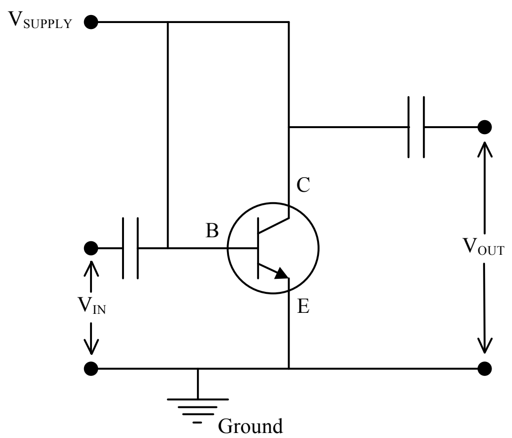


The bottom rail may be shown as being connected to “ground” (effectively Earth), as 0V (because by the time voltage has gone that far through the circuit it’s been used up on the resistance of the circuit’s components), or labelled as negative (because if a battery powers the circuit, the negative terminal connects to this rail). The supply may also be shown as coming from the right of the diagram.

Coupling

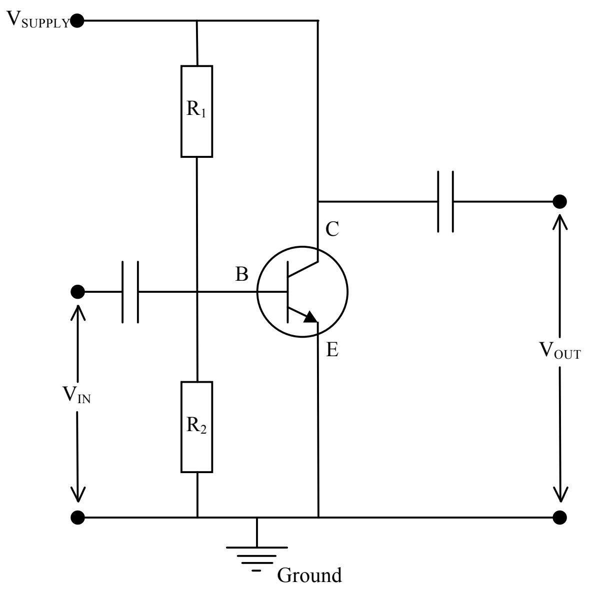
Coupling might be better referred to as **de**coupling, because while it “couples” the input to the transistor and the transistor to the output, the purpose of coupling is actually to “decouple” any DC that may be present in the input and output from the desired AC.

Coupling involves using capacitors between the AC input and B, and between C and the AC output. Because capacitors allow AC to pass but not DC, they are useful for removing any DC content present in the AC signal. At the input, unintended DC would modify the specific amount of supply voltage required at B. Unintended DC at the output would mean less than optimal performance of whatever device (often a loudspeaker) is connected.



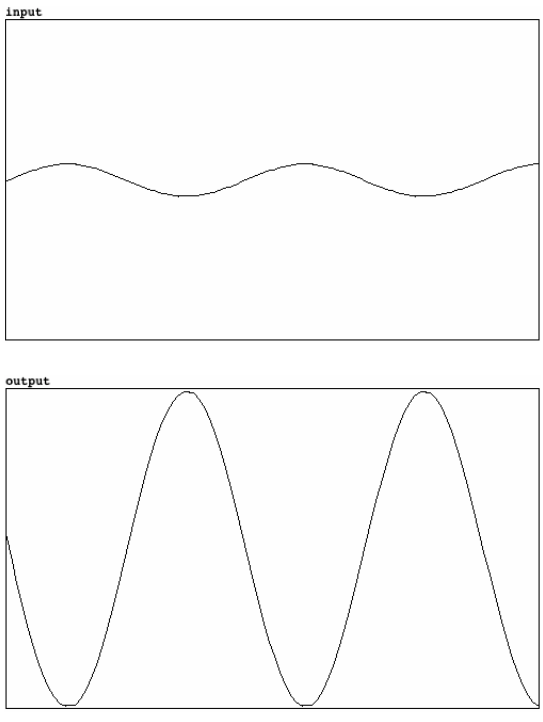
Biasing

According to the "characteristic curve" of a typical npn BJT, a specific level of voltage is required to allow current to flow efficiently (without significant resistance) from B to E (as B to E acts as a forward biased diode). Generally, for the typical npn BJT with which this study is concerned, this voltage is 0.65V. A voltage dividing circuit (2 resistors in series) is used to create a 0.65V division of the DC voltage supply. This 0.65V is connected across B and E.



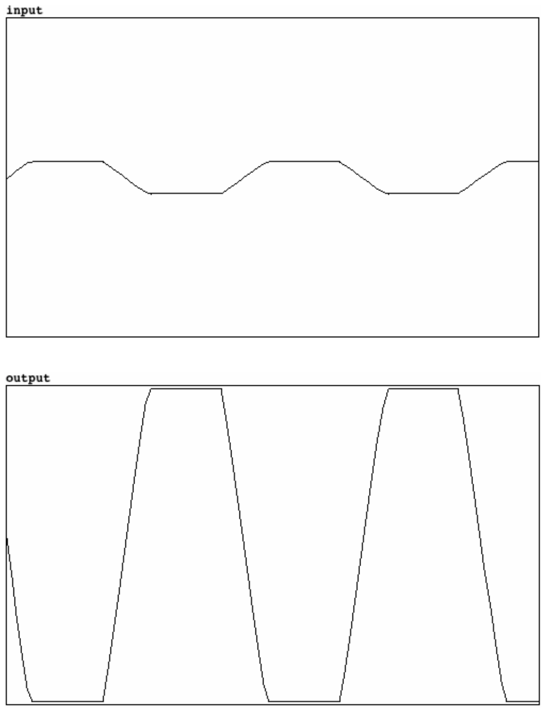
Inverting

As the input to and output from a transistor are effectively through oppositely biased diodes, the transient of the AC into B and C is always reversed (when it's increasing at B it's decreasing at C). Because of this the AC waveform of the output is always **inverted** from the waveform at the input (crests are troughs and troughs are crests).



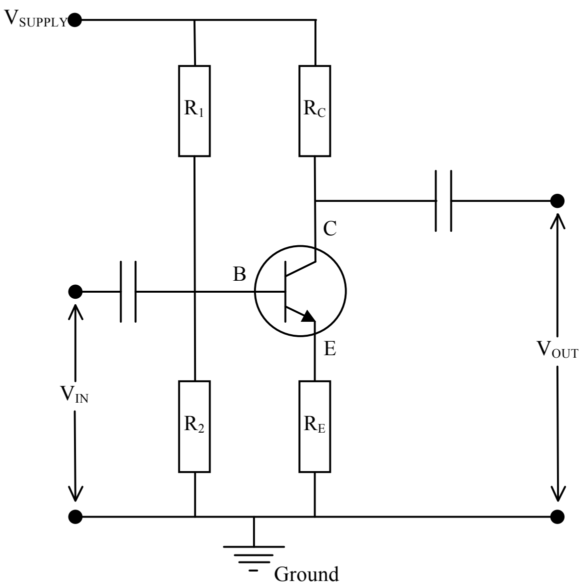
Clipping

AC input across B and E is centred around the 0.65V supply voltage required for efficient current flow. If the peak voltage of the AC input is too high, such that the crests and troughs of the AC waveform are beyond the transistor's amplification abilities, the crests and troughs are "clipped". This is a "distortion" of the waveform and is replicated at the AC output (across C and E). Voltage of the AC input may be limited or controlled by a resistor at B.



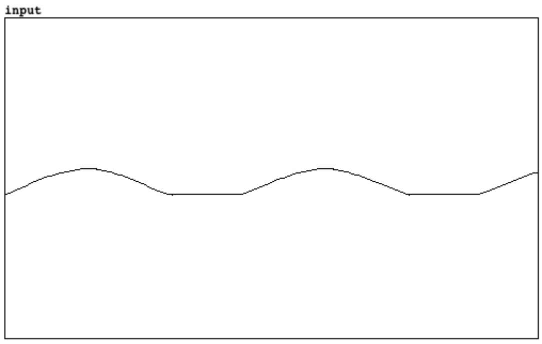
Resistors at C to limit or control the supply voltage across C and E, and at E to limit or control the voltage of the AC output, are usually included to prevent clipping at the output. As these resistors affect the current from C to E, they both have an effect on the resistance of the transistor as it acts as a reverse biased diode.

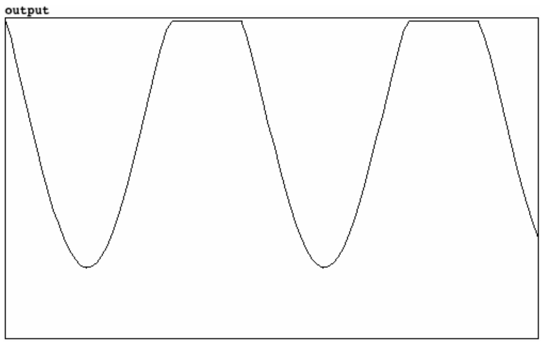
The resistor at E is in series with B to E of the transistor, and is hence in parallel to R_2. Therefore, along with B to E, it also acts as a load resistance and affects the voltage across R_2 which is supplied to B.



Cutoff

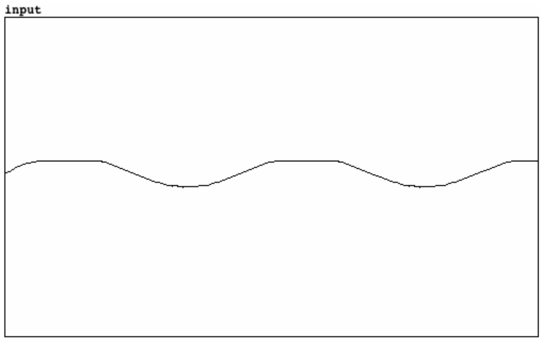
If the input is incorrectly biased, such that the supply voltage to B is **less than** 0.65V, the peak voltage of the AC input may be such that the **troughs** of the waveform are beyond the transistor's amplification abilities, and the **troughs are clipped** (at the **input**). This is "**cutoff**". As the output waveform is an inversion of the input, cutoff is seen as the **clipped crests at the output**. Cutoff is so called because the voltage at the input decreases to a level at which the transistor "switches off" or "cuts out".

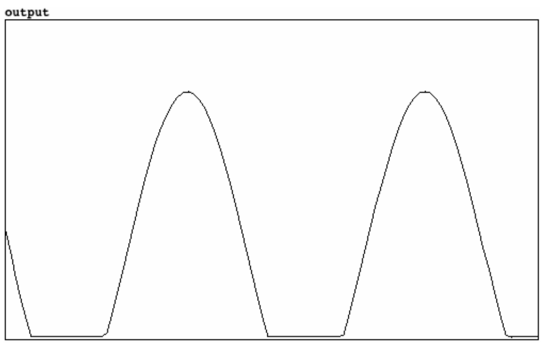




Saturation

If the input is incorrectly biased, such that the supply voltage to B is **greater than** 0.65V, the peak voltage of the AC input may be such that the **crests** of the waveform are beyond the transistor's amplification abilities, and the **crests are clipped** (at the **input**). This is "**saturation**". As the output waveform is an inversion of the input, saturation is seen as the **clipped troughs at the output**. Saturation is so called because the voltage at the input increases to a level at which the transistor cannot be used to increase it any further across C and E.





Gain

In terms of voltage, gain is the ratio of the AC signals V_{OUT} to V_{IN}. It can also be thought of as the number of times by which V_{IN} is multiplied at the output, or the gradient of a V_{OUT}/V_{IN} graph.

$$Gain = \frac{V_{OUT}}{V_{IN}}$$

Current gain is the ratio of the AC output to input.

$$Current\ Gain = \frac{I_{OUT}}{I_{IN}} = \frac{I_C}{I_B}$$

Although not actually negative in value, **gain is usually indicated as negative**, but only because the output of transistor amplifiers are inverted from the input.