Exploring the Bipolar Junction Transistor (BJT)

Simple explanation without complex mathematics

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The two basic types of transistors in use today are the Bipolar Junction Transistor (BJT) and the Field Effect Transistor (FET). Field Effect Transistor (FET) uses different terms for the legs and will be addressed as a separate topic. This article will focus on the BJT.

In the previous article on diodes, I addressed the issue of conventional current flow and electron current flow. I will continue using electron flow for this article. Refer to Figure 1 for a refresh.

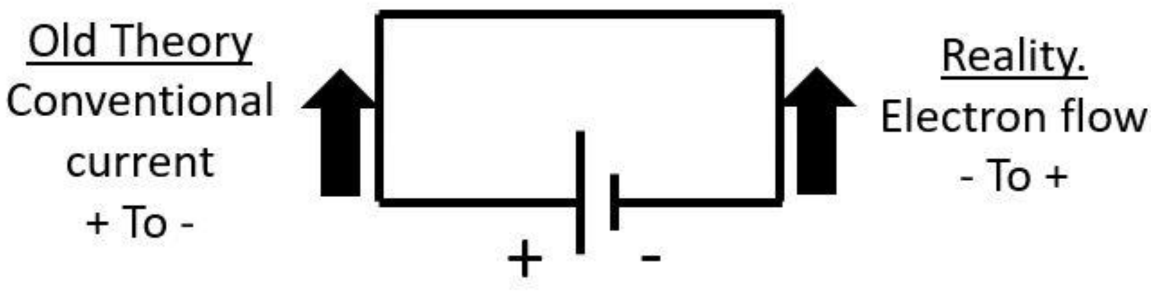

Figure 1: Diagram of old current theory and reality.

Sandwich Transistor

The bipolar point-contact transistor was invented in December 1947 at the Bell Telephone Laboratories by John Bardeen, Walter Brattain and William Shockley. The junction version known as the Bipolar Junction Transistor (BJT), was invented by Shockley in 1948. A press release in 1951 announced the discovery of this new "sandwich" transistor.

The origin of the name transistor seems different depending on the source. The common theme is that it is an abbreviated combination of the words transconductance (or transfer) and Varistor. Researcher John Pierce suggested the name transistor, and this has remained the name of choice.

The transistor revolutionised the electronics field. The size of devices shrunk, and the power consumption levels dropped. No longer did the devices need mains power to run as they could be easily powered by a battery. The development of battery-operated domestic transistor radios expanded the consumer base.

Since their development, the design of transistors has reduced in size many fold. Now hundreds of components, including transistors, are etched into integrated circuits (ICs).

Modern Transistor

A transistor can be used as a fast switch, or as an amplifying device. The main concept is that a small current in one leg of the transistor can control a greater current in another leg.

Looking at Figure 2, a BJT, as a black box, has three legs: Collector, Base, Emitter. A small input on the base can produce a greater output on the collector[i]. This signal is inverted as the base voltage rises, the current through the transistor increases, dropping the voltage at the collector.

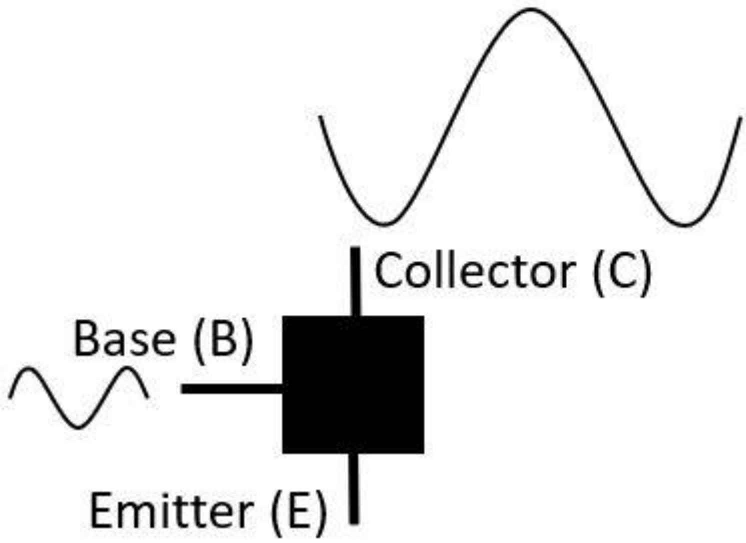

Figure 2: BJT as a black box.

The measure of the amplification or gain of a transistor is called Beta (β) or h. There are many applications for transistors and the gain will vary depending on the application.

Some transistors have metal cases and these need to be attached to heat sinks to remove excess heat from the transistor during operation.

Base material

The base material of transistors is usually Silicon (Si) or Germanium (Ge). Neither of these are great conductors so the manufacturer will dope (inject an impurity) into the material. Doping with aluminium creates a base material lacking an electron and these are called holes. The resulting material in called a P type.

Doping the base material with phosphorus creates a base material with an extra electron. The resulting material in called a N type.

When a N type and P type base material are joined, the P type has the holes, and the N type has the electrons looking to fill the holes. A small number of electrons will flow to fill the holes at the junction. This small junction area is called the depletion layer.

As the name BJT implies, there are two junctions in the transistor where the materials join. Using the two material types, the BJTs can be configured as:

- NPN
- PNP

Common Terms

Below is a shortened list of common terms when referring to transistors. Understanding these will aid in reading the transistor data sheets.

V_{EB}	Voltage between the Emitter and Base
V_{CB}	Voltage between the Collector and Base
V_{CE}	Voltage between the Collector and Emitter
$V_{BE\ (sat)}$	The voltage between the Base and Emitter, when sufficient Ibe current is being applied, to fully saturate the BJT.
V_B	Voltage between the Base and ground.
V_C	Voltage between the Collector and ground.
V_E	Voltage between the Emitter and ground.
Beta (β) or hFE	Beta (hFE) is a transistor's DC current gain at a particular temperature, current and voltage. $\beta = I_C / I_B$
hfe	hfe is a transistor's AC current gain which is less and decreases with increasing frequency.
I_B	Current in the Base
I_C	Current in the Collector
I_E	Current in the Emitter

NPN

The NPN transistor needs a voltage on the base approximately 0.7 V greater than the emitter to cause the electrons to flow. This voltage is needed to pull the electrons across the depletion layer. In doing so, electrons will also flow from the emitter to the collector. Refer to Figure 3.

NPN transistor applications

- NPN transistors are mainly used in switching applications.
- Used in amplification circuits.
- Used in the Darlington pair circuits to amplify weak signals.

- NPN transistors are used in applications where there is a need to sink (take in) a current (i.e. current flows into the collector).
- Used in some classic amplifier circuits, such as 'push-pull' amplifier circuits.
- Temperature sensors.
- Very High Frequency applications.

A common small signal NPN transistor is the 2N3904. Search and read the data sheet.

A common power NPN transistor is the 2N3055. Search and read the data sheet for a comparison.

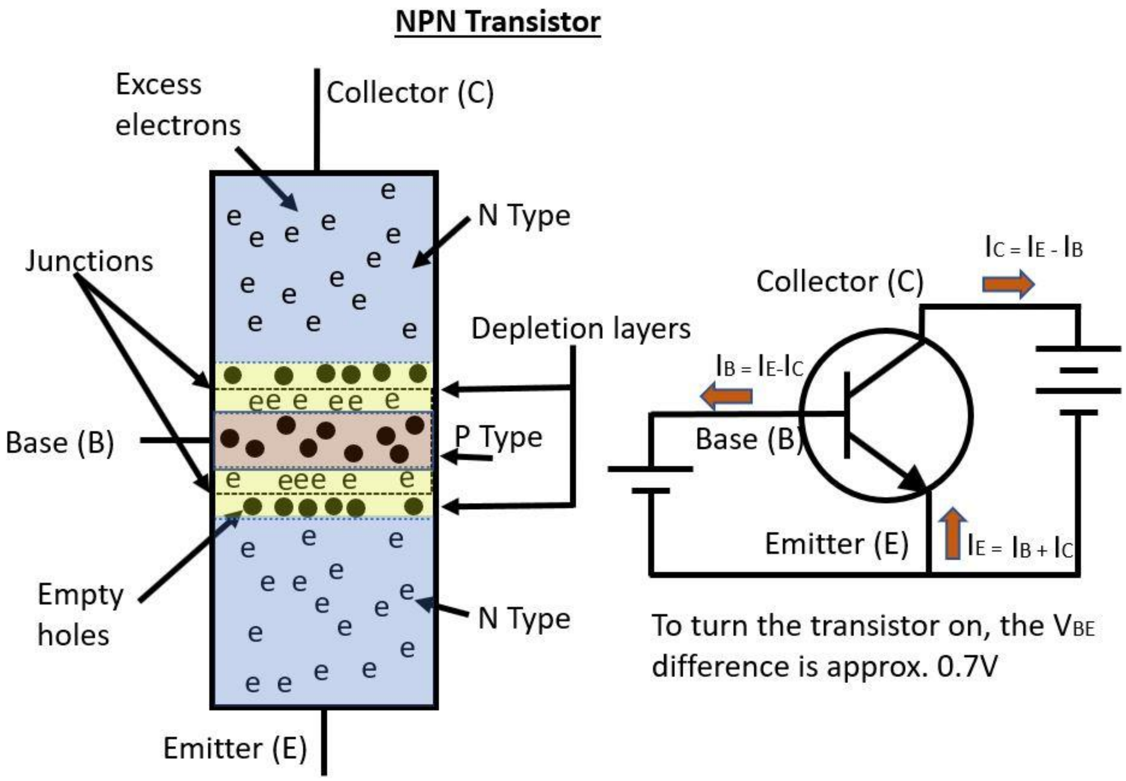

Figure 3: NPN Transistor.

PNP

The PNP transistor needs a voltage on the base approximately 0.7 V less than the emitter to cause the electrons to flow. This voltage is needed to pull the electrons across the depletion layer. In doing so, electrons will also flow from the collector to the emitter. Refer to Figure 3.

PNP transistor applications

- Used to source (send out) a current (i.e. current flows out of the collector).
- Used as switches.
- Amplifying circuits.
- PNP transistors are used when we need to turn off something by button push (e.g. emergency shutdown).
- Used in Darlington pair circuits.

- Used in matched pair circuits to produce continuous power.
- Used in heavy motors to control current flow.
- Used in robotic applications.

A common small signal PNP transistor is the 2N3906. Search and read the data sheet.

A common power NPN transistor is the 2N3054. Search and read the data sheet for a comparison.

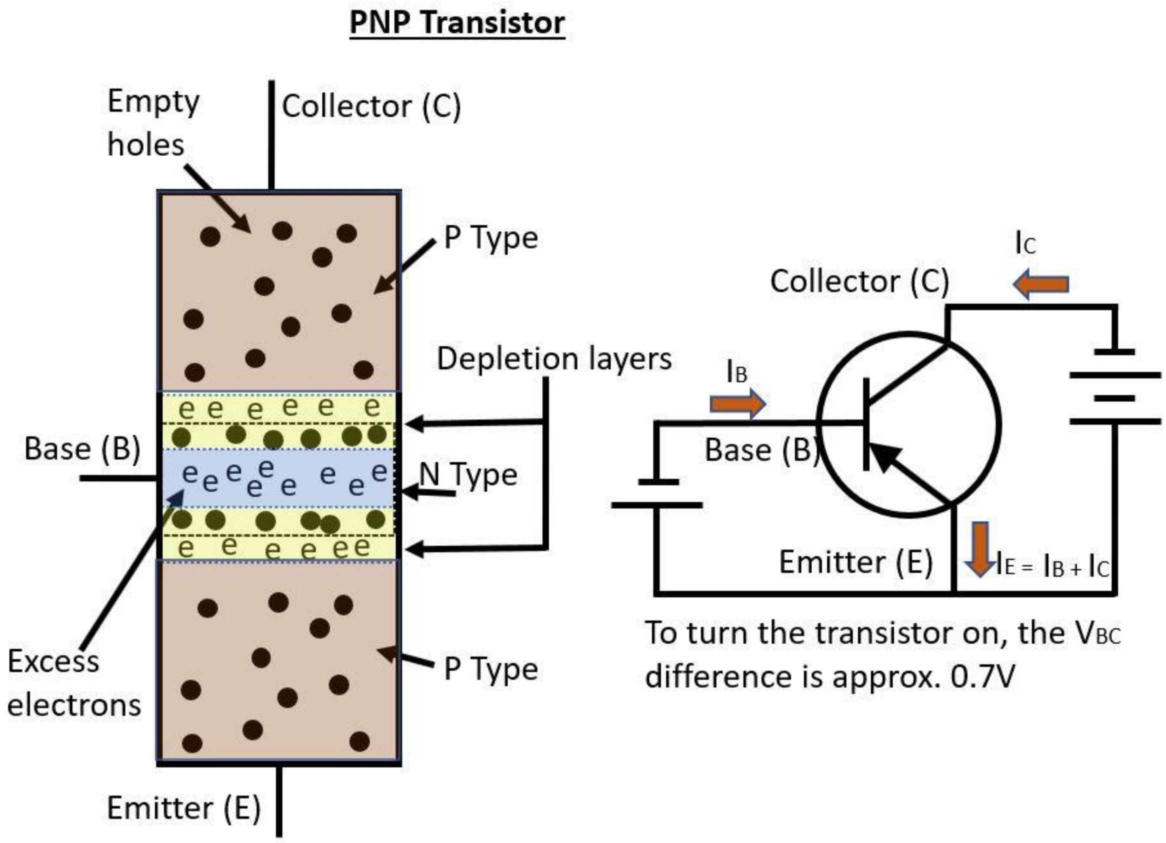

Figure 4: PNP Transistor.

Amplifier Configurations

There are three basic single-stage BJT amplifier configurations as shown in Figure 5.

<u>Common-emitter</u> - A common-emitter typically used as a voltage amplifier and offers high current gain (typically two hundred), medium input resistance, and a high output resistance. The output of a common emitter amplifier is 180 degrees out of phase to the input signal.

<u>Common-base</u> - A common-base (also known as grounded-base) is typically used as a current buffer or voltage amplifier.

<u>Common-collector</u> - A common collector amplifier (also known as an emitter follower) is typically used as a voltage buffer.

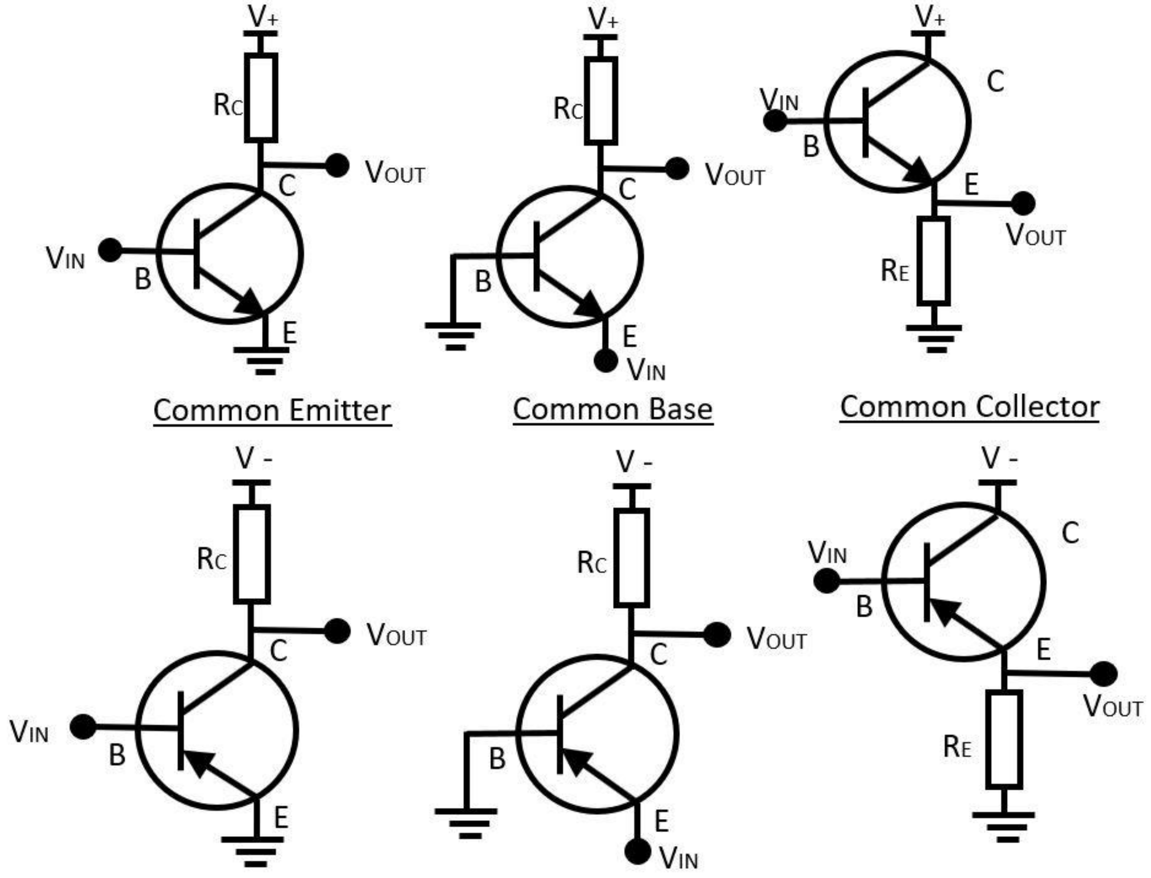

Figure 5: Transistor Configurations.

Darlington Pair

A Darlington transistor (also known as a Darlington pair) combines two BJTs in a way that it creates a very high current gain. Compounding amplification is where the current is amplified by the first transistor and then amplified again by the second transistor.

The transistor is a single unit as it has only one emitter, collector, and base. The Darlington transistor was invented by Sidney Darlington in 1953.

This transistor is also known as a “Super Beta Transistor” due to its high amplification properties. See Figure 6.

Push Pull Amplifier

A Push-Pull Amplifier is a power amplifier using a PNP and a NPN transistor to supply high power to the load. One transistor, a NPN, pushes the output on positive half cycle and other, a PNP pulls on negative half cycle. The advantage of Push-Pull amplifier is that there is no power dissipated in the output transistor when a signal is not present. See Figure 6.

Amplifier Classes

<u>Class A</u> - Class A amps are simple devices using one transistor and transmit over the full 360 degrees of the signal. Class A efficiency is only 30%.

Class B – Class B uses two transistors, each operating in only 180 degrees of the signal. This provides a greater amplification and clearer signal. The downside is that each transistor requires 0.7 V to turn on and this can cause distortion. This area is termed the 'Dead Zone'.

Class AB – Diodes are fitted to the circuit to bias the transistors across the dead zone and minimise distortion.

Class C – Class C power amplifier is where the transistor conducts for less than one half of the input cycle. The reduced conduction angle improves efficiency but causes distortion. Theoretical maximum efficiency of a Class C amplifier is around 90%.

In latter years additional amplifier classes have been developed. Further information about these and the above classes can be soured from reputable sources.

Study amplifier drawings on the internet and see if you can recognise any of the amplifier configurations.

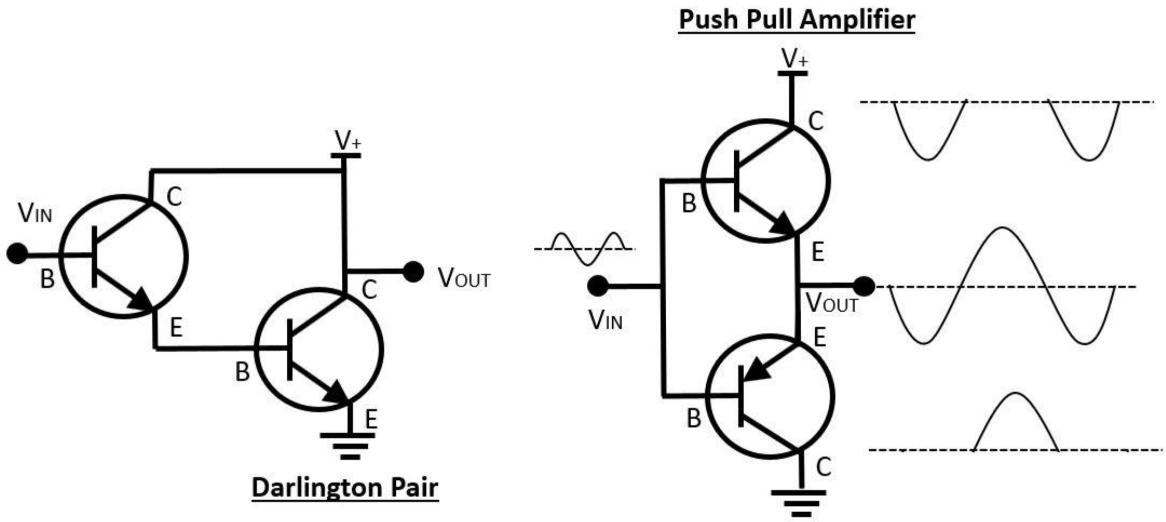

Figure 6: Darlington Pair and a Push Pull Amplifier.

Tip. Looking at the symbol for the BJTs, I use the arrowhead to remind me which is which.

If it points inward, it is a PNP and points outward it is an NPN. Also, electron flow goes opposite to the arrow in the transistor.

If you have a topic you would like to be addressed in a future instalment of Newcomers' Notebook, email Jules at jp.bqt@bigpond.net.au

Have fun and stay safe.