Newcomers' Notebook

From developments in a lab arose a solid-state survivor

Behold, the Bipolar Junction Transistor!

Jules Perrin VK3JFP

The two basic types of transistors in wide use today are the Bipolar Junction Transistor (BJT) and the Field Effect Transistor (FET). The FET differs in construction and uses different terms for its leads; I will address it in a separate article. This article focuses on the BJT.

In a previous Newcomers' Notebook on diodes (Vol.90 No.3, 2022, pp56-57), I addressed the issue of *conventional current flow* and electron current flow. I will continue using electron current flow here. Refer to **Figure 1** for a refresh.

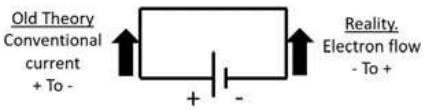

Figure 1. Diagram of 'conventional current' flow theory and reality.

Sandwich transistor

The bipolar point-contact transistor was invented in December 1947 at the Bell Telephone Laboratories in the USA. The junction version, known as the Bipolar Junction Transistor (BJT), was developed in 1948. A press release in 1951 announced the development of this new 'sandwich' transistor. The point contact transistor languished as the BJT took off. Mass-produced silicon transistors appeared during the early-1950s.

The origin of the name transistor varies, depending on who's telling the story. The common theme is that it is an abbreviated combination of the words transconductance (or transfer) and varistor (or resistor). "Transistor" stuck and has remained the name of choice.

The transistor revolutionised the field of electronics. The size of devices shrank, and power consumption levels plummeted. No longer did a product's active devices (valves or tubes) generally need mains power to run as the application of transistors ensured they could be easily powered by a battery. The development of battery-operated domestic transistor radios grew 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) on a small slice of silicon.

Two applications

A transistor can be used as a switch, or as an amplifier. The main concept is that a small current in one lead of the transistor can control a greater current flow between the other two leads.

Looking at **Figure 2**, you'll see a BJT as a 'black box' (the insides not revealed) with three leads: Collector, Base and Emitter. A small current change in the base – the input signal – can produce a greater change in the current flow between the Emitter and Collector. The shape of the signal gets inverted. As the base-emitter voltage rises, the current flow between emitter and collector of the transistor increases through the collector load, dropping the voltage at the collector.

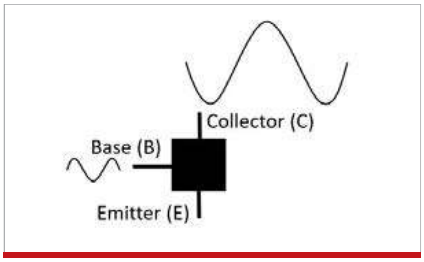

Figure 2. The BJT as a 'black box' – one needn't know what's inside. Operation of the circuit is what's of interest.

The measure of the amplification, or gain, of a transistor is called Beta (β), often expressed as hFE (for DC, or "large signal", values) or hfe ("small signal"). The 'FE' or 'fe' may be written as a subscript. There are many applications for transistors and the use of their gain parameter varies according to the application.

TRANSISTOR PACKAGES

A transistor's small slice of silicon is mounted inside a specified package, of which there are hundreds of standard types. Generally, a transistor type's packaging reflects its field of application.

Here, small signal transistors are largely grouped on the left, while the three relatively larger packages are power transistors.

The two transistors furthest left are surface-mount devices developed for high density circuit applications on specialised printed circuit boards.

On the inside: Left – a small signal device. Right – a power device; the metal package helps carry away heat. (images: Wikimedia)

Some transistors are housed in plastic cases (they'll be small signal types), while others are mounted in metal cases (power transistors); some have a plastic case incorporating a metal lug (which also generally signifies they're power transistors). The lug may be connected to the emitter, the collector, or totally isolated.

The metal case or lug of power transistors is for mounting the package to a heatsink so that heat is dissipated to keep the transistor within its designed operating temperature range.

Base material

The base material of transistors is usually silicon (Si) or germanium (Ge). Neither of these is a great conductor; so, the manufacturer "dopes" the material (injects an impurity). Doping with aluminium creates a base material lacking an electron and these are called holes. The resulting material is called P-type.

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

When N-type and P-type base materials 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, region or zone.

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

Table 1 is a short list of common terms used when referring to transistors. Understanding these will help you in reading transistor data sheets.

NPN

The NPN transistor needs a voltage between the base and emitter of about 0.7 V for silicon (Si) and 0.3 V for germanium (Ge) to cause the electrons to flow between the emitter and the collector. This voltage is needed to move the electrons across the depletion layer. In doing so, electrons will also flow between the emitter and the collector.

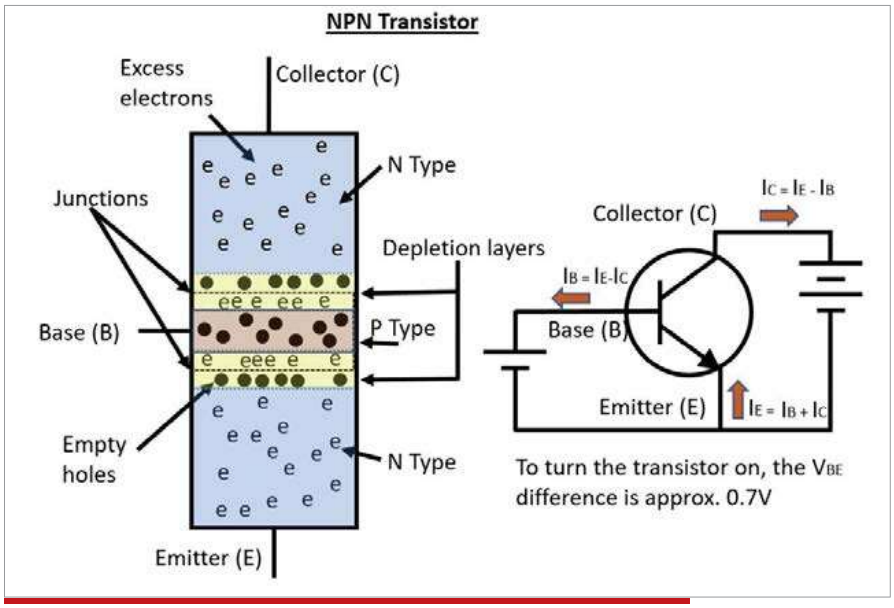

Figure 3. The construction model and basic operation of the NPN transistor.

See **Figure 3.**

NPN transistors are used:

- in switching applications
- in amplifier circuits
- in Darlington pair circuits to provide very high amplification
- as temperature sensors
- in some very high frequency applications.

A common small-signal NPN transistor is the 2N3904. Search for and read the data sheet. A common power NPN transistor is the 2N3055. Search for and read the data sheet for a comparison.

PNP

As with the NPN, the silicon PNP transistor needs a base-emitter voltage of about 0.7 V to pull the electrons across the depletion layer and cause electron flow between emitter and collector. The comparable VBE for germanium (Ge) is 0.3 V. See Figure 4. Note the polarity difference with Figure 3.

PNP transistors are used:

- as switches
- in amplifying circuits
- in Darlington pair circuits
- in 'complementary' circuits with NPN transistors
- in motor control applications.

A common small signal PNP transistor is the 2N3906. If you search for and read the data sheet, you'll see that it's complementary to the 2N3904. A common power NPN transistor is the 2N2995. Its datasheet reveals that it's complementary to the 2N3055.

Table 1.

V_{EB} or V_{BE}	Voltage between the Emitter and Base
V_{CB}	Voltage between the Collector and Base
V_{CE}	Voltage between the Collector and Emitter
$V_{BE\ (sat)}$	Voltage between the Base and Emitter, when sufficient IBE current is applied to fully saturate the BJT; saturation is when VCE is at its minimum, sometimes called 'fully turned on'
V_B	Voltage between the Base and circuit common (often called 'ground')
V_C	Voltage between the Collector and common, or ground
V_E	Voltage between the Emitter and common, or ground
Beta (β) or h_{FE}	Beta (h_{FE}) is a transistor's DC current gain at a particular temperature, current and voltage. β or $h_{FE} = i_{CE} / i_{BE}$
hfe	hfe is a transistor's AC current gain, which decreases with increasing signal frequency
I_B	Current in the Base
I_C	Current in the Collector
I_E	Current in the Emitter

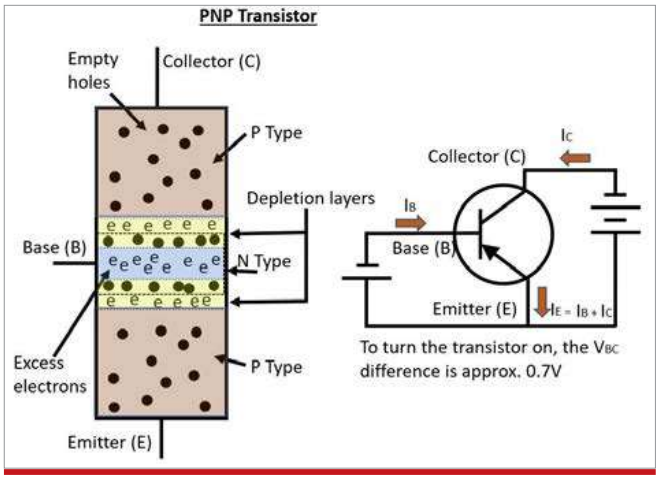

Figure 4. The construction model and basic operation of the PNP transistor.

Amplifier configurations

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

Common emitter. This is typically used as a voltage amplifier and offers high current gain (typically two hundred), medium input resistance, and a high-ish output resistance. The output of a common-emitter amplifier is 180 degrees out of phase with the input signal.

Common base. Also known as grounded-base, this is typically used as a current buffer or voltage amplifier when inter-electrode capacitances are critical, e.g., to avoid unwanted feedback between the emitter and collector circuits, as in RF amplifiers.

Common collector. Also known as an emitter-follower, this is typically used as a voltage buffer. Input resistance is quite high and output resistance is very low. So, this circuit can provide impedance transformation without altering the phase of the signal.

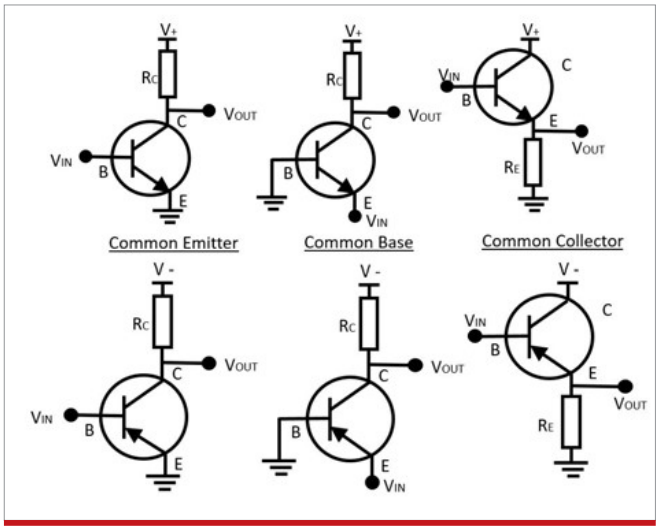

Figure 5. Transistor amplifier configurations.

The Darlington pair

Invented by Sidney Darlington in 1953, the Darlington pair, or Darlington transistor, combines two BJTs to create a very high current gain.

Compounding amplification is achieved where the input current change is amplified by the first transistor and then amplified again by the second transistor. Gain of 100,000 up to a million can be achieved. See **Figure 6.**

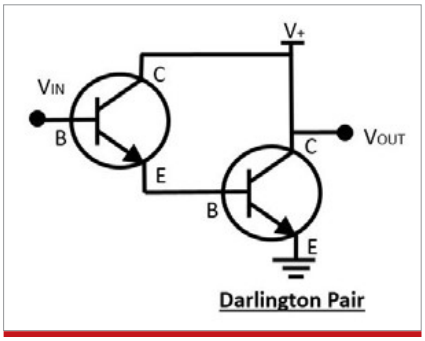

Figure 6. The Darlington pair achieves high current gain.

The Darlington transistor configuration is treated as a single unit as it has only one emitter, collector, and base; no external connection to the base of the second transistor is available.

Some Darlingtons are on the one silicon slice, or die; e.g, the BD678. You can create a Darlington with two discrete transistors, such as a 2N3904 driving a 2N3055.

This device is also known as a 'Super beta transistor' because of its high amplification properties.

Complementary symmetry push-pull amplifier

This circuit uses a pair of PNP – NPN transistors with complementary specifications and ratings to supply high power to a load. It is widely used in audio power amplifiers. It is the most efficient configuration for transforming DC power from the power supply to the AC power driving the load.

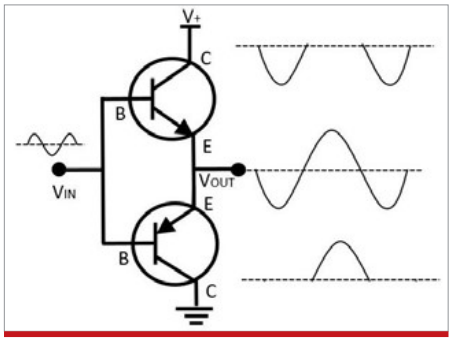

Figure 7. The ingenious complementary symmetry push-pull amplifier has many advantages.

Referring to **Figure 7**, the bottom (PNP) transistor pushes the output on the positive half cycle of the input signal, while the top one (NPN) pulls load current on the negative half cycle.

Which leg is which?

Looking at the symbol for a BJT, I use the arrowhead to remind me which leg is which. If it points inward, it is a PNP. If it points outward, it is an NPN. Also, electron flow goes opposite to the arrow in the transistor.

If you'd like to go further on the subject of understanding and using BJTs, take a look at this instructive website: https://tinyurl.com/TheBJT

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.