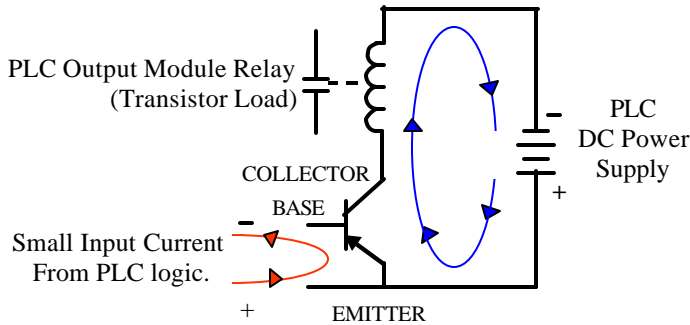


**Typical Transistor Switching Circuit**



Note: The arrow on the emitter lead of the transistor shows the direction of conventional current flow (positive to negative) through the transistor.

**Introduction**

- The transistor is a semiconductor device that can function as a signal *amplifier* or as a solid-state *switch*. A typical switching circuit using a PNP transistor is shown at the left.
- In a transistor a very small current input signal flowing emitter-to-base is able to *control* a much larger current which flows from the system power supply, through the transistor emitter-to-collector, through the load, and back to the power supply.
- In this example the input control signal loop is shown in red and the larger output current loop is shown in blue. With no input the transistor will be turned OFF (cutoff) and the relay will be dropped out. When the low-level input from the PLC microprocessor turns the transistor ON (saturates) current flows from the power supply, through the transistor, and picks the relay.

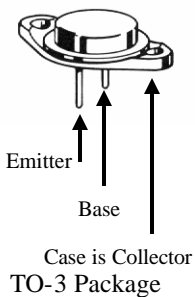
Transistors

**Transistor Packages**

There are many transistor case designs. Some conform to JEDEC Standards and are defined by Transistor Outline (TO) designations. Several case designs are illustrated below. Solid-state devices other than transistors are also housed in these same packages. In general, the larger the unit, the greater the current or power rating of the device.

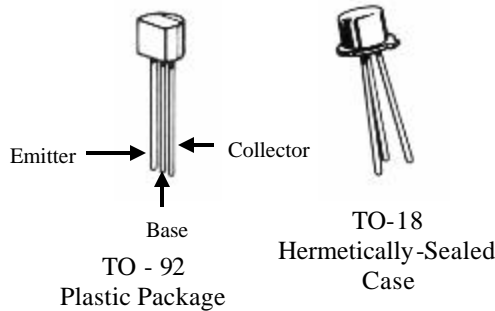
**Power Transistor**

Shown about 1/2 actual size.



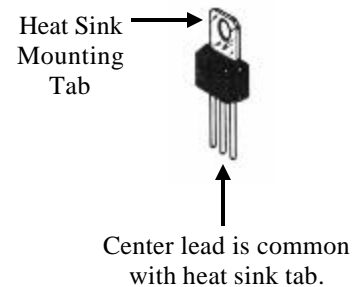
**Small Signal Transistors**

Shown about twice actual size.



**Power Tab Package**

Shown about actual size. Used for power transistors, three-terminal voltage regulators, and SCR's.



**JEDEC Numbering System**

The Joint Electronic Device Engineering Council - JEDEC - has established semiconductor interchangeability and cross-reference standards. Devices which bear the same JEDEC number can directly substituted. For example: A 2N4123 transistor is an NPN device with specific voltage and current ratings, a specified gain (amplification factor), conforms to specific temperature standards, and is housed in the TO-92 plastic package having a standardized pin configuration. A device bearing this number can be substituted regardless of the manufacturer.

However, there are thousands of semiconductors that do not conform to JEDEC standards. In order to insure device interchangeability, many manufacturers of electronic systems purchase semiconductors that meet their specific system requirements and then assign their own part numbers.

Component substitution is one of the most difficult problems facing industrial electricians and technicians.

## Introduction

There are three main classifications of transistors each with its own symbols, characteristics, design parameters, and applications. See below and the following pages for additional details and applications on each of these transistor types. Several special-function transistor types also exist which do not fall into the categories below, such as the unijunction (UJT) transistor that is used for SCR firing and time delay applications. These special-function devices are described separately.

- Bipolar transistors are considered *current driven* devices and have a relatively low input impedance. They are available as NPN or PNP types. The designation describes the polarity of the semiconductor material used to fabricate the transistor.
- Field Effect Transistors, FET's, are referred to as *voltage driven* devices which have a high input impedance. Field Effect Transistors are further subdivided into two classifications: 1) Junction Field Effect Transistors, or JFET's, and 2) Metal Oxide Semiconductor Field Effect Transistors or MOSFET's.
- Insulated Gate Bipolar Transistors, known as IGBT's, are the most recent transistor development. This hybrid device combines characteristics of both the Bipolar Transistor with the capacitive coupled, high impedance input, of the MOS device.

DEVICE NAME	SYMBOL		CHARACTERISTICS
Bipolar Transistor	NPN	PNP	A small input <i>current</i> signal flowing emitter-to-base in the transistor controls the transistor emitter-to-collector internal resistance.  Used as amplifiers or switches in a wide variety of equipment ranging from small signal applications to high power output devices.
FET Junction Field Effect Transistor	N-CHANNEL	P-CHANNEL	Input <i>voltage</i> signal is applied to the gate-source junction in a reverse biased mode, resulting in a high input impedance. Input signal varies the source-to-drain internal resistance. Applications include high input impedance amplifier circuitry.
MOS Metal Oxide Semiconductor Field Effect Transistor	N-CHANNEL	P-CHANNEL	Similar to the JFET above except the input <i>voltage</i> is capacitive coupled to the transistor. The device is easily fabricated, inexpensive, and has a low power drain, but is easily damaged by static discharge. Computer chips utilize CMOS
IGBT Insulated Gate Bipolar Transistor			Similar to the Bipolar NPN above except the input <i>voltage</i> is capacitive coupled to the transistor as with the MOSFET devices. Main application is as a switch for the output section of small and medium size Variable Frequency Drives (VFD's).

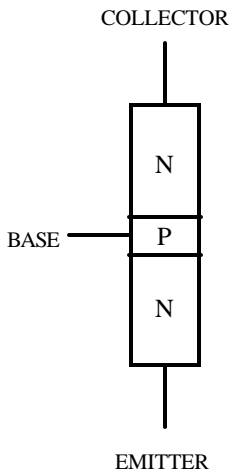
### Introduction

Bipolar transistors have the following characteristics:

- Bipolar transistors are a three-lead device having an *Emitter*, a *Collector*, and a *Base* lead.
- The Bipolar transistor is a *current* driven device. A very small amount of current flow emitter-to-base (base current measured in microamps -  $\mu\text{A}$ ) can control a relatively large current flow through the device from the emitter to the collector (collector current measured in milliamps - mA). Bipolar transistors are available in complimentary polarities. The NPN transistor has an emitter and collector of N-Type semiconductor material and the base material is P-Type semiconductor material. In the PNP transistor these polarities are reversed: the emitter and collector are P-Type material and the base is N-Type material.
- NPN and PNP transistors function in essentially the same way. The power supply polarities are simply reversed for each type. The only major difference between the two types is that the NPN transistor has a higher frequency response than does the PNP (because electron flow is faster than hole flow). Therefore high frequency applications will utilize NPN transistors.

Note: Bipolar transistors are usually connected in the Common Emitter Configuration meaning that the emitter lead is common to both the input and output current circuits. The Common Collector and the Common Base configurations are sometimes used in the input or output stages of an amplifier when impedance matching is required. **The following discussion is limited to the Common Emitter Configuration characteristics.**

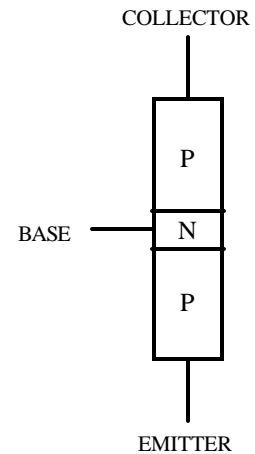
### NPN Transistor Simplified Diagram



### Construction

- The bipolar transistor is a three-layer semiconductor.
- The base lead connects to the center semiconductor material of this three-layer device. The base region is dimensionally thin compared to the emitter and collector regions.
- Two PN (diode) junctions exist within a bipolar transistor. One PN junction exists between the emitter and the base region, a second exists between the collector and the base region. (See How to Test a Bipolar Transistor on Sheet 4.)

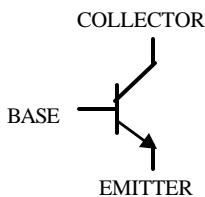
### PNP Transistor Simplified Diagram



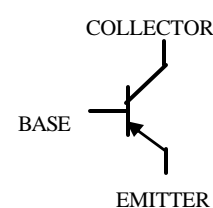
### Bipolar Transistor Symbols

- The arrow is always on the emitter lead and points in the direction of *conventional* current flow (positive-to-negative). As with the diode, the nose of the arrow points to the negative, or N-Type semiconductor material, and the tail of the arrow is toward the P-Type material.
- The arrow on the NPN points away from the base. (Remember as NPN = Not Pointing in.)
- The arrow on the PNP points toward the base. (Remember as PNP = Pointing in Pointer.)

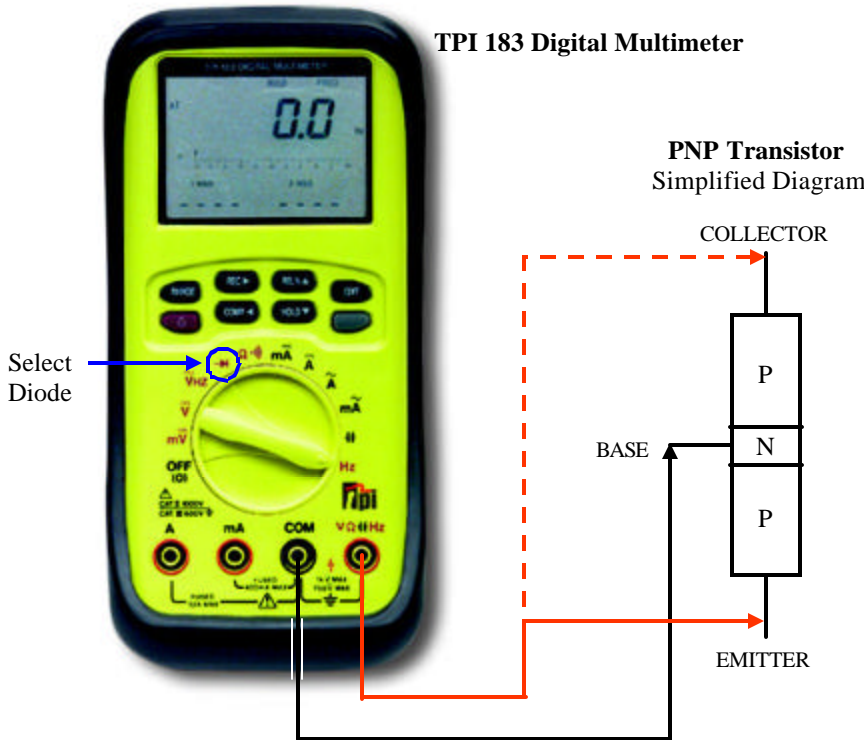
### NPN Symbol



### PNP Symbol

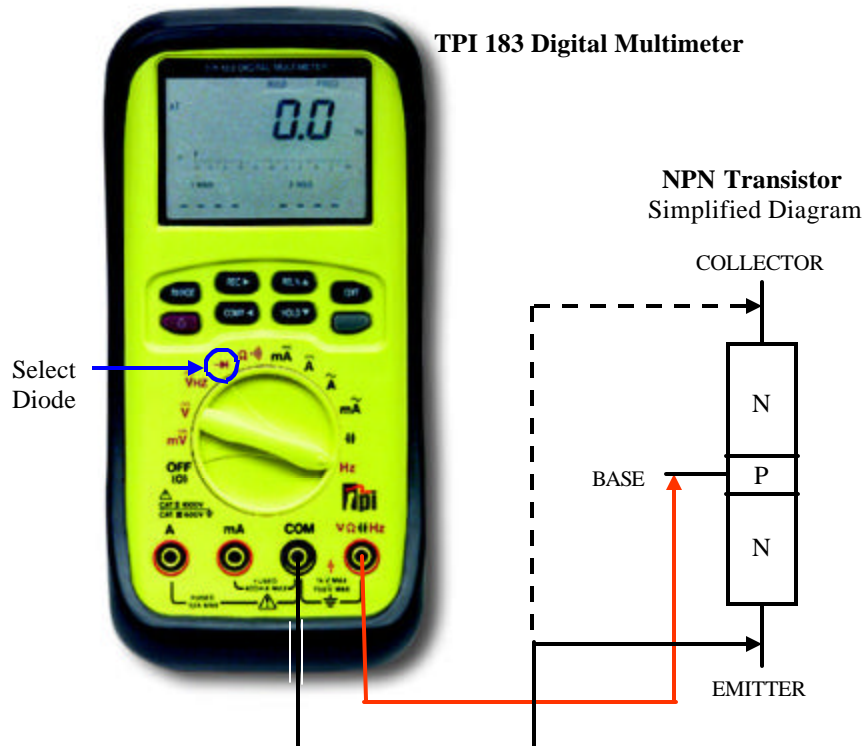


An ohmmeter can be used to test the base-to-emitter PN junction and the base-to-collector PN junction of a bipolar junction transistor in the same way that a diode is tested. You can also identify the polarity (NPN or PNP) of an unknown device using this test. In order to do this you will need to be able to identify the emitter, base, and collector leads of the transistor. Refer to a semiconductor data reference manual if you are not sure of the lead identification. Note: While this test can be used to determine that the junctions are functional and that the transistor is not open or shorted, it will not convey any information about the common emitter current gain (amplification factor) of the device. A special transistor tester is required to measure this parameter known as the Hfe or Beta .



**PNP Test Procedure**

- Connect the meter leads with the polarity as shown and verify that the base-to-emitter and base-to-collector junctions read as a forward biased diode: 0.5 to 0.8 VDC.
- Reverse the meter connections to the transistor and verify that both PN junctions do not conduct. Meter should indicate an open circuit. (Display = OUCH or OL.)
- Finally read the resistance from emitter to collector and verify an open circuit reading in both directions. (Note: A short can exist from emitter to collector even if the individual PN junctions test properly.)

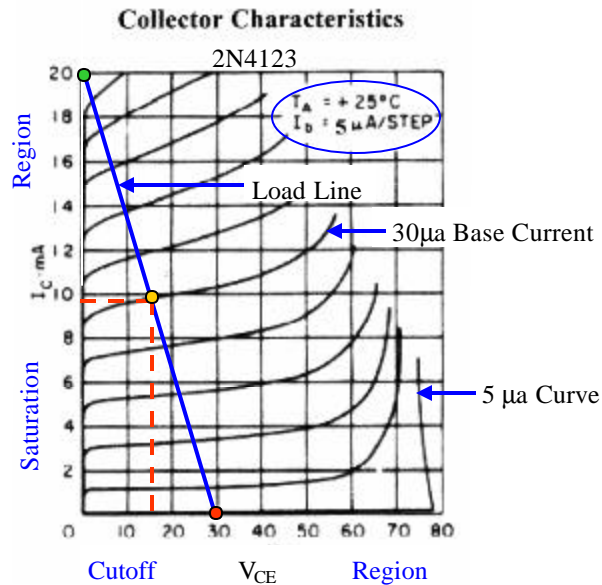


**NPN Test Procedure**

- Connect the meter leads with the polarity as shown and verify that the base-to-emitter and base-to-collector junctions read as a forward biased diode: 0.5 to 0.8 VDC.
- Reverse the meter connections to the transistor and verify that both PN junctions do not conduct. Meter should indicate an open circuit. (Display = OUCH or OL.)
- Finally read the resistance from emitter to collector and verify an open circuit reading in both directions. (Note: A short can exist from emitter to collector even if the individual PN junctions test properly.)

### Transistor Curves

A number of performance curves are published on any particular transistor. The Collector Characteristic Curves are among the most useful. This set of curves plots the Collector-Emitter Voltage ( $V_{CE}$ ) and the Collector Current ( $I_C$ ) in milliamps for various values of Base Current ( $I_b$ ) in microamps. In the drawing below each curve represents a base current step of 5 microamps beginning with the bottom curve and progressing upward.



- Saturation Region**  
 The transistor is fully turned ON and the value of collector current  $I_C$  is determined by the value of the load resistance  $R_L$ . The voltage drop across the transistor  $V_{CE}$  is near zero.
- Cut Off Region**  
 The transistor is fully turned OFF and the value of the collector current  $I_C$  is near zero. Full power supply voltage appears across the transistor. Because there is no current flow through the transistor, there is no voltage drop across the load resistor  $R_L$ .
- Active Region (Linear Amplification Area)**  
 Is the region to the left of the load line. Linear amplifiers operate in this area of the curves.

### Curve Interpretation

The following design consideration refers to the schematic diagram on the following page. In this example a power supply voltage of 30 volts DC was selected and the maximum collector current established at 20 milliamps.

- Before the Collector Characteristic Curves can be utilized a load line must be established which shows the circuit operation of the specific application. Here the maximum applied voltage  $V_{CE}$  is shown by the red dot and the Maximum Collector Current  $I_C$  is shown by the green dot. A load line has been constructed between these two points.
- To evaluate the circuit operation, select a specific base current and follow it to the intersection of the base current line and the load line (shown by the yellow dot). From intersection of the selected curve and the load line, project straight down to determine the  $V_{CE}$  (the voltage which will appear across the transistor from emitter to collector as a result of the 30 microamp base current) and project straight across to determine  $I_C$  (the current which will flow in the collector as a result of the specified base current).

In this example for a base current  $I_b$  of 30 microamps: the transistor collector voltage  $V_{CE}$  across the transistor will be 15 volts, and the collector current  $I_C$  is 10 milliamps. The voltage across the amplifier load resistor  $R_L$  will be the difference between the power supply voltage of 30 VDC and the 15 volts dropped across the transistor.

### The Common Emitter Configuration

The emitter lead is common to both the input and output current loops. This is the most common circuit configuration because it provides both a current gain and a voltage gain. The common base and common collector configurations are generally used for impedance matching only.

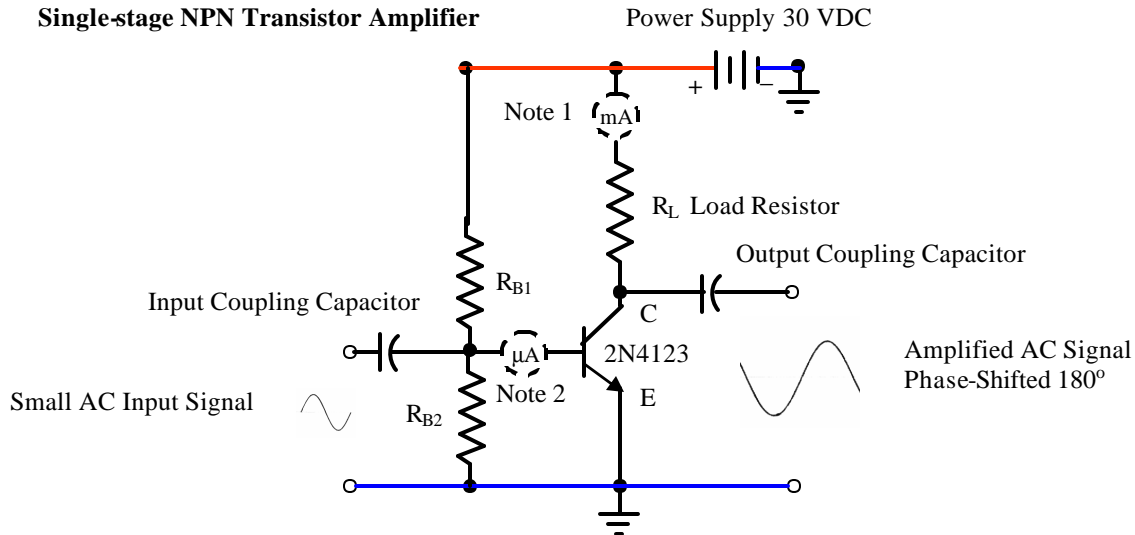
The common emitter current gain is defined as the BETA or  $H_{fe}$  (which stands for: **H** parameters, forward current transfer ratio, common emitter configuration).

There is a 180 degree phase shift between the input and output signals in the common emitter configuration.

### Amplification

An amplifier is a circuit that uses a small input variable to *control* a larger output quantity. Amplifiers may be electronic, electrical, hydraulic, pneumatic or mechanical. In the case of a bipolar transistor amplifier a small base current in microamps changes the transistor internal resistance and controls a larger amount of current in milliamps or amps which flows through the transistor emitter to collector. The emitter to collector current is *sourced* by the system power supply. The transistor load is normally placed in the collector circuit of the transistor. Transistor amplifiers can amplify either AC or DC signals. A single transistor circuit will have a specific circuit gain, or amplification factor. Where additional gain is required multiple stages of amplification are employed.

### Single-stage NPN Transistor Amplifier



### Circuit Analysis

**Biasing** - The two rules for biasing a common emitter amplifier (either NPN or PNP) are:

- 1) The emitter-to-base junction is always *forward* biased. In this example because the transistor is an NPN the base is P-Type material. The voltage divider consisting of  $R_{B1}$  and  $R_{B2}$  provides this forward bias as the base will be positive with respect to the emitter. Resistors are sized to set the *quiescent* or steady state operating point at the middle of the load line (shown by the yellow dot on load line).
- 2) The collector is always *reverse* biased. Because this is an NPN the collector is N-Type material so the collector is connected to the power supply positive.

**Load Resistor** - Is sized to limit the collector current to 20 milliamps (shown by the green dot on the curves) when the transistor is fully turned on (saturated). Use Ohms Law to calculate this: Power supply voltage divided by  $I_C$ .

**Supply Voltage** - Any voltage can be used as long as it is below the maximum allowable collector voltage for the transistor (which for the 2N4123 is 40 VDC). 30 VDC has been chosen for this example and is shown by the red dot.

**Input Signal** - This is the AC signal to be amplified. For example: a microvolt radio signal off of an antenna. This signal passes through the input coupling capacitor and adds to the base bias during the positive half-cycle and subtracts from the base bias during the negative half-cycle. It is said that the signal "swings around the base bias".

**Output Signal** - The AC input signal applied to the transistor base causes the DC collector current to vary from its quiescent steady-state value upward and downward at an AC rate. The AC component of the signal then passes through the output coupling capacitor for further amplification or detection. To prevent output waveform distortion (amplitude limiting or clipping) the output signal should not hit the cutoff or saturation levels of the transistor.