

**USER MANUAL FOR DARLINGTON TIP-120 TRANSISTOR,
A NON-LINEAR POWER AMPLIFIER FUNCTIONAL MODULE**

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1. INTRODUCTION

Most commonly, a transistor is used as an amplifier or a gate. As an amplifier, the transistor can be used to amplify a signal in four modes: as a voltage-controlled voltage amplifier, as a voltage-controlled current amplifier, as a current-controlled voltage amplifier, and as a current-controlled current amplifier. Transistors are composed of three functional terminals -- the base (B), the collector (C), and the emitter (E), as shown in Figure 1(a). Ultimately, the current flowing through a transistor depends upon the base current and the resulting voltage. The TIP 120 transistor that we use in the lab (Figure 1(b)) is a combination of two transistors, which form a configuration known as a *Darlington-pair*. Figure 1(b) shows how the emitter voltage from the first transistor is the base voltage of the second transistor, making the Darlington-pair transistor a more effective linear amplifier.

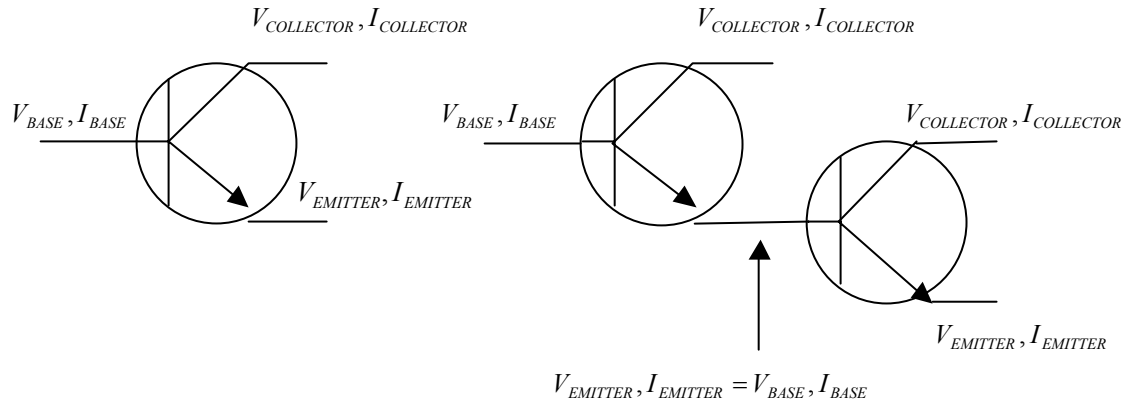


Figure 1 (a) Basic layout for a transistor; (b) Basic layout for a Darlington-pair transistor.

The purpose of this user manual is to develop a relationship between the base current and the emitter current in order to see how the TIP120 transistor acts as a linear power amplifier. Using Ohm's Law and Kirchoff's Voltage and Current Laws, we will determine the ideal ranges characterized by the collector region of the transistor. Figure 2 displays that we will use. By varying the base load resistance and reading the voltage across a fixed emitter load resistance, we will determine the behavior of the transistor.

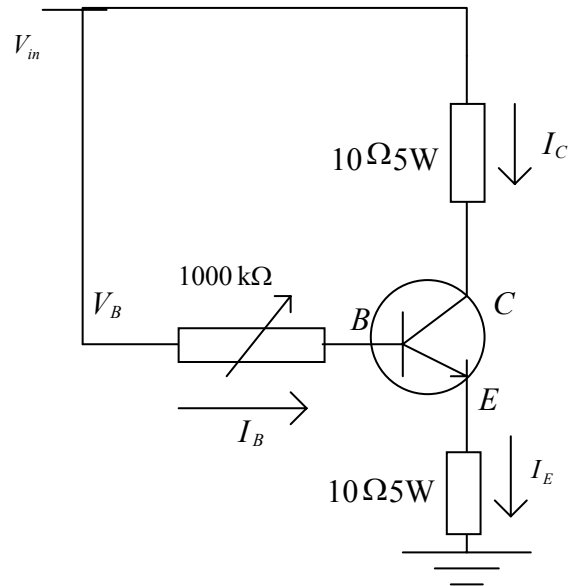


Figure 2 Amplifier circuit using TIP-120 bipolar junction transistor (NPN)

2. THEORY AND PREDICTIONS

The transistor uses a base signal that, in a specific range of values, will control the collector current. This is primarily due to the composition of the transistor. A bipolar junction transistor (BJT)—the kind we will use in this laboratory—composed of one layer of non-doped material (p) and two layers of doped material (n). When current flows from the base to the emitter, the electrons fill “holes” in the middle p layer, allowing the electrons in the layer to move towards the positively charged n layer at the emitter. When current flows from the collector to the emitter, the “holes” in the p layer empty and the electrons pass across the emitter.

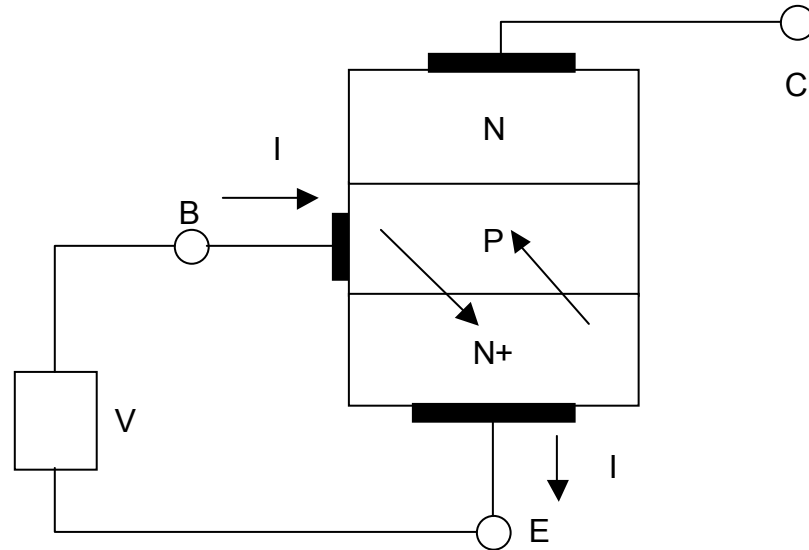


Figure 3 Schematic of the *npn* bipolar junction transistor

Every transistor has a *collector characteristic*. A family of curves relating the collector-emitter voltage, the collector current, and the base current determines the *collector characteristic*.

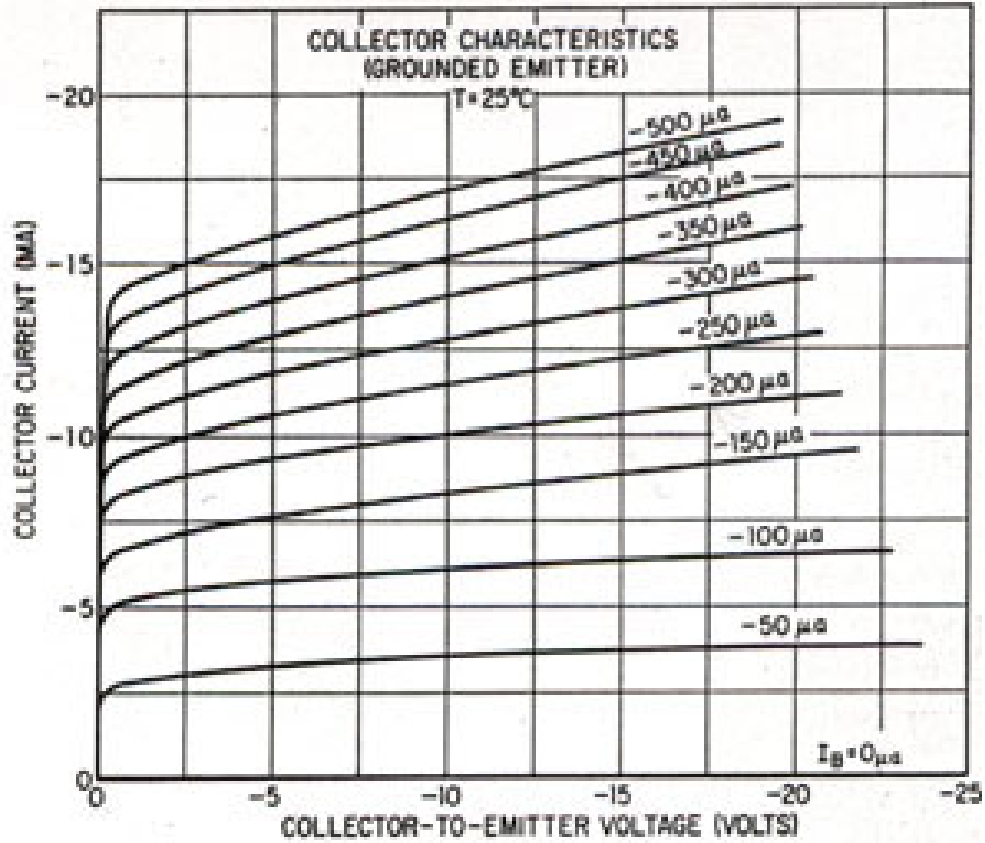


Figure 4 Collector characteristic for TIP 120 bipolar junction transistor
(Characteristic courtesy of American Microsemiconductor, 2001)

From this family of characteristic curves, there is a set of ideal values of the emitter current that allow the most collector current to flow across the transistor. This set includes points at which the base current magnifies the collector current by some maximum gain (Equation 1).

$$I_C = I_B \beta \quad (1)$$

Here, I_C is the collector current, I_B is the base current, and β is the maximum gain. (Beta is defined by the manufacturer of the transistor in question). In transistors, a

flow of electrons towards the emitter is favored, so the emitter current, I_E , is equal to the sum of the base current, I_B (Equation 2).

$$I_E = I_C + I_B \quad (2)$$

By combining Equations 1 and 2, we find an expression directly relating the base current and the collector current according to beta.

$$I_E = I_B(1 + \beta) \quad (3)$$

The important aspect of the Darlington-pair the fact that whereas the collector current is constant throughout the circuit, the base currents differ; the collector currents are in parallel relative to each other. The gain in the first transistor is like any other single transistor (Equation 3). However, looking at the second transistor, we see that the base current is equal to the emitter current.

$$I_{E_1} = I_{B_1}(1 + \beta) = I_{B_2} \quad (4)$$

Because the collector currents are in parallel relative to each other, each collector current is equivalent. If we consider the value of the second collector current, we find that it is equal to the base current times the gain value. We can now find the influence of the gain value on the base current, in order to find the total emitter current from the Darlington pair.

$$I_{E_2} = I_{B_2} + I_{C_2} = I_{E_2} + I_{C_2} \quad (5)$$

$$I_{E_2} = I_{B_1}(\beta + 1) + I_{C_2} \quad (6)$$

$$I_{E_2} = \beta(I_{B_1}(\beta + 1)) + I_{B_1}(\beta + 1) \quad (7)$$

$$I_{E_{total}} = I_{B_1}(\beta^2 + 2\beta + 1) = I_{B_{overall}}(\beta + 1)^2 \quad (8)$$

In this equation, we see that instead of an increase by a factor $\beta+1$, it increases quadratically, indicating that Darlington transistor to be a more effective amplifier than a single transistor. Figure 4 shows the ideal relationship of the total collector current, $I_{E_{total}}$, versus the initial base current, I_B , with the amplification value as specified by industry, $\beta = 31$ (Fairchild Semiconductor, 2001). The industry-nominal value for the amplification factor for voltage is 1000. According the Ohm's law, this 1000 is directly proportional to the current, so the current amplification factor may also be 1000. Since this is representative of the whole configuration, it must be derived from the equation $\beta^2 + 2\beta + 1 = 1000$, so $\beta = 30.606$.)

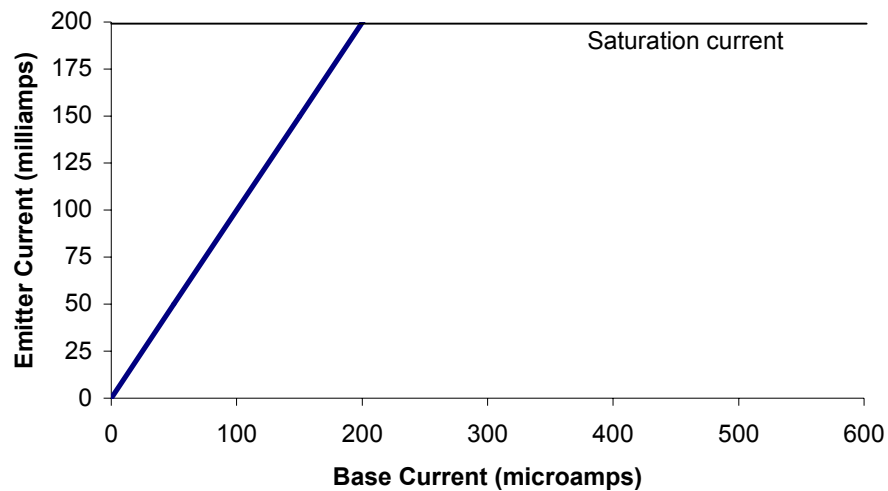


Figure 5 Predicted variation of the emitter current, I_E , according to change in the base current, I_B , in a Darlington configuration transistor, when $V_{in} = 5V$.

Like the single transistors, there are physical limits for the Darlington pair. The collector characteristic has three important regions: the cutoff region, the active linear region, the saturation region. The cutoff region is the region in which the collector and

base currents are oppose each other. The voltages generally cancel each other out because the collector current tends to flow away from the transistor. If the collector is preceded by a large, parallel resistance, R_C , then the current will be small, and the collector-emitter voltage, V_{CE} , small, as well. Power amplification occurs in the active linear region. This occurs at moderate, forward-flowing levels of collector current. At any point where the emitter current amplifies linearly, the TIP120 is active. The saturation region is the region in which both the base current and the collector current both flow to the emitters. Because of the presence of these regions, the collector characteristic is important in determining the base current and collector current. At both the cutoff and saturation regions, the relation becomes asymptotic to these limits. However, we should remember that there is no set relationship for the general transistor. Each has unique mechanical characteristics that vary the collector characteristic.

3. FUNCTIONAL MODULE DESCRIPTION

Figure 6 contains a picture of the TIP-120 transistor functional module. In the picture the major electronic components are: the resistors, the diode, the TIP transistor, the potentiometer, the two input voltage terminals, the ground terminal, and the voltage output terminal. One of the input terminals receives a +5V signal while the other input terminal receives +15V. Both of the ground terminals are grounded. The functional module consists of one circuit that acts as a linear power amplifier. Figure 7 is the circuit schematic of the following functional module.

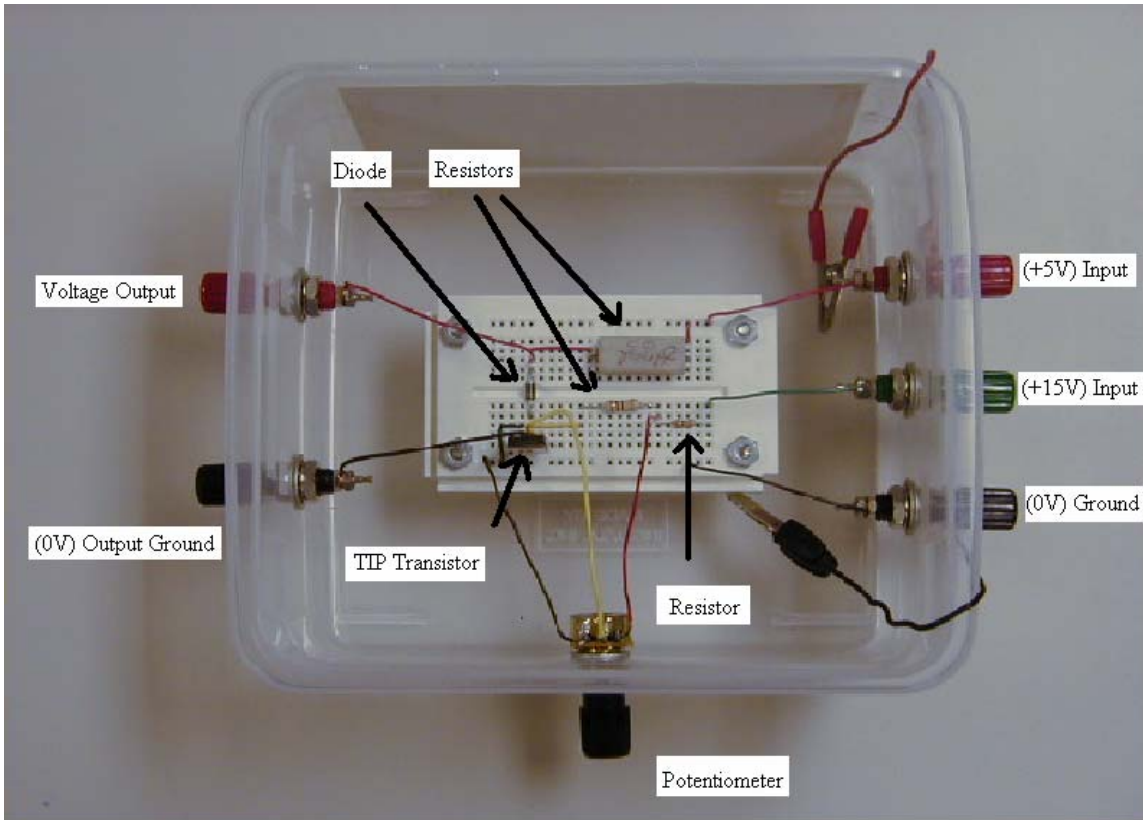


Figure 6 Labeled picture of the power transistor circuit functional module.

4. WIRING INSTRUCTIONS

Table 1 Wiring directions for the bipolar junction transistor amplifier circuit.

Red	Source voltage, 5V
	Source to rheostat
	Rheostat out
	Rheostat to base terminal
	Source to collector resistor
	Collector resistor to collector terminal
	Collector terminal out
Black	Ground voltage, 0V
	Emitter resistor to ground
Yellow	Signal wire
	Emitter terminal out
	Emitter terminal to emitter resistance

5. APPARATUS

Table 2 Apparatus Needed for Testing

Digital multimeter, or equivalent ohmmeter, ammeter, and voltmeter
Power source
Voltage box, with ground (0 volts), -15, +15, and +5 volt outlets
5/64" flathead screwdriver

6. TESTING SEQUENCE

Adjust the base rheostat with the screwdriver. Read the resulting base current with the multimeter, in microampere mode, and then connect the rheostat to the circuit. Then, with the multimeter in milliampere mode, read both the emitter current. Table 3 describes the expected results when the base current is varied, while $V_{in} = 4.96V$. Figure 4 shows the graph of the test data, illustrating (1) the linear relationship of amplification of the emitter current in the active region, and (2) the physical limitations of the saturated and cutoff regions of the TIP120.

Table 3 Experimental variation of the emitter current, I_E , as the base current, I_B , is varied, when $V_{in} = 5V$.

Base current (μA)	Emitter Current (mA)
50.3	0.03
75.3	0.26
100.6	0.97
126.7	2.2
133.5	2.36
150.6	2.94
164.7	3.86
170.9	4.58
175.8	6.49
180.6	38.15
187	58
200.8	93.8
248.3	137.5
304.1	160.6
351.8	163.6
408	164.5
506	165.2
548	165.5
608	165.8
721	166.3
804	166.6
914	166.6
1033	166.8

1541	167.6
2031	167.8
3233	168.8

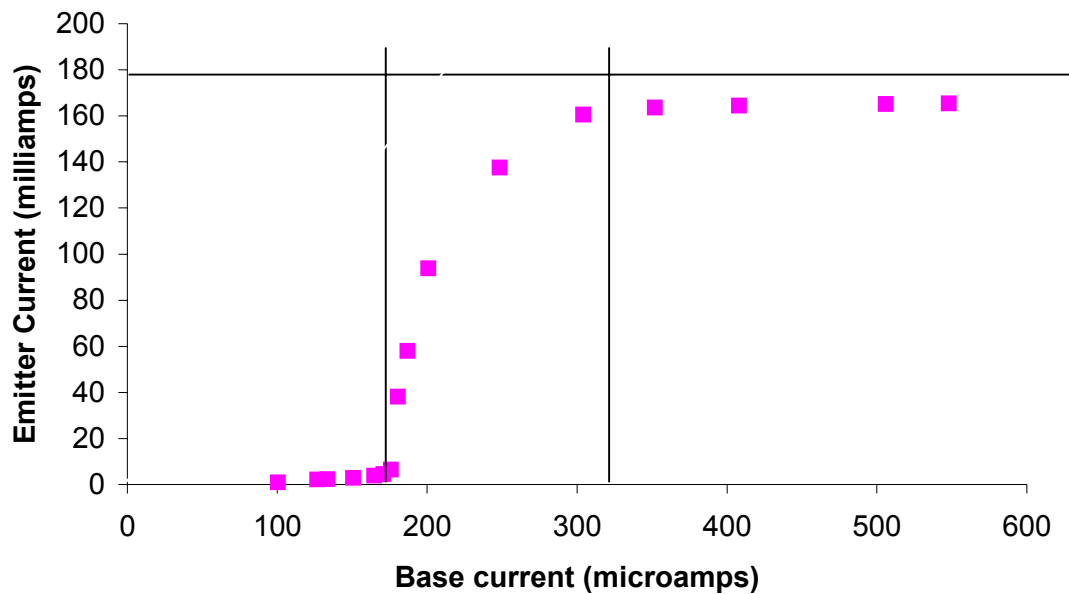


Figure 8 Variation of the emitter current, I_E , according to change in the base current, I_B , in a Darlington transistor TIP 120, when $V_{in} = 5V$.

7. LIST OF PARTS

Table 4 Required components

Piece	Value	Unit
TIP-120 Transistor	Not applicable	Not applicable
Rheostat	[0,1]	k Ω
Static resistor	10, 5	Ω ; W
Red wire	Not applicable	Not applicable
Black wire	Not applicable	Not applicable

Yellow wire	Not applicable	Not applicable
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A. TIP 120 TRANSISTOR SPECIFICATIONS