Leakage currents in BJT

Leakage Currents

In the common-base circuits in Figure 5.11, if we set the current source $i_E = 0$, transistors will be cut off, but the B–C junctions will still be reverse biased. A reverse-bias leakage current exists in these junctions, and this current corresponds to the reverse-bias saturation current in a diode, as described in Chapter 1. The direction of these reverse-bias leakage currents is the same as that of the collector currents. The term I_{CBO} is the collector leakage current in the common-base configuration, and is the collector-base leakage current when the emitter is an open circuit. This leakage current is shown in Figure 5.15(a).

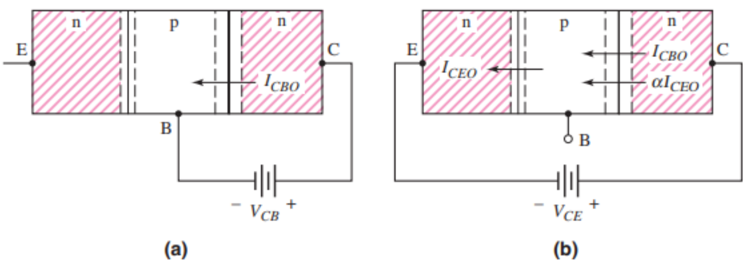

Figure 5.15 Block diagram of an npn transistor in an (a) open-emitter configuration showing the junction leakage current I_{CBO} and (b) open-base configuration showing the leakage current I_{CEO}

Another leakage current can exist between the emitter and collector with the base terminal an open circuit. Figure 5.15(b) is a block diagram of an npn transistor in which the base is an open circuit ($i_B = 0$). The current component I_{CBO} is the normal leakage current in the reverse-biased B–C pn junction. This current component causes the base potential to increase, which forward biases the B–E junction and induces the B–E current I_{CEO}. The current component αI_{CEO} is the normal collector current resulting from the emitter current I_{CEO}. We can write

$$I_{CEO} = \alpha I_{CEO} + I_{CBO} \tag{5.19(a)}$$

or

$$I_{CEO} = \frac{I_{CBO}}{1-\alpha} \cong \beta I_{CBO} \tag{5.19(b)}$$

Transistor Datasheet BC547B

Parameters	Symbol	Test Condition	Value	Unit
Collector Emitter Voltage	V_{CEO}	I_C = 1mA, I_B = 0	>45	V
Collector Base Voltage	V_{CBO}	I_C = 10µA, I_E = 0	>50	
Emitter Base Voltage	V_{EBO}	I_E = 10µA, I_C = 0	>6.0	
$(1+\beta) I_{CBO} = I_{CEO}$ Collector Cut off Current	I_{CBO}	V_{CB} = 30V, I_E = 0 T_J = 150°C V_{CB} = 30V, I_E = 0	<50 <5.0	nA µA
	I_{CES}	V_{CE} = 50V, V_{BE} = 0 T_J = 125°C	<15	nA
Collector Cut off Current		V_{CE} = 50V, V_{BE} = 0	<4.0	µA
DC Current Gain $\beta = h_{FE}$	h_{FE}	I_C = 2mA, V_{CE} = 5V	200	-
Collector Emitter Saturation Voltage	$V_{CE\ (sat)}$	I_C = 10mA, I_B = 0.5mA I_C = 100mA, I_B = 5mA	<0.25 V <0.60	V
Base Emitter Saturation Voltage	$V_{BE\ (sat)}$	I_C = 10mA, I_B = 0.5mA I_C = 100mA, I_B = 5mA	Typical 0.70 Typical 0.90	
Base Emitter On Voltage	$V_{BE\ (on)}$	I_C = 2mA, V_{CE} = 5V I_C = 10mA, V_{CE} = 5V	0.55 - 0.70 <0.72	

$V_{BE_{ON}} = 0.7V$

BC547B

General Purpose Transistor

multicomp

Electrical Characteristics (T_a = 25°C unless otherwise specified)

Parameters	Symbol	Test Condition	Value	Units
Dynamic Characteristics				
Transition Frequency	f_T	I_C = 10mA, V_{CE} = 5V f = 100MHz	Typical 300	MHz
Collector Output Capacitance	C_{cbo}	V_{CB} = 10V, f = 1MHz	<4.50	pF
Emitter Input Capacitance	C_{ib}	V_{EB} = 0.5V, f = 1MHz	Typical 9.0	pF
Noise Figure	NF	I_C = 0.2mA, V_{CE} = 5V R_s = 1kΩ, f = 200Hz	<10	dB
Small Signal Current Gain $\beta_{ac} = h_{fe}$	h_{fe}	I_C = 2mA, V_{CE} = 5V	Typical 330	-
Input Impedance	h_{ie}	I_C = 2mA, V_{CE} = 5V	3.2 - 8.5	kΩ
Voltage Feedback Ratio	h_{re}	I_C = 2mA, V_{CE} = 5V	Typical 2.0	x 10^{-4}
Output Impedance	h_{oe}	I_C = 2mA, V_{CE} = 5V	<60	µΩ

"h-parameter model"

Specifications

Transistor Biasing

1.10 TRANSISTOR BIASING

The basic function of a transistor is to do amplification. The weak signal is given to the transistor and amplified output is obtained from collector. The process of raising the strength of weak signal without any

change in its general shape is known as faithful amplification. The basic problems involved in the design of transistor circuits is establishing and maintaining the proper collector to emitter voltage and collector current in the circuit. This condition is known as transistor biasing. The biasing conditions must be maintained despite variations in temperature, variations in gain and leakage current and variation in supply voltages.

Necessity of Transistor Biasing:

variation in supply voltages.

1.10.1 Necessity of Biasing

For faithful amplification, following conditions must be satisfied:

(i) Proper zero signal collector current (I_C)

(ii) Proper base emitter voltage (V_{BE})

(iii) Proper collector-emitter voltage (V_{CE})

The value of I_C and V_{CE} is expressed in terms of operating point or quiescent point Q. For faithful amplification, Q point must be selected properly. The fulfillment of the above conditions is known as transistor biasing.

Need for Stabilization

1.10.2 Need For Stabilization (Why Q-Point Changes)

The collector current I_C depends on reverse saturation current I_{CO}, current gain β and base emitter voltage V_{BE}. These parameters are temperature dependent i.e. as temperature changes, these parameters change. Hence collector current I_C changes. Due to this, Q point changes. Hence Q point has to be stabilized against temperature variation.

(1) I_{CO} : The collector current is given by

$I_{CO} < I_{CBO}, I_{CEO}$

$$I_C = \beta I_B + (\beta + 1) I_{CO}$$

ChatGPT "Thermal Runaway" in a BJT

The collector leakage current I_{CO} doubles for every 10 °C rise in temperature. The flow of collector current produces heat at the collector junction. This increases the temperature, therefore leakage current I_{CO} increases. Hence, collector current I_C again increases. This increase in I_C increases temperature of collector junction which increases I_{CO} again. The effect is cumulative and at one stage I_C is so large which damages the transistor. This process is known as **thermal runaway.**

Not in syllabus

(2) β : The transistor parameter β is temperature and device dependent. β increases with the increase in temperature. Value of β is different even for transistors of same type. If transistor is replaced by another transistor even of the same type, the value of β is different. Hence, collector current changes. Therefore, Q-point changes. S_β or S'

(3) V_{BE} : The base emitter voltage V_{BE} decreases at the rate of 2.5 mV/°C i.e. device starts operating at lower voltages. Hence, base current changes which changes collector current and hence the Q-point. $S_{V_{BE}}$ or S''

The process of stabilizing Q-point is called as thermal stabilization.There are three methods to bias the BJT.

(1) Fixed bias
(2) Collector to base bias
(3) Voltage divider bias

1.10.3 Stability Factor (S)

The rate of change of collector current w.r.t. collector leakage current I_{CO} at constant β and V_{BE} is called as stability factor.

$$\boxed{\text{Stability factory } S = \left.\frac{\partial I_C}{\partial I_{CO}}\right|_{\beta,\ V_{BE} = \text{constant}}}$$

I_{CO} I_{CBO} I_{CEO}

Expression for stability factor

We know that, $I_C = \beta I_B + (\beta + 1) I_{CO}$

Differentiating w.r.t. I_C,

$$1 = \beta \frac{\partial I_B}{\partial I_C} + (\beta + 1) \frac{\partial I_{CO}}{\partial I_C}$$

$$1 - \beta \frac{\partial I_B}{\partial I_C} = (\beta + 1) \frac{\partial I_{CO}}{\partial I_C} = \frac{(\beta + 1)}{\frac{\partial I_C}{\partial I_{CO}}}$$

$$1 - \beta \frac{\partial I_B}{\partial I_C} = \frac{(\beta + 1)}{S}$$

$$\boxed{S = \frac{\beta + 1}{1 - \beta \frac{\partial I_B}{\partial I_C}}}$$

$S_{I_{CO}}$