Bipolar junction transistor

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__BJT__ redirects here. For the japanese proficiency test, see Business Japanese Proficiency Test.

A **bipolar junction transistor** (**BJT**) is a type of transistor. It is a three-terminal device constructed of doped semiconductor material and may be used in amplifying or switching applications. Bipolar transistors are so named because their operation involves both electrons and holes.

Although a small part of the base–emitter current is carried by the majority carriers, the main current is carried by minority carriers in the base, and so BJTs are classified as 'minority-carrier' devices.

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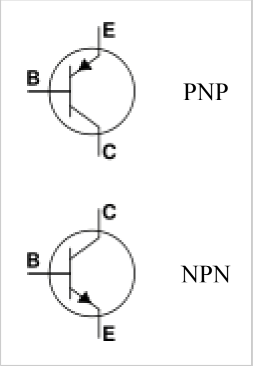


The schematic symbols for PNP- and NPN-type BJTs.

Introduction

An NPN transistor can be considered as two diodes with a shared anode region. In typical operation, the emitter–base junction is forward biased and the base–collector junction is reverse biased. In an NPN transistor, for example, when a positive voltage is applied to the base–emitter junction, the equilibrium between thermally generated carriers and the repelling electric field of the depletion region becomes unbalanced, allowing thermally excited electrons to inject into the base region. These electrons wander (or "diffuse") through the base from the region of high concentration near the emitter towards the region of low concentration near the collector. The electrons in the base are called *minority carriers* because the base is doped p-type which would make holes the *majority carrier* in the base.

The base region of the transistor must be made thin, so that carriers can diffuse across it in much less time than the semiconductor's minority carrier lifetime, to minimize the percentage of carriers that recombine before reaching the collector–base junction. The collector–base junction is reverse-biased, so little electron injection occurs from the collector to the base, but electrons that diffuse through the base towards the collector are swept into the collector by the electric field in the depletion region of the collector–base junction.

Voltage, current, and charge control

The collector–emitter current can be viewed as being controlled by the base–emitter current (current control), or by the base–emitter voltage (voltage control). These views are related by the current–voltage relation of the base–emitter junction, which is just the usual exponential current–voltage curve of a p-n junction (diode).

The physical explanation for collector current is the amount of minority-carrier charge in the base region. Detailed models of transistor action, such as the Gummel–Poon model, account for this charge explicitly to explain transistor behavior more exactly. The charge-control view easily handles photo-transistors, where minority carriers in the base region are created by the absorption of photons, and handles the dynamics of turn-off, or recovery time, which depends on charge in the base region recombining. However, since base charge is not a signal that is visible at the terminals, the current- and voltage-control views are usually used in circuit design and analysis.

In linear circuit design, the current-control view is often preferred, since it is approximately linear. That is, the collector current is approximately 'beta' times the base current. The voltage-control model requires an exponential function to be taken into account.

Transistor 'alpha' and 'beta'

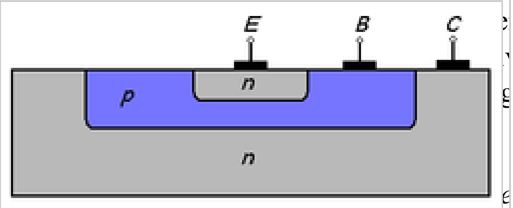
The proportion of electrons able to cross the base and reach the collector is a measure of the BJT efficiency. The heavy doping of the emitter region and light doping of the base region cause many more electrons to be injected from the emitter into the base than holes to be injected from the base into the emitter. The base current is the sum of the holes injected into the emitter and the electrons that recombine in the base—both small proportions of the emitter to collector current. Hence, a small change of the base current can translate to a large change in electron flow between emitter and collector. The ratio of these currents I_c/I_b, called the *current gain*, and represented by β or h_{fe}, is typically greater than 100 for transistors. Another important parameter is the base transport factor, α_T. The base transport factor is the proportion of minority carriers injected from the emitter that diffuse across the base and are swept across the base–collector junction without recombining. This has values usually between 0.98 and 0.998. Alpha and beta are related by the following identities:

$$\alpha_T = \frac{I_{\mathrm{Cp}}}{I_{\mathrm{Ep}}} \text{ (pnp device)}$$

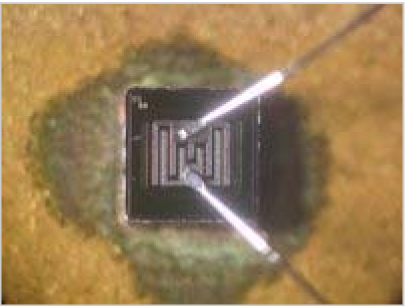
$$\beta_F = \frac{I_{\mathrm{C}}}{I_{\mathrm{B}}}$$

$$\beta_F = \frac{\alpha_F}{1 - \alpha_F}$$

Structure



Simplified cross section of an *npn* bipolar junction transistor



Die of a KSY34 high-frequency NPN transistor, base and emitter connected via bonded wires

onductor regions, the *emitt*
, *p* type, *n* type and *p* type i
is connected to a terminal,

ter and the *collector* and is
resistivity material. The collector surrounds emitter region, making it al
injected into the base region to escape being lected, thus making the resu
ection view of a BJT indica hat the collector–base junction has
a much larger area than the emitter–base junction.

The bipolar junction transistor, unlike other transistors, is not a symmetrica vice. This means that interchanging the collector and the emitter makes the transistor leave the forward active mode and start to operate in reverse mode. Because the transistor's internal structure is usually optimized to forward-mode operation, interchanging the collector and the emitter makes the values of α and β of reverse operation much smaller than those found in forward operation; usually, the α of the reverse mode is lower than 0.5. The lack of symmetry is primarily due to the doping ratios of the emitter and the collector. The emitter is heavily doped, while the collector is lightly doped, allowing a large reverse bias voltage to be applied before the collector–base junction breaks down. The collector–base junction is reverse biased in normal operation. The reason the emitter is heavily doped is to increase the emitter injection efficiency: the ratio of carriers injected by the emitter to those injected by the base. For high current gain, most of the carriers injected into the emitter–base junction must come from the emitter.

Small changes in the voltage applied across the base–emitter terminals causes the current that flows between the *emitter* and the *collector* to change significantly. This effect can be used to amplify the input voltage or current. BJTs can be thought of as voltage-controlled current sources, but are more simply characterized as current-controlled current sources, or current amplifiers, due to the low impedance at the base.

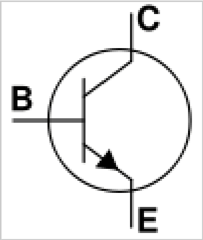
Early transistors were made from germanium but most modern BJTs are made from silicon. A significant minority are also now made from gallium arsenide, especially for very high speed applications (see HBT, below).

NPN

NPN is one of the two types of **bipolar transistors**, in which the letters "N" and "P" refer to the majority charge carriers inside the different regions of the transistor. Most bipolar transistors used today are NPN, since electron mobility is higher than hole mobility in semiconductors.

NPN transistors consist of a layer of P-doped semiconductor (the "base") between two N-doped layers. NPN transistors are commonly operated with the emitter at ground and the collector connected to a positive voltage through an electric load. A small current entering the base in common-emitter mode is amplified in the collector output.

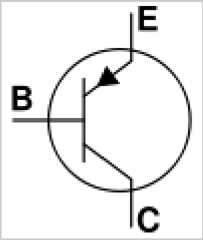
The arrow in the NPN transistor symbol is on the emitter leg and points in the direction of the conventional current flow when the device is in forward active mode.



The symbol of an NPN Bipolar Junction Transistor.

PNP

The other type of BJTs is PNP with the letters "P" and "N" referring to the majority charge carriers inside the different regions of the transistor. Few transistors used today are PNP, since the NPN type gives better performance in most circumstances.



The symbol of a PNP BJT.

PNP transistors consist of a layer of N-doped (often doped with boron) semiconductor between two layers of P-doped (often with arsenic) material. PNP transistors are commonly operated with the collector at ground and the emitter connected to a positive voltage through an electric load. A small current entering the base prevents current from flowing between the collector and emitter.

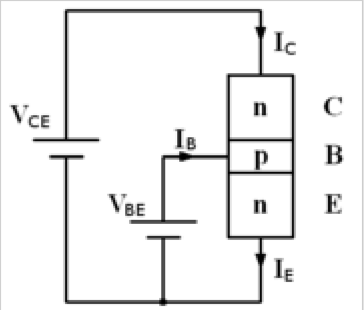
Heterojunction bipolar transistor

The heterojunction bipolar transistor (HBT) is an improvement of the BJT that can handle signals of very high frequencies up to several hundred GHz. It is common nowadays in ultrafast circuits, mostly RF systems.

Heterojunction transistors have different semiconductors for the elements of the transistor. Usually the emitter is composed of a larger bandgap material than the base. This helps reduce minority carrier injection from the base when the emitter-base junction is under forward bias and increases emitter injection efficiency. The improved injection of carriers into the base allows the base to have a higher doping level, resulting in lower resistance to access the base electrode. With a regular transistor, also referred to as homojunction, the efficiency of carrier injection from the emitter to the base is primarily determined by the doping ratio between the emitter and base. Because the base must be lightly doped to allow the high injection efficiency its resistance is relatively high. With a hererojunction the base can be highly doped allowing a much lower base resistance and consequently higher frequency operation.

Two commonly used HBT's are silicon–germanium and aluminum gallium arsenide. Silicon–germanium is widely used because it is compatible with standard silicon digital processes, allowing integration of very high speed circuitry with complex lower speed digital circuitry.

Transistors in circuits



Structure and use of npn transistor

The diagram opposite is a schematic representation of an npn transistor connected to two voltage sources. To make the transistor conduct appreciable current (on the order of 1 mA) from C to E, V_{BE} must be above a threshold voltage sometimes referred to as the cut-in voltage. The cut-in voltage is usually about 600 mV for silicon BJTs. This applied voltage causes the lower p-n junction to 'turn-on' allowing a flow of electrons from the emitter into the base. Because of the electric field existing between base and collector (caused by V_{CE}), the majority of these electrons cross the upper p-n junction into the collector to form the collector current, I_C. The remainder of the electrons recombine with holes, the majority carriers in the base, making a current through the base connection to form the base current, I_B . As shown in the diagram, the emitter current, I_E, is the total transistor current which is the sum of the other terminal currents. That is:

$$I_E = I_B + I_C$$

In the diagram, the arrows representing current point in the direction of the electric or conventional current—the flow of electrons is in the opposite direction of the arrows since electrons carry negative electric charge. The ratio of the collector current to the base current is called the *DC current gain*. This gain is usually quite large and is often 100 or more.

It should also be noted that the emitter current is related to V_{BE} exponentially. At room temperature, increasing V_{BE} by about 60 mV increases the emitter current by a factor of 10. The base current is approximately proportional to the emitter current, so it varies the same way.

Regions of operation

Bipolar transistors have five distinct regions of operation, defined mostly by applied bias:

- **Forward-active** (or simply, **active**): The emitter-base junction is forward biased and the base-collector junction is reverse biased. Most bipolar transistors are designed to afford the greatest common-emitter current gain, β_f in forward-active mode. If this is the case, the collector-emitter current is approximately proportional to the base current, but many times larger, for small base current variations.
- **Reverse-active** (or **inverse-active** or **inverted**): By reversing the biasing conditions of the forward-active region, a bipolar transistor goes into reverse-active mode. In this mode, the emitter and collector regions switch roles. Since most BJTs are designed to maximise current gain in forward-active mode, the β_f in inverted mode is several (2 - 3 for the ordinary germanium transistor) times smaller. This transistor mode is seldom used, usually being considered only for failsafe conditions and some types of bipolar logic.
- **Saturation**: With both junctions forward-biased, a BJT is in saturation mode and facilitates high current conduction from the emitter to the collector. This mode corresponds to a logical "on", or a closed switch.
- **Cutoff**: In cutoff, biasing conditions opposite of saturation (both junctions reverse biased) are present. There is very little current flow, which corresponds to a logical "off", or an open switch.
- **Avalanche breakdown region**

While these regions are well defined for sufficiently large applied voltage, they overlap somewhat for small (less than a few hundred millivolts) biases. For example, in the typical grounded-emitter configuration of an NPN BJT used as a pulldown switch in digital logic, the "off" state never involves a reverse-biased junction because the base voltage never goes below ground; nevertheless the forward bias is close enough to zero that essentially no currrent flows, so this end of the forward active region can be regarded as cutoff region.

History

The bipolar (point-contact) transistor was invented in December 1947 at the Bell Telephone Laboratories by John Bardeen and Walter Brattain under the direction of William Shockley. The junction version, invented by Shockley in 1951, enjoyed three decades as the device of choice in the design of discrete and integrated circuits. Nowadays, the use of the BJT has declined in favour of CMOS technology in the design of digital integrated circuits.

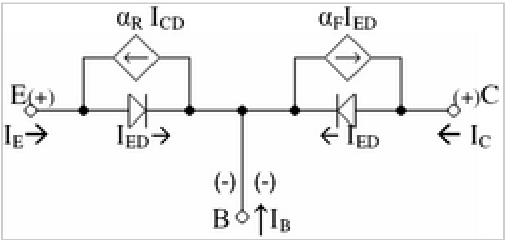
Germanium transistors

The germanium transistor was more common in the 1950s and 1960s, and while it exhibits a lower "cut off" voltage, making it more suitable for some applications, it also has a greater tendency to exhibit thermal runaway.

Theory and modeling

Ebers–Moll model

The emitter and collector currents in normal operation are well modeled by the Ebers–Moll model:



Ebers-Moll Model for PNP Transistor

Ebers-Moll Model for NPN Transistor

$$I_{\rm E} = I_{\rm ES}\left(e^{\frac{V_{\rm BE}}{V_{\rm T}}} - 1\right)$$

$$I_{\rm C} = \alpha_F I_{\rm ES}\left(e^{\frac{V_{\rm BE}}{V_{\rm T}}} - 1\right)$$

The base internal current is mainly by diffusion and

$$J_p(Base) = \frac{qD_p p_{bo}}{W}\left[e^{\frac{V_{EB}}{V_T}}\right]$$

Where

- $I_{\rm E}$ is the emitter current
- $I_{\rm C}$ is the collector current
- α_F is the common base forward short circuit current gain (0.98 to 0.998)
- $I_{\rm ES}$ is the reverse saturation current of the base–emitter diode (on the order of 10^{-15} to 10^{-12} amperes)
- $V_{\rm T}$ is the thermal voltage kT / q (approximately 26 mV at room temperature $\approx$ 300 K).
- $V_{\rm BE}$ is the base–emitter voltage
- W is the base width

The collector current is slightly less than the emitter current, since the value of α_F is very close to 1.0. In the BJT a small amount of base–emitter current causes a larger amount of collector–emitter current. The ratio of the allowed collector–emitter current to the base–emitter current is called *current gain*, β or $h_{\rm FE}$. A β value of 100 is typical for small bipolar transistors. In a typical configuration, a very small signal current flows through the base–emitter junction to control the emitter–collector current. β is related to α through the following relations:

$$\alpha_F = \frac{I_{\rm C}}{I_{\rm E}}$$

$$\beta_F = \frac{I_{\rm C}}{I_{\rm B}}$$

$$\beta_F = \frac{\alpha_F}{1 - \alpha_F}$$

Emitter Efficiency: $\eta = \frac{J_p(Base)}{J_E}$

Another set of equations used to describe the three currents in the any operating region are given below. These equations are based on the transport model for a Bipolar Junction Transistor.

$$i_{\rm C} = I_{\rm S}\left(e^{\frac{V_{\rm BE}}{V_{\rm T}}} - e^{\frac{V_{\rm BC}}{V_{\rm T}}}\right) - \frac{I_{\rm S}}{\beta_{\rm R}}\left(e^{\frac{V_{\rm BC}}{V_{\rm T}}} - 1\right)$$

$$i_{\mathrm{B}} = \frac{I_{\mathrm{S}}}{\beta_{\mathrm{F}}}\left(e^{\frac{V_{\mathrm{BC}}}{V_{\mathrm{T}}}} - 1\right) + \frac{I_{\mathrm{S}}}{\beta_{\mathrm{R}}}\left(e^{\frac{V_{\mathrm{BE}}}{V_{\mathrm{T}}}} - 1\right)$$

$$i_{\mathrm{E}} = I_{\mathrm{S}}\left(e^{\frac{V_{\mathrm{BE}}}{V_{\mathrm{T}}}} - e^{\frac{V_{\mathrm{BC}}}{V_{\mathrm{T}}}}\right) + \frac{I_{\mathrm{S}}}{\beta_{\mathrm{F}}}\left(e^{\frac{V_{\mathrm{BE}}}{V_{\mathrm{T}}}} - 1\right)$$

Where

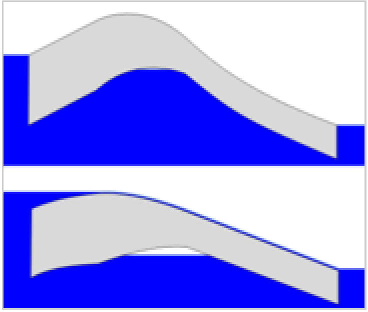
- i_C is the collector current
- i_B is the base current
- i_E is the emitter current
- β_F is the forward common emitter current gain (20 to 50)
- β_R is the reverse common emitter current gain (0 to 20)
- I_S is the reverse saturation current (on the order of 10^{-15} to 10^{-12} amperes)
- V_T is the thermal voltage (approximately 26 mV at room temperature $\approx$ 300 K).
- V_{BE} is the base–emitter voltage
- V_{BC} is the base–collector voltage

Base-width modulation

As the applied collector–base voltage (V_{BC}) varies, the collector–base depletion region varies in size. This is often called the "Early Effect" after its discoverer James M. Early.

This effectively means a variation in the width of the base region of the BJT. An increase in the collector–base voltage, for example, causes a greater reverse bias across the collector–base junction, increasing the collector–base depletion region width, decreasing the width of the base. This has two consequences :

- There is a lesser chance for recombination within the "smaller" base region.
- The charge gradient is increased across the base, and consequently, the current of minority carriers injected across the emitter junction increases.



Graded hetero-junction bipolar transistor. Top=closed, bottom=open, grey=band gap, blue=electrons, white=holes, y-axis=energy. Left=emitter, middle=base, right=collector

Both factors increase the collector or "output" current of the transistor due to an increase in the collector–base voltage.

In the forward active region the Early Effect modifies the collector current (i_C) and the forward common emitter current gain (β_F) to the following equations.

$$i_{\mathrm{C}} = I_{\mathrm{S}} e^{\frac{v_{\mathrm{BE}}}{V_{\mathrm{T}}}}\left(1 + \frac{V_{\mathrm{CB}}}{V_{\mathrm{A}}}\right)$$

$$\beta_F = \beta_{F0}\left(1 + \frac{V_{CB}}{V_A}\right)$$

Where

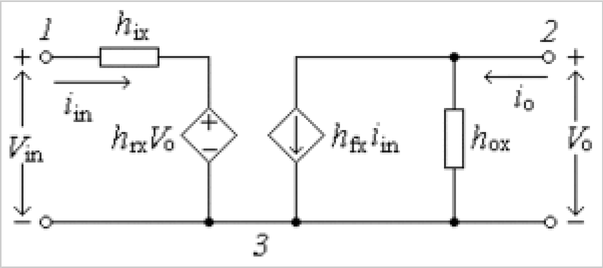
- V_{CB} is the collector–base voltage
- V_A is the Early voltage (15 V to 150 V)
- β_{F0} is forward common-emitter current gain when $V_{CB} = 0$ V

Punchthrough

When the base–collector voltage reaches a certain (device specific) value, the base–collector depletion region boundary meets the base–emitter depletion region boundary. When in this state the transistor effectively has no base. The device thus loses all gain when in this state.

h-parameter model

Another model commonly used to analyse BJT circuits is the *h-parameter* model. This model is a 2-port network particularly suited to BJTs as it lends itself easily to the analysis of circuit behaviour, and may be used to develop further accurate models. As shown the term *"x"* in the model represents the BJT lead depending on the topology used. For common-emitter mode the various symbols take on the specific values as –



Generalised h-parameter model of an NPN BJT. *replace **x** with **e**, **b** or **c** for CE, CB and CC topologies respectively.*

- x = 'e' since it is a CE topology
- Terminal 1 = Base
- Terminal 2 = Collector
- Terminal 3 = Emitter
- i_{in} = Base current (i_b)
- i_o = Collector current (i_c)
- V_{in} = Base-to-emitter voltage (V_{BE})
- V_o = Collector-to-emitter voltage (V_{CE})

and the h-parameters are given by –

- $h_{ix} = h_{ie}$ - The input impedance of the transistor (corresponding to the emitter resistance r_e).
- $h_{rx} = h_{re}$ - Represents the dependence of the transistor's I_B–V_{BE} curve on the value of V_{CE}. It is usually very small and is often neglected (assumed to be zero).
- $h_{fx} = h_{fe}$ - The current-gain of the transistor. This parameter is often specified as h_{FE} or the DC current-gain (β_{DC}) in datasheets.
- $h_{ox} = h_{oe}$ - The output impedance of transistor. This term is usually specified as an admittance and has to be inverted to convert it to an impedance.

As shown, the h-parameters have lower-case subscripts and hence signify AC conditions or analyses. For DC conditions they are specified in upper-case. For the CE topology, an approximate h-parameter model is commonly used which further simplifies the circuit analysis. For this the h_{oe} and h_{re} parameters are ignored (rather, they are set to infinity and zero, respectively). It should also be noted that the h-parameter model is suited to low-frequency, small-signal analysis. For high-frequency analyses this model is not used since it ignores the inter-electrode capacitances which come into effect at high frequencies.

Gummel–Poon charge-control model

The Gummel–Poon model [1] is a detailed charge-controlled model of BJT dyanamics, which has been adopted and elaborated by others to explain transistor dynamics in greater detail than the terminal-based models typically do [1] (http://ece-www.colorado.edu/~bart/book/book/chapter5/ch5_6.htm#5_6_2).

Applications of transistors

The BJT remains a device that excels in some applications, such as discrete circuit design, due to the very wide selection of BJT types available and because of knowledge about the bipolar transistor characteristics. The BJT is also the choice for demanding analog circuits, both integrated and discrete. This is especially true in very-high-frequency applications, such as radio-frequency circuits for wireless systems. The bipolar transistors can be combined with MOSFET's in an integrated circuit by using a BiCMOS process to create innovative circuits that take advantage of the best characteristics of both types of transistor.

Temperature sensors

Because of the known temperature and current dependence of the forward-biased base–emitter junction voltage, the BJT can be used to measure temperature by subtracting two voltages at two different bias currents in a known ratio [2] (http://www.maxim-ic.com/appnotes.cfm/appnote_number/689).

Logarithmic converters

Since base–emitter voltage varies as the log of the base–emitter and collector–emitter currents, a BJT can also be used to compute logarithms and anti-logarithms. A diode can also perform these nonlinear functions, but the transistor provides more circuit flexibility.

Vulnerabilities of transistors

Exposure of the transistor to ionizing radiation causes radiation damage. Radiation causes a buildup of 'defects' in the base region that act as recombination centers. The resulting reduction in mean carrier lifetime causes gradual loss of gain of the transistor.

See also

- Transistor models
- SPICE

References

1. ^ H. K. Gummel and R. C. Poon, "An integral charge control model of bipolar transistors," *Bell Syst. Tech. J.*, vol. 49, pp. 827--852, May-June 1970

External links

- Lessons In Electric Circuits - Biploar Junction Transistors (http://www.faqs.org/docs/electric/Semi/SEMI_4.html) (Note: this site shows current as a flow of electrons, rather than the convention of showing it as a flow of holes, so the arrows may appear the wrong way around)
- Characteristic curves (http://www.st-and.ac.uk/~www_pa/Scots_Guide/info/comp/active/BiPolar/bpcur.html)
- A water analogy (http://www.satcure-focus.com/tutor/page4.htm) (See also hydraulic analogy)
- The transistor (http://www.play-hookey.com/semiconductors/transistor.html) at play-hookey.com
- How Do Transistors Work? (http://amasci.com/amateur/transis.html) by William Beaty
- www.brookdale.cc.nj.us/fac/engtech/aandersen/engi242/bjt_models.pdf (http://www.brookdale.cc.nj.us/fac/engtech/aandersen/engi242/bjt_models.pdf)

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Category: Transistors

Common emitter

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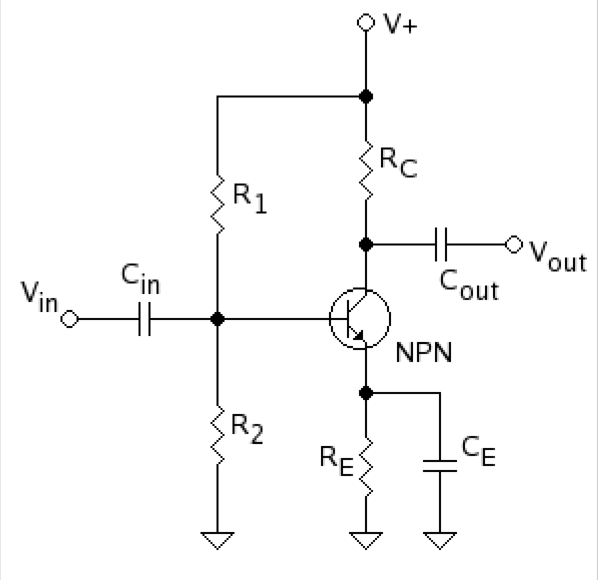
A **common emitter** is a type of electronic amplifier stage based on a bipolar transistor in series with a load element such as a resistor. The term "common emitter" refers to the fact that the emitter node of the transistor (indicated by an arrow symbol) is connected to a "common" power rail, typically the 0 volt reference or ground node. The collector node is connected to the output load, and the base node acts as input.



Common emitter amplifier, voltage divider bias (CEVDB) circuit configuration

Contents

Explanation of circuit

The electronic circuit diagram (right) shows a common emitter configuration with voltage divider bias (CEVDB). In the figure, the common emitter circuit comprises the load resistor R_C and NPN transistor with the output connected as shown; the other circuit elements are used for biasing the transistor and signal coupling/decoupling.

The resistor R_E between the emitter node and the shared ground appears at first glance to contradict the strict definition of "common emitter", but the term is still appropriate here because, for all frequencies of interest, the capacitor C_E acts as a low impedance by decoupling the emitter to ground. The emitter resistor provides a form of negative feedback called *emitter degeneration*, which increases the stability and linearity of the amplifier, especially in response to temperature changes.

For the common emitter circuit on the right this is necessary to ensure the transistor is in the active mode and thus prevent it from acting as a rectifier which would cause clipping on the negative portion the input signal, resulting in a distorted output.

The resistors R_1 and R_2 are chosen to ensure the base-emitter voltage is approximately 0.7 volts, which is the "on" voltage for a BJT transistor. These resistors, along with R_E, also determine the quiescent current flowing through the transistor and therefore its gain.

Application

Common emitter circuits are used to amplify weak voltage signals, such as the faint radio signals detected by an antenna. They are also used in a special analog circuit configuration known as a current mirror, where a single shared input is used to drive a set of identical transistors, each of whose current drive output will be nearly identical to each other, even if they are driving dissimilar output loads.

Small-signal characteristics

(The parallel lines indicate components in parallel.)

Inherent voltage gain:

With C_E present or $R_E = 0$:

$$\frac{V_{\text{out}}}{V_{\text{in}}} = -g_m(R_{\text{C}} \| R_{\text{load}})$$

Without C_E and $R_E > 0$:

$$\frac{V_{\text{out}}}{V_{\text{in}}} = \frac{-\beta_0(R_{\text{C}} \| R_{\text{load}})}{r_\pi + (1+\beta_0)R_{\text{E}}}$$

Transistors have widely varying transconductances (g_m), even among the same model, and affected strongly by temperature changes. Depending purely on the transconductance of the transistor to set the gain can have unpredictable effects. *Emitter degeneration* acts like negative feedback to minimize the effect this has on the overall gain of the amplifier. When R_E is included, if $g_m R_E \gg 1$ and $R_{\text{load}} \gg R_C$, the above formula can be approximated as:

$$\frac{V_{\text{out}}}{V_{\text{in}}} = -\frac{R_{\text{C}}}{R_{\text{E}}}$$

Input resistance:

With C_E present or $R_E = 0$:

$$r_{\text{in}} = R_1 \| R_2 \| r_\pi$$

Without C_E and $R_E > 0$:

$$r_{\text{in}} = R_1 \| R_2 \| (r_\pi + (1+\beta_0)R_{\text{E}})$$

Current gain:

$$A_{\text{vm}} \frac{r_{\text{in}}}{R_{\text{load}}}$$

Output resistance:

$$r_{\text{out}} = R_{\text{C}}$$

The variables not listed in the schematic are:

- g_m is the transconductance in siemens, calculated by $g_m = I_\mathrm{C}/V_\mathrm{T}$, where:
    - I_C is the collector bias current
    - $V_\mathrm{T} = kT/q$ is the *thermal voltage*, calculated from Boltzmann's constant, the charge on an electron, and the transistor temperature in kelvins. At room temperature this is about 25 mV (Google calculator (http://www.google.com/search?hl=en&q=300+kelvin+*+k+%2F+elementary+charge+in+millivolts+%3D)).
- $\beta_0 = I_\mathrm{C}/I_\mathrm{B}$ is the current gain at low frequencies (commonly called h_{FE}). This is a parameter specific to each transistor, and can be found on a datasheet.
- $r_\pi = \beta_0/g_m = V_\mathrm{T}/I_\mathrm{B}$

See also

External links

- Basic BJT Amplifier Configurations (http://people.deas.harvard.edu/~jones/es154/lectures/lecture_3/bjt_amps/bjt_amps.html)
- NPN Common Emitter Amplifier (http://230nsc1.phy-astr.gsu.edu/hbase/electronic/npnce.html) — HyperPhysics
- The Common Emitter Amplifier (http://www.phys.ualberta.ca/~gingrich/phys395/notes/node81.html), Physics Lecture Notes, D.M. Gingrich, University of Alberta Department of Physics

Retrieved from "http://en.wikipedia.org/wiki/Common_emitter"

Categories: Electronic amplifiers | Transistors

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