sistor Gain: hFE, hfe & Beta, β

t gain is one of the important electronic circuit design specifications for a transistor – three figures are often seen: Beta β, hFE & hfe, each of which is different.

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r Tutorial Includes:

basics Gain: Hfe, hfe & Beta Transistor specifications BJT Early Effect Transistor and diode g codes Choosing replacement transistors

component data: Transistor component data

cuit, the current gain of a bipolar transistor will be of paramount importance. Whether the circuit is common ommon collector, etc, and whether it uses NPN transistors or PNP transistors.

other parameters of these semiconductor devices are also important, the current gain is particularly key he bipolar transistor is a current operated device.

istor current gain is normally specified in terms of hFE, hfe, or the Greek letter Beta β. Although these rs are very similar ata first glance, they are different and the right quantity should be used for the relevant of an electronic circuit design.

BC547 Plastic leaded transistor

signing any transistor circuit, it is necessary to ensure there is sufficient gain to enable the circuit to operate Gain levels can be very high for many small signal devices, with current gains up to 1000 not uncommon, wer transistors, gains are very much lower and can sometimes be in the region of only 25 - 50.

current gain specifications for transistors normally have a very wide tolerance, and therefore circuits need to to accommodate this. However the minimum transistor gain must be sufficient to support the correct of the particular circuit design.

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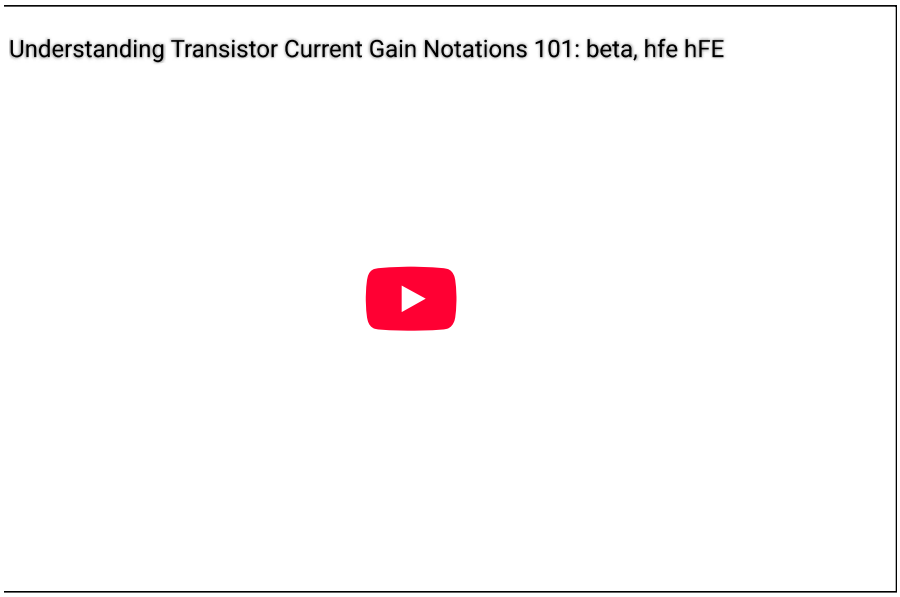
14 JUNE 2025

Fact of the day: It was in this month in 1916 that W Schottky in Germany described the principle of the superhet radio as a powerful and selective amplifier. He never made the receiver to prove his idea and was beaten to this goal by Edwin Armstrong. Also on this day in 1923, Charles Jenkins, an inventor from Dayton, Ohio, who invented a mechanical television system called radiovision and claimed to have transmitted the earliest moving silhouette images.

Quote: *I never lose, I either win or I learn.* Nelson Mandela

Point to ponder: The name of the search engine Google is a play on the word googol, meaning a figure of 1 followed by a hundred zeros. The name was chosen to give an indication of the size of the indexing.



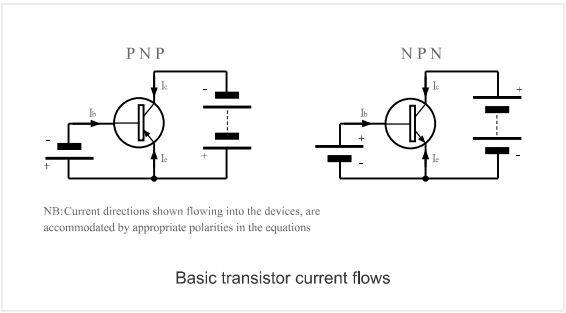
Video: Understanding Transistor Current Gain Notations

sistor gain & Beta, β

ansistors are what are termed current controlled devices. In other words the current flowing int he base ntrols the level of current in the collector. Accordingly the current gain between the base and collector is the factor in any transistor circuit design.

dertaking many calculations in an electronic circuit design, the transistor current gain is given in terms of the :er Beta; β.

e forward current gain for the transistor when operated in a common emitter mode. Common emitter is one re common circuit configurations for transistor circuit designs.



Basic transistor current flows

it is not strictly exact, the equation below is more than accurate enough for all practical calculations. This gain equation is the one that is seen in most instances.

$$\mathrm{Ic} \approx B \cdot \mathrm{Ib}$$

ent gain of the transistor is used not only to set up the bias conditions for the circuit design, but also to at there is sufficient gain within the circuit to give the overall required function.

ple when designing a common emitter transistor circuit, the current gain figures are used to ensure that the divider setting the bias for the base is able to provide sufficient current.

the emitter current, it is possible to determine the base current that is needed and hence design the divider to provide sufficient current at the required voltage.

more . . . . *in-depth transistor gain equations and theory.*

sistor hfe

· Hfe, hfe are often seen quoted as the current gain figure for a transistor. This can lead to some confusion, s to explain what each one means.

on for using hfe is that it refers to way of measuring the input and output parameters of a transistor.

eters are one of the basic parameters used when treating a circuit as a black box. However as a transistor low input impedance and a high output impedance a form of parameter known as h or hybrid parameters

forward transfer characteristic, i.e. transistor gain when used in the common emitter mode.

ctly the same as the transistor Beta, β - it is just a little more correct to use it in datasheets.

small signal transistor gain

istor gain varies slightly when measured for DC and for small signal variations.

ions for the two figures are slightly different. Often BDC is used for the DC gain, and BAC is used for the AC h may also be referred to as the transistor small signal gain.

for hfe. Hfe with a capital H is used for the DC gain, where as the AC or small signal gain is denoted by hfe all letter h.

sistor gain summary

a number of different notations that are used for transistor current gain. It is worth understanding exactly are and what differences exist between them.

β: This is the basic notation for the forward current gain of a transistor and it is widely used in many onic circuit design calculations.

This is the current gain for a transistor expressed as an h parameter (hybrid parameter). The letter f indicates is a forward transfer characteristic, and the letter e indicates it is for a common emitter configuration. The etter h indicates it is a small signal gain. hfe and small signal Beta are the same. This figure is widely used sistor data sheets and hence within the circuit design calculations.

The hFE parameter differs from hfe in that it is the h parameter for the DC or large signal steady state d current gain. This figure will be used when setting up bias conditions or for use within power supply circuit ıs, or other circuits where the DC gain is important.

ent abbreviation used for the transistor gain, hFE, hfe & Beta are all widely used, although the parameters nd to be more widely used in datasheets.

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wide variation in levels of current gain found in all transistors, this makes the exact figures for current gain a emic. Any transistor circuit design should be able to accommodate a wide variation iin the level of current ther it is small signal or DC.

ts to note

several points which are of interest when judging the level of current gain that a transistor has:

of power transistors: The gain of power transistors is typically very much less than that of small signal s. In fact power transistors may have current gain figures of less than 50.

ack of gain can be overcome by using another transistor to drive the power transistor, the overall current gain e increased to the desired level. Darlington configurations where two transistors are used together may also eful to increase the overall current gain while also retaining the high current capability of the power transistor.

nt gain varies widely: It is worth noting that for any transistor type there can be a very large spread en different devices. Normally the performance of the circuit does not depend directly on the actual current especially as negative feedback is often included, or for switching applications the actual gain is not critical.

always wise to ensure there is enough current gain available using the minimum figure given in the eets.

tion of current gain

ally expected that the value of current gain β for a bipolar transistor is constant, however there are some that occur in the value of β or h_{FE}.

ations with collector current: The collector current level can cause a variation in the level of β or or h_{FE}.

low current: This occurs when the bipolar transistor is running at very low current levels as a result of kage mechanisms being seen and affecting the overall transistor current. For example the specification for a 109B operating with a collector current, I_C of 10μA and a collector emitter voltage V_{CE} of 5V has a minimum n of 40, whereas for a collector current, I_C of 2mA and a collector emitter voltage V_{CE} of 5 V it has a imum gain of 200.

high current: It is found that the level of the bipolar transistor current gain β starting to reduce as the rent is increased. This results from a high level injection occurring.

ally the bipolar transistor is biassed to operate in its linear region for analogue signals and it can be assumed e current gain is constant. Accordingly, for good linear operation, the transistor should be operated well its operating range and not running into the rails or drawing excessive current for the particular onductor device.

erature effects on current gain β: Temperature has a major effect on many bipolar transistor parameters, which is the current gain, β / h_{FE}, etc.

ency: The frequency of operation will have a marked effect on the value of current gain. For low ncies, the value of h_{fe}, i.e. the small signal gain will not vary too much from the value for DC h_{FE} figure - a ule of thumb is that the mid figure for h_{FE} can be used. As the circuit operation for any circuit should not be ly dependent upon the actual gain for the semiconductor device. If the frequency rises and even starts to ach the f_T of the device, then a lower gain figure must be used.

facturing spreads: As a result of the tolerances in the manufacturing processes, the current gain of transistors will vary over a considerable range. (See below).

lescriptions the variations of β described for bipolar transistors can be equally applicable to h_{FE}.

sheet specifications of current gain

lt of the manufacturing processes, bipolar transistors typically have a wide range in their values of current

ly mentioned, figures for both H_{fe} the DC gain and h_{fe} the small signal AC gain. Often figures for both rs are specified.

ing the specification, the test conditions are outlined. The current level and collector emitter voltage are specified.

of the spread of current gain levels in these electronic components, figures for minimum, typical and may be given. Often, not all of these figures are give: sometimes only the minimum figure for the current be specified.

can be a significant variation in gain for a given type of transistor, a suffix letter on the end of the transistor er may specify the band of gain expected for that particular device. For example a BC109B has a current between 200 and 450, and a BC109C has a current gain h_{FE} between 420 and 800.

covers it.

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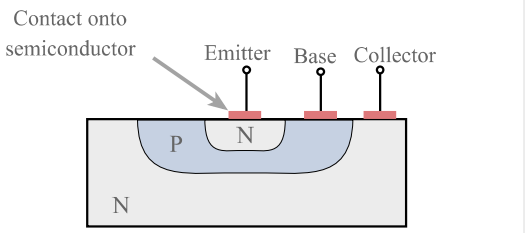
ons for large gain differences between transistors

e most obvious facts about transistor parameters, is the very wide variation in the levels of gain between ransistors of the same type.

ge variations in the current gain: β h_{FE} and h_{fe} can occur between the same transistor type, between batches and even different transistors manufactured ont he same wafer.

nt gain depends on manufacturing characteristics such as the thickness of the base and the doping level. e not exactly the same from one batch to another or even one transistor to another, so the gain will vary tly.

t the structure of a planar transistor, it can be seen that the base region thickness is dependent upon the which the doping for the collector region and emitter region extends. As the base region is so thin, even iations in the depth of the doping can cause large variations in the base region thickness on top of any in doping of the base region.



Simplified planar transistor structure

these variations are summed together, these give rise to the large variation in the levels of current gain: β h_{fe} that are seen.

meter h_{FE} measurements

ital multimeters, DMMs have a capacity for measuring the gain of a transistor. This can be quite a useful especially for checking whether a transistor is still functioning or not.

this type of measurement is incorporated in the lower end digital multimeters as it is not a particularly test and is generally more appropriate for hobbyist and 'quick check' style measurements of the transistor

Digital multimeter showing the controls & connections

figures given within a datasheet are taken under set conditions, whereas the measurement incorporated igital multimeter will not be defined in the same way.

the measurements made by DMMs will use DC voltages and therefore the measurement is of h_{FE} rather small signal gain h_{fe} value. Also the conditions of voltage and current for the test will not be known as these ormally provided in the digital multimeter datasheet.

ansistor gain measurements incorporated within DMMs are often useful for a quick look type of nent, but their values of gain may not always be as accurate as the other functions on the test instrument.

the circuit used, and whether NPN transistors or PNP transistors are used, the current gain of the transistor arameter. Although there are significant gain variations, most circuits are tolerant to the actual gain of the requiring it to be sufficient to ensure correct operation.

PREVIOUS PAGE NEXT PAGE

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