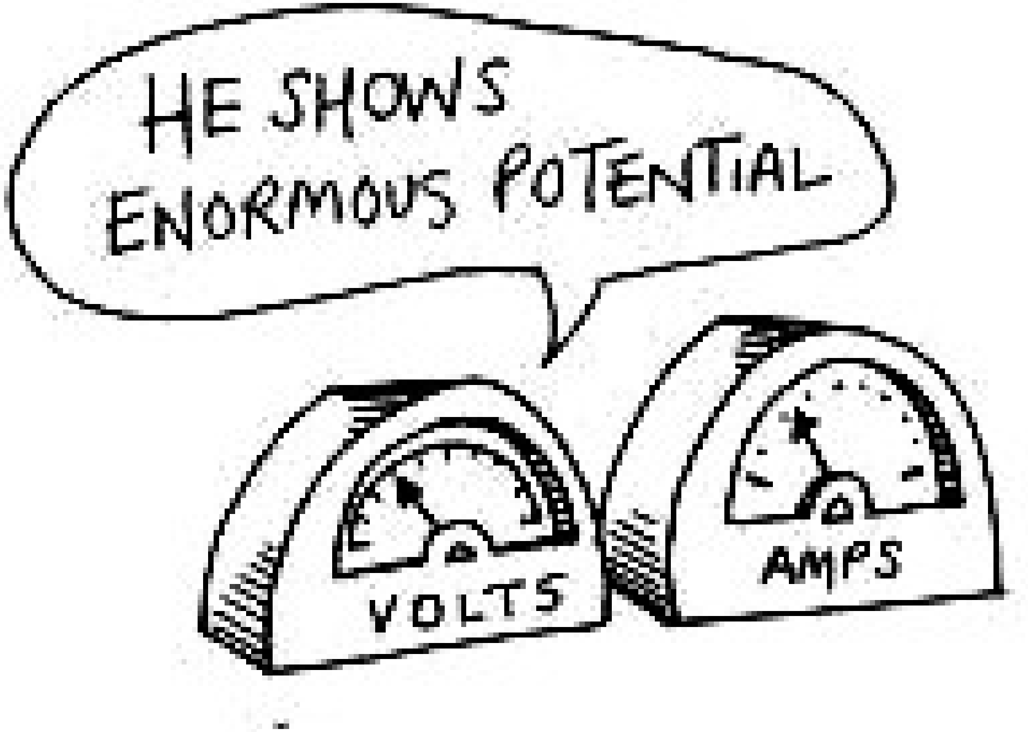
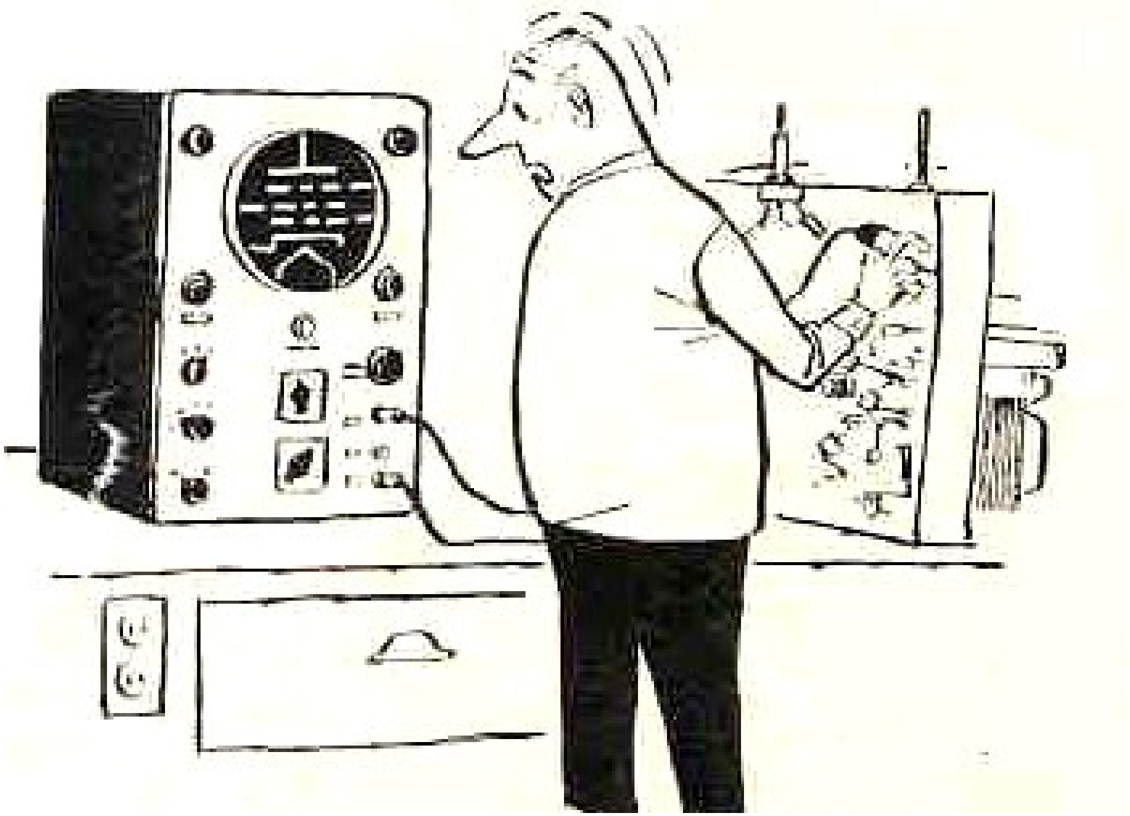
The New England Radio Discussion Society electronics course (Phase 3 cont'd)



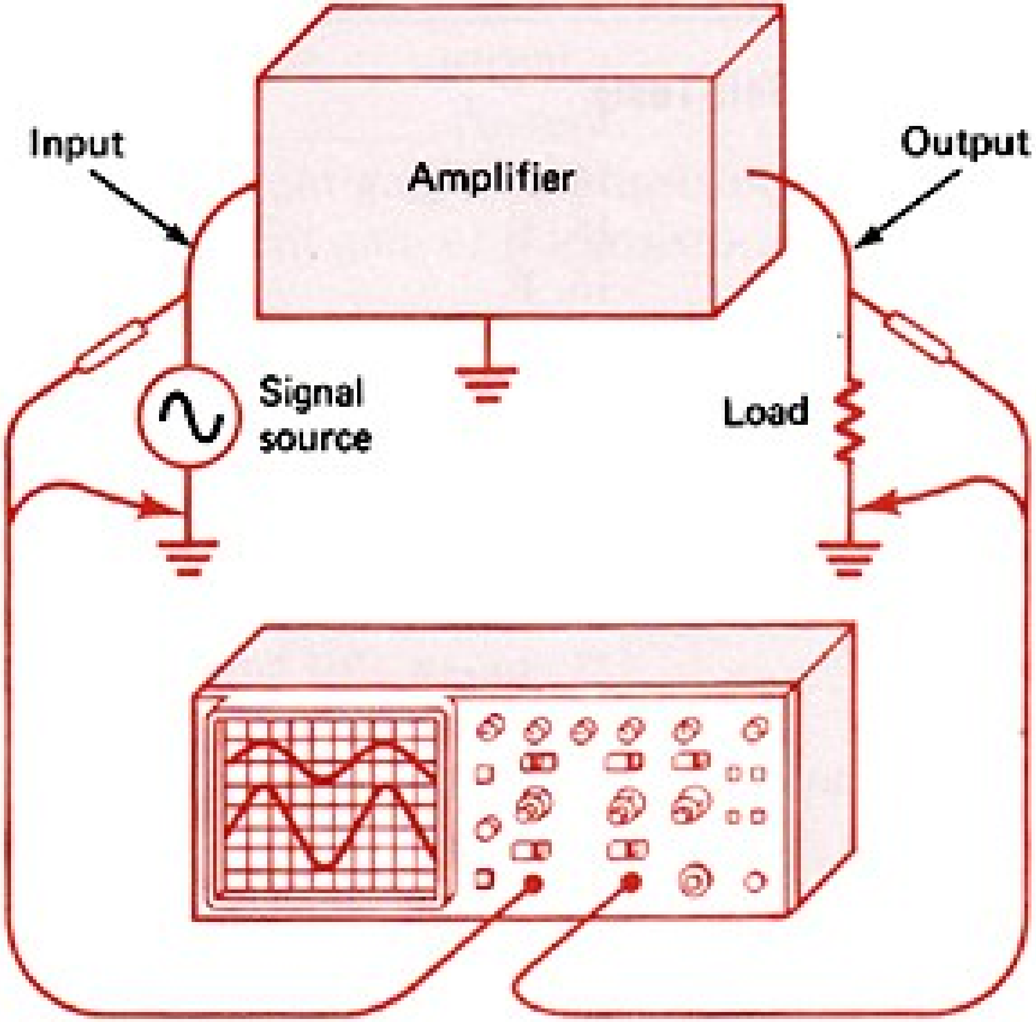
Introduction to transistors

AI2Q – Dec.
2016

Let’s start with a few *amplifier* fundamentals!



Who needs an amplifier, anyway?



Gain = $\frac{\text{output}}{\text{input}}$

An *amplifier* is a circuit “block” that provides more output than its input.

Here we’re using a dual-trace oscilloscope to compare input and output *signal levels*.

The ratio of an amplifier’s input to its output is called *gain*, and gain is indicated by the upper-case letter A.

***Gain* can be expressed as a function of voltage ratios.**

$$A_V = \frac{V_{\text{out}}}{V_{\text{in}}} = \text{voltage gain}$$

Voltage gain is usually used for what are dubbed *small-signal* amplifiers.

Ratios can also be expressed as current *gain*.

$$A_I = \frac{I_{\text{out}}}{I_{\text{in}}} = \text{current gain}$$

Gain can also be expressed for power (W).

In this example the output power is 8 watts and the input is 500-mW.

$$A_P = \frac{P_{\text{out}}}{P_{\text{in}}} = \frac{8\ \text{W}}{0.5\ \text{W}} = 16$$

Logarithms are used to express ratios as *decibels (dB)*.

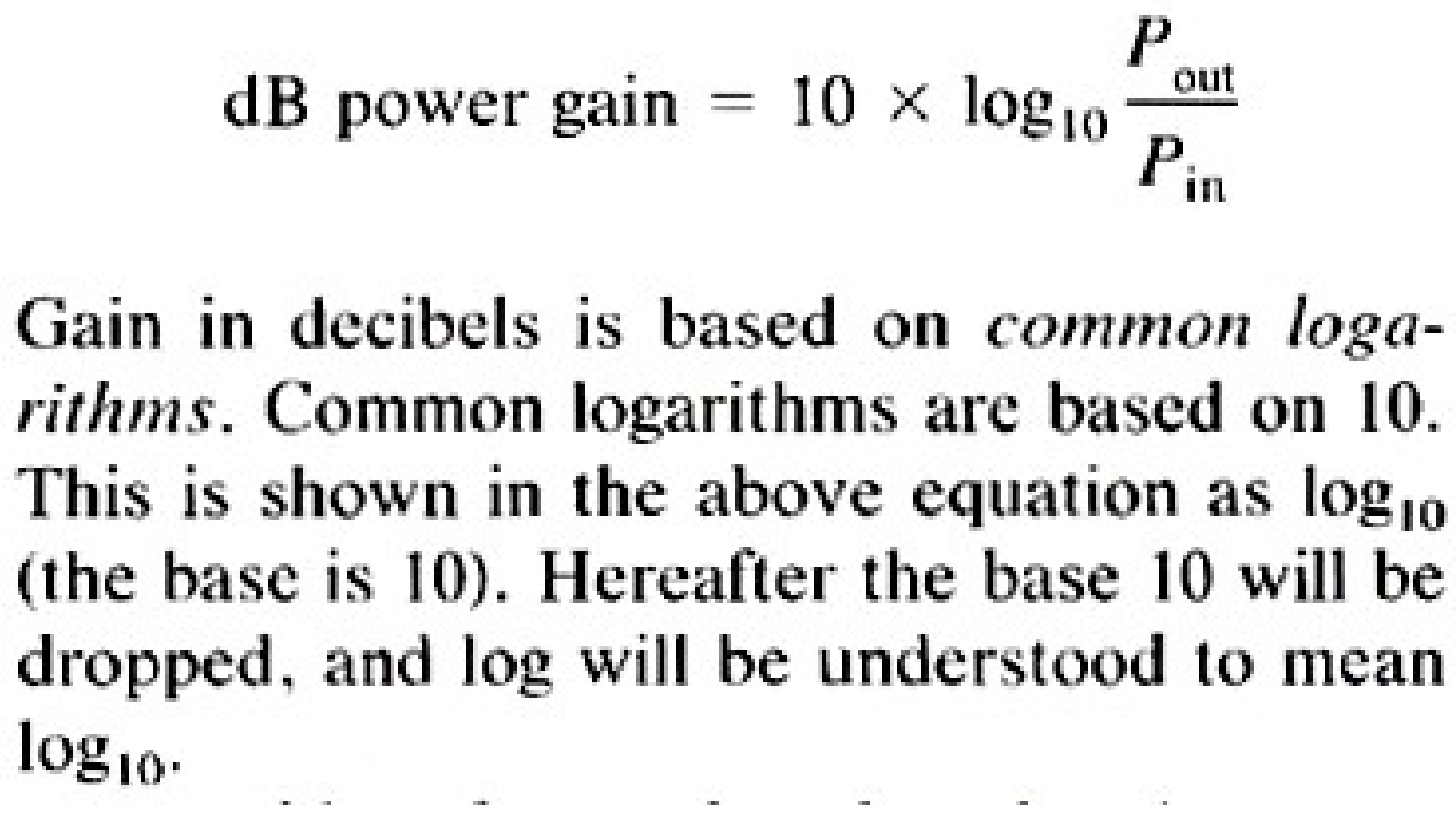
The loudness response of the human ear is not linear.

It is *logarithmic*.

Common logarithms are *powers of 10*. For example,

$$
\begin{aligned}
10^{-3} &= 0.001 \\
10^{-2} &= 0.01 \\
10^{-1} &= 0.1 \\
10^{0} &= 1 \\
10^{1} &= 10 \\
10^{2} &= 100 \\
10^{3} &= 1000
\end{aligned}
$$

The logarithm of 10 is 1. The logarithm of 100 is 2. The logarithm of 1000 is 3. The logarithm of 0.01 is −2. Any positive number can be converted to a common logarithm. Logarithms can be found with a scientific calculator. Enter the number and then press the "log" key to obtain the common logarithm for the number.



$$\text{dB power gain} = 10 \times \log_{10} \frac{P_{\text{out}}}{P_{\text{in}}}$$

Gain in decibels is based on *common logarithms*. Common logarithms are based on 10. This is shown in the above equation as $\log_{10}$ (the base is 10). Hereafter the base 10 will be dropped, and log will be understood to mean $\log_{10}$.

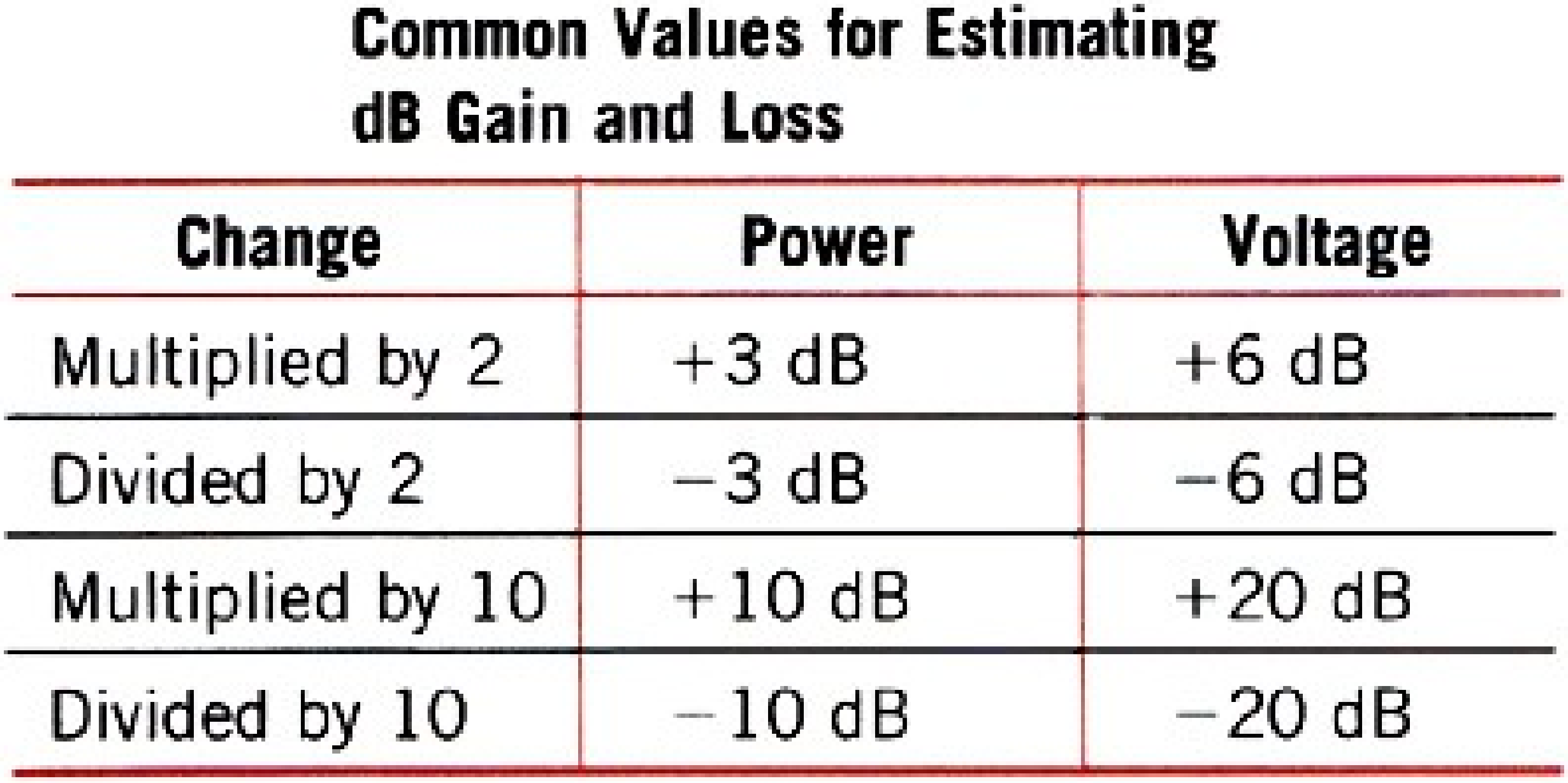
NOTE: a dB is a tenth of a *Bel.* The Bel is named after Alexander Graham Bell.

Here is the dB equation for voltage:

$$\text{dB voltage gain} = 10 \times 2 \times \log \frac{V_{\text{out}}}{V_{\text{in}}}$$

$$= 20 \times \log \frac{V_{\text{out}}}{V_{\text{in}}}$$

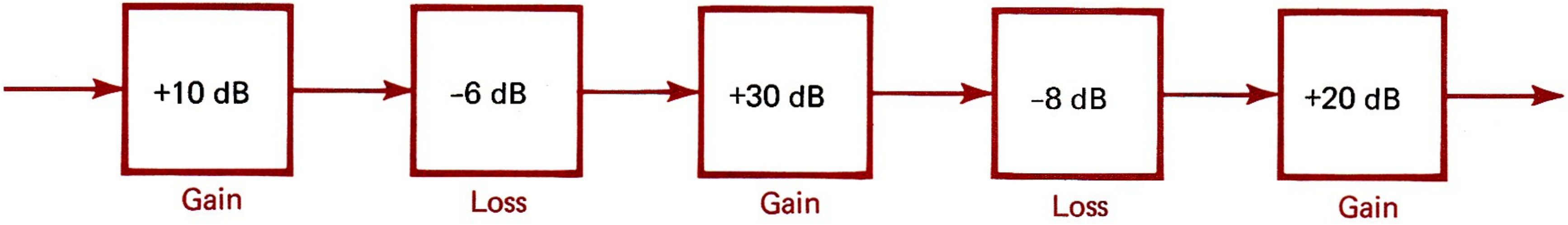
VOLTAGE



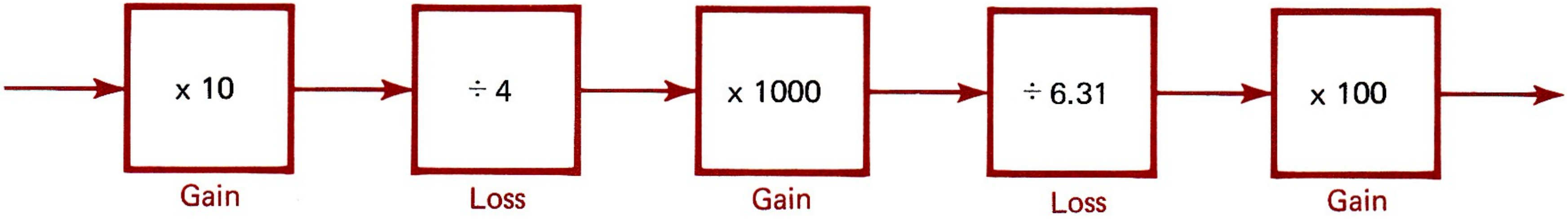
Common Values for Estimating dB Gain and Loss

Change	Power	Voltage
Multiplied by 2	+3 dB	+6 dB
Divided by 2	−3 dB	−6 dB
Multiplied by 10	+10 dB	+20 dB
Divided by 10	−10 dB	−20 dB

The dB is a useful unit when comparing gain and *loss* in various electronics “stages”



Gain and loss in decibels

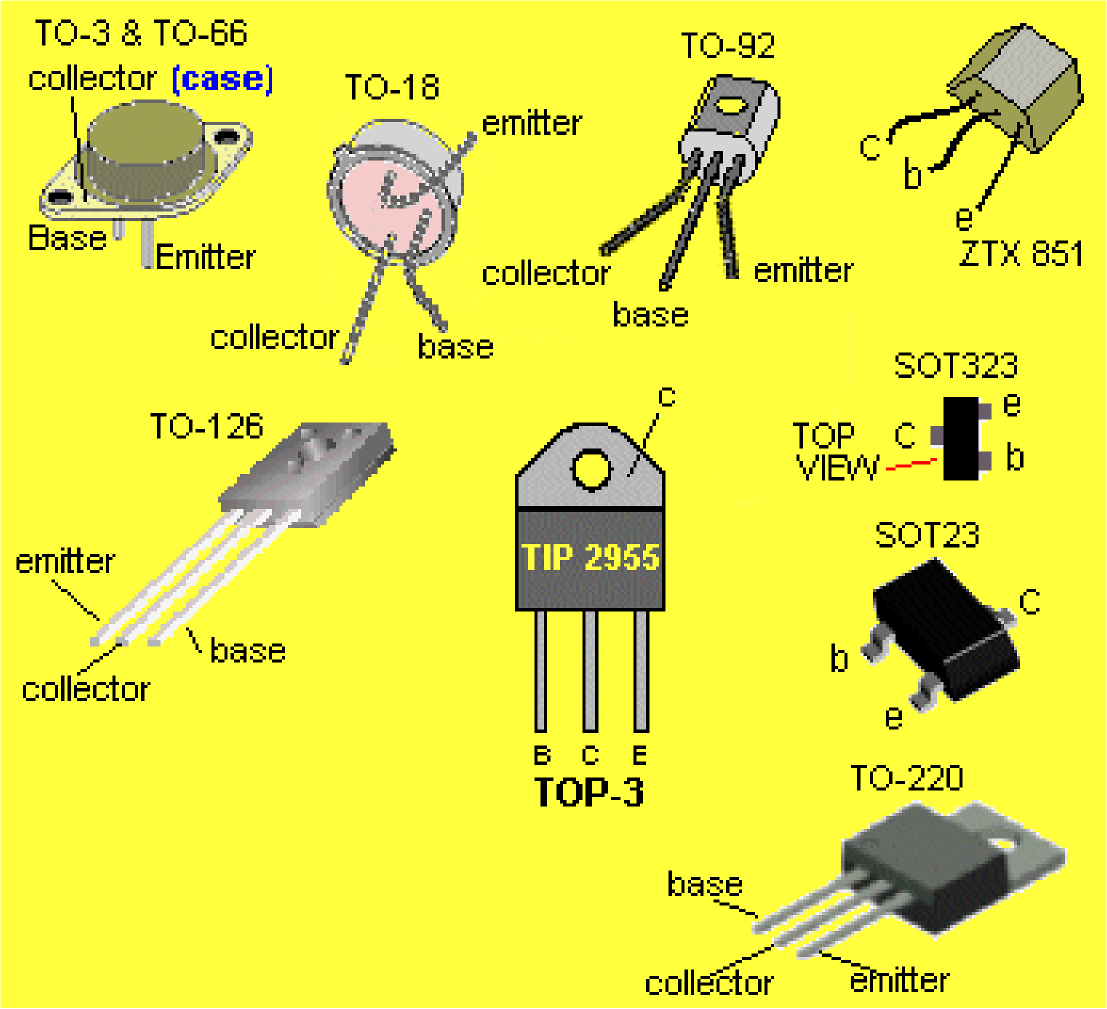


Gain and loss in ratios.

The solid-state “transfer resistor” is at the heart of the amplifier.
It’s commonly known as the
***trans-istor*.**

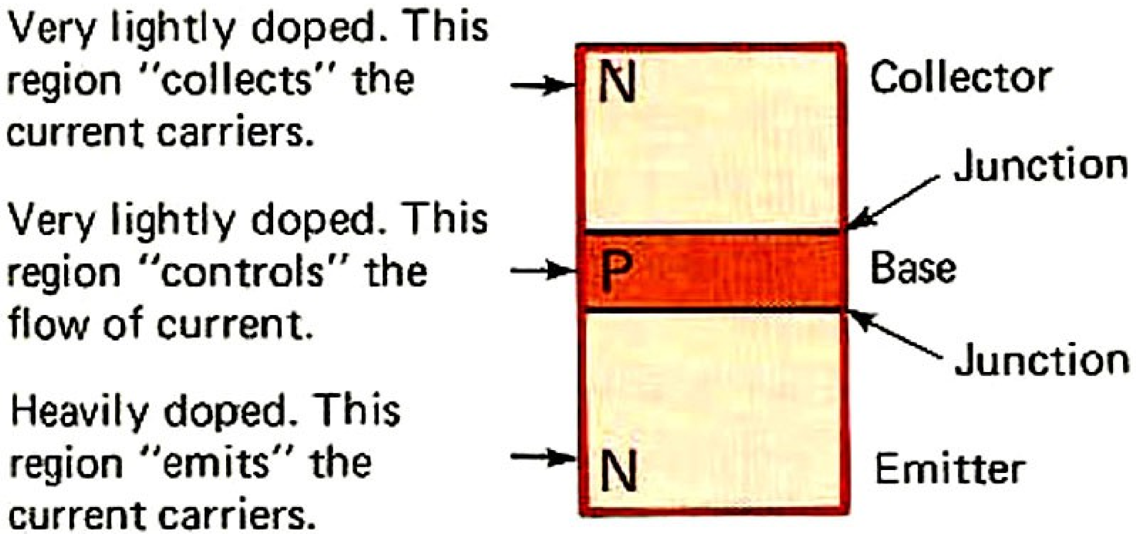
Sometimes the acronym XSTR is used as an abbreviation for the word transistor.

Typical transistor packages



So, what’s inside a XSTR?

A *bipolar* NPN transistor’s structure



Very lightly doped. This region “collects” the current carriers.

Very lightly doped. This region “controls” the flow of current.

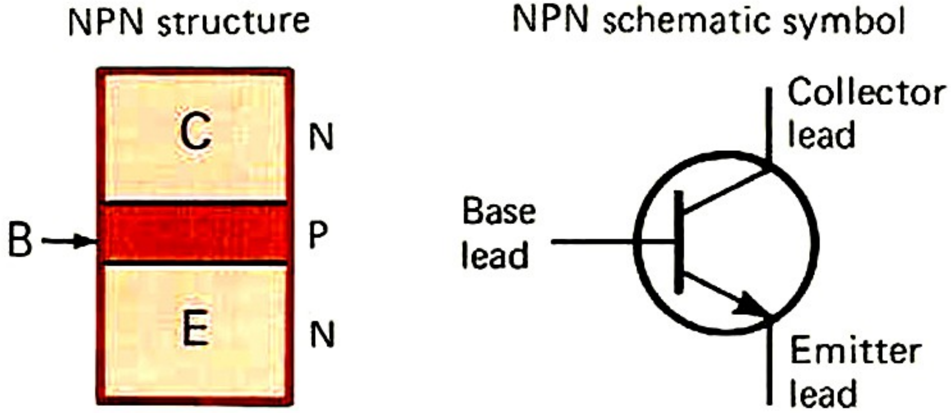
Heavily doped. This region “emits” the current carriers.

NPN transistor structure

The *collector* collects the carriers. The emitter emits the carriers. The base acts as the control region. The *base* can allow none, some, or many carriers to flow from the emitter to the collector.

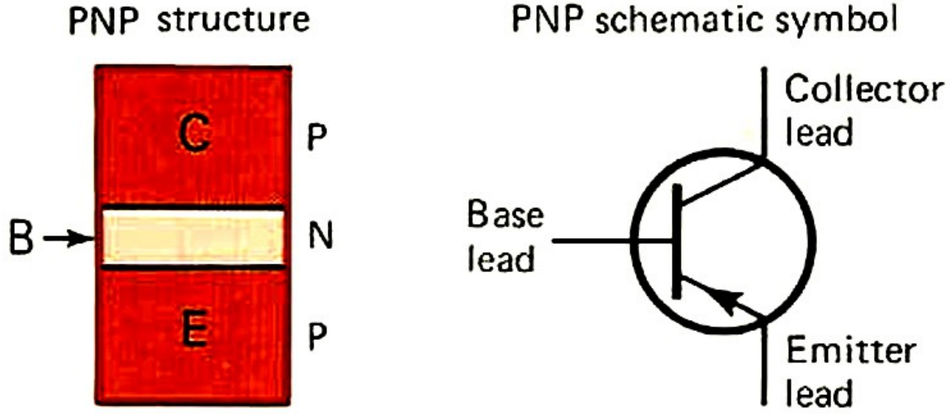
Bipolar junction transistors are also sometimes referred to as *BJT*s.

NPN = “Not Pointing iN



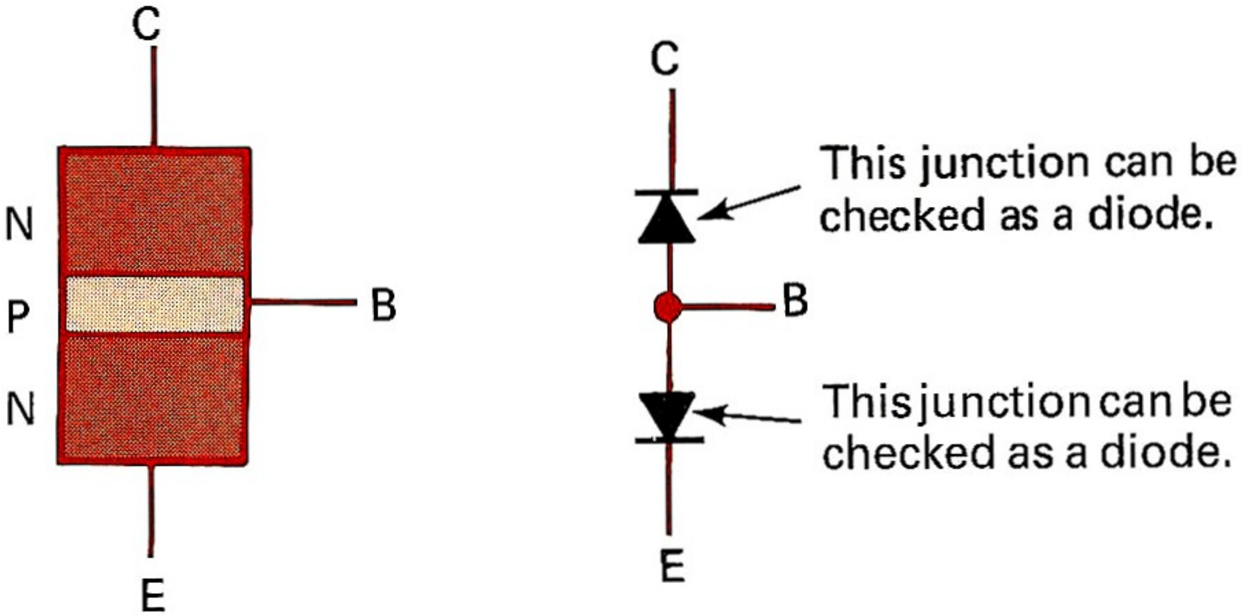
Positive base region between two negative regions

There are also PNP bipolar junction transistors.



Negative base region between two positive regions

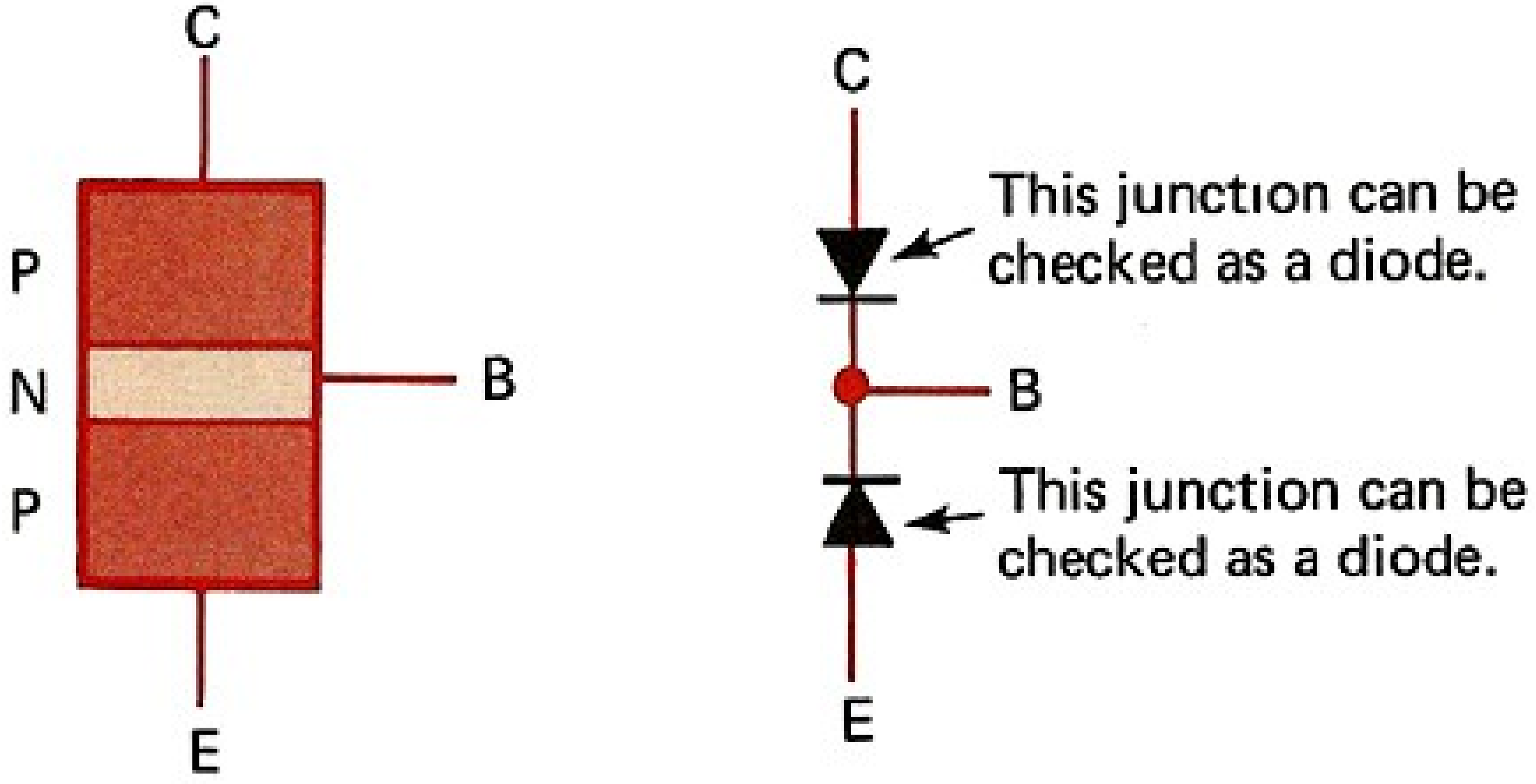
You can think of a BJT's junctions as two back-to-back diodes.



This junction can be checked as a diode.

This junction can be checked as a diode.

Ditto for PNP bipolar devices



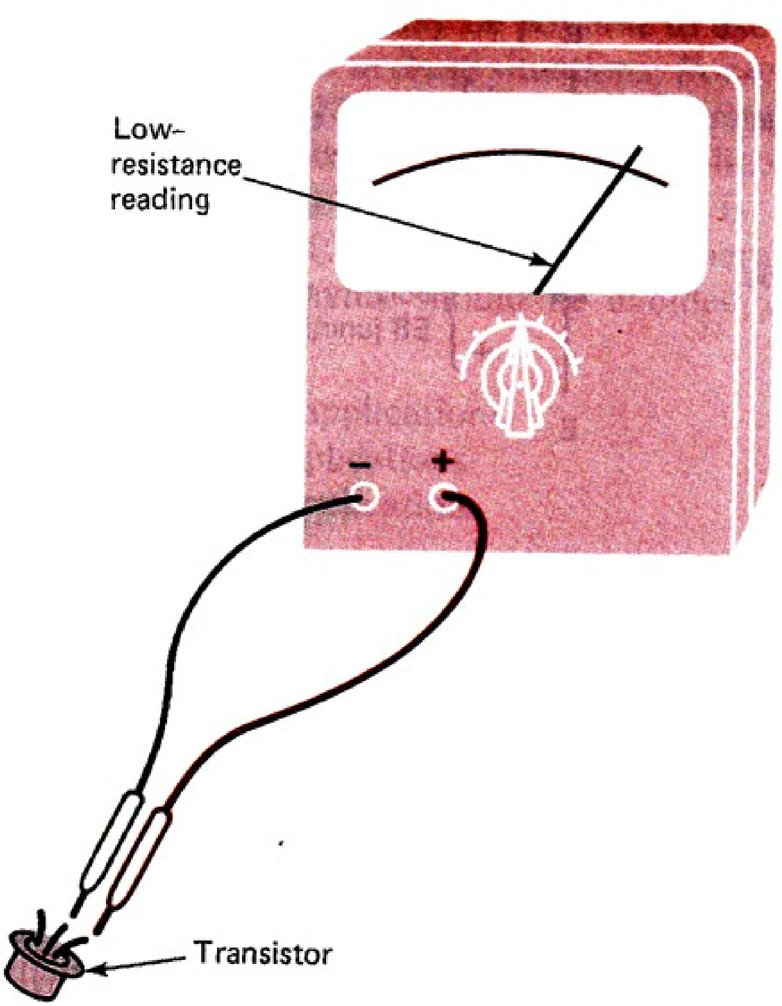
This junction can be checked as a diode.

This junction can be checked as a diode.

N1QX's Simpson 260 VOM

You can check BJT "diode" junctions (*not soldered into a circuit*) with an ohmmeter that has high enough voltage across its probes to turn on a PN "diode" junction in the forward direction.

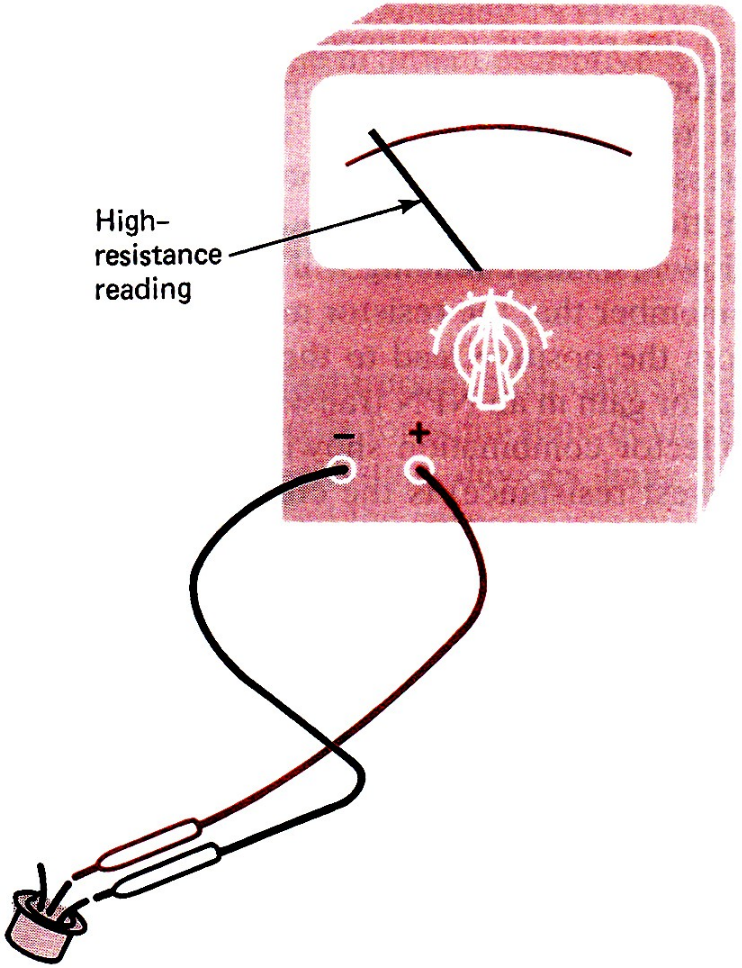
Your ohmmeter will read quite low (*i.e.* 15 ohms).



Simpson 260 VOM

Here’s the same BJT junction under test, with the polarity of the ohmmeter leads reversed.

The “diode” is now reverse biased, and the ohmmeter reads very high (*i.e.* 25-kohms)



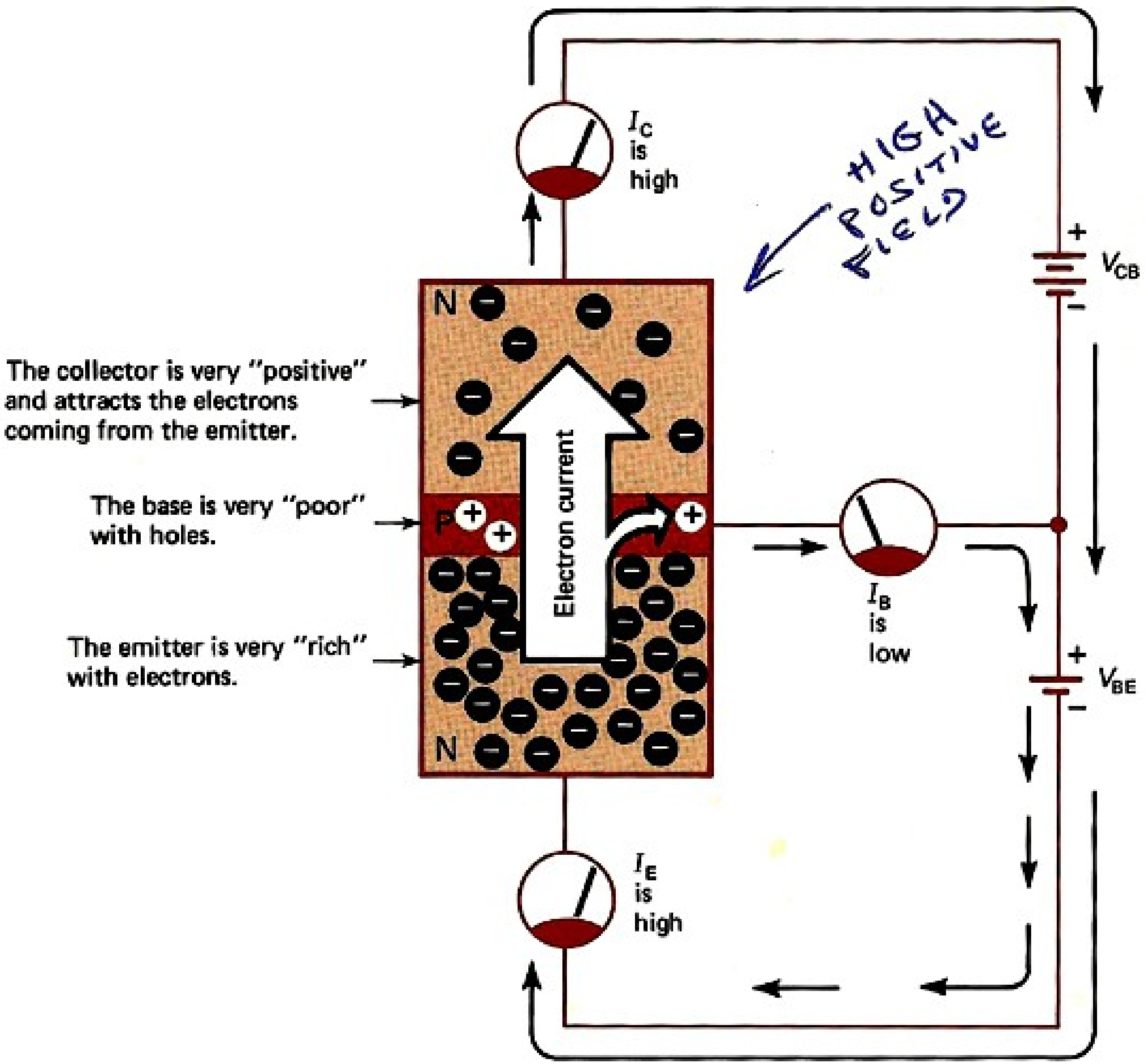
A typical value for the B-to-C resistance might be 10,000 ohms. It’s high since the B-C junction is reverse biased.

On the other hand, the B-E resistance might be 100 ohms or so. It’s low because the B-E junction is forward biased.

What happens inside the NPN xstr?

(1) In this diagram the emitter-to-base junction is forward biased.

(2) The collector-to-base junction is <u>always</u> reverse biased.



The collector is very "positive" and attracts the electrons coming from the emitter.

The base is very "poor" with holes.

The emitter is very "rich" with electrons.

(1) The *collector* collects the carriers.

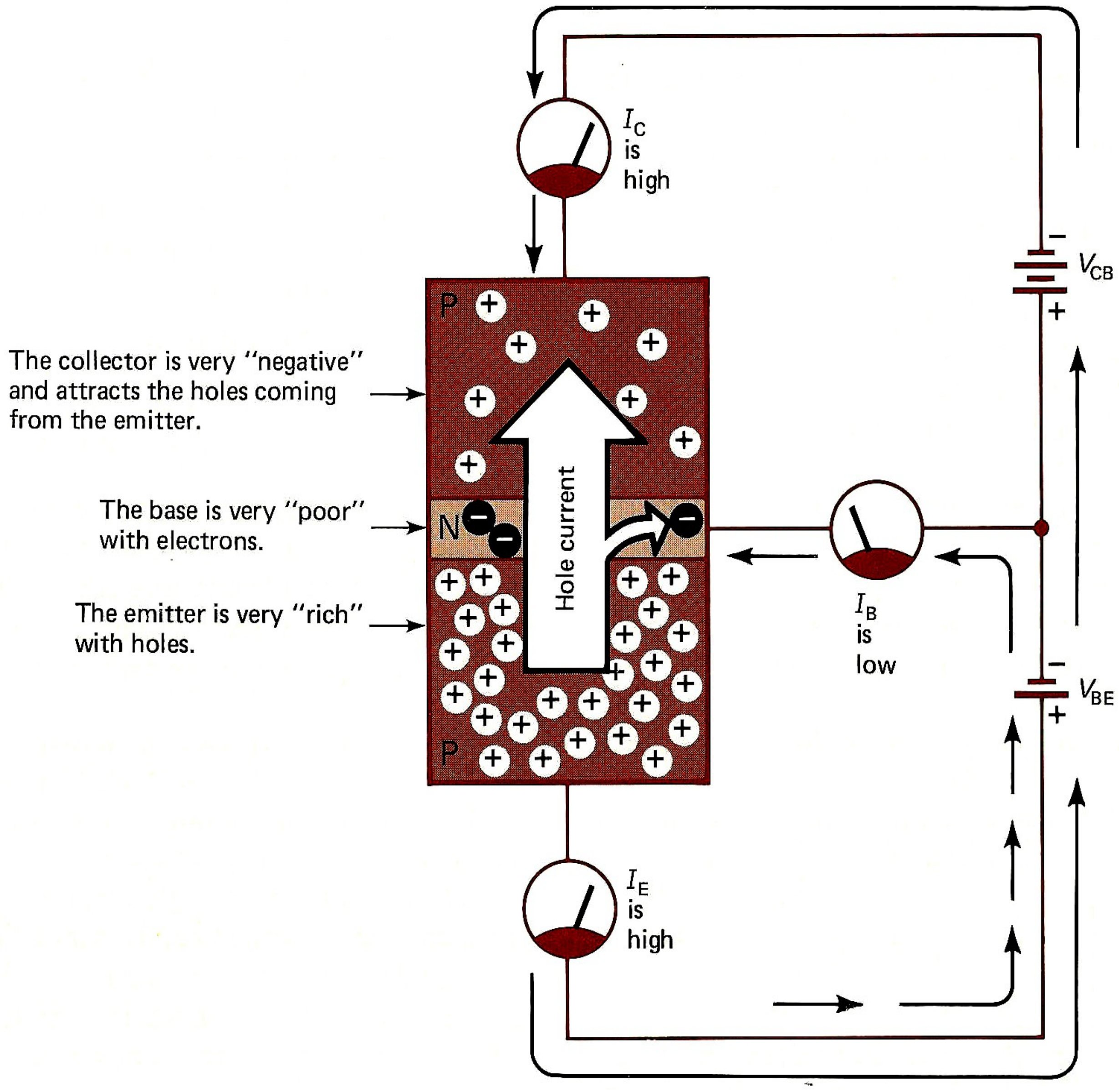
(2) The *emitter* emits the carriers.

(3) The *base* acts as a control region.
It is *extremely* thin.

The base can permit (a) no carriers, or (b) some carriers, or (c) many carriers to flow from emitter to collector.

Here’s current flow in a PNP BJT.

Note how the B-E junction is again forward biased in this example, and how the B-C junction is <u>always</u> reverse biased.

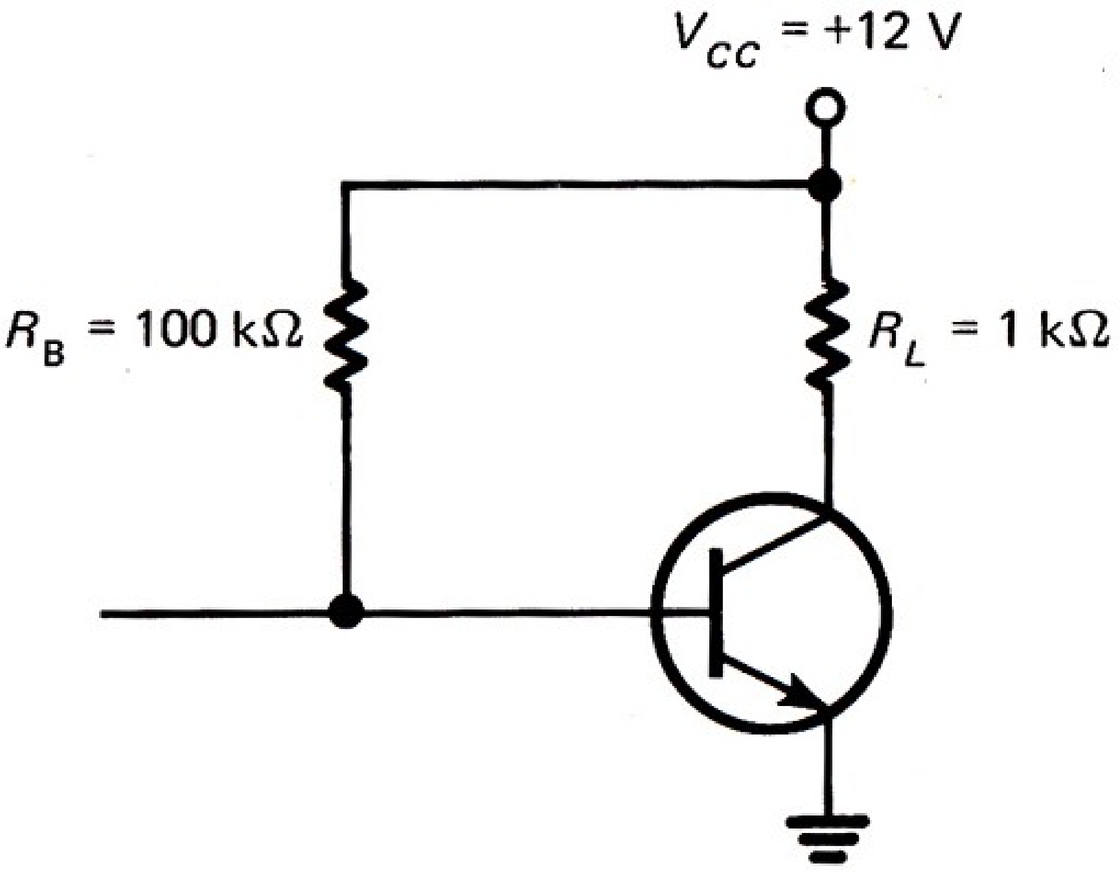


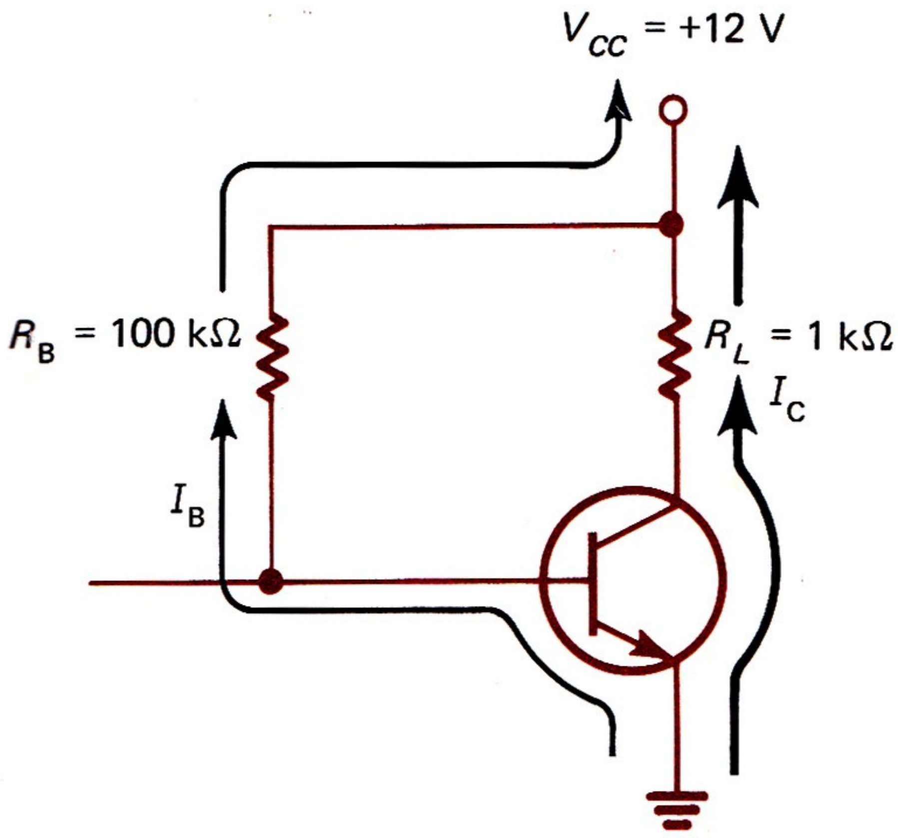
The collector is very “negative” and attracts the holes coming from the emitter.

The base is very “poor” with electrons.

The emitter is very “rich” with holes.

Here’s how an NPN xstr might be connected in an actual 12V circuit. This configuration is known as a *common-emitter* amplifier.





A very small base current can cause a large emitter-to-collector current to flow.

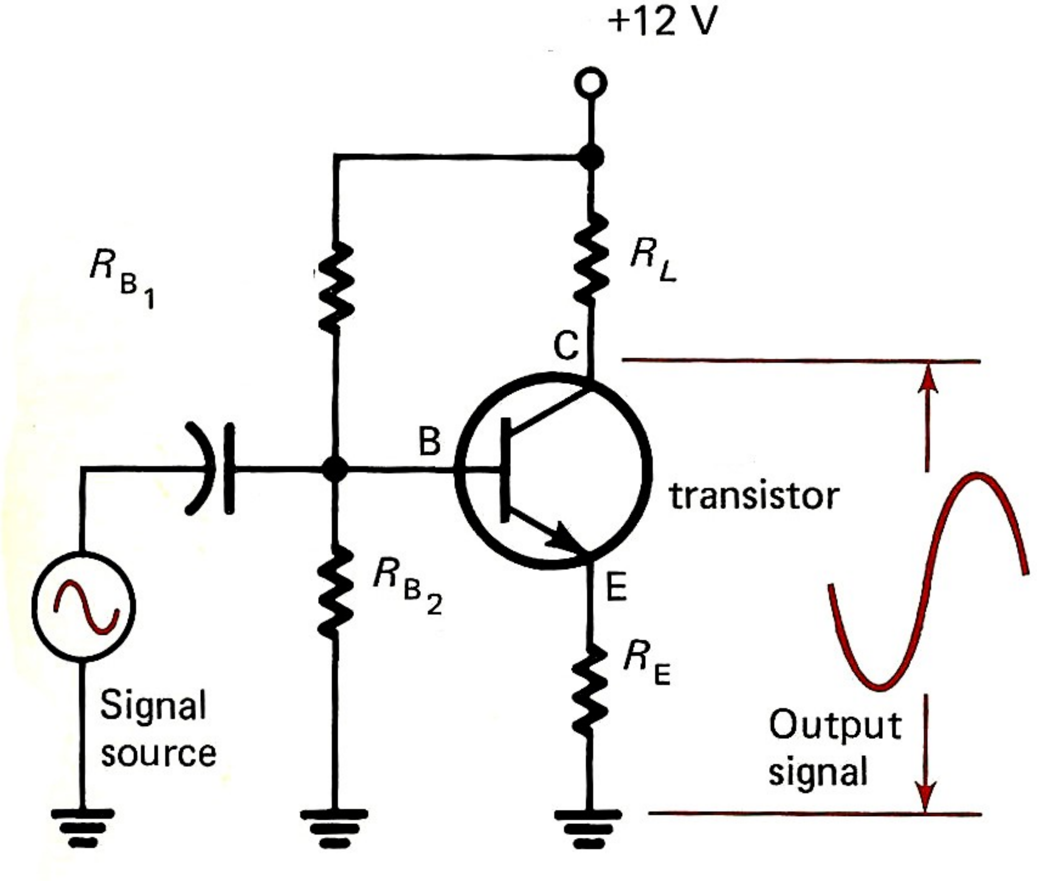
The gain of the transistor is called beta, or *hFe*. It is called out in a device's spec sheet.

The *hFe* multiplied by the base current reveals how much collector current can flow in the common-emitter simple circuit.

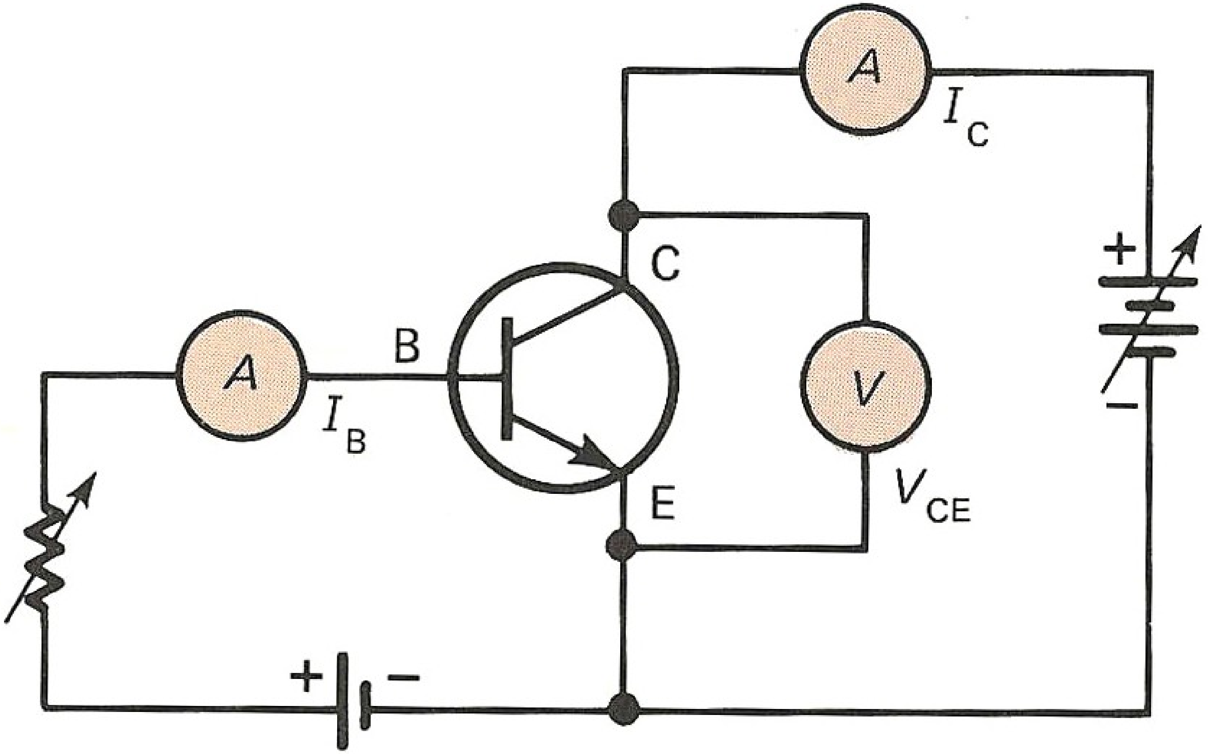
In practice,, the *beta* of a BJT varies from transistor to transistor, even for the same part number!

That makes the simple amplifier unsuitable for all but the most basic applications, as it is sensitive to beta and temperature.

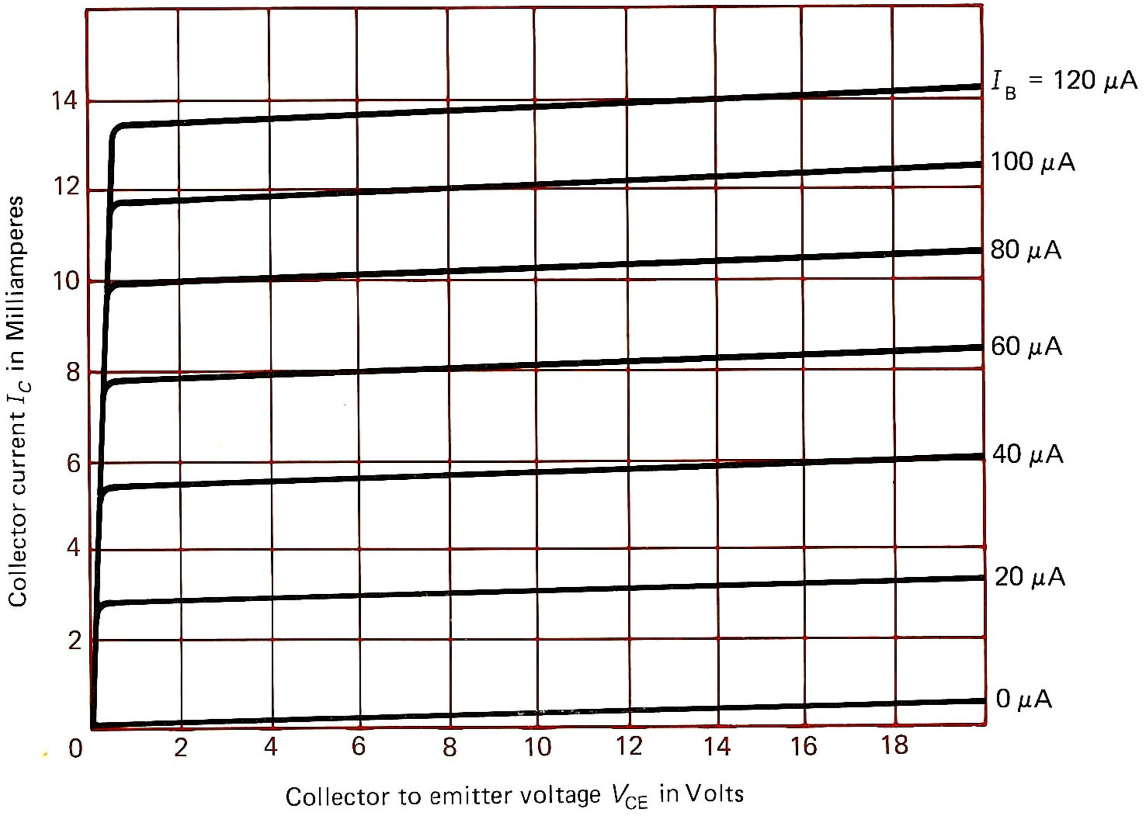
Here’s a better NPN circuit, showing AC input and output signals.



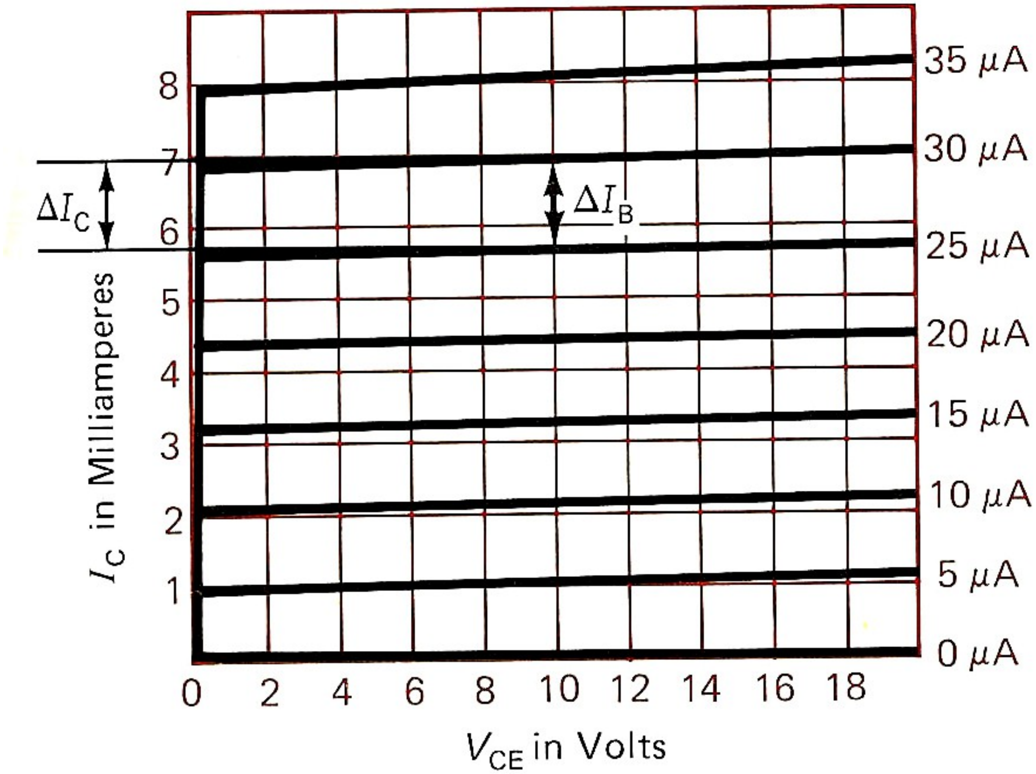
Instrumentation can collect data about the phenomena



The data can be plotted as a "collector family" of curves

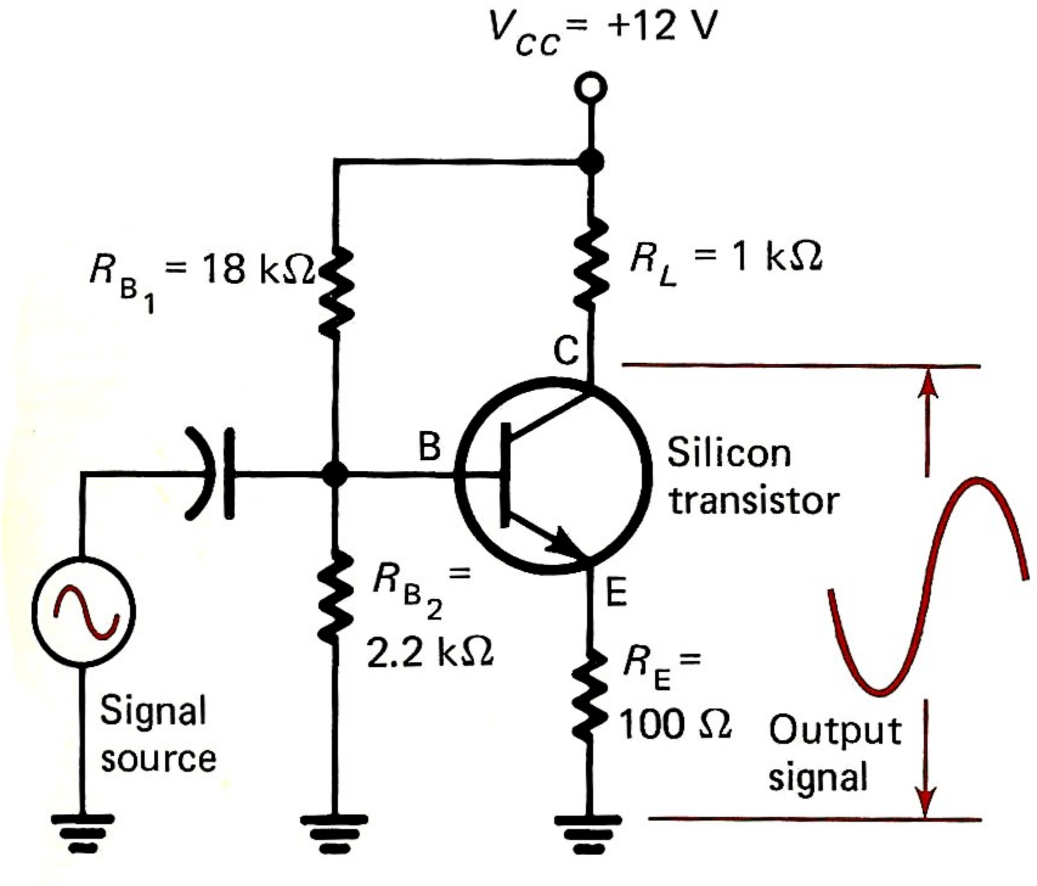


The curves can be used to determine *hFe* (gain)

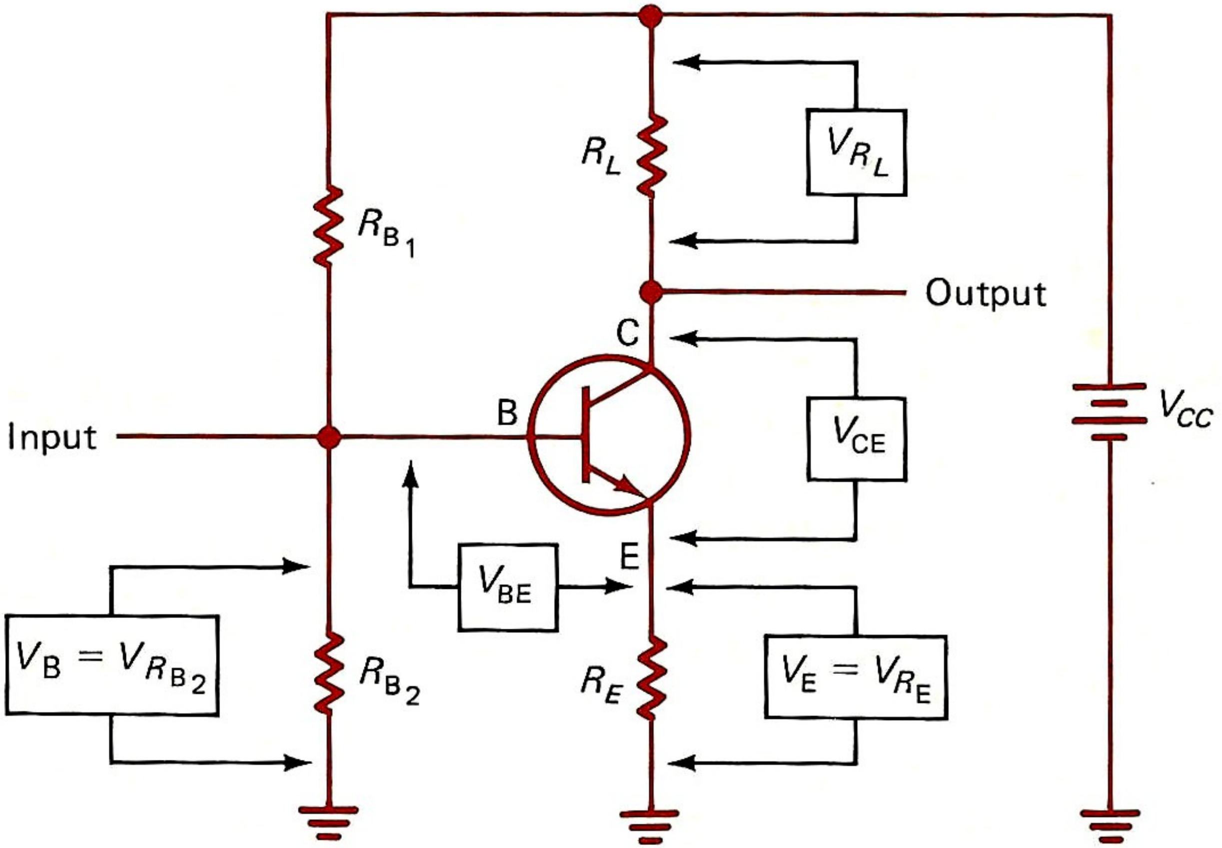


$$\beta_{ac} = h_{fe} = \frac{\Delta I_C}{\Delta I_B} = \frac{1.3\text{ mA}}{5\ \mu\text{A}} = 260$$

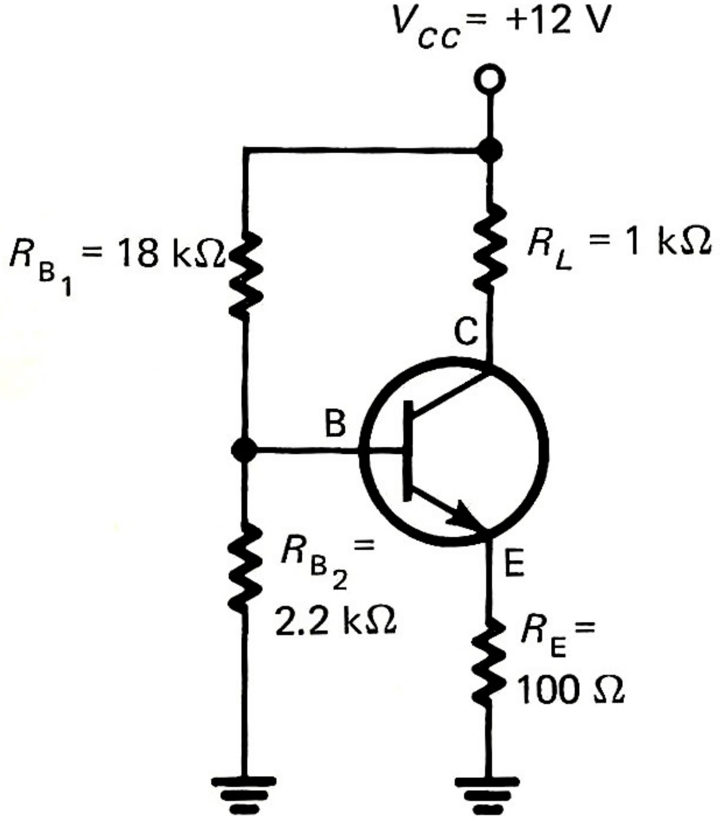
Let’s take a closer look at the common-emitter circuit, but with some typical values



Voltage drops in the example common-emitter circuit



Our example circuit



Determine the base voltage

Using Ohm’s Law:

Rb1 + Rb2 = 18 kohms + 2.2 kohms = 20.2 kohms

Then I = E/R = 12V/20.2 kohms = 594 uA

Then Eb = I x Rb2 = 594 uA x 2.2 kohms = 1.307V

The base voltage reveals the emitter voltage

The base to emitter “diode” drop is 0.7V, so the emitter voltage *MUST* be

1.307V – 0.7V = 0.607V = Ee.

Knowing that, you can determine the emitter resistor’s current flow.

Ie = Ee / Re = 0.607V / 100 ohms = 6.07 mA.

The collector current can be assumed to be the same as the emitter current, as the emitter-to-base current is *very, very* low (usually less than 1% of the collector current).

So, the collector current in this example circuit also
equals 6.07 mA,

or 6 mA amongst friends.

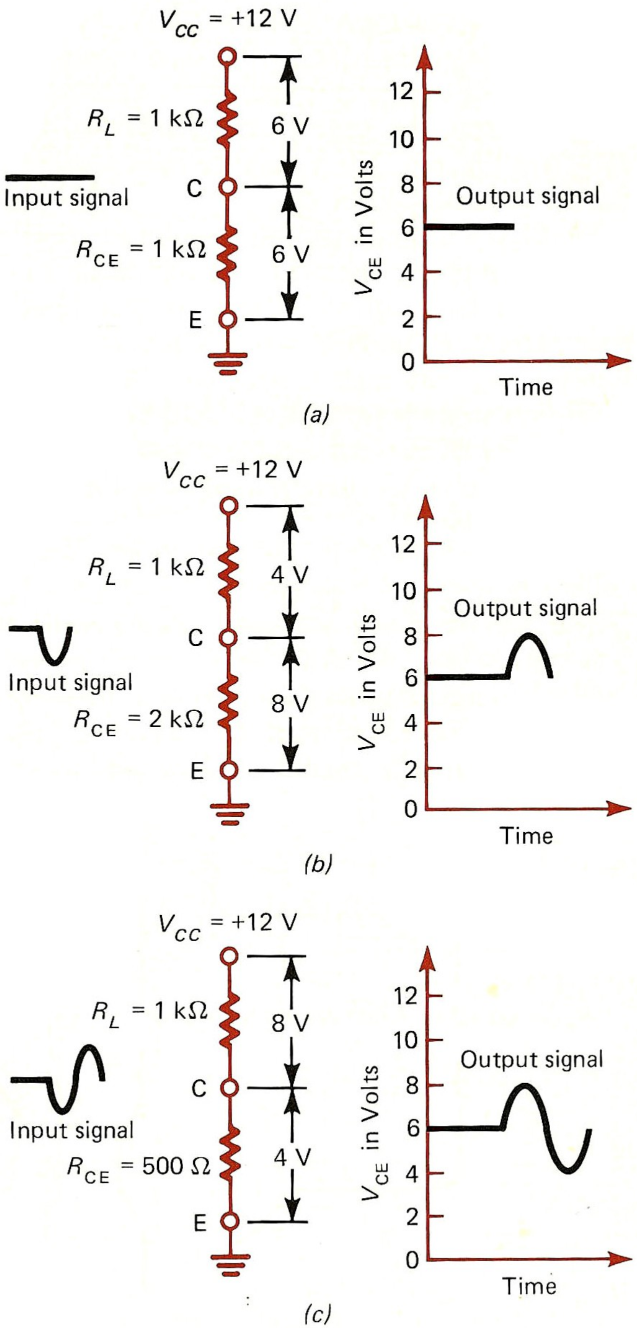
Using Ohms Law you can multiply the collector current and the collector “load” resistor value to determine the IR drop across the collector resistor.

So, 6 ma x 1000 ohms = 6V. This is half the applied voltage (Vcc). Therefore you can say the transistor is operating in the middle of its range. Put another way, the transistor’s collector voltage can swing from 0V to 6V.

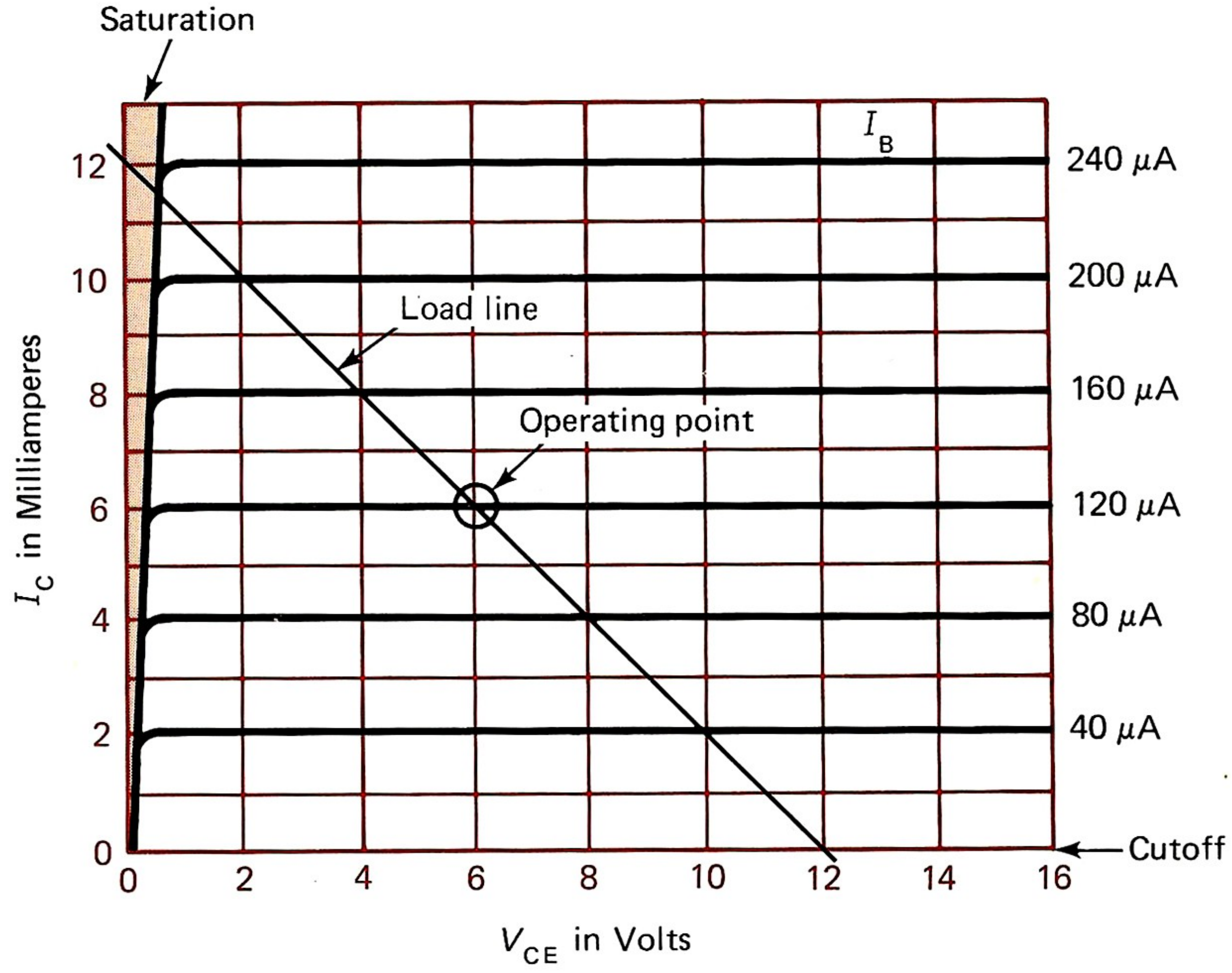
Here’s how an output swing, as a sine wave, is developed, assuming a sine wave is applied to the base in this example.

Notice how the output is 180-degrees out-of-phase with the input.

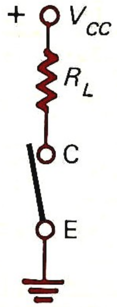
The common-emitter amplifier is an inverter.



Add a visualization tool called the "load line" to the collector family of curves



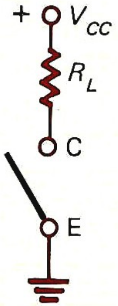
Some conditions of conduction



Saturation

$V_{CE} = 0$ and I_C is maximum

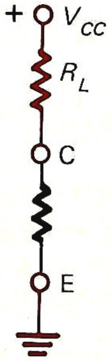
(a)



Cutoff

$V_{CE} = V_{CC}$ and $I_C = 0$

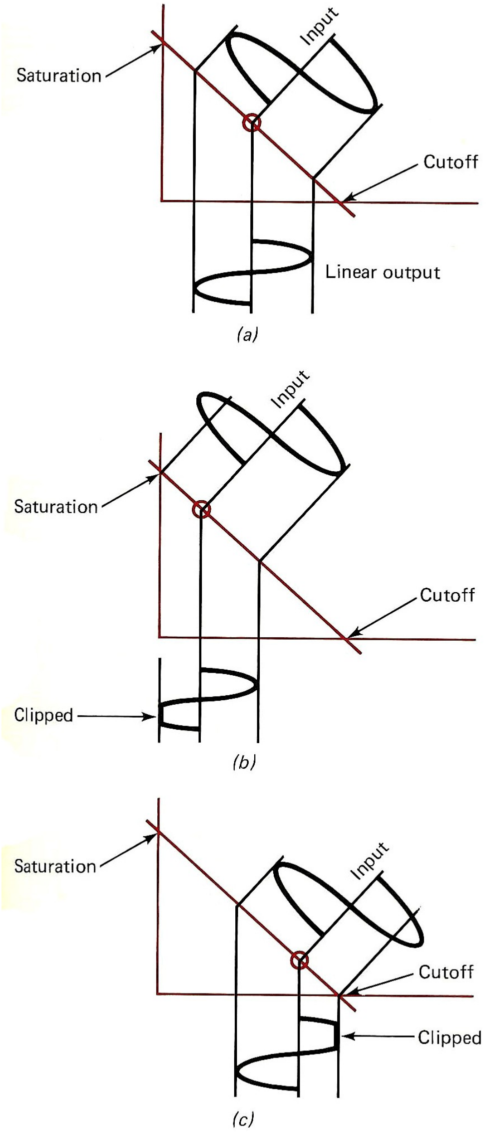
(b)



Active

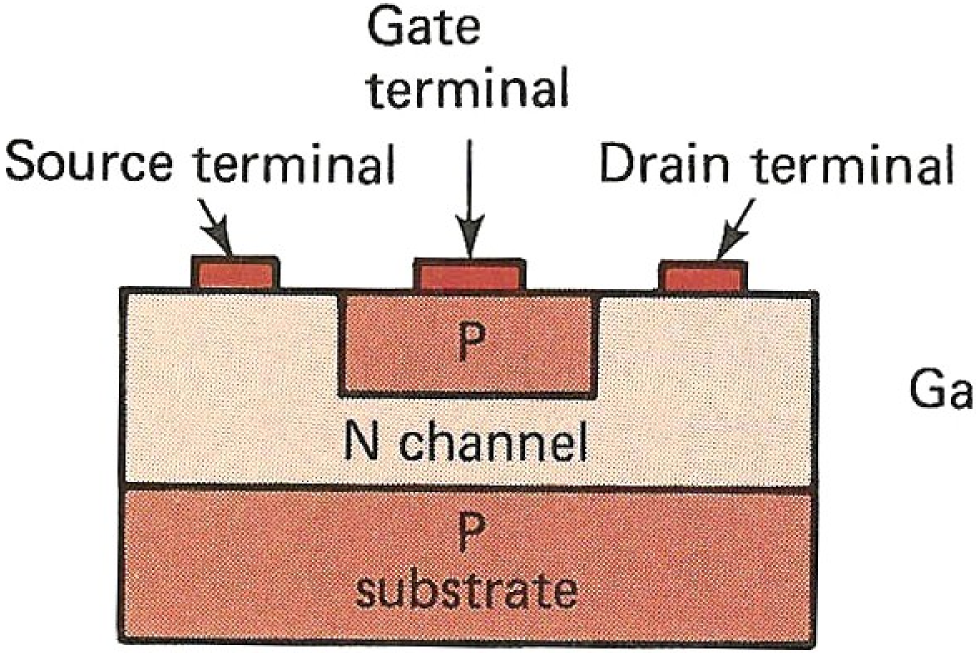
$V_{CE} \approx 1/2\ V_{CC}$ and $I_C = 1/2$ maximum

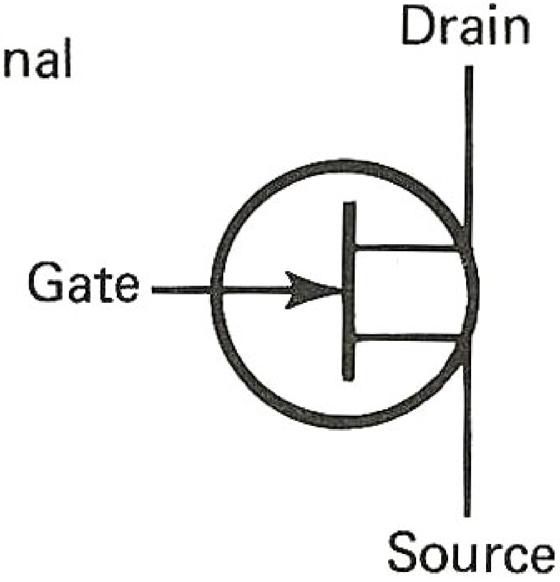
(c)



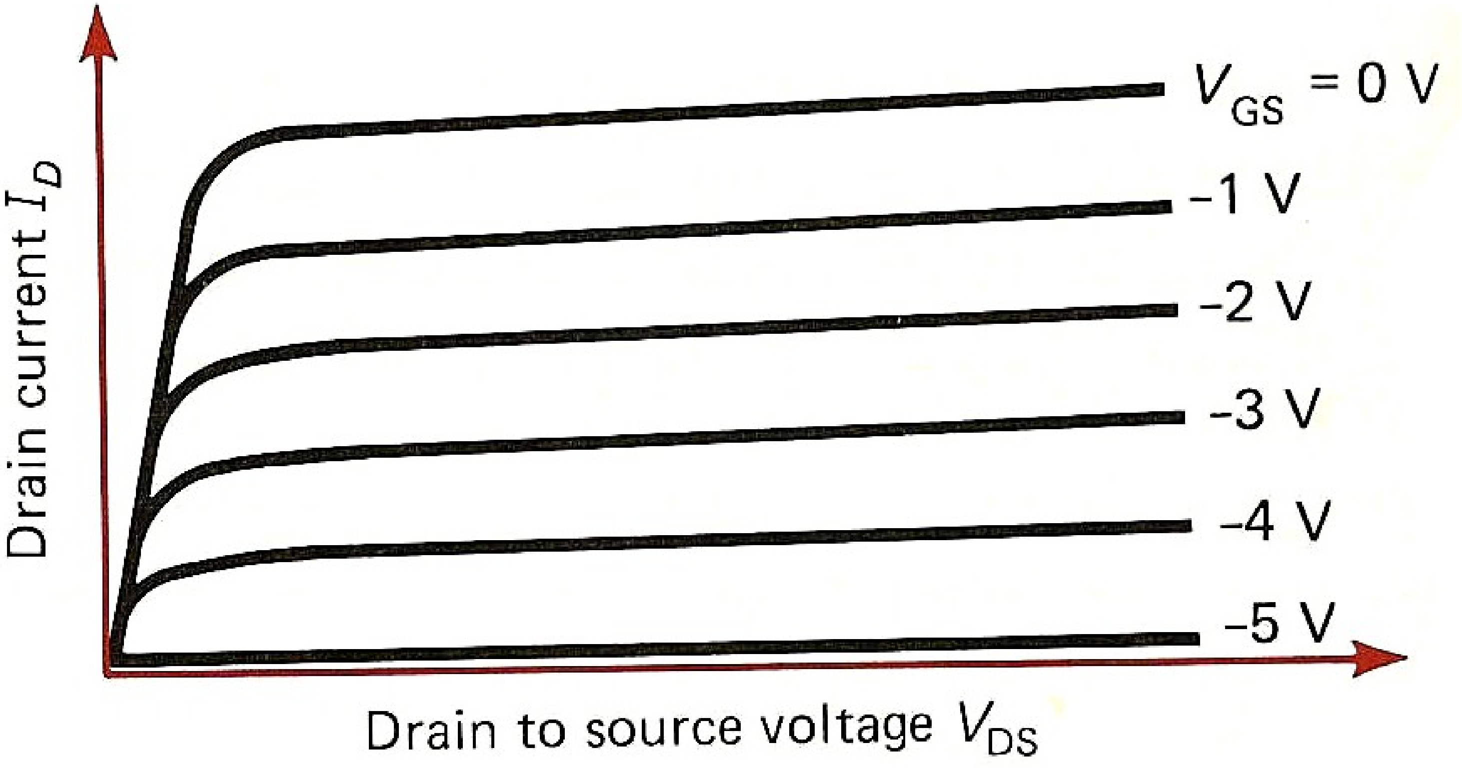
Where you bias the device on the load line establishes its *Q point*.

JFET *field effect transistors*





JFET characteristic curves

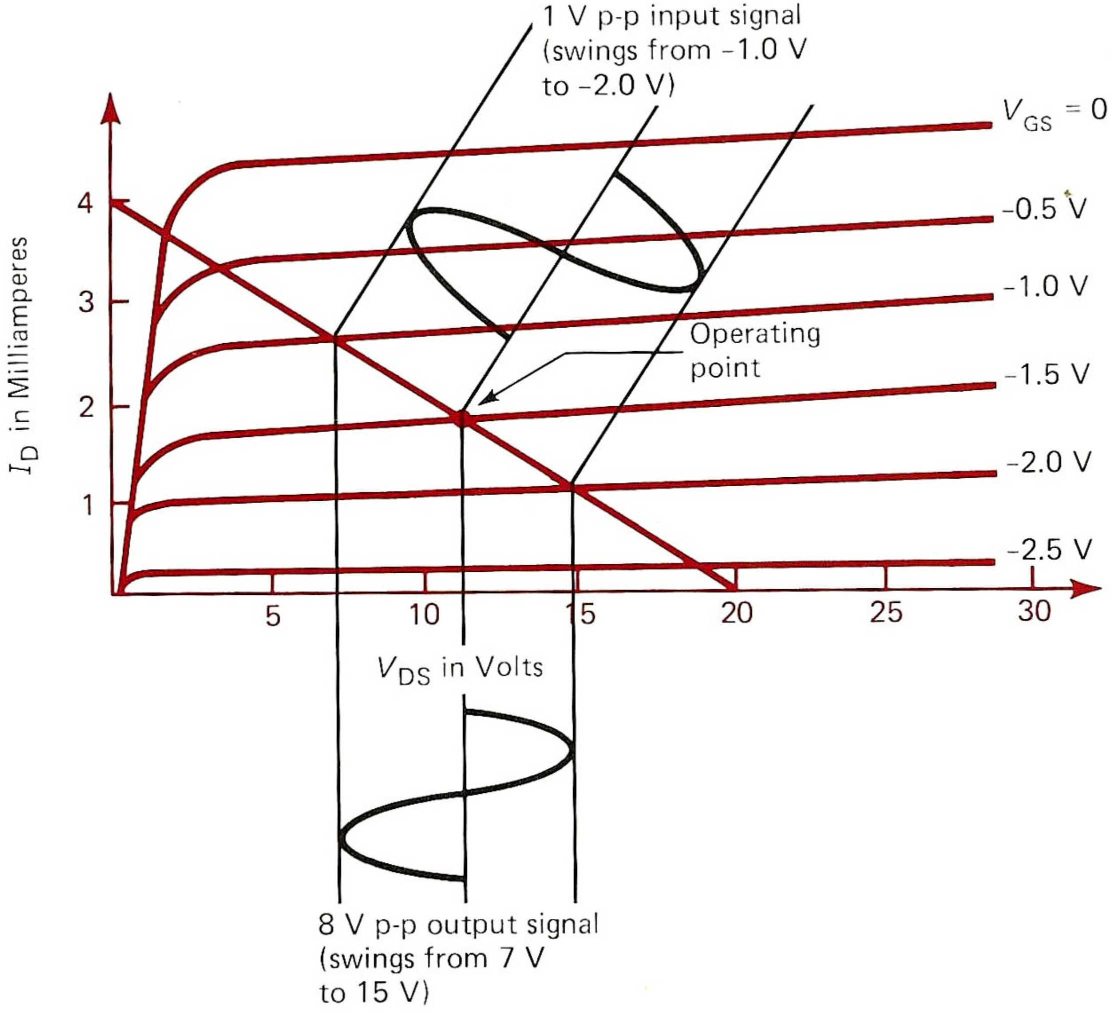


JFETs operate in what’s called the *depletion mode*.

In a junction xstr no current flows until base current is provided.

In a JFET current flows until high enough gate voltage removes carriers from the channel, and cuts off conduction.

JFET drain-family characteristic curves



Enough for now!

Vy 73, AI2Q