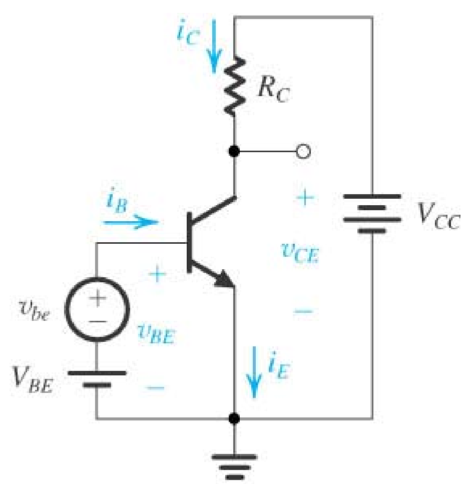
Lecture 13: The BJT as a Signal Amplifier.

One very useful application of the transistor is an amplifier of time varying signals.

Next semester in EE 322, you will build a radio that receives signals at power levels as low as pW and amplifies them to power levels near 1 W!

This happens through the use of frequency selective filters and the use of signal amplifiers formed from transistors. It is such capabilities that make telecommunications possible.

Consider the "conceptual BJT amplifier" circuit shown below:



(Fig. 7.20a)

The DC voltages provide the biasing. The input signal is v_{be} and the output signal is v_c.

We will assume the transistor is biased so that V_C is greater than V_B by an amount that allows for sufficient "signal swing" at the collector, but the transistor remains in the active mode at all times. That is, the transistor does not become saturated or cutoff during the cycle.

From the circuit above, the total base-to-emitter voltage is

$$v_{BE} = \underbrace{V_{BE}}_{\text{DC}} + \underbrace{v_{be}}_{\text{AC}} \tag{1}$$

Correspondingly, the collector current is

$$i_C = I_S e^{v_{BE}/V_T} = \underbrace{I_S e^{V_{BE}/V_T}}_{I_C} e^{v_{be}/V_T} \tag{2}$$

or using (7.52)

$$i_C = I_C e^{v_{be}/V_T} \tag{(7.56),(3)}$$

For small v_{be} such that $v_{be} \ll 2V_T$ (i.e., the small-signal approximation), then (3) can be approximated by

$$i_C \approx I_C\left(1+\frac{v_{be}}{V_T}\right) = \underbrace{I_C}_{\text{DC}} + \underbrace{\frac{I_C}{V_T}v_{be}}_{\text{AC}} \tag{(7.57),(4)}$$

This is a familiar result: We saw something very similar with small signals and diodes back in Lecture 4.

The time varying current in (4)

$$i_c = \frac{I_C}{V_T}v_{be} \tag{(7.60),(5)}$$

can be written as

$$\boxed{i_c = g_m v_{be}} \tag{(7.61),(6)}$$

where $$\boxed{g_m \equiv \frac{I_C}{V_T} \quad [\mathrm{S}]} \qquad (7.62),(7)$$

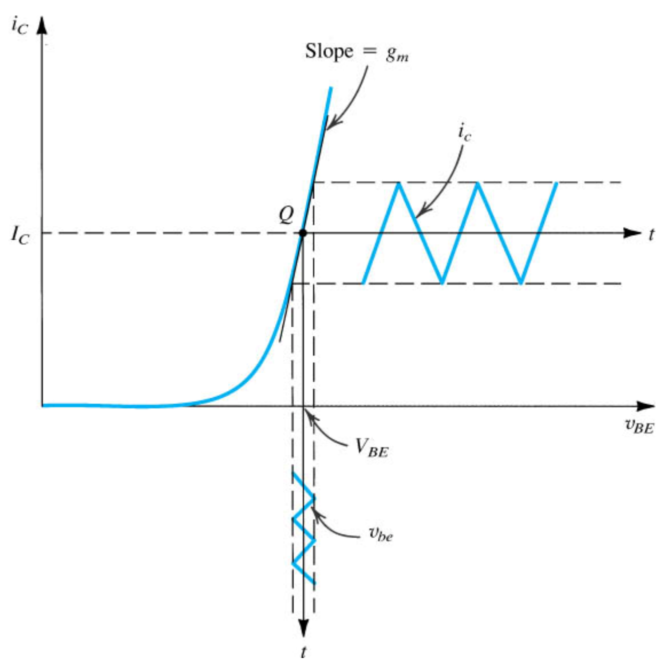
is defined as the transistor small-signal transconductance. Its units are Siemens. Note that $g_m \propto I_C$.

Significance of the BJT Small-Signal Transconductance

What is the physical significance of g_m? First, g_m is the slope of the i_C-v_{BE} characteristic curve at the Q point:

$$g_m = \left.\frac{\partial i_C}{\partial v_{BE}}\right|_{i_C = I_C} \qquad (7.63),(8)$$

Consider the plot shown in Fig. 7.21.



(Fig. 7.21)

With $i_C = I_S e^{v_{BE}/V_T}$ from (2), the right-hand side of (8) becomes

$$\frac{\partial i_C}{\partial v_{BE}} = \frac{I_S}{V_T} e^{v_{BE}/V_T} \underbrace{=}_{(3)} \frac{i_C}{V_T} \tag{9}$$

Therefore

$$g_m = \left. \frac{\partial i_C}{\partial v_{BE}} \right|_{i_C = I_C} = \frac{I_C}{V_T} \tag{10}$$

as we defined in (6).

Observe that:

- The small-signal v_{be} assumption restricts the operation of the BJT to nearly linear portions of the i_C-v_{BE} characteristic curve.
- From (6), the BJT behaves as a voltage controlled current source for small signals: The small-signal v_{be} controls the small-signal i_c.

Signal Voltage Gain

Second, g_m has an important relationship to the signal voltage gain in this circuit. Using KVL in Fig. 7.20a, the total collector voltage is

$$v_C = V_{CC} - i_C R_C = V_{CC} - \left(I_C + i_c \right) R_C$$
$$= \underbrace{V_{CC} - I_C R_C}_{=V_C} - i_c R_C$$

or

$$v_C = \underbrace{V_C}_{\text{DC}} - \underbrace{i_c R_C}_{\text{AC}} \tag{7.76),(11}$$

where V_C is the DC voltage at the collector.

So from (11), the AC signal at the collector is

$$v_c = -i_c R_C \qquad (7.77),(12)$$

This result is negative, which means this circuit operates as an inverting amplifier for small, time varying signals.

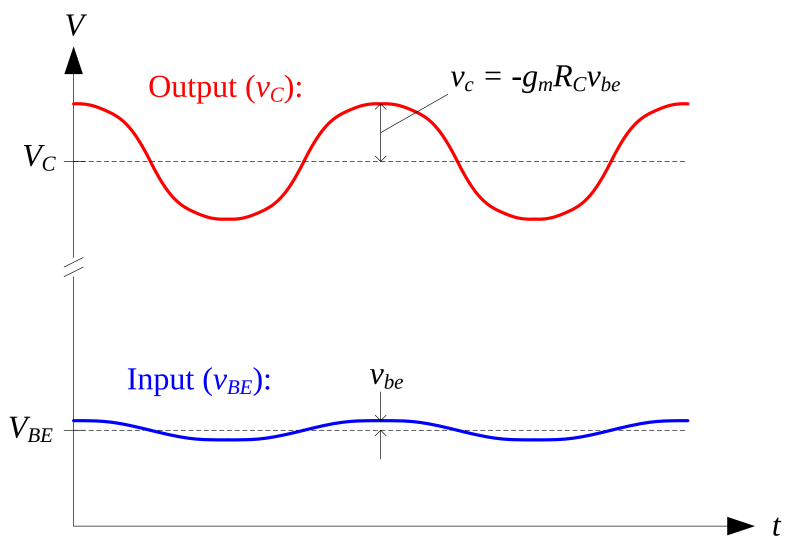
From (6), $i_c = g_m v_{be}$. Using this result in (12) gives

$$v_c = -g_m v_{be} R_C = -\left(g_m R_C\right) v_{be} \qquad (7.77),(13)$$

Consequently, the small-signal AC voltage gain A_v is

$$A_v = \frac{v_c}{v_{be}} = -g_m R_C \qquad (7.78),(14)$$

In a broad sense, we can see that this transistor circuit can act an amplifier of the time varying input signal, provided this input voltage remains small enough.



g_m is a very important amplifier parameter since the voltage gain in (14) is directly proportional to g_m. BJTs have a relatively large g_m compared to field effect transistors, which we will consider in the next chapter. Consequently, BJTs have better voltage gain in such circuits.