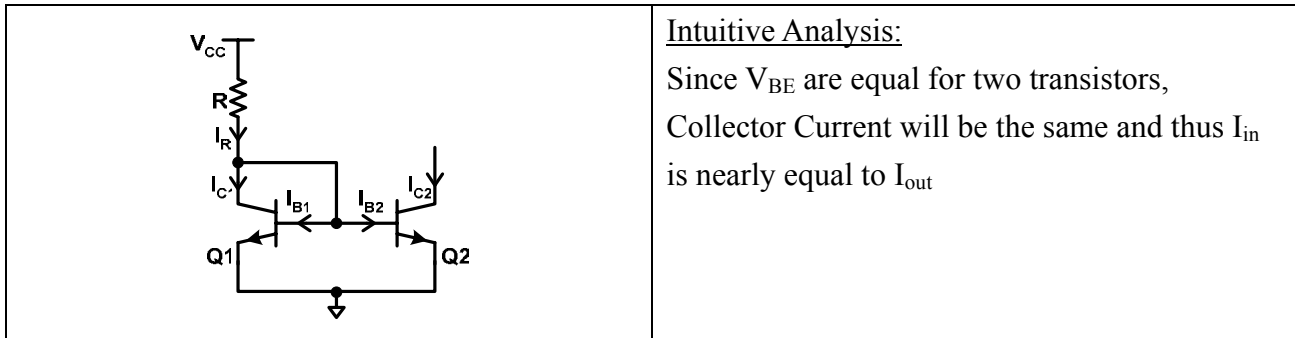


## Tutorial 7: Review on BJT Circuits

### Large Signal Analysis:

#### Simple Current Mirror:



#### Qualitative Analysis:

Assume both transistors are in active region: ( $I_c = \beta I_b, I_c = I_s e^{\frac{V_{BE}}{V_T}}$ )

Since  $V_{B1} = V_{B2}$ ,

Thus  $I_{C1} = I_{C2}, I_{B1} = I_{B2}$

$$I_R = I_{C1} + (I_{B1} + I_{B2})$$

$$I_R = I_{C1} + 2I_{B1}$$

$$I_R = I_{C1} + \frac{2}{\beta} I_{C1}$$

$$I_R = \left(\frac{\beta + 2}{\beta}\right) I_{C1}$$

If  $\beta$  is very large,  $I_R = I_{C1}$  (That's why we call this circuit current Mirror)

Example: Assume we want  $I_{C2} = 20\mu A$ , given  $V_T = 25mV$ ,  $V_{cc} = 15V$ , at  $V_{BE} = 0.7V$ ,  $I_C = 500\mu A$

$$500\mu = I_s e^{\frac{0.7}{0.025}}$$

$$20\mu = I_s e^{\frac{V_{BE1}}{0.025}}$$

$$e^{\frac{V_{BE1} - 0.7}{0.025}} = 0.04$$

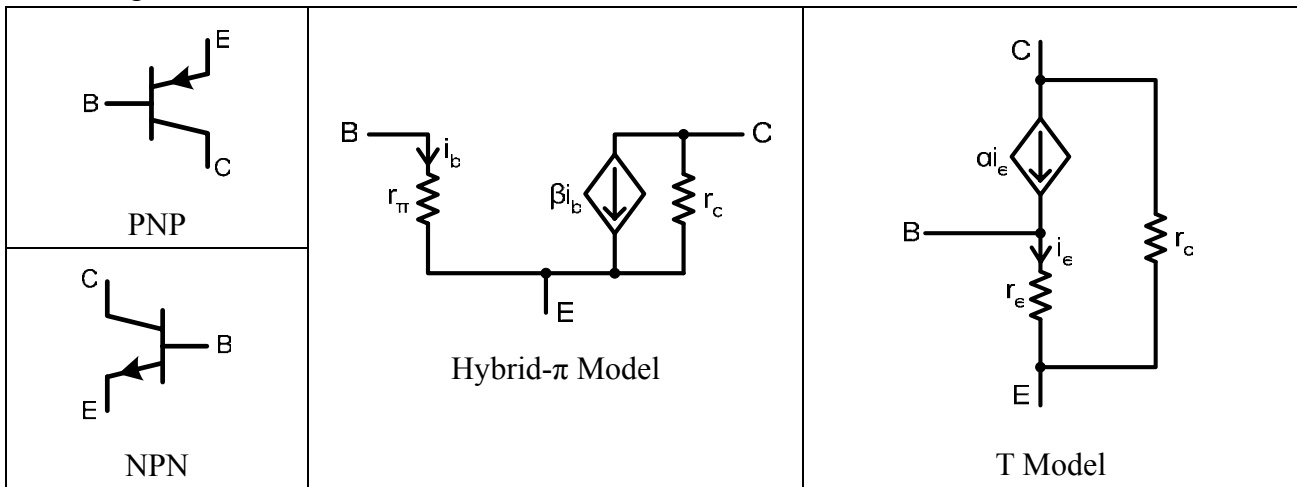
$$V_{BE1} = 0.7 + 0.025 \ln(0.04) = 0.62V$$

$$R = \frac{15 - 0.62}{I_R} = \frac{15 - 0.62}{20\mu} = 719k\Omega$$

In IC design, large value of resistors is not desired. Thus there are other kinds of current mirror to reduce the size of resistors.

**Small Signal Analysis of BJT circuits:**

Small Signal Model of BJT:



Model Parameters:

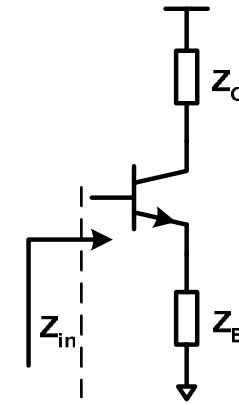
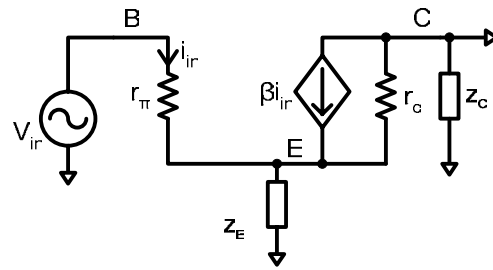
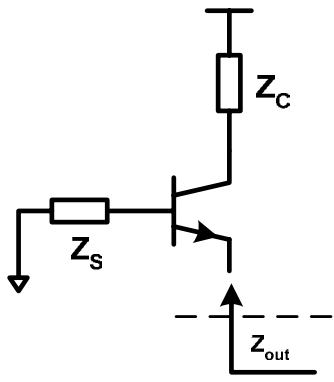
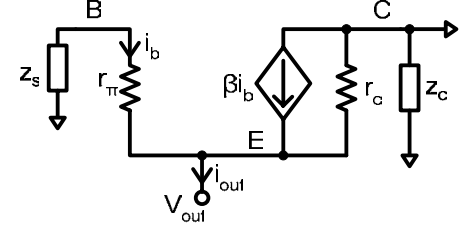
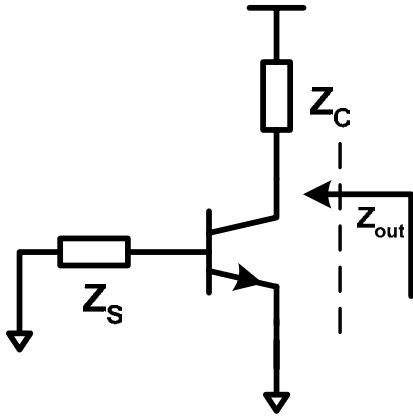
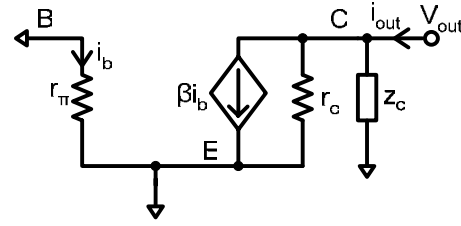
In terms of DC Bias Current:		
$g_m = \frac{I_C}{V_T}$	$r_e = \frac{V_T}{I_E} = \alpha \frac{V_T}{I_C}$	
$r_\pi = \frac{V_T}{I_B} = \beta \frac{V_T}{I_C}$	$r_o = \frac{V_A}{I_C} \left( = \frac{1}{\eta g_m} \right)$	
In terms of $g_m$		
$r_e = \frac{\alpha}{g_m}$	$r_\pi = \frac{\beta}{g_m}$	
In terms of $r_e$		
$g_m = \frac{\alpha}{r_e}$	$r_\pi = (\beta + 1)r_e$	$g_m + \frac{1}{r_\pi} = \frac{1}{r_e}$
Relationship between $\alpha$ and $\beta$		
$\beta = \frac{\alpha}{1 - \alpha}$	$\alpha = \frac{\beta}{\beta + 1}$	$\beta + 1 = \frac{1}{1 - \alpha}$

(Extracted from pp271, "Microelectronic Circuits 4<sup>th</sup> Edition, Sedra / Smith, Oxford University Press")

**Finding impedance at a point**

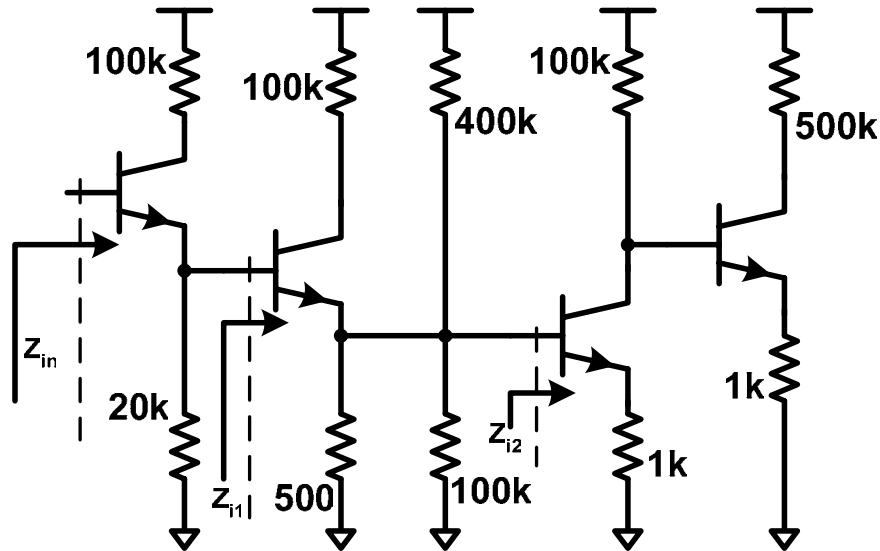
Method to determine the equivalent impedance viewed at a point:

1. Disable all independent voltage source (by short) and independent current source (by open).
2. Apply a voltage at that point. Find the current drawn from the source.
3. Impedance = voltage/current

Impedance looking into different terminal:	
 <p style="text-align: center;"><math>Z_i = r_{\pi} + (\beta + 1)Z_e</math></p>	 <p style="text-align: center;"><math>V_{in} = i_{in}r_{\pi} + (\beta + 1)i_{in}Z_E</math>  <math>Z_{in} = \frac{V_{in}}{i_{in}} = r_{\pi} + (\beta + 1)Z_E</math></p>
 <p style="text-align: center;"><math>Z_{out} = \frac{Z_B + r_{\pi}}{\beta + 1}</math></p>	 <p style="text-align: center;"><math>V_{out} = i_b(r_{\pi} + Z_S)</math>  <math>i_{out} = (\beta + 1)i_b</math>  <math>Z_{out} = \frac{r_{\pi} + Z_S}{\beta + 1}</math></p>
 <p style="text-align: center;"><math>Z_{out} = Z_C</math></p>	 <p style="text-align: center;">Since <math>r_o \gg Z_C</math> &amp; <math>i_b = 0</math>  <math>Z_{out} = Z_C \parallel r_o \approx Z_C</math></p>

Example 1:

Find the input impedance of the following amplifier, assume all transistors are biased into active region. ( $h_{ie} = 1k\Omega$ ,  $h_{fe} = 99$ )



( $h_{fe} = \beta$ )

For this question, you can trace from the first stage to the last stage or reverse.

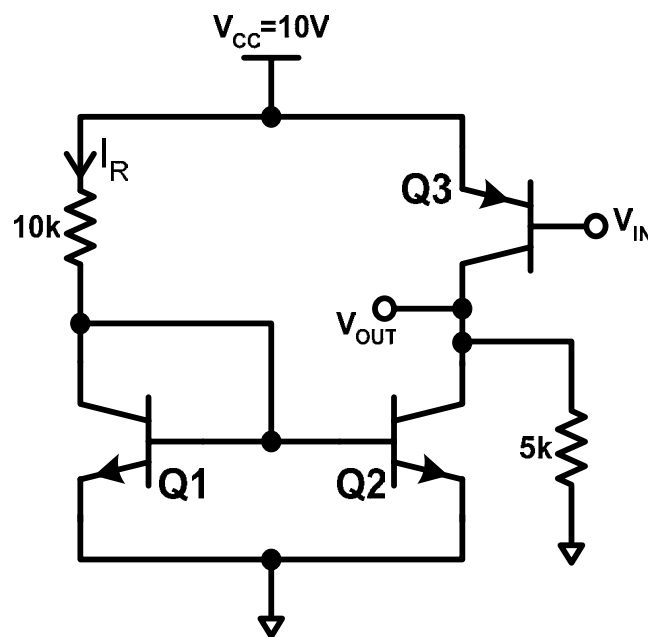
$$Z_{in} = h_{ie} + (\beta + 1)(20k \parallel Z_{i1})$$

$$Z_{i1} = h_{ie} + (\beta + 1)(500 \parallel 100k \parallel 400k \parallel Z_{i2})$$

$$Z_{i2} = h_{ie} + (\beta + 1)(1k)$$

Which leads to  $Z_{i2} = 101k\Omega$ ,  $Z_{i1} = 50.446k\Omega$  and  $Z_{in} = 143.32k\Omega$

Example 2:



For the circuit on the last page, assume transistor Q3 is biased correctly.  $V_{BE} = 0.7V$  for Q1,  $\beta_{NPN} = 200$ ,  $\beta_{PNP} = 40$  and  $V_T = 25mV$ . You can also ignore all the base currents.

The following equations are for your reference:

$$h_{ie} = r_{\pi} = \frac{\beta}{g_m}, g_m = \frac{I_C}{V_T}, r_{out} \text{ for both NPN and PNP transistors: } \frac{1}{g_m (1 \times 10^{-4})}$$

- Calculate DC collector current of Q2.
- Calculate the equivalent load impedance of Q3.
- Calculate the small signal gain.

Solution:

- $I_{C1} = I_{C2}$ ,  $I_{B1} = I_{B2}$  (Since  $V_{BE1} = V_{BE2}$ )

$$10 = I_R \times 10k + V_{BE1}$$

$$I_R = I_{C1} + I_{B1} + I_{B2} = \frac{\beta + 2}{\beta} I_{C1} = \frac{\beta + 2}{\beta} I_{C2}$$

$$10 = \frac{\beta + 2}{\beta} I_{C2} \times 10k + 0.7$$

$$I_{C2} = 920.8 \mu A$$

- $Z_{LOAD} = 5k // r_{out3} // r_{out2}$

$r_{out3}$ : Impedance looking into collector of Q3

$r_{out2}$ : Impedance looking into collector of Q2

$$g_m = \frac{920.8 \mu}{25m} = 36.83 \times 10^{-3} \Omega^{-1}$$

$$r_{out3} = r_{out2} = 271.5k\Omega$$

$$Z_{LOAD} = 4.82k\Omega$$

- 

$$V_{in} = I_{in} Z_{in}$$

$$V_{out} = I_{out} Z_{out}$$

$$I_{out} = \beta I_{in}$$

$$Z_{in} = r_{\pi} = \frac{40}{36.83 \times 10^{-3}}$$

$$Z_{out} = 4.82k$$

$$\text{Therefore, } \frac{V_{out}}{V_{in}} = \beta \frac{4.82k \times 36.83^{-3}}{40} = 177.6$$