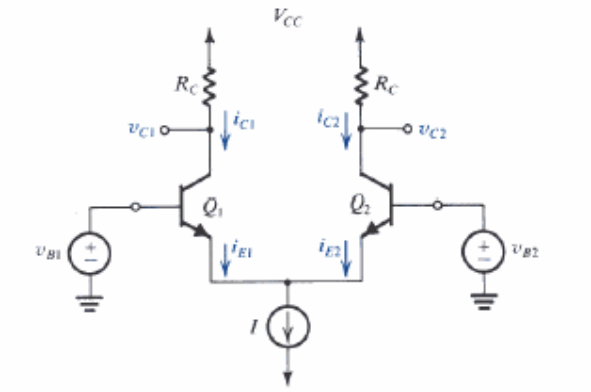
Tutorial 13

14 Apr. 2004

The BJT Differential Amplifier

Description of Operation

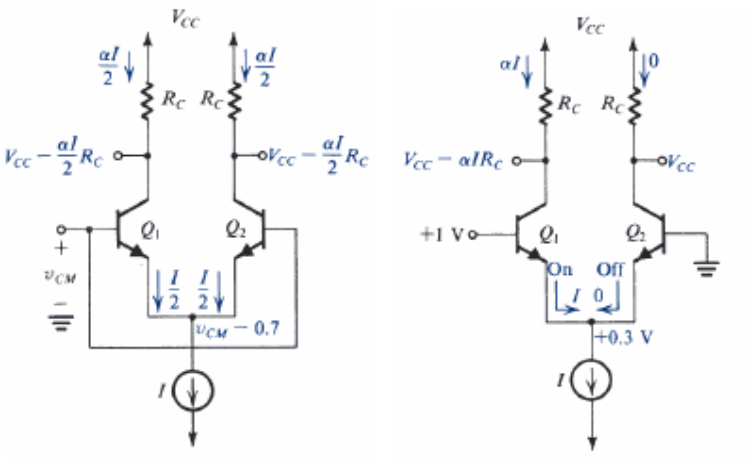
The differential amplifier is the most widely used circuit building block in analog integrated circuits. The differential amplifiers can be implemented with BJTs, MOSFETs and MESFETs. We focus on the differential amplifiers implemented with BJTs.



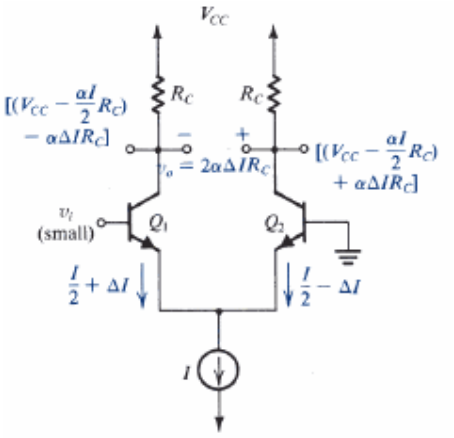
The basic BJT differential-pair configuration
It consists of two matched transistors, Q1 and Q2, whose emitters are joined together and biased by a constant-current I.

Two different modes of operation of the differential pair:

1. The differential pair with a **common-mode** input signal v_{CM}
2. The differential pair with a **differential (-mode)** input signal

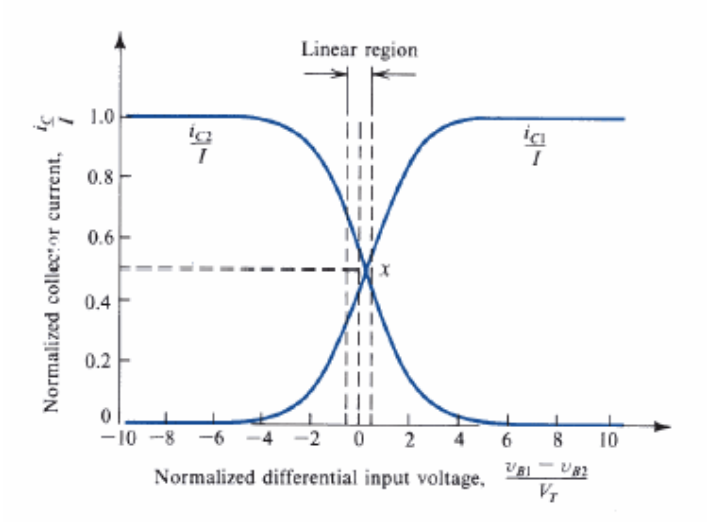


The differential pair with a “large”
Differential input signal

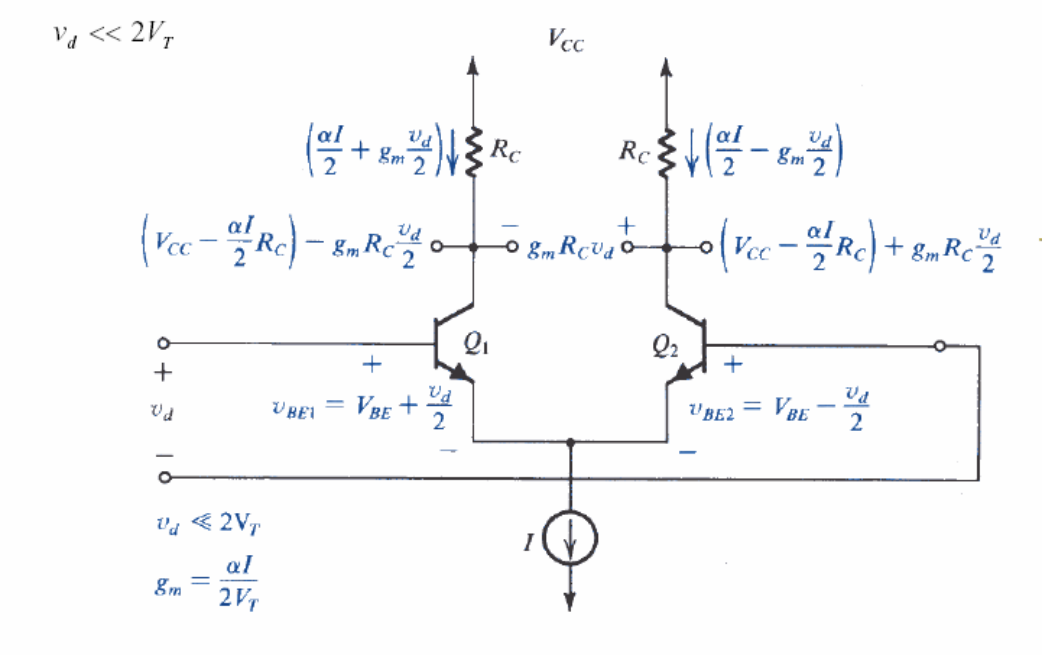


The differential pair with a small differential input signal v_i

$$I_{C1} = \frac{\alpha I_{EE}}{1 + e^{-V_d/V_T}} \qquad I_{C2} = \frac{\alpha I_{EE}}{1 + e^{+V_d/V_T}}$$



Small-Signal Operation



$$i_{C1} = \frac{\alpha I}{2} + \frac{\alpha I}{2V_T}\frac{v_d}{2}$$

$$i_{C2} = \frac{\alpha I}{2} - \frac{\alpha I}{2V_T}\frac{v_d}{2}$$

Some Formulas

1. Differential Input Resistance

$$R_{id} = 2(\beta + 1)(r_e + R_E)$$

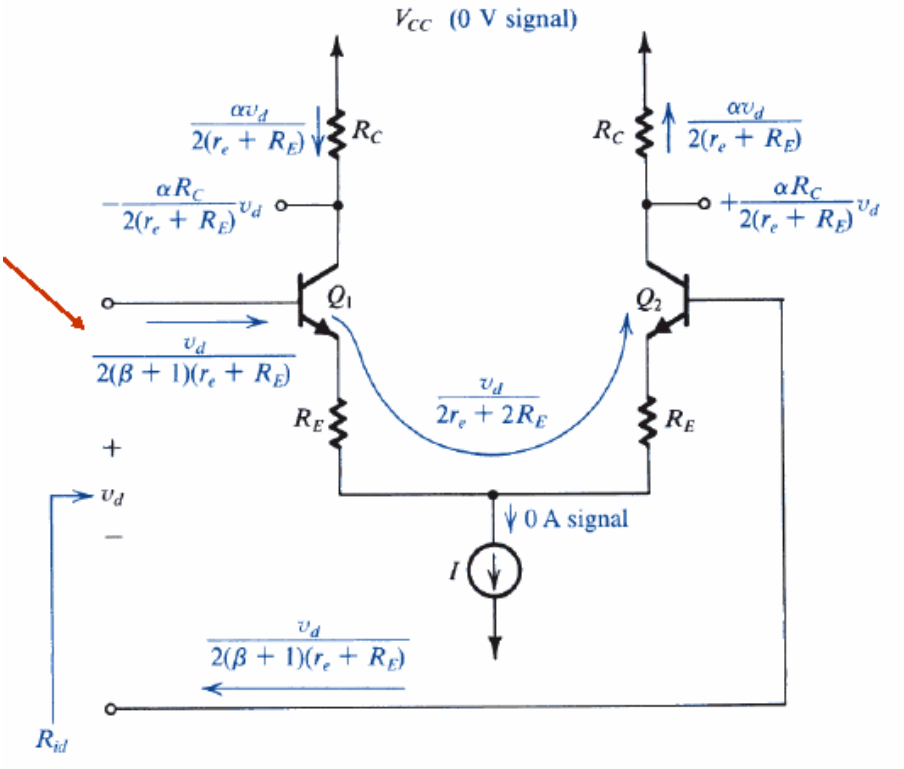
(β+1) times the total resistance in the emitter.

2. Differential Voltage gain

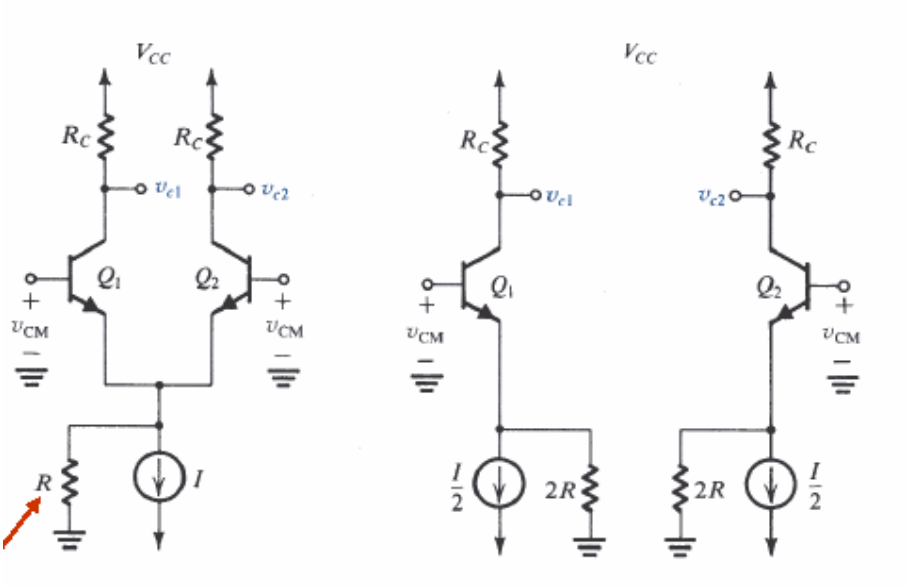
$$A_d = -\frac{2\alpha R_C}{2(r_e + R_E)} \approx -\frac{R_C}{r_e + R_E}$$

⇩

$$-\frac{\text{Total resistance in collector circuit}}{\text{Total resistance in emitter circuit}}$$



3. *Common-Mode Voltage Gain*



$$v_{c1} = v_{c2} = -v_{CM}\frac{\alpha R_C}{2R + r_e} \approx -v_{CM}\frac{\alpha R_C}{2R}$$

$$A_{cm} = -\frac{\alpha R_C}{2R}$$

Example 1.

For the circuit of Fig 1. with an input of +1V as indicated, and with I=1 mA. Vcc= 5V, Rc=3 k O, and $\beta = 100$, find the voltage at the emitters and the collector voltages.

Assume that the BJTs have v_{BE}=0.7 V at $i_C = 1mA$

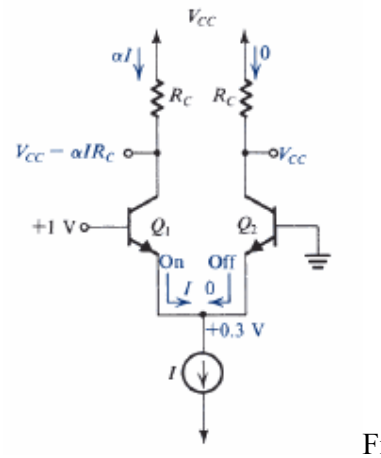


Fig 1

Example 2.

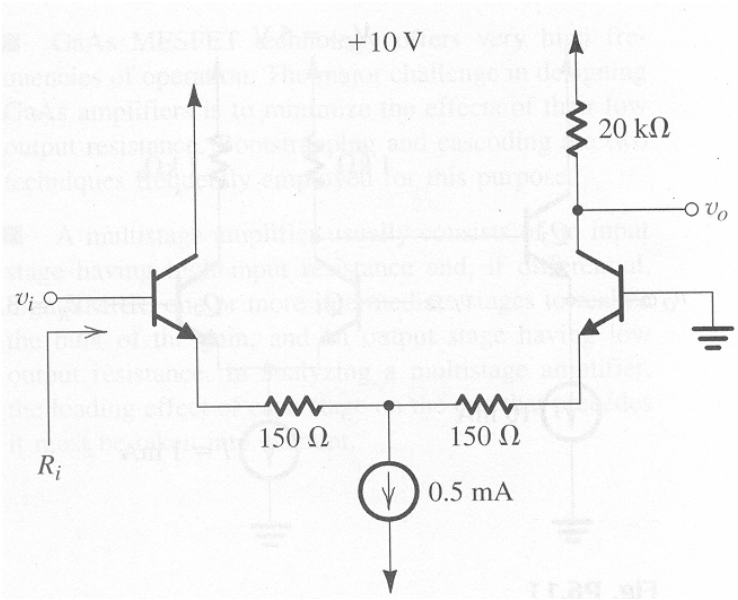
A BJT differential amplifier is biased from a 2-mA constant current source and includes a 100-O resistor in each emitter. The collectors are connected to Vcc via 5-KO resistors. A differential input signal of 0.1 V is applied between the two bases.

(a) Find the signal current in the emitters (i_e) for each BJT

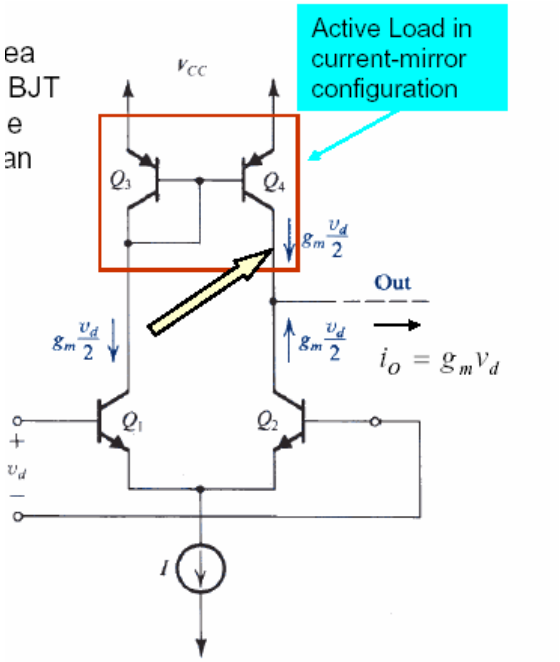
(b) What is the total emitter current in each BJT.
(c) What is the signal voltage at each collector? Assume $\alpha = 1$
(d) What is the voltage gain realized when the output is taken between the two collectors.

Example 3.

Find the voltage gain and the input resistance of the amplifier show in Fig 2. assuming $\beta = 100$



4. *BJT Differential Amplifier with Active Load*



1. Active device occupy much less silicon area than medium and large sized resistors.
2. BJT load transistor is usually connected as a constant-current source and thus presents the amplifier transistor with a very- high resistance load. Thus amplifiers that utilize active loads can achieve higher voltage gains than those with passive loads

Output Resistors and Output signal voltage

$$R_o = r_{o2} \,//\, r_{o4} \qquad v_o = g_m v_d R_o$$

Voltage gain:

$$\frac{v_o}{v_d} = g_m (r_o / 2)$$

Consider

$$g_m = I_C / V_T \quad \text{and} \quad r_o = V_A / I_C$$

$$\frac{v_o}{v_d} = \frac{V_A}{2V_T}$$

Example 4.

The differential amplifier in Fig 3 is operated with $I = 100\mu A$, with devices for which $V_A = 160V$ and $\beta = 100$. What differential input resistance, output resistance, equivalent transconductance, and open-circuit voltage gain would you expect? What will the voltage gain be if the input resistance of the subsequent stage is 1MO

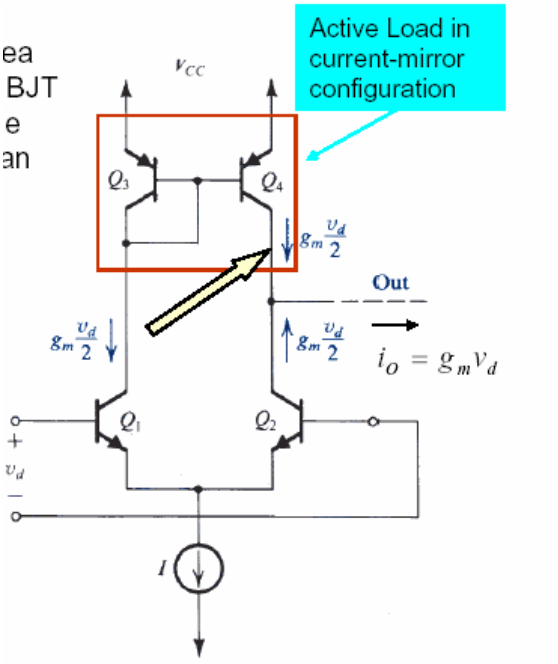


Fig 3

Example 5.

Design the circuit of Fig 3 using a basic current mirror to implement the current source I. It is required that the equivalent transconductance be 5 mA/V. Use $\pm 5 - V$ power supplies and BJTs that have $\beta = 150$ and V_A=100V, Give the complete circuit with component values and specify the differential input resistance Ri, the output resistance Ro, the open-circuits voltage gain, the input bias current.