EXPERIMENT # 3
BJT CURRENT MIRRORS

THEORETICAL BACKGROUND

- Current Mirrors are used as current sources to bias circuits on ICs because they use fewer components and hence require little chip area.
- Two current mirror circuits will be studied in this lab:
    - Wilson Current Source
    - Widlar Current Source
- The use of current mirrors to provide bias current to the other circuits is shown in *figure # 1*. In this figure two stages of current mirrors are supplying bias current to two different circuits. The stages in a current mirror circuit can be extended if more circuits are needed to be attached for current biasing

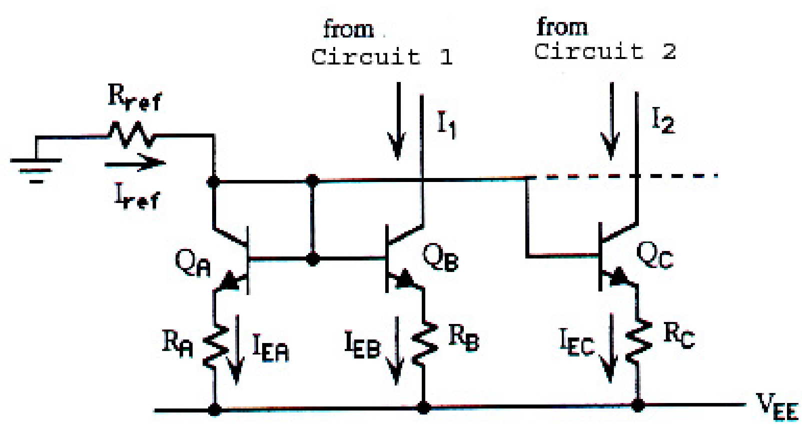


Figure # 1

- In a current mirror circuit, all transistors are matched; they have same value of current gain β_f and same size so for the equal value of V_{BE}, the collector currents I_C are equal.
- In *figure # 1*, if the small base currents are ignored and transistors are in active region then

$$I_{ref} = \frac{-(V_{EE} + 0.7)}{R_A + R_{ref}} \quad (1)$$

- Also applying *KVL* in the lower loop of transistors *A* and *B*, one can write

$$-I_{EA}R_A + I_{EB}R_B + V_{BE_B} - V_{BE_A} = 0 \quad (2)$$

- Again, ignoring small base currents of transistors *A* and *B*, $I_{EA} = I_{ref}$ and $I_{EB} = I_1$, (2) can be written as

$$-I_{ref}R_A + I_1R_B + V_{BE_B} - V_{BE_A} \approx 0 \tag{3}$$

- Using diode *voltage-current* relationship, the current through the forward biased *emitter-base* junction of the transistors can be written as

$$I_D = I_S[e^{\frac{V_D}{\eta V_T}} - 1] \tag{4}$$

- Since in forward bias, I_S (saturation current) is small, hence above equation can be written as

$$I_D \approx I_S e^{\frac{V_D}{\eta V_T}} \tag{5}$$

- Since transistors are matched, hence $I_{SA} = I_{SB}$, $V_D = V_{BE}$, $I_D = I_E$ and assuming η=1, using (3) and (5), I_1 can be written as

$$I_1 = I_{ref}\frac{R_A}{R_B} + \frac{V_T}{R_B}\ln\frac{I_{ref}}{I_1} \tag{6}$$

where V_T = 26mV at room temperature

- Equation (6) is the relation for *Wilson Current Mirror*.
- If I_1 and I_{ref} are very close in value, $\ln\frac{I_{ref}}{I_1} \approx 0$ and

$$\frac{I_1}{I_{ref}} \approx \frac{R_A}{R_B} \tag{7}$$

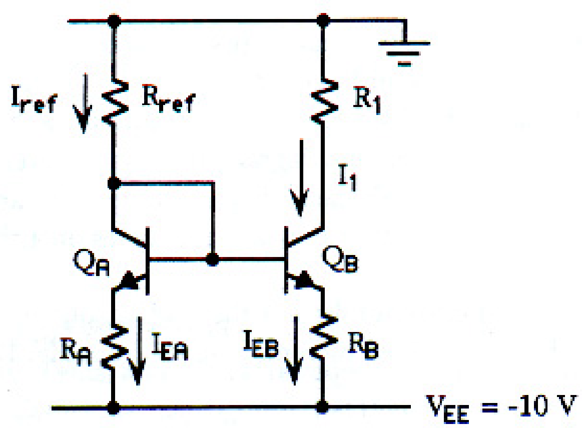
- If very low biased current is required, *Widlar Current Mirror* can be used. It is obtained by removing R_A from *figure #1*. With R_A removed, (6) can be written as

$$I_1 = \frac{V_T}{R_B}\ln\frac{I_{ref}}{I_1} \tag{8}$$

which is the defining relationship of *Widlar Current Source*

PRELAB (1% of the Total Grade)

1. Derive equation (6), using (3) and (5)
2. Design Wilson Current source as shown in *circuit # 2* for I_{ref} =1 mA i.e. first calculate the values of $R_{ref} + R_A$ using (1), then choose some suitable value for either R_{ref} or R_A and calculate the other resistor (keep R_{ref} larger than R_A). Now choose two values of I_1 less than I_{ref} =1 mA and two values of I_1 greater than I_{ref} =1 mA and for each case find values of R_B by solving (6). Calculate the value of V_{CE} for transistor Q_B for each of the four values of I_1 and make sure that your transistor is in active region, i.e., V_{CEB} >> 0.2V. Use $V_{EE} = -10V$ and any value of R_B up to $10K\Omega$. Since R_1 does not appear in either (1) or (6) so you can choose a suitable value for it without effecting your results (for e.g. R_1 =3KΩ)
3. Now design a Widlar Current Source by removing R_A from Wilson source and again calculate the value of R_{ref} for I_{ref} =1 mA. As it can be seen from (8) that for Widlar source I_1 can not exceed I_{ref}, hence choose two values of I_1 less than I_{ref} =1 mA and for each value, calculate the value of R_B from (8) as you did it for Wilson source. Calculate the value of V_{CE} for transistor Q_B for each of the four values of I_1 and make sure that your transistor is in active region, i.e., V_{CEB} >> 0.2V.



Circuit # 2

LAB PROCEDURE

1. Implement *step # 2* of prelab. For each case measure:
   a. I_1
   b. I_{ref}
   c. V_{CE} of transistor *B* to make sure that it is not in the saturation region.

2. Implement *step # 3* of the prelab and measure the same quantities as you did for Wilson source.

DATA ANALYSIS

- Compare and analyze the measured and calculated values of Wilson and Widlar current sources from equations (1), (6) and (8). Discuss and interpret your results in detail.

NOTE:
Label the transistors that you used in this lab to use in the next lab