

DEPARTMENT OF ELECTRICAL ENGINEERING AND COMPUTER SCIENCE
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
CAMBRIDGE, MASSACHUSETTS 02139

TRANSISTOR BIAS STABILITY AS A FUNCTION OF β_F VARIATIONS
by Ron Roscoe

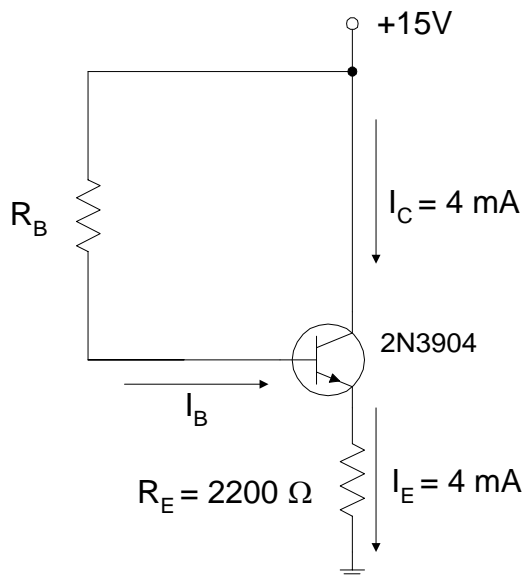


Figure 1: Single resistor transistor biasing circuit.

$$\beta_F = 100; \quad I_C = \beta_F I_B; \quad I_E = (\beta_F + 1) I_B; \quad I_E \approx I_C$$

$$I_B R_B + 0.7V + I_C R_E = V_{CC}$$

$$I_B R_B + 0.7V + \beta_F I_B R_E = V_{CC}$$

$$I_B (R_B + \beta_F R_E) = V_{CC} - 0.7V$$

$$I_B = \frac{(V_{CC} - 0.7V)}{R_B + \beta_F R_E} \quad (1)$$

$$I_C = \frac{\beta_F (V_{CC} - 0.7V)}{R_B + \beta_F R_E} \quad (2)$$

$$R_B + \beta_F R_E = \frac{\beta_F (V_{CC} - 0.7V)}{I_C}$$

$$R_B + 100 \times 2200\Omega = \frac{100(15V - 0.7V)}{4mA}$$

$$R_B + 220k\Omega = \frac{1430}{4} \times 10^3 \Omega$$

$$R_B + 220k\Omega = 358k\Omega$$

$$R_B = 138k\Omega$$

Variation of Collector Current with Beta

I_C	β_F
2.9 mA	50
4.0 mA	100
5.0 mA	200
5.4 mA	300
$\Delta I_C = 2.5 \text{ mA}$	

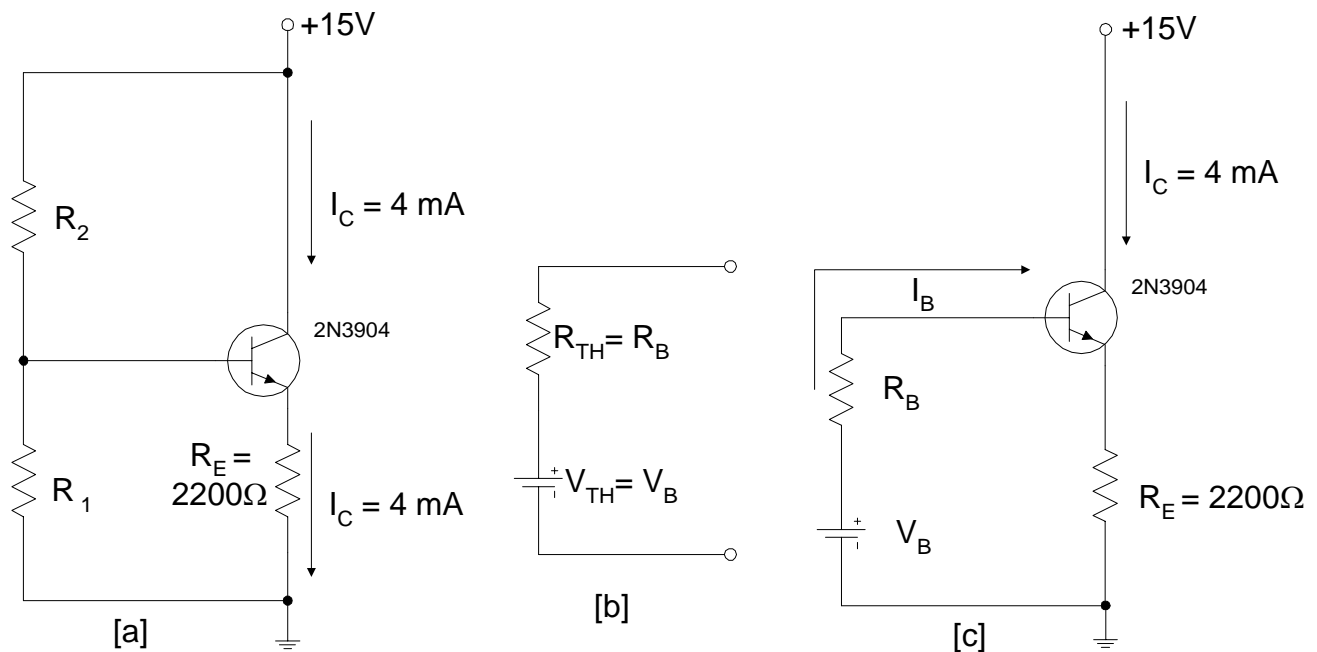


Figure 2: Two-resistor biasing circuit and Thevenin Equivalent for analysis.

$$V_B = \frac{R_2}{R_1 + R_2} \times V_{cc} \quad (3)$$

$$R_B = \frac{R_1 R_2}{R_1 + R_2} \quad (4)$$

$$V_B - I_B R_B - 0.7V - I_C R_E = 0$$

$$V_B = I_B R_B + 0.7V + \beta_F I_B R_E$$

$$V_B - 0.7V = I_B R_B + \beta_F I_B R_E = I_B (R_B + \beta_F R_E)$$

$$I_B = \frac{(V_B - 0.7V)}{R_B + \beta_F R_E} \quad (5)$$

$$I_C = \frac{\beta_F (V_B - 0.7V)}{R_B + \beta_F R_E} \quad (6)$$

Equation (6) is an equation with two unknowns: V_B and R_B . Analyzing the denominator of equation (6) we note that if R_B is kept small compared to the product $\beta_F R_E$ then the β_F 's in the numerator and denominator will cancel if we can

ignore R_B . As a general rule of thumb, keeping R_B no greater than ten times R_E will give good bias stability over a wide range of β_F values. R_B cannot be lowered to zero since the internal impedance of the battery is zero, and thus any AC source that is capacitor-coupled into the transistor stage will be shorted out. We will continue the example using $R_B = 22k\Omega$. Now we can solve eqn. (6) for V_B .

$$4mA \times (22k\Omega + 220k\Omega) = 100(V_B - 0.7V)$$

$$4mA \times 242k\Omega = 100V_B - 70$$

$$968 + 70 = 100V_B$$

$$V_B = 10.4V$$

Given $V_B = 10.4V$ and $R_B = 22k\Omega$, we can now solve equations (3) and (4) for R_1

$$V_B = \frac{R_1}{R_1 + R_2} \times V_{CC}$$

$$\text{and } R_2 \cdot R_1 + R_2 = R_1 \left(\frac{V_{CC}}{V_B} \right) = R_1 \left(\frac{15V}{10.4V} \right) = 1.45R_1$$

$$R_1 + R_2 = 1.45R_1$$

$$0.45R_1 = R_2$$

$$\frac{R_1 R_2}{R_1 + R_2} = R_B = 22k\Omega$$

$$\frac{R_1 \times 0.45R_1}{R_1 + 0.45R_1} = 22k\Omega$$

$$\frac{0.45R_1^2}{1.45R_1} = 22k\Omega$$

$$0.310R_1 = 22k\Omega$$

$$R_1 = 70.9k\Omega \quad \text{use } 68k\Omega$$

$$R_2 = 0.45R_1 = 0.45 \times 70.9k\Omega = 31.9k\Omega \quad \text{use } 33k\Omega$$

Check I_C variation with change in β_F using equation (6):

$$I_C = \frac{\beta_F(V_B - 0.7V)}{R_B + \beta_F R_E} \quad (6)$$

$$I_C = \frac{\beta_F(10.4 - 0.7V)}{22k\Omega + \beta_F 2200\Omega}$$

I_C	β_F
3.7 mA	50
4.0 mA	100
4.2 mA	200
4.3 mA	300
$\Delta I_C = 0.6 \text{ mA}$	

Looking at the partial circuit shown in Figure 2c; we can see that our goal is to keep the product of the collector (emitter) current and the emitter resistor constant. This voltage is 8.8 volts for $I_C = 4 \text{ mA}$. Note that the 0.7V base-emitter voltage is essentially constant. If we can keep the voltage drop due to $I_B R_B$ as small as possible by keeping R_B small (since we have no control over I_B); then it becomes obvious that the emitter resistor voltage drop is essentially set by the V_B battery voltage minus the base-emitter voltage.