Literature:

Biasing design: P 432 - 456

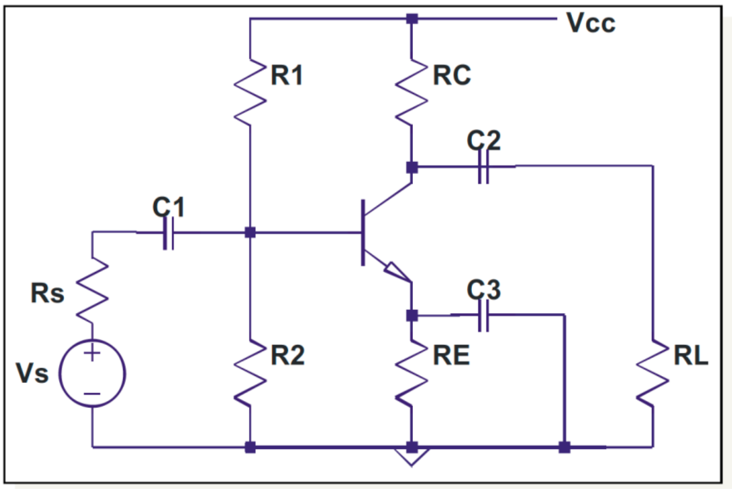
Assignments:

11.1:

Design an amplifier by using a BC547B transistor that can provide a voltage gain of $A_v = -50$. $R_S = 1\ K\Omega$, $R_L = 10\ K\Omega$, $V_{CC} = 15$ V and the output swing peak value $v_{o,p} = 3$ V. In addition, we assume that $\beta = 300$, $V_{CE,sat} \leq 0.3$ V and $r_o \gg R_L$. Try to design the amplifier with lowest distortion for the given gain requirement.

Verify using LTspice gain and distortion for your design when fully equipped and optimize. If necessary, modify your design and verify again gain and distortion. 1kHz is used as test frequency.

Solution:



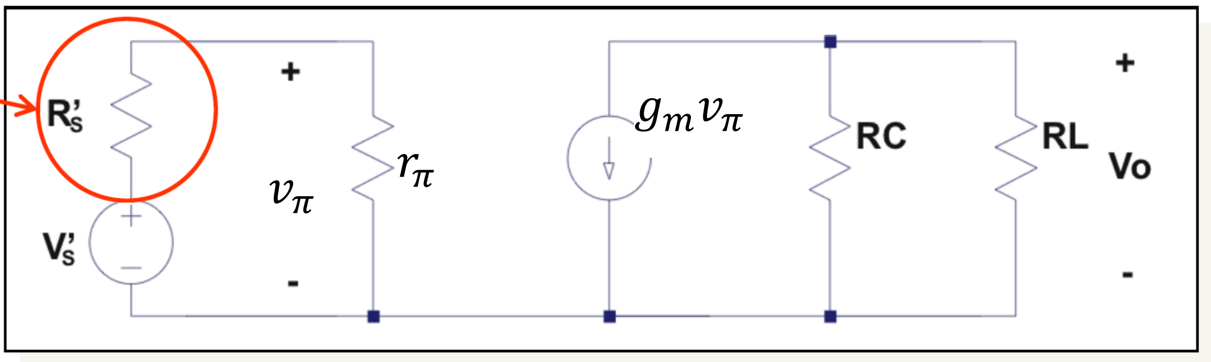
Definition & assumption:

$$v_S' = \frac{R_B}{R_B + R_S} v_S$$

$$R_S' = R_S \parallel R_B$$

$$r_o >> R_C \parallel R_L$$

$$R_B = R_1 || R_2$$

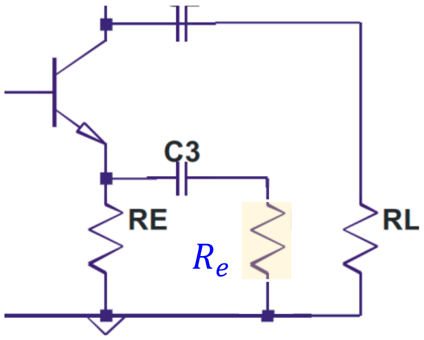


1. Determine $V_{R_C} = V_{CC} - V_{R_E} - V_{CE,sat} - V_{o,p} = 15 - 3 - 0.3 - 3 = 8.7$ V
2. Determine optimal R_C to maximize gain for the fixed V_{R_C}:

$$R_C = \sqrt{\frac{R_S' R_L V_{R_C}}{\beta V_T}} \approx \sqrt{\frac{R_S R_L V_{R_C}}{\beta V_T}} = 3.34\ K\Omega$$

3. Determine $I_C = \frac{V_{R_C}}{R_C} = \frac{8.7\ V}{3.34\ K\Omega} = 2.6\ mA$
4. Determine $R_E = \frac{V_{R_E}}{I_C} = \frac{3\ V}{2.6\ mA} \approx 1.2\ K\Omega$
5. Determine $R_B \approx \frac{\beta}{10} R_E = 36\ K\Omega$
6. Calculate $R_S' = R_S||R_B \approx 0.973\ K\Omega$, recalculate $R_C = \sqrt{\frac{R_S' R_L V_{R_C}}{\beta V_T}} = 3.29\ K\Omega$
7. The gain $A_v = \frac{v_o}{v_s} = \frac{v_o}{v_s'} \cdot \frac{v_s'}{v_s} = A_v' \cdot \frac{R_B}{R_B+R_S} = -\frac{1}{\left(\frac{1}{g_m}+\frac{R_S'}{g_m r_\pi}\right)\left(\frac{1}{R_C}+\frac{1}{R_L}\right)} * \frac{R_B}{R_B+R_S} = -181.9$

   $|A_v|$ is much larger than 50. So we can add a resistor in emitter to reduce the total harmonic distortion.
8. Determine the resistance R_e': $A_v = \frac{v_o}{v_s} = \frac{v_o}{v_s'} \cdot \frac{v_s'}{v_s} = A_v' \cdot \frac{R_B}{R_B+R_S} = -50$ ➔$A_v' = -50 \cdot \frac{36+1}{36} = -51.39 = -(R_C||R_L)/(\frac{1}{g_m} + R_e' + \frac{R_S'}{\beta})$ ➔$R_e' = -\frac{(R_C||R_L)}{A_v'} - \frac{1}{g_m} - \frac{R_S'}{\beta} = 34.9\ \Omega$. $R_e' = R_E||R_e$ ➔$R_e = \frac{1}{\frac{1}{R_e'} - \frac{1}{R_E}} = 35.9\Omega \approx 36\ \Omega$



9. Calculate the amplitude (i.e. peak value) of the v_S', $v_{s,p}' = \frac{v_{o,p}}{A_v'} = \frac{3\ V}{51.39} = 58.4\ mV$.

   Calculate the harmonic distortion term $F = 1 + g_m\left(\frac{R_S'}{\beta} + R_e'\right) = 1 + \frac{I_C}{V_T}\left(\frac{R_S'}{\beta} + R_e'\right) = 4.81$ ➔$HD_2 = \frac{\frac{\frac{1}{4} \cdot v_{s,p}'}{V_T}}{F^2} = 2.42\%$

10. Determine R_1 and R_2.

$$V_{BB} = I_C R_E + V_{BE} + \frac{I_C}{\beta} R_B = 4.13\ V$$

$R_B = \frac{R_1 R_2}{R_1 + R_2}$ and $V_{BB} = V_{CC} \frac{R_2}{R_1 + R_2}$

$\Rightarrow R_1 = \frac{V_{CC}}{V_{BB}} R_B = 130.1\ K\Omega$ and $R_2 = R_1 \frac{V_{BB}}{V_{CC} - V_{BB}} = 49.4\ K\Omega$

11. Check by the LTspice

    Is the gain larger or smaller than 50?

    If it is smaller, try to modify R_e to have the gain >=50.