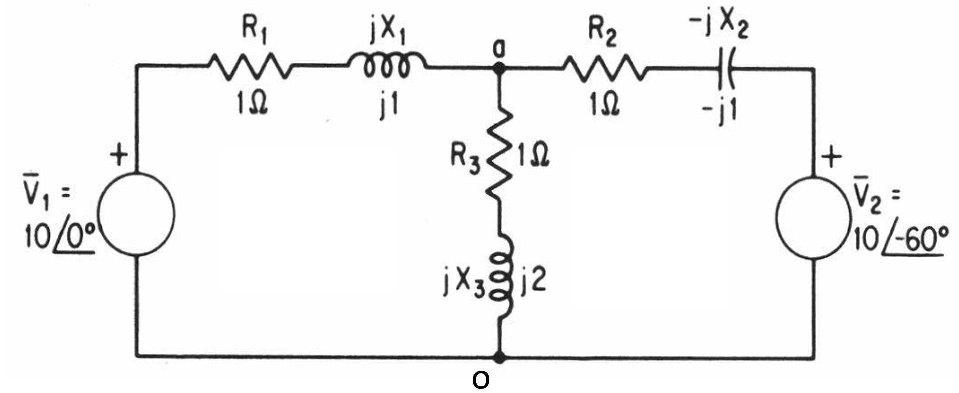
EE101
Tutorial-5 (11 Sep 2014)

Q1. Use Norton's theorem to find the current through R_3, X_3 branch in the circuit shown below.



Q2. For the transistor amplifier circuit with collector-emitter feedback biasing shown in Figure 1, find the value of

a. I_B
b. V_C
c. V_E
d. V_{CE}

(Assume that $V_{BE} = 0.7\ V$ in forward biased condition)

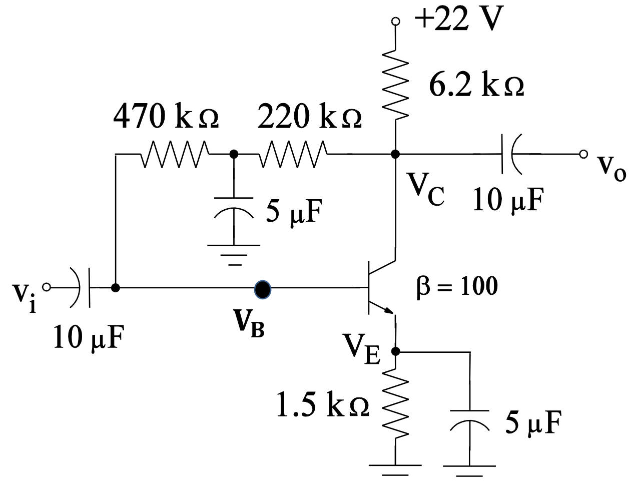


Figure 1

Q3. In Figure 2, the transistor is in active region with the quiescent C-E voltage $V_{CEQ} = 4\ V$. Assume that $V_{BE} = 0.7\ V$, $V_T = 26\ mV$, BJT output resistance r_o is very high (> 100 kΩ), and all capacitors are short-circuited at applied signal frequency. Find the value of

a. R_1
b. r_e
c. $A_v = \frac{v_o}{v_i}$
d. A_v, if a load $R_L = 2\ k\Omega$ is connected across A-B.
e. $A_{v_s} = \frac{v_o}{v_s}$, if $R_L = 2\ k\Omega$ is connected across A-B and assuming that applied voltage source has a resistance of $R_s = 0.5\ k\Omega$.

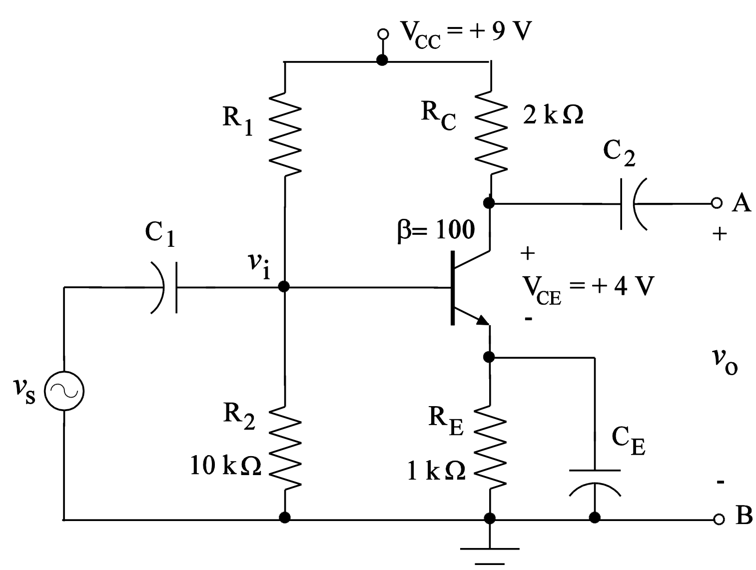


Figure 2

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Solutions

Q1. Impedance between the terminals a-o,

$Z_N = (R_1+jX_1) \,||\, (R_2-jX_2)$

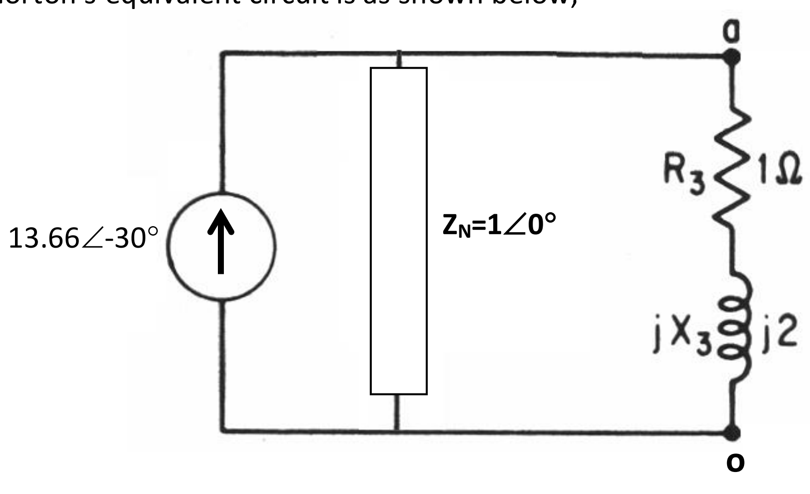
Therefore,

$$Z_N \quad = (1+j1)//(1-j1) \quad = \frac{\sqrt{2}\angle 45^\circ \times \sqrt{2}\angle -45^\circ}{1+j1+1-j1} = 1\angle 0^\circ \;\; \Omega$$

Short circuit current across a-o,

$$\begin{aligned} I_{sc} &= \frac{V_1}{R_1+jX_1} + \frac{V_2}{R_2-jX_2} = \frac{10\angle 0^\circ}{1+j1} + \frac{10\angle -60^\circ}{1-j1} = 5\sqrt{2}\angle -45^\circ + 5\sqrt{2}\angle -15^\circ \\ &= 6.83 - j1.83 + 5 - j5 = 11.83 - j6.83 \\ &= 13.66\angle -30^\circ \;\; \text{A} \end{aligned}$$

The Norton's equivalent circuit is as shown below,

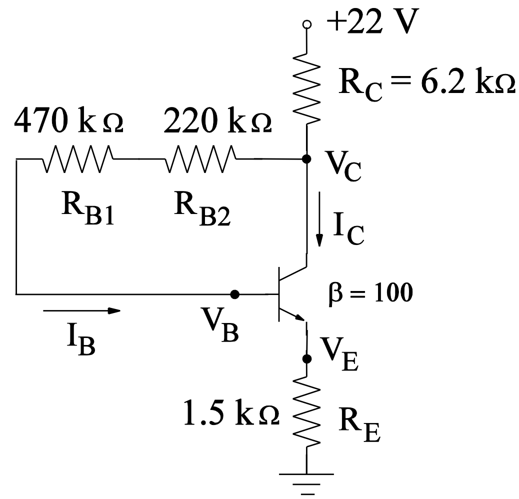


And the current through R_3, X_3 is computed as:

$$\begin{aligned} I_3 &= I_{sc} \times \frac{1\angle 0^\circ}{1\angle 0^\circ + 1 + j2} \quad = 13.661\angle -30^\circ \times \frac{1}{2\sqrt{2}\angle 45^\circ} \\ &= 4.83\angle -75^\circ \;\; \text{A} \end{aligned}$$

Q2. For determining the dc current and voltages, the DC-equivalent circuit for the given transistor amplifier is shown below.

In the given circuit V_B is expected is higher than V_E, so the B-E junction would be forward biased and we assume that the transistor is in **active region** of operation, i.e., $I_C = \beta I_B$



(a) On applying KVL in the input (base) loop we have

$$V_{CC} = I_B(R_{B1} + R_{B2}) + V_{BE} + (I_B + I_C)(R_C + R_E)$$

$$I_B = \frac{V_{CC} - V_{BE}}{(R_{B1} + R_{B2}) + (\beta + 1)(R_C + R_E)}$$

$$I_B = \frac{22\ V - 0.7\ V}{(470\ k\Omega + 220\ k\Omega) + 101(6.2\ k\Omega + 1.5\ k\Omega)} \cong 14.51\ \mu A$$

(b) $V_C = V_{CC} - (\beta + 1)I_B R_C = 22\ V - 101 \times 14.51\ \mu A \times 6.2\ k\Omega$
$= 22\ V - 9.09\ V$
$= 12.91\ V$

(c) $V_E = (\beta + 1)I_B R_E = 101 \times 14.51\ \mu A \times 1.5\ k\Omega \cong 2.20\ V$

(d) $V_{CE} = V_C - V_E = 12.91\ V - 2.20\ V = 10.71\ V$

Check: $V_B = V_E + 0.7\ V = 2.9\ V$ and so $V_{CB} = 12.91\ V - 2.9\ V = 10.01\ V$. Thus C-B junction is reversed biased and assumption about transistor being in active region is valid.

Q3. Given that $V_{CEQ} = 4\ V$ and the transistor is in active region, so $I_C = \beta I_B$

(a) On applying KCL in the output (collector) loop, we have

$$V_{CC} = I_C R_C + V_{CEQ} + I_E R_E = I_C R_C + V_{CEQ} + \left(1 + \frac{1}{\beta}\right) I_C R_E$$

$$I_C = \frac{V_{CC} - V_{CEQ}}{R_C + \left(1 + \frac{1}{\beta}\right) R_E} = \frac{9\ V - 4\ V}{2\ \text{k}\Omega + 1.01 \times 1\ \text{k}\Omega} = 1.66\ mA$$

and

$$I_B = \frac{I_C}{\beta} = \frac{1.66\ mA}{100} = 0.0166\ mA$$

.

For the voltage-divider biasing, find the Thevenin's equivalent as seen by B-E terminals of BJT as

$$V_{Th} = \left(\frac{9 \times 10\ k\Omega}{10\ k\Omega + R_1}\right) V \quad \text{and} \quad R_{Th} = (10\ k\ \parallel\ R_1)\ \Omega$$

Now applying KVL in the input (base) loop, we have

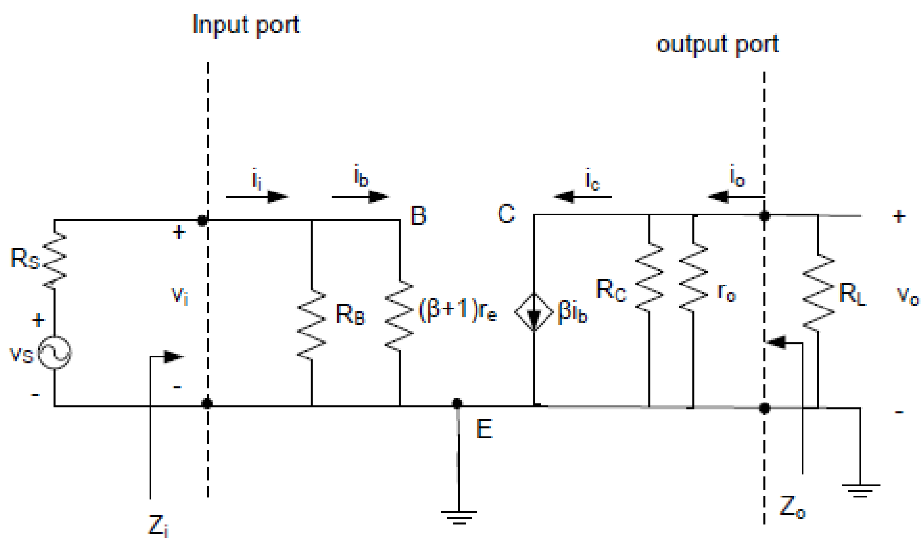
$$\left(\frac{9 \times 10\ k\Omega}{10\ k\Omega + R_1}\right) V = \left(\frac{R_1 \times 10\ k\Omega}{10\ k\Omega + R_1}\right) I_B + V_{BE} + (1 + \beta) I_B R_E$$

$$\left(\frac{90\ k\Omega - 0.166 R_1}{10\ k\Omega + R_1}\right) V = 0.7\ V + 101(0.0166\ mA \times 1 k\Omega) \cong 2.38\ V$$

$$90\ k\Omega - 0.166 R_1 = 23.8\ k\Omega + 2.38 R_1 \quad \Rightarrow \quad R_1 = \frac{66.2\ k\Omega}{2.546} = 26\ k\Omega$$

(b) $I_E = (1 + \beta) I_B \cong 1.68\ mA$, so $\quad r_e = \frac{26\ mV}{I_E} = \frac{26\ mV}{1.68\ mA} \cong 15.5\ \Omega$

The AC equivalent circuit of the given amplifier circuit (Given for reference purpose only)



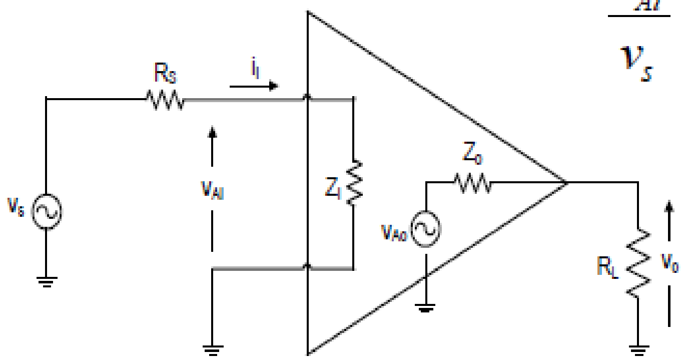
(c) Using the derived expression, the voltage gain,

$$A_v = \frac{v_o}{v_i} = -\frac{R_C \parallel r_o}{r_e} \cong -\frac{R_C}{r_e} = -\frac{2\ k\Omega}{15.5\ \Omega} = -129$$

(d) The voltage gain with load R_L connected across A-B,

$$A_v' = -\frac{R_C \parallel R_L}{r_e} = -\frac{2\ k\Omega \parallel 2\ k\Omega}{15.5\ \Omega} = -64.5$$

(e) The voltage gain of amplifier with source resistance R_s and load resistance R_L included, is derived as below (the below material is copied from that in slides)



$$\frac{v_{Ai}}{v_s} = \frac{Z_i}{Z_i + R_s} \qquad \frac{v_o}{v_{Ao}} = \frac{R_L}{R_L + Z_o}$$

$$A_v^* = \frac{v_o}{v_s} = \frac{v_o}{v_{Ao}} \frac{v_{Ao}}{v_{Ai}} \frac{v_{Ai}}{v_s}$$

$$= \frac{R_L}{R_L + Z_o} A_v \frac{Z_i}{Z_i + R_s}$$

$$A_{v_s} = \frac{v_o}{v_s} = \frac{Z_i}{R_s + Z_i} \times A_v \times \frac{R_L}{Z_o + R_L}$$

where Z_i is the input resistance and Z_o is the output resistance of amplifier, respectively

$$Z_i = (R_1 \parallel R_2) \parallel (\beta + 1)r_e = (26\ k\Omega \parallel 10\ k\Omega) \parallel (101 \times 15.5\ \Omega) \cong 1.29\ k\Omega$$

$$Z_o \cong R_C = 2\ k\Omega$$

$$A_{v_s} = \frac{1.29\ k\Omega}{0.5\ k\Omega + 1.29\ k\Omega} \times (-129) \times \frac{2\ k\Omega}{2\ k\Omega + 2\ k\Omega} \cong -46.5$$

Note for the reduction in the overall gain of the amplifier due to inclusion of load resistance and/or source resistance.