# K. J. SOMAIYA COLLEGE OF ENGINEERING
# DEPARTMENT OF ELECTRONICS ENGINEERING
# ELECTRONIC CIRCUITS
## Low & High-frequency response of single-stage amplifier

**Numerical 1**: For the circuit shown in figure 1, determine $I_{CQ}$, lower cut-off frequency due to $C_S$, $C_C$, $C_E$, overall cut-off frequency $f_L$ and midband voltage in dB. Given: $\beta = 100$, $r_o = \infty$

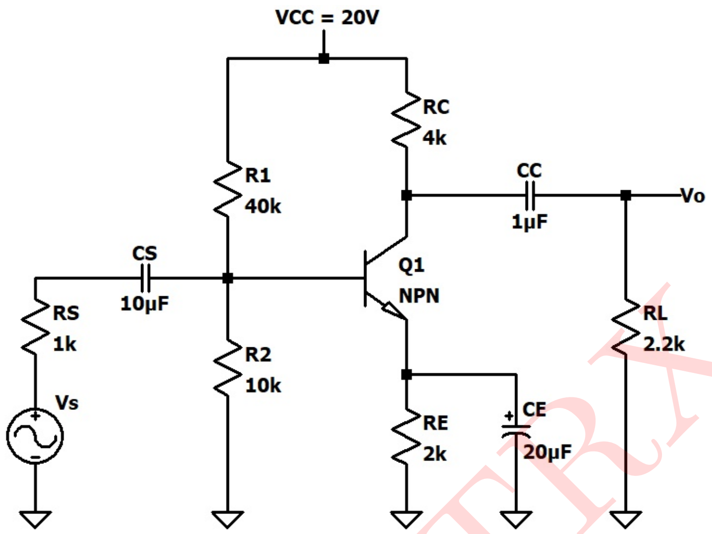


Figure 1: Circuit 1

**Solution:**

The given circuit 1 is a voltage divider bias configuration employing npn BJT.

For DC biasing, the capacitors will act as an open source.

**DC Analysis:**

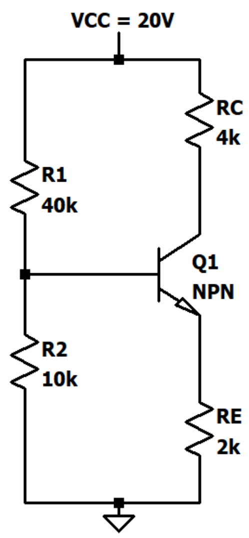


Figure 2: DC Equivalent Circuit

$R_B = \dfrac{R_1 \times R_2}{R_1 + R_2}$

$R_B = \dfrac{40 \times 10^3 \times 10 \times 10^3}{40 \times 10^3 + 10 \times 10^3} = \mathbf{8\ k\Omega}$

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

$V_G = \dfrac{20 \times 10 \times 10^3}{40 \times 10^3 + 10 \times 10^3} = \mathbf{4\ V}$

Thevenin's Equivalent circuit:

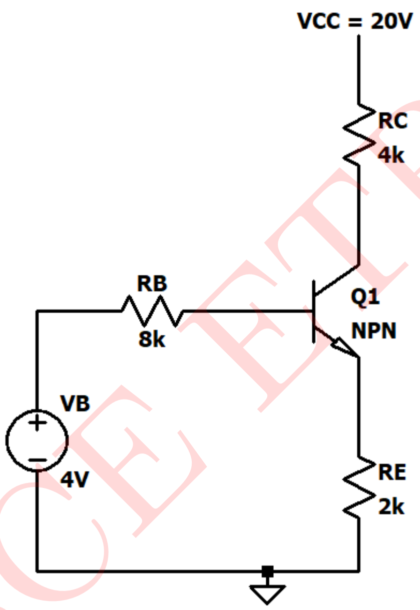


Figure 3: Thevenin's Equivalent circuit

$I_{BQ}$ can be calculated by applying KVL to the base-emitter loop,

$V_B - I_B R_B - V_{BE} - I_E R_E = 0$

$I_B R_B + (1+\beta) I_B R_E = V_B - V_{BE}$ ...($\because I_E = (1+\beta) I_B$)

$I_B(R_B + (1+\beta)R_E) = V_B - V_{BE}$

$I_B = \dfrac{V_B - V_{BE}}{R_B + (1+\beta)R_E}$

$I_B = \dfrac{4 - 0.7}{8 \times 10^3 + (1+100) \times 2 \times 10^3} = \mathbf{15.71\ \mu A}$

$I_{CQ} = \beta I_B$

$I_{CQ} = 100 \times 15.71 \times 10^{-6} = \mathbf{1.571\ mA}$

$I_E = (1+\beta) I_B$

$I_E = (1+100) \times 15.71 \times 10^{-6} = \mathbf{1.586\ mA}$

**AC Analysis:**

$$r_\pi = \frac{\beta V_T}{I_E}$$

$$r_\pi = \frac{10 \times 26 \times 10^{-3}}{1.586 \times 10^{-3}} = \mathbf{1.64\ k\Omega}$$

$$g_m = \frac{I_{CQ}}{V_T}$$

$$g_m = \frac{1.571 \times 10^{-3}}{26 \times 10^{-3}} = \mathbf{60.423\ mA/V}$$

$$r_0 = \infty \qquad ...\text{(given)}$$

Small Signal Equivalent Circuit is shown in figure 4:

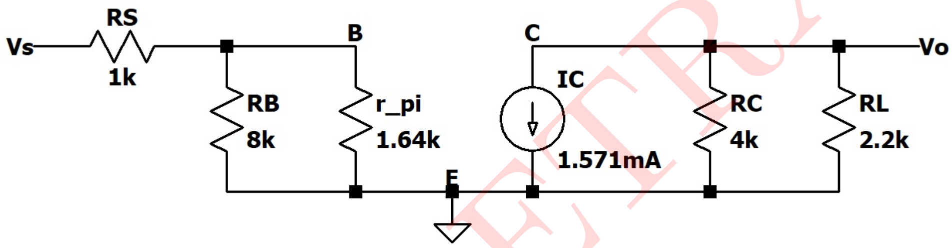


Figure 4: Small Signal Equivalent Circuit

$V_o$ = voltage developed across $(R_c \ || \ R_L)$

$$V_o = -g_m V_\pi (R_c \ || \ R_L) \qquad ...(1)$$

but, $V_\pi$ = voltage across $(R_B \ || \ r_\pi)$

$$V_\pi = \frac{(R_B \ || \ r_\pi)}{R_S + (R_B \ || \ r_\pi)} V_s$$

Substituting this in equation 1,

$$V_o = -g_m \frac{(R_B \ || \ r_\pi) V_s}{R_S + (R_B \ || \ r_\pi)} (R_C \ || \ R_L)$$

$$\frac{V_o}{V_S} = A_{V(mid)} = -g_m (R_C \ || \ R_L) \frac{(R_B \ || \ r_\pi)}{R_S + (R_B \ || \ r_\pi)}$$

$$A_{V(mid)} = -60.423 \times 10^{-3} \frac{(4 \times 10^3 \ || \ 2.2 \times 10^3) \times (8 \times 10^3 \ || \ 1.64 \times 10^3)}{1 \times 10^3 + (8 \times 10^3 \ || \ 1.64 \times 10^3)}$$

$$A_{V(mid)} = \frac{-60.423 \times 10^{-3} \times 1.419 \times 10^3 \times 1.361 \times 10^3}{1 \times 10^3 + 1.361 \times 10^3} = \mathbf{-49.425}$$

$$A_{V(mid)dB} = 20\log_{10}(|A_{V(mid)}|)$$

$$A_{V(mid)dB} = 20\log_{10}(49.425) = \mathbf{33.8789\ dB}$$

Lower cut-off frequency analysis:

a) Due to $C_S$ alone

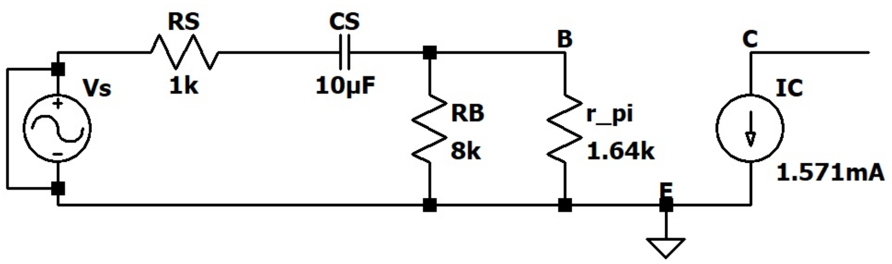


Figure 5: Small Signal Low Frequency Equivalent Circuit for $C_S$ alone

$R_i = R_B \ || \ r_\pi$

$R_i = (8 \times 10^3 \ || \ 1.64 \times 10^3) = \mathbf{1.361\ k\Omega}$

$$f_{L\,C_S} = \frac{1}{2\pi C_S R_{eq}}$$

$$f_{L\,C_S} = \frac{1}{2\pi C_S (R_S + R_i)}$$

$$f_{L\,C_S} = \frac{1}{2\pi \times 10 \times 10^{-6} \times (1 \times 10^3 + 1.361 \times 10^3)} = \mathbf{6.741\ Hz}$$

b) Due to $C_C$ alone

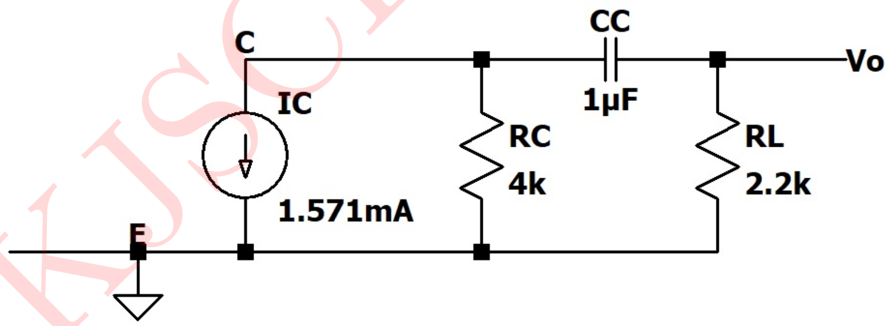


Figure 6: Small Signal Low Frequency Equivalent Circuit for $C_C$ alone

$R_{eq} = R_C + R_L$

$R_{eq} = 4 \times 10^3 + 2.2 \times 10^3 = \mathbf{6.2\ k\Omega}$

$$f_{L\,C_C} = \frac{1}{2\pi C_C R_{eq}}$$

$$f_{L\,C_C} = \frac{1}{2\pi \times 1 \times 10^{-6} \times 6.2 \times 10^3} = \mathbf{25.67\ Hz}$$

b) Due to $C_E$ alone

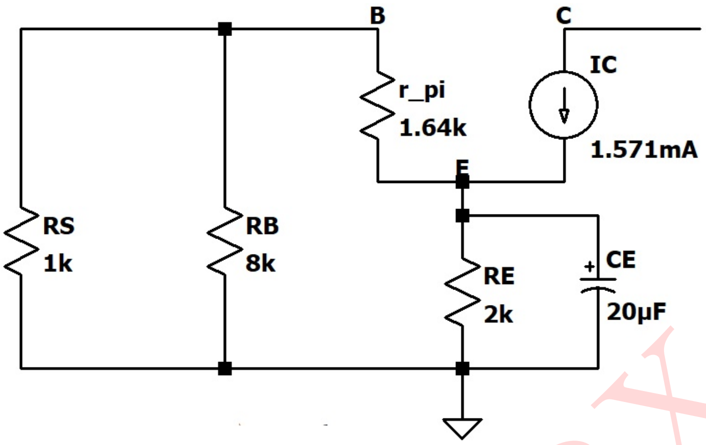


Figure 7: Small Signal Low Frequency Equivalent Circuit for $C_E$ alone

$$R_{eq} = R_E \;||\; \left(\frac{(R_S \;||\; R_B) + r_\pi}{(1+\beta)}\right)$$

$$R_{eq} = 2\times 10^3 \;||\; \left(\frac{(1\times 10^3 \;||\; 8\times 10^3) + 1.64\times 10^3)}{1+100}\right) = \mathbf{24.\;73}\;\Omega$$

$$f_{L\,C_E} = \frac{1}{2\pi C_C R_{eq}}$$

$$f_{L\,C_E} = \frac{1}{2\pi \times 20\times 10^{-6}\times 24.73} = \mathbf{321.785\ Hz}$$

Overall cut-off frequency $f_L$ will be the highest $f_L$ among $C_S$, $C_C$ and $C_E$

$f_L = f_{L\,C_E}$ ...($\because C_E$ has highest $f_L$)

$f_L = $ **321.785 Hz**

**SIMULATED RESULTS:**

Above circuit is simulated in LTspice. The results are presented below:

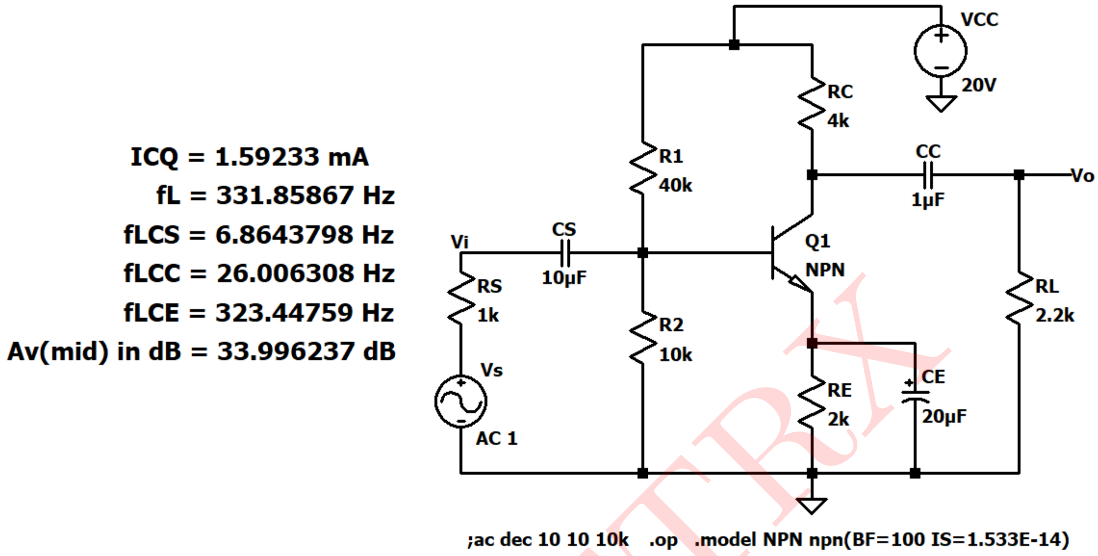


Figure 8: Circuit Schematic 1: Results

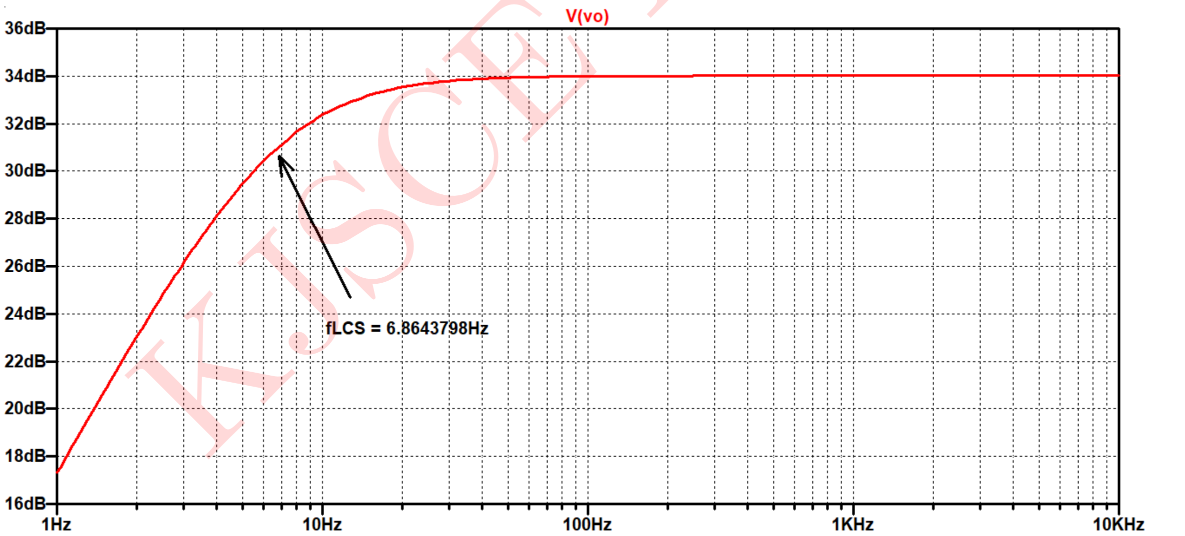


Figure 9: Low Frequency Response for $C_S$ alone

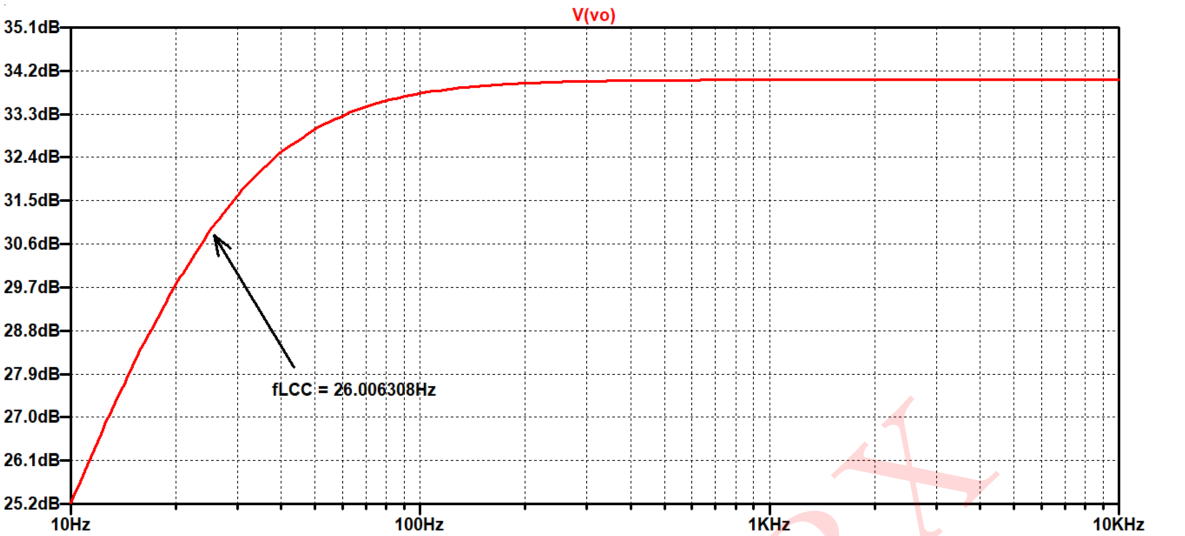


Figure 10: Low Frequency Response for $C_C$ alone

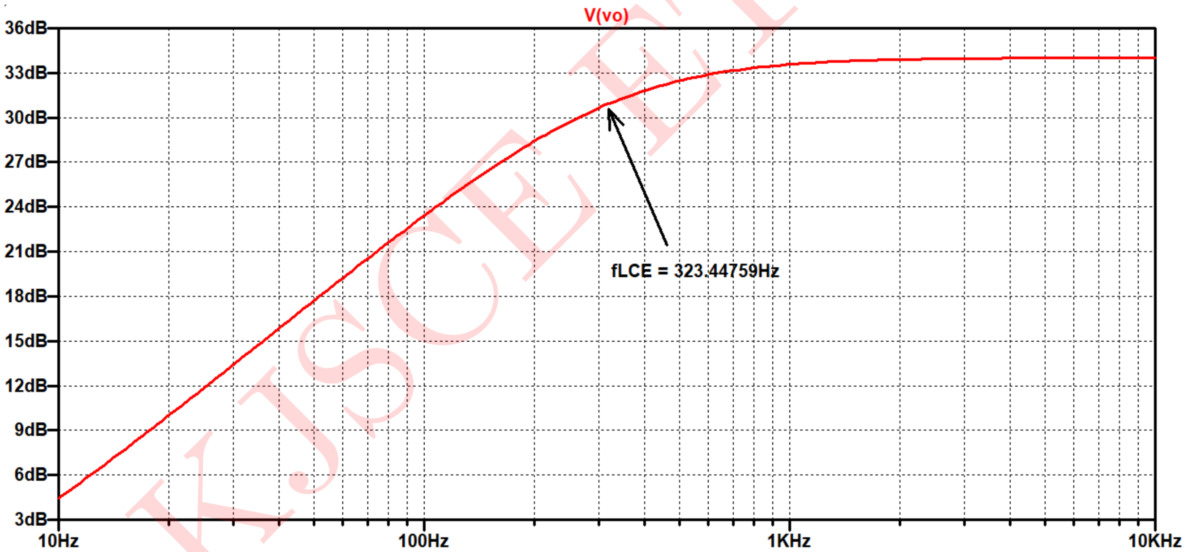


Figure 11: Low Frequency Response for $C_E$ alone

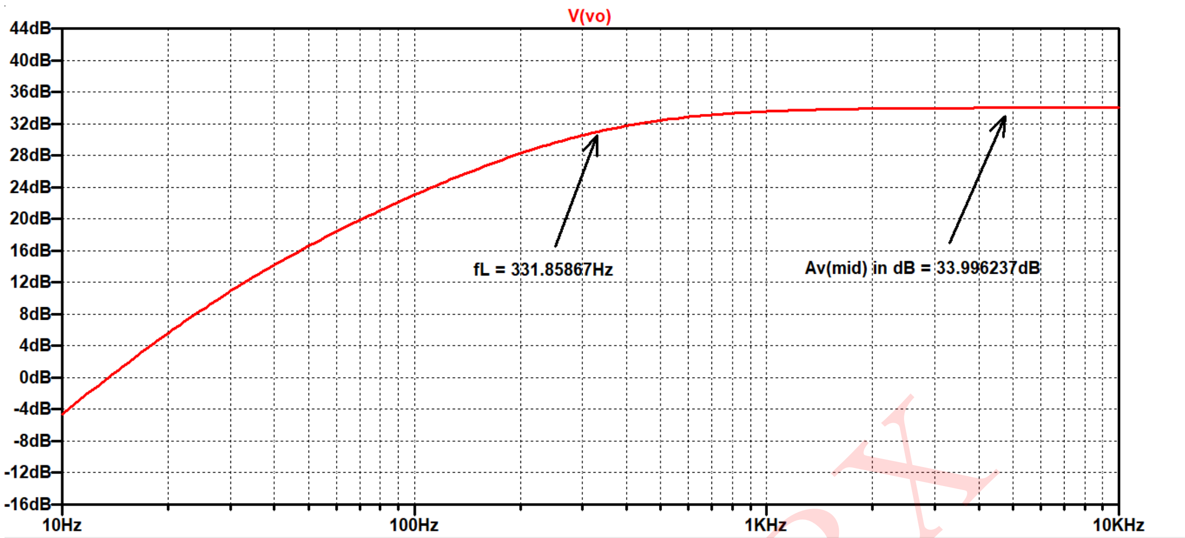


Figure 12: Low Frequency Response for the Circuit

**Comparison of theoretical and simulated values:**

| Parameters | Theoretical Values | Simulated Values |
|---|---|---|
| $I_{CQ}$ | 1.571 mA | 1.5923 mA |
| Lower cut-off frequency due to $C_S$ | 6.741 Hz | 6.8643 Hz |
| Lower cut-off frequency due to $C_C$ | 25.67 Hz | 26.0063 Hz |
| Lower cut-off frequency due to $C_E$ | 321.785 Hz | 323.4475 Hz |
| Overall cut-off frequency $f_L$ | 321.785 Hz | 331.8586 Hz |
| Midband voltage gain $A_{V(mid)}$ in dB | 33.8789 dB | 33.9962 dB |

Table 1: Numerical 1

**Numerical 2**: For the circuit shown in figure 13, the transistor parameters are: $k_n = 0.8$ mA/$V^2$, $V_{TN} = 2$ V, $\lambda = 0$. Determine $I_{DQ}$, $V_{GSQ}$, midband voltage gain in dB, lower cut-off frequency due to $C_{C1}$, $C_{C2}$, $C_S$ and overall cut-off frequency $f_L$

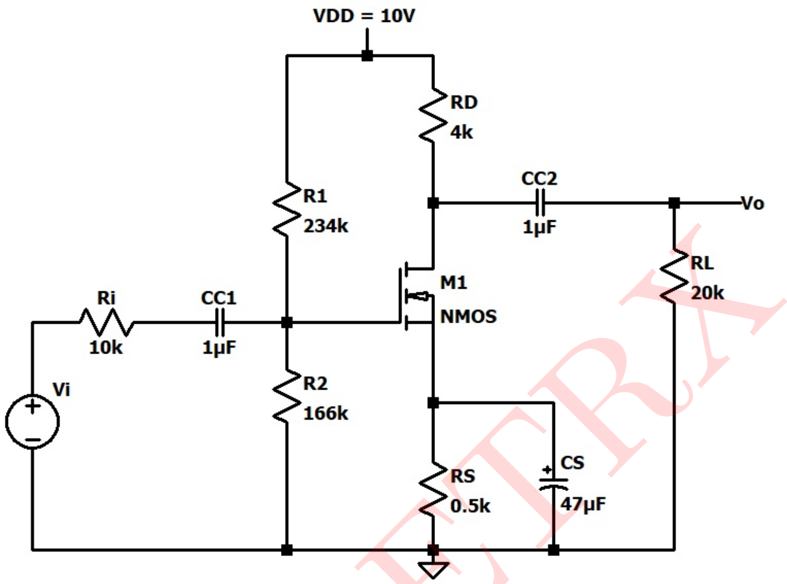


Figure 13: Circuit 2



**Solution:**

The given circuit 2 is a voltage divider bias configuration employing NMOS.

For DC biasing, the capacitors will act as an open source.

**DC Analysis:**

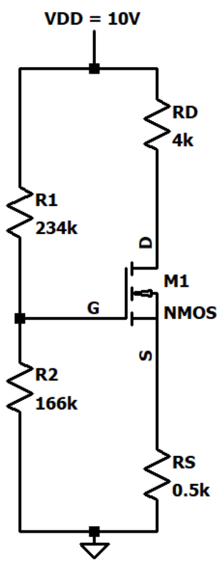


Figure 14: DC Equivalent Circuit

$$R_G = \frac{R_1 \times R_2}{R_1 + R_2}$$

$$R_B = \frac{234 \times 10^3 \times 166 \times 10^3}{234 \times 10^3 + 166 \times 10^3} = \mathbf{97.11\ k\Omega}$$

$$V_G = \frac{V_{DD} \times R_2}{R_1 + R_2}$$

$$V_G = \frac{10 \times 166 \times 10^3}{234 \times 10^3 + 166 \times 10^3} = \mathbf{4.15\ V}$$

Thevenin's Equivalent circuit:

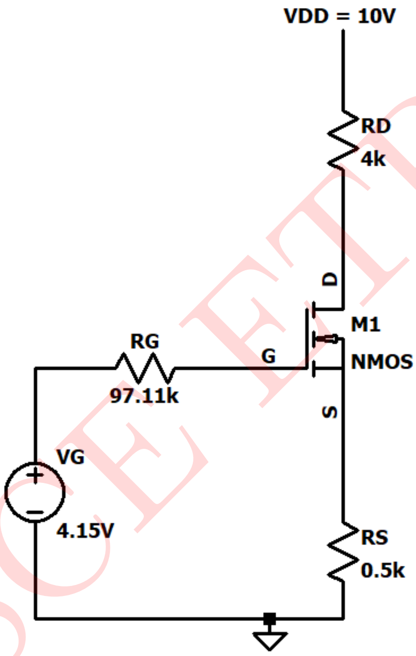


Figure 15: Thevenin's Equivalent circuit



$V_{GS}$ can be calculated by applying KVL to the gate-source loop,

$V_G - I_G R_G - V_{GS} - I_D R_S = 0$

$V_{GS} = V_G - I_D R_S$ ...($\because I_G = 0$)

$V_{GS} = 4.15 - I_D 0.5 \times 10^3$ ...(1)

From current equation,

$I_D = k_n(V_{GS} - V_{TN})^2(1 + \lambda V_{DS})$

$I_D = k_n(V_{GS} - V_{TN})^2$ ...($\because \lambda = 0$)

$I_D = 0.8 \times 10^{-3}(4.15 - 0.5 \times 10^3 I_D - 2)^2$ ...(from 1)

$I_D = 0.8 \times 10^{-3}(2.15 - 0.5 \times 10^3 I_D)^2$

$I_D = 0.8 \times 10^{-3}(4.6225 - 2.15 \times 10^3 I_D + 0.25 \times 10^6 I_D^2)$

$I_D = 3.698 \times 10^{-3} - 1.72 I_D + 200 I_D^2$

$200 I_D^2 - 2.72 I_D + 3.698 \times 10^{-3} = 0$

$I_D = \mathbf{12.06\ mA}$ or $I_D = \mathbf{1.53\ mA}$

Let, $I_D = 12.06$ mA

$V_{GS} = 4.15 - 12.06 \times 10^{-3} \times 0.5 \times 10^3 = \mathbf{-1.88\ V}$

Let, $I_D = 1.53$ mA

$V_{GS} = 4.15 - 1.53 \times 10^{-3} \times 0.5 \times 10^3 = \mathbf{3.385\ V}$

$V_{GS}$ cannot be negtive for n-mosfet.

$I_{DQ} = \mathbf{1.53\ mA}$

$V_{GSQ} = \mathbf{3.385\ V}$

**AC Analysis:**

$g_m = 2k_n(V_{GS} - V_{TN})$

$g_m = 2 \times 0.8 \times 10^{-3}(3.385 - 2) = \mathbf{2.216\ mA/V}$

$r_d = \dfrac{1}{\lambda I_{DQ}} = \dfrac{1}{0} = \infty$ ...(given)

Small Signal Equivalent Circuit is shown in figure 16:

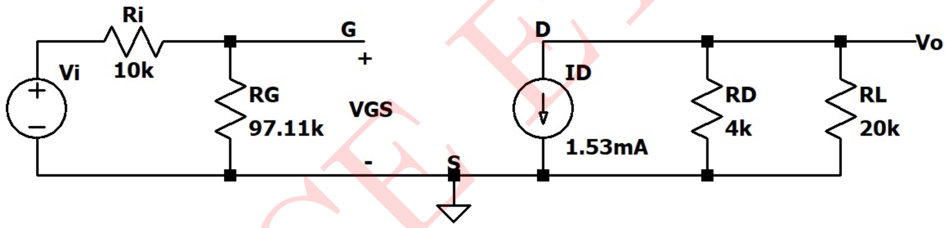


Figure 16: Small Signal Equivalent Circuit

Output voltage $V_o$ = voltage developed across $(R_D \ || \ R_L)$ due to $g_m V_{gs}$

$V_o = -g_m V_{gs}(R_D \ || \ R_L)$

$V_{gs} = \dfrac{R_G}{R_G + R_i} V_i$ ...(Voltage divider)

$$V_o = -g_m \left( \frac{R_G}{R_G + R_i} \right) V_i (R_D \ || \ R_L)$$

$$\frac{V_o}{V_i} = A_{V(mid)} = -g_m \left( \frac{R_G}{R_G + R_i} \right) (R_D \ || \ R_L)$$

$$A_{V(mid)} = -2.216^{-3} \left( \frac{97.11 \times 10^3}{97.11 \times 10^3 + 10 \times 10^3} \right) (4 \times 10^3 \ || \ 20 \times 10^3)$$

$A_{V(mid)} = -2.216 \times 10^{-3}(0.9066)(3.33 \times 10^3) = \mathbf{-6.69}$

$A_{V(mid)dB} = 20\log_{10}(|A_{V(mid)}|)$

$A_{V(mid)dB} = 20\log_{10}(6.69) = \mathbf{16.5085\ dB}$

Lower cut-off frequency analysis:

a) Due to $C_{C1}$ alone

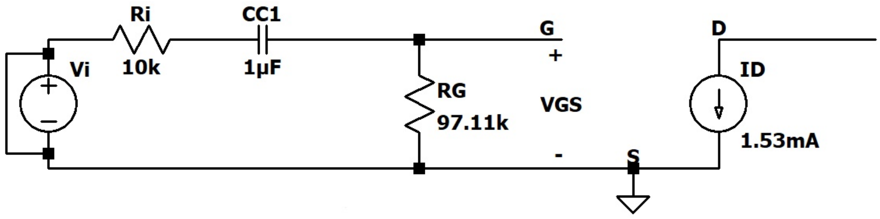


Figure 17: Small Signal Low Frequency Equivalent Circuit for $C_{C1}$

$R_{eq} = R_i + R_G$

$R_i = (10 \times 10^3 + 97.11 \times 10^3) = \mathbf{107.11\ k\Omega}$

$$f_{L\,C_{C1}} = \frac{1}{2\pi C_{C1} R_{eq}}$$

$$f_{L\,C_S} = \frac{1}{2\pi \times 1 \times 10^{-6} \times 107.11 \times 10^3} = \mathbf{1.4859\ Hz}$$

b) Due to $C_{C2}$ alone

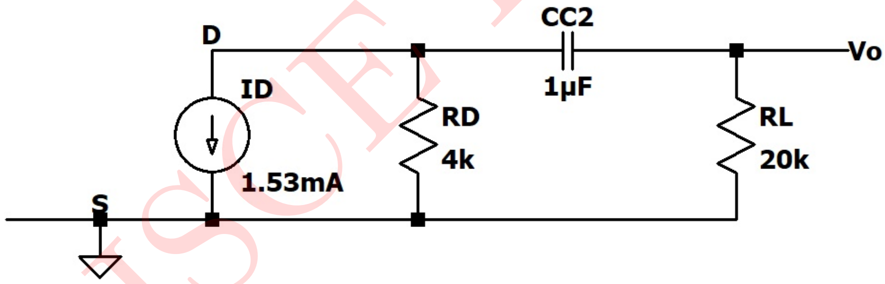


Figure 18: Small Signal Low Frequency Equivalent Circuit for $C_{C2}$

$R_{eq} = R_D + R_L$

$R_i = 4 \times 10^3 + 20 \times 10^3 = \mathbf{24\ k\Omega}$

$$f_{L\,C_{C2}} = \frac{1}{2\pi C_{C2} R_{eq}}$$

$$f_{L\,C_S} = \frac{1}{2\pi \times 1 \times 10^{-6} \times 24 \times 10^3} = \mathbf{6.6314\ Hz}$$

b) Due to $C_S$ alone

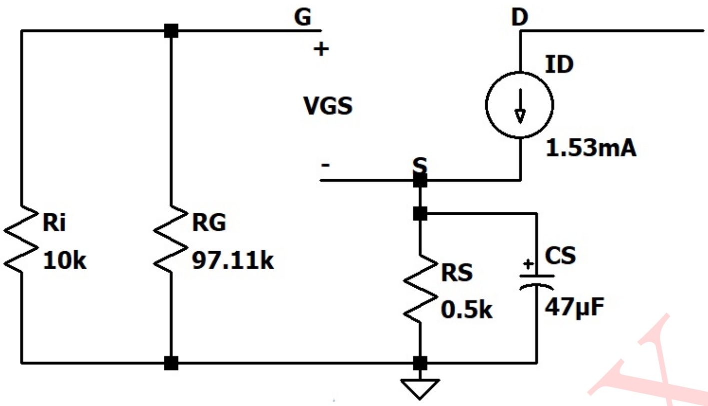


Figure 19: Small Signal Low Frequency Equivalent Circuit for $C_S$

$$R_{eq} = R_S \ || \ \left(\frac{1}{g_m}\right)$$

$$R_{eq} = 0.5 \times 10^3 \ || \ \left(\frac{1}{2.216 \times 10^{-3}}\right) = \mathbf{237.1916} \ \Omega$$

$$f_{L\,C_S} = \frac{1}{2\pi C_S R_{eq}}$$

$$f_{L\,C_S} = \frac{1}{2\pi \times 47 \times 10^{-6} \times 237.1916} = \mathbf{14.2765\ Hz}$$

Overall cut-off frequency $f_L$ will be the highest $f_L$ among $C_{C1}$, $C_{C2}$ and $C_S$

$f_L = f_{L\,C_S}$ ...($\because C_S$ has highest $f_L$)

$f_L = \mathbf{14.2765\ Hz}$

**SIMULATED RESULTS:**

Above circuit is simulated in LTspice. The results are presented below:

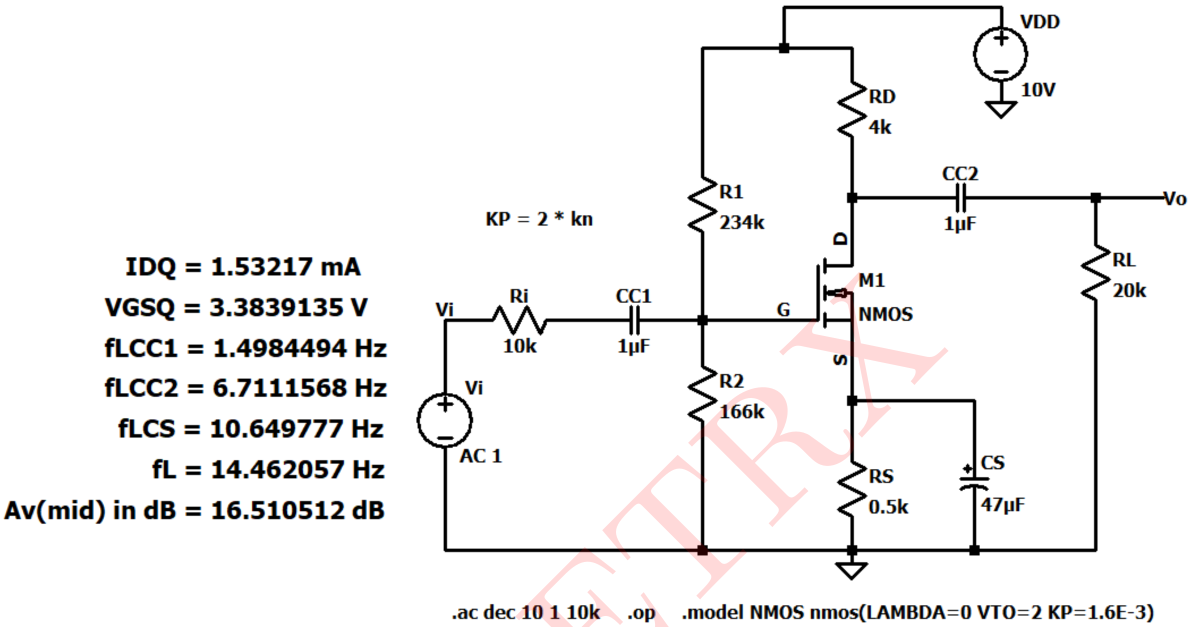


Figure 20: Circuit Schematic 2: Results

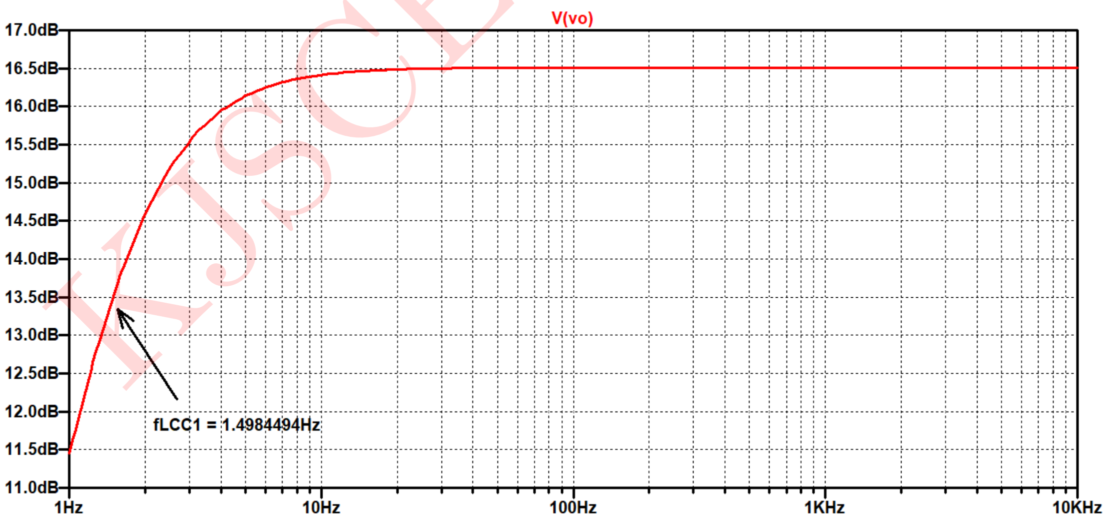


Figure 21: Low Frequency Response for $C_{C1}$

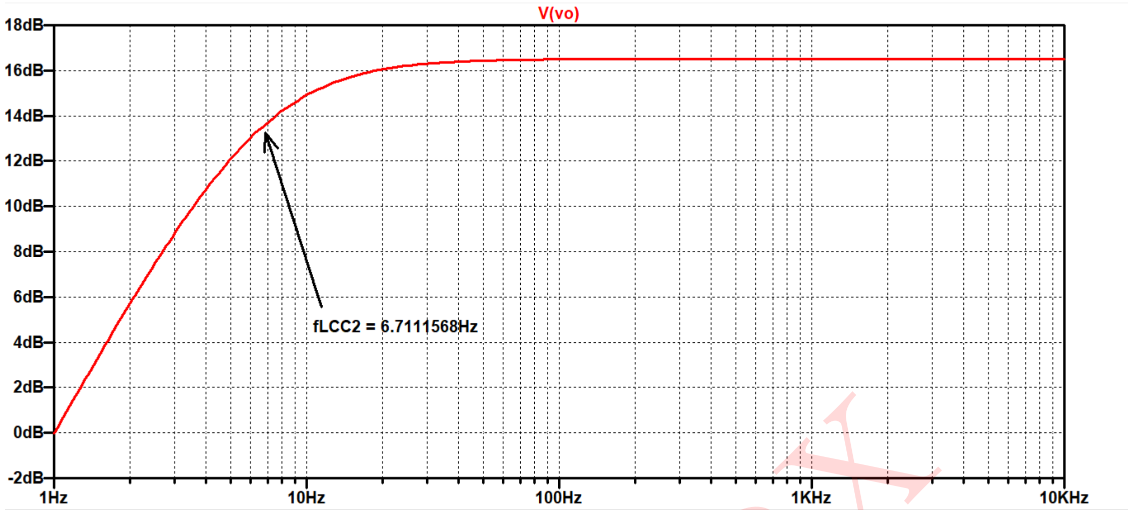


Figure 22: Low Frequency Response for $C_{C2}$

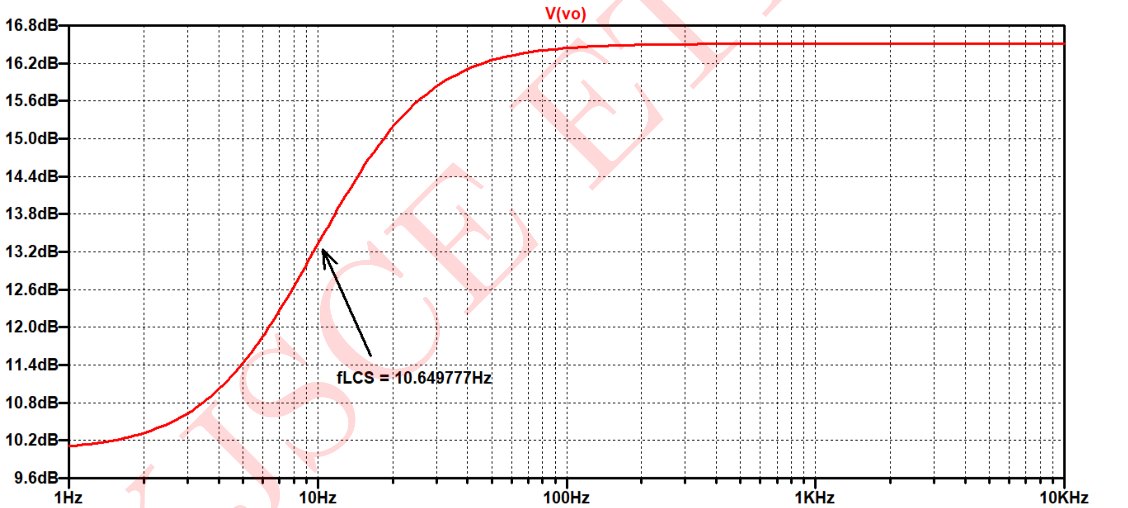


Figure 23: Low Frequency Response for $C_S$

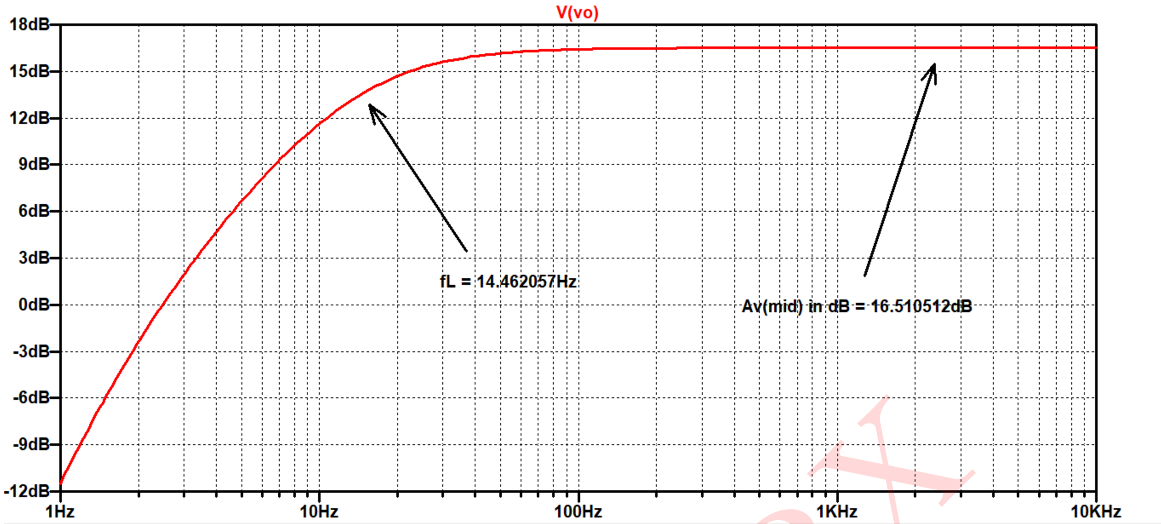


Figure 24: Low Frequency Response for the Circuit

**Comparison of theoretical and simulated values:**

| Parameters | Theoretical Values | Simulated Values |
|---|---|---|
| $I_{DQ}$ | 1.53 mA | 1.5321 mA |
| $V_{GSQ}$ | 3.385 V | 3.3839 V |
| Lower cut-off frequency due to $C_{C1}$ | 1.4859 Hz | 1.4984 Hz |
| Lower cut-off frequency due to $C_{C2}$ | 6.6314 Hz | 6.7111 Hz |
| Lower cut-off frequency due to $C_S$ | 14.2765 Hz | 10.6497 Hz |
| Overall cut-off frequency $f_L$ | 14.2765 Hz | 14.4620 Hz |
| Midband voltage gain $A_{V(mid)}$ in dB | 16.5085 dB | 16.5105 dB |

Table 2: Numerical 2

**Numerical 3**: For the circuit shown in figure 25, determine: $I_{CQ}$, $V_{CEQ}$, lower cut-off frequency due to $C_S$, $C_C$ and $C_E$, overall cut-off frequency $f_L$, overall cut-off frequency $f_H$ and midband voltage gain in dB.

Given: $\beta = 100$, $r_o = \infty$, $C_{be} = 36$ pF, $C_{bc} = 4$ pF, $C_{ce} = 1$ pF, $C_{wi} = 6$ pF, $C_{wo} = 8$ pF

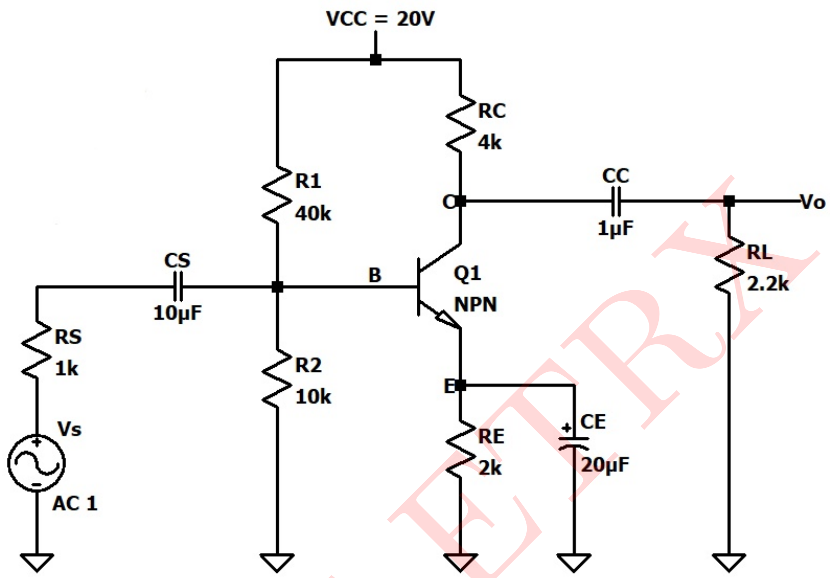


Figure 25: Circuit 3

**Solution:**

The given circuit 3 is a voltage divider bias configuration employing npn BJT.

For DC biasing, the capacitors will act as an open source.

**DC Analysis:**

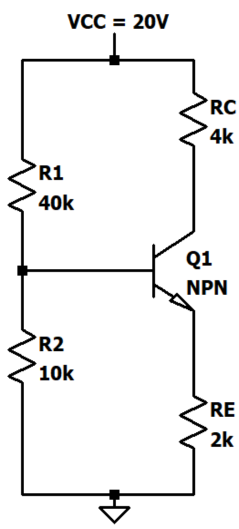


Figure 26: DC Equivalent Circuit

$$R_B = \frac{R_1 \times R_2}{R_1 + R_2}$$

$$R_B = \frac{40 \times 10^3 \times 10 \times 10^3}{40 \times 10^3 + 10 \times 10^3} = \mathbf{8\ k\Omega}$$

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

$$V_G = \frac{20 \times 10 \times 10^3}{40 \times 10^3 + 10 \times 10^3} = \mathbf{4\ V}$$

Thevenin's Equivalent circuit:

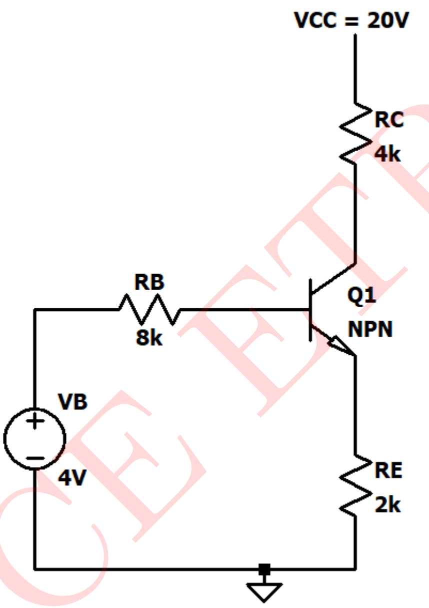


Figure 27: Thevenin's Equivalent circuit

$I_{BQ}$ can be calculated by applying KVL to the base-emitter loop,

$$V_B - I_B R_B - V_{BE} - I_E R_E = 0$$

$$I_B R_B + (1+\beta) I_B R_E = V_B - V_{BE} \qquad ...(\because I_E = (1+\beta) I_B)$$

$$I_B(R_B + (1+\beta)R_E) = V_B - V_{BE}$$

$$I_B = \frac{V_B - V_{BE}}{R_B + (1+\beta)R_E}$$

$$I_B = \frac{4 - 0.7}{8 \times 10^3 + (1+100) \times 2 \times 10^3} = \mathbf{15.71\ \mu A}$$

$$I_{CQ} = \beta I_B$$

$$I_{CQ} = 100 \times 15.71 \times 10^{-6} = \mathbf{1.571\ mA}$$

$$I_E = (1+\beta) I_B$$

$$I_E = (1+100) \times 15.71 \times 10^{-6} = \mathbf{1.586\ mA}$$

$V_{CEQ}$ can be calculated by applying KVL to the collector-emitter loop,

$$V_{CC} - I_C R_C - V_{CE} - I_E R_E = 0$$

$$V_{CE} = V_{CC} - I_C R_C - I_E R_E$$

$$V_{CE} = 20 - 1.571 \times 10^{-3} \times 4 \times 10^3 - 1.586 \times 10^{-3} \times 2 \times 10^3 = \mathbf{10.544\ V}$$

**AC Analysis:**

$$r_\pi = \frac{\beta V_T}{I_E}$$

$$r_\pi = \frac{100 \times 26 \times 10^{-3}}{1.586 \times 10^{-3}} = \mathbf{1.64\ k\Omega}$$

$$g_m = \frac{I_{CQ}}{V_T}$$

$$g_m = \frac{1.571 \times 10^{-3}}{26 \times 10^{-3}} = \mathbf{60.423\ mA/V}$$

$$r_0 = \infty \qquad \text{...(given)}$$

Small Signal Equivalent Circuit is shown in figure 28:

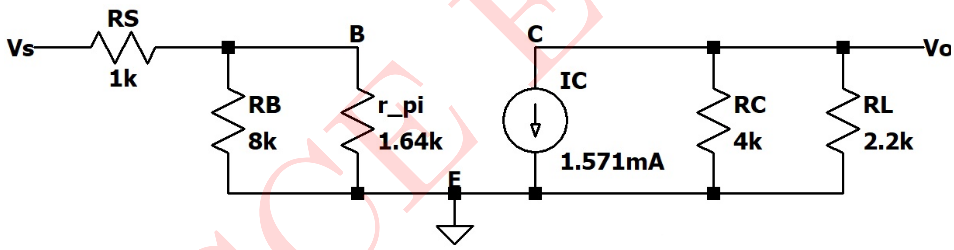


Figure 28: Small Signal Equivalent Circuit

Output voltage $V_o$ = voltage developed across $(R_C\ ||\ R_L)$ due to $g_m V_\pi$

$$V_o = -g_m V_\pi (R_C\ ||\ R_L) \qquad \text{...(1)}$$

$$V_\pi = \text{Voltage across } (R_B\ ||\ r_\pi)$$

$$V_\pi = \frac{(R_B\ ||\ r_\pi)}{R_S + (R_B\ ||\ r_\pi)} V_S \qquad \text{...(Voltage divider)}$$

Substituting in equation 1,

$$V_o = -g_m \frac{(R_B\ ||\ r_\pi)}{R_S + (R_B\ ||\ r_\pi)} V_S (R_C\ ||\ R_L)$$

$$\frac{V_o}{V_i} = A_{V(mid)} = -g_m (R_C\ ||\ R_L) \frac{(R_B\ ||\ r_\pi)}{R_S + (R_B\ ||\ r_\pi)}$$

$$A_{V(mid)} = -60.423 \times 10^{-3} \frac{(4 \times 10^3\ ||\ 2.2 \times 10^3)(8 \times 10^3\ ||\ 1.64 \times 10^3)}{1 \times 10^3 + (8 \times 10^3\ ||\ 1.64 \times 10^3)}$$

$$A_{V(mid)} = \frac{-60.423 \times 10^{-3} \times 1.419 \times 10^3 \times 1.361 \times 10^3}{1 \times 10^3 + 1.361 \times 10^3} = \mathbf{-49.425}$$

$$A_{V(mid)dB} = 20\log(|A_{V(mid)}|)$$

$$A_{V(mid)dB} = 20\log(49.425) = \mathbf{33.8789\ dB}$$

Lower cut-off frequency analysis:

a) Due to $C_S$ alone

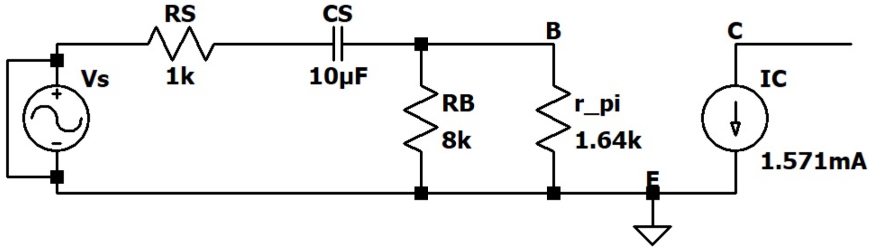


Figure 29: Small Signal Low Frequency Equivalent Circuit for $C_S$ alone

$R_i = R_B \; || \; r_\pi$

$R_{eq} = 8 \times 10^3 \; || \; 1.64 \times 10^3 = \mathbf{1.361\ k\Omega}$

$$f_{L\,C_S} = \frac{1}{2\pi C_S R_{eq}}$$

$$f_{L\,C_S} = \frac{1}{2\pi C_S (R_S + R_i)}$$

$$f_{L\,C_S} = \frac{1}{2\pi \times 10 \times 10^{-6} \times (1 \times 10^3 + 1.361 \times 10^3)} = \mathbf{6.741\ Hz}$$

b) Due to $C_C$ alone

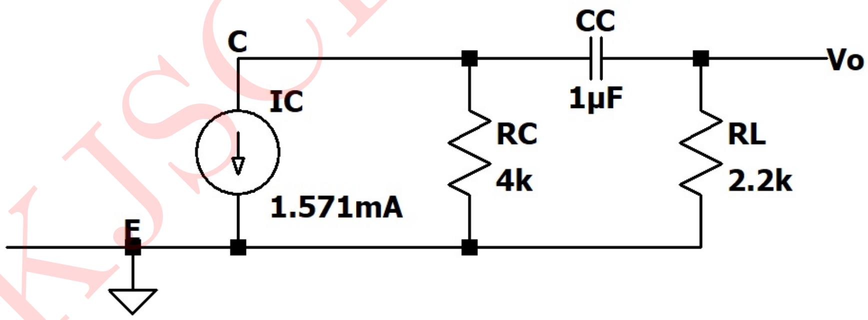


Figure 30: Small Signal Low Frequency Equivalent Circuit for $C_C$ alone

$R_{eq} = R_C + R_L$

$R_i = 4 \times 10^3 + 2.2 \times 10^3 = \mathbf{6.2\ k\Omega}$

$$f_{L\,C_C} = \frac{1}{2\pi C_C R_{eq}}$$

$$f_{L\,C_S} = \frac{1}{2\pi \times 1 \times 10^{-6} \times 6.2 \times 10^3} = \mathbf{25.67\ Hz}$$

b) Due to $C_E$ alone

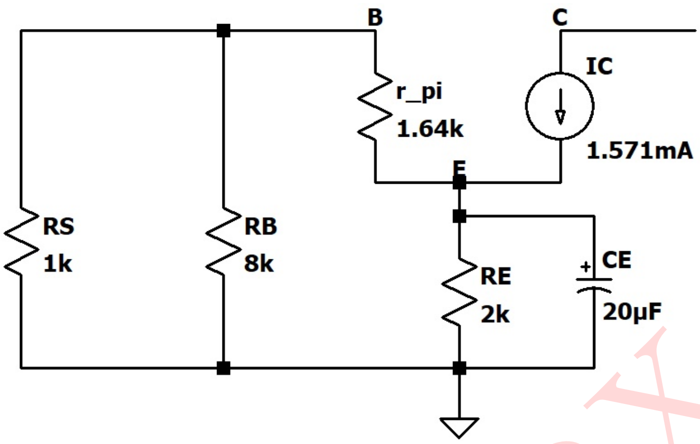


Figure 31: Small Signal Low Frequency Equivalent Circuit for $C_E$ alone

$$R_{eq} = R_E \ || \ \left( \frac{(R_S \ || \ R_B) + r_\pi}{(1+\beta)} \right)$$

$$R_{eq} = 2 \times 10^3 \ || \ \left( \frac{(1 \times 10^3 \ || \ 8 \times 10^3) + 1.64 \times 10^3}{1+100} \right) = \mathbf{24.73 \ \Omega}$$

$$f_{L\,C_E} = \frac{1}{2\pi C_E R_{eq}}$$

$$f_{L\,C_E} = \frac{1}{2\pi \times 20 \times 10^{-6} \times 24.73} = \mathbf{321.785 \ Hz}$$

Overall cut-off frequency $f_L$ will be the highest $f_L$ among $C_S$, $C_C$ and $C_E$

$f_L = f_{L\,C_E}$ ...($\because C_E$ has highest $f_L$)

$f_L = \mathbf{321.785 \ Hz}$

Higher cut-off frequency analysis:

$C_{mi} = (1-A)C_\mu$

$C_{mi} = (1-A)C_{bc}$ ...($\because C_\mu = C_{bc}$)

$C_{mi} = (1+49.425) \times 4 \times 10^{-12} = \mathbf{2.017 \times 10^{-10} \ F}$

$$C_{mo} = \left(1 - \frac{1}{A}\right) C_\mu$$

$$C_{mo} = \left(1 - \frac{1}{A}\right) C_{bc} \qquad ...(\because C_\mu = C_{bc})$$

$$C_{mo} = \left(1 - \frac{1}{-49.425}\right) \times 4 \times 10^{-12} = \mathbf{4.08 \times 10^{-12} \ F}$$

$C_i = C_{wi} + C_{be} + C_{mi}$

$C_i = 6 \times 10^{-12} + 36 \times 10^{-12} + 2.017 \times 10^{-10} = \mathbf{2.247 \times 10^{-10} \ F}$

$C_o = C_{wo} + C_{ce} + C_{mo}$

$C_i = 8 \times 10^{-12} + 1 \times 10^{-12} + 4.08 \times 10^{-12} = \mathbf{1.308 \times 10^{-11} \ F}$

a) Due to $C_i$ alone

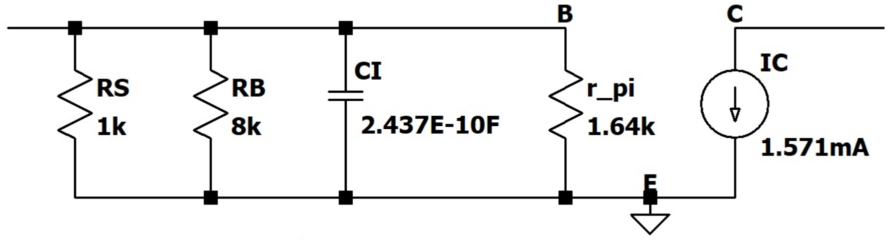


Figure 32: Small Signal High Frequency Equivalent Circuit for $C_i$ alone

$$R_{eq} = R_S \ || \ R_B \ || \ r_\pi$$

$$R_{eq} = R_{eq} = 1 \times 10^3 \ || \ 8 \times 10^3 \ || \ 1.64 \times 10^3 = \mathbf{576.45} \ \Omega$$

$$f_{Hi} = \frac{1}{2\pi C_i R_{eq}}$$

$$f_{Hi} = \frac{1}{2\pi \times 2.437 \times 10^{-10} \times 576.45} = \mathbf{1.1329 \ MHz}$$

b) Due to $C_o$ alone

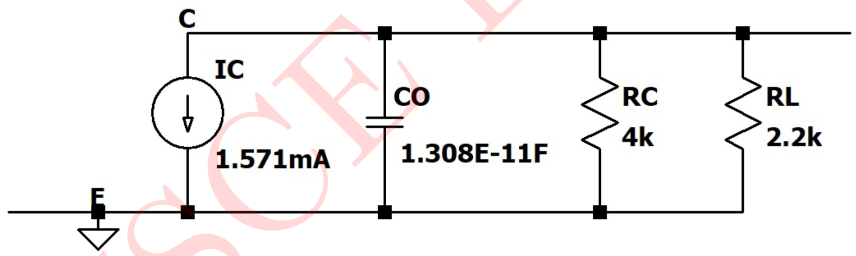


Figure 33: Small Signal High Frequency Equivalent Circuit for $C_o$ alone

$$R_{eq} = R_C \ || \ R_L$$

$$R_{eq} = 4 \times 10^3 \ || \ 2.2 \times 10^3 = \mathbf{1.419 \ k}\Omega$$

$$f_{Ho} = \frac{1}{2\pi C_o R_{eq}}$$

$$f_{Ho} = \frac{1}{2\pi \times 1.308 \times 10^{-11} \times 1.419 \times 10^3} = \mathbf{8.5749 \ MHz}$$

Overall cut-off frequency $f_H$ will be the lowest $f_H$ among $C_i$ and $C_o$

$f_H = f_{Hi}$ ...($\because C_i$ has highest $f_H$)

$f_H = \mathbf{1.1329 \ MHz}$

**SIMULATED RESULTS:**

Above circuit is simulated in LTspice. The results are presented below:

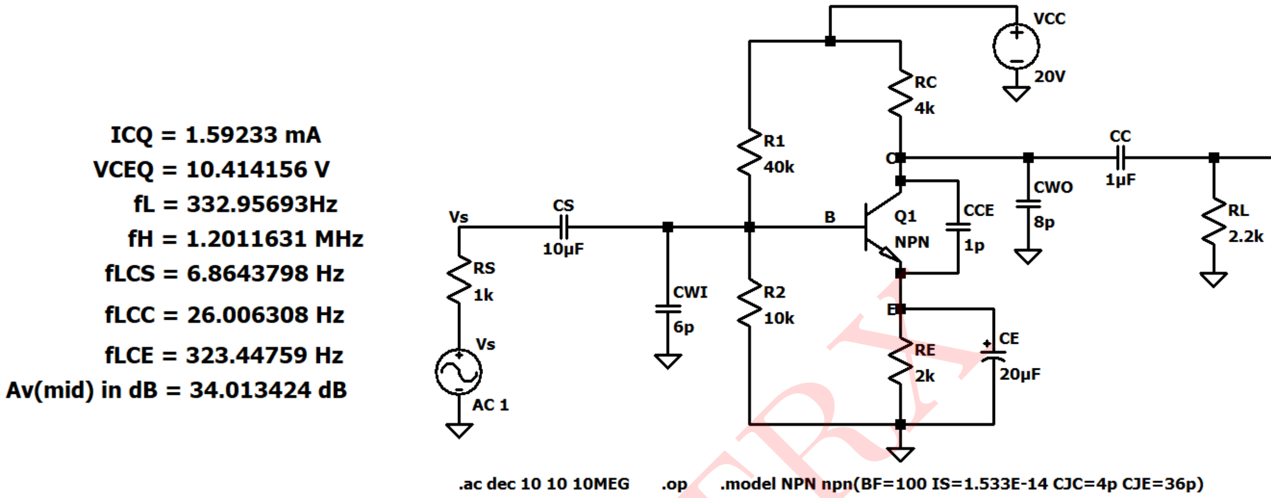


Figure 34: Circuit Schematic 3: Results

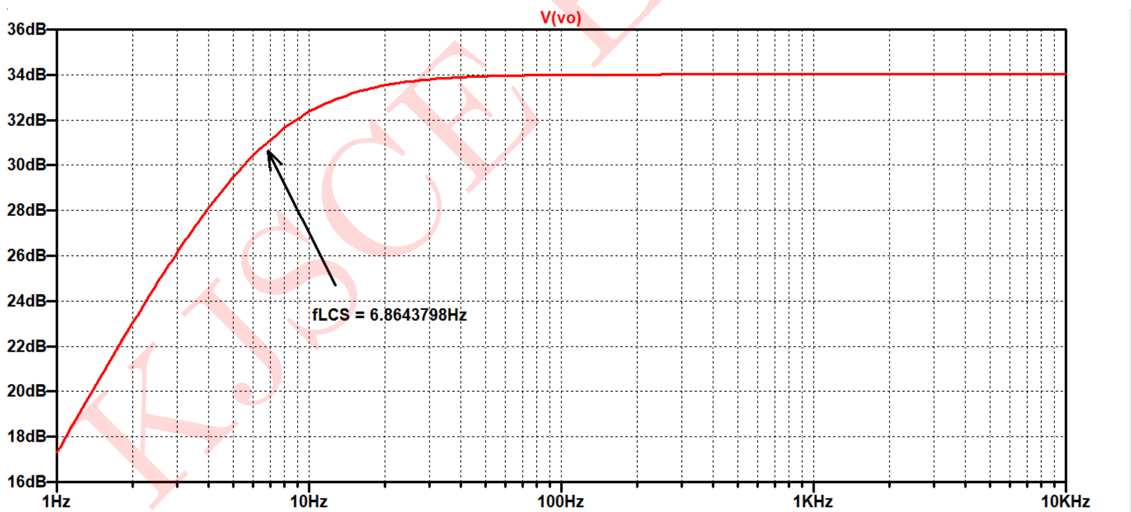


Figure 35: Low Frequency Response for $C_S$

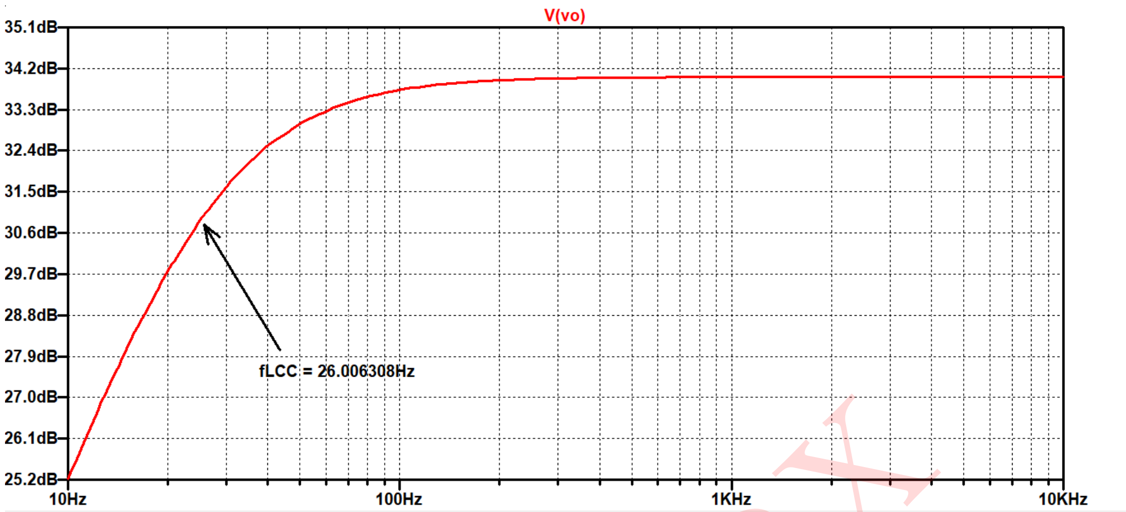


Figure 36: Low Frequency Response for $C_C$

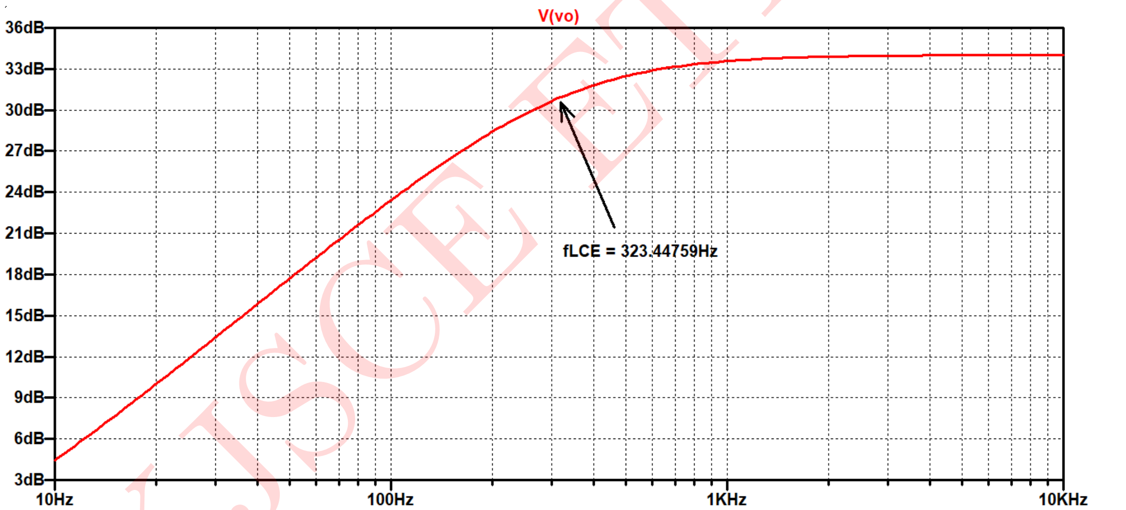


Figure 37: Low Frequency Response for $C_E$

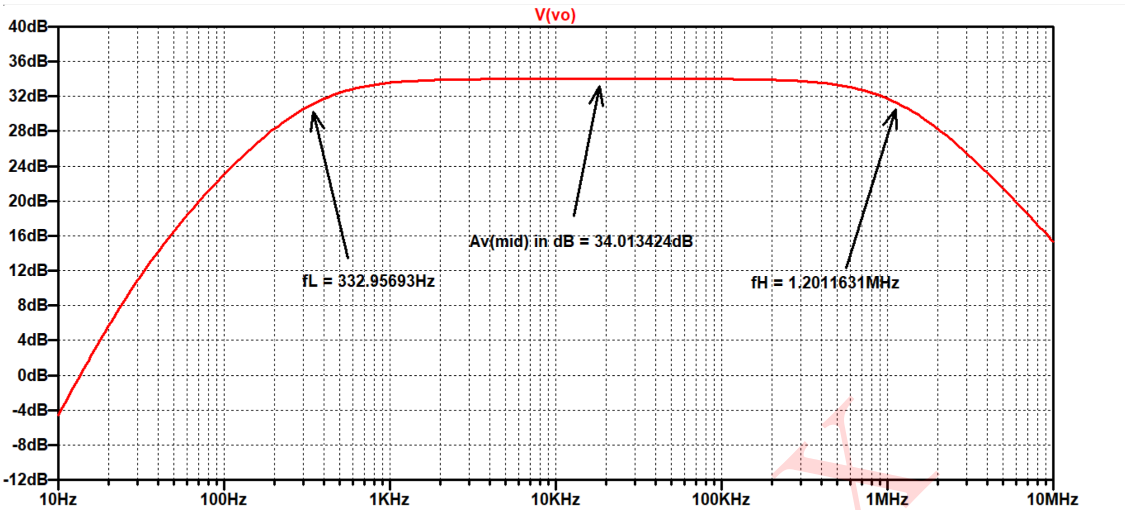


Figure 38: Low Frequency Response for the Circuit

**Comparison of theoretical and simulated values:**

| Parameters | Theoretical Values | Simulated Values |
|---|---|---|
| $I_{CQ}$ | 1.571 mA | 1.5923 mA |
| $V_{CEQ}$ | 10.544 V | 10.4141 V |
| Lower cut-off frequency due to $C_S$ | 6.741 Hz | 6.8643 Hz |
| Lower cut-off frequency due to $C_C$ | 25.67 Hz | 26.0063 Hz |
| Lower cut-off frequency due to $C_E$ | 321.785 Hz | 323.4475 Hz |
| Overall cut-off frequency $f_L$ | 321.785 Hz | 332.9569 Hz |
| Overall cut-off frequency $f_H$ | 1.1329 MHz | 1.2011 MHz |
| Midband voltage gain $A_{V(mid)}$ in dB | 33.8789 dB | 34.0134 dB |

Table 3: Numerical 3

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