MINI PROJECT 1

UNIVERSITY OF BRITISH COLUMBIA
ELEC 301

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Introduction

Mini Project 1 report is based on solving electrical circuits using Miller' Theorem and the method of open – circuit (OC) and short- circuit (SC) time constants. Along with the Class notes, Circuit Maker 2000 has also been used to simulate AC Analysis and create Bode Plots respectively.

Problems

Part 1

- Part A

Given $T(s) = \frac{V_o(s)}{V_s(s)} = 0.125 \times \frac{10^5}{s+10^5} \times \frac{10^6}{s+10^6} \times \frac{10^7}{s+10^7}$

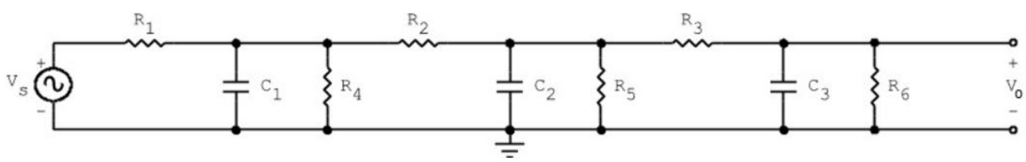


Figure 1.1: Circuit for Part 1

Since, $C_1 > C_2 > C_3$ they will be short in the respective order.
Frequency of the poles, calculated from T(s),

$$\omega_{p1} = 10^5 \frac{rad}{s}\,;\ \omega_{p2} = 10^6 \frac{rad}{s}\ ;\ \omega_{p3} = 10^7 \frac{rad}{s}$$

<u>Short Circuit – Open Circuit test</u>

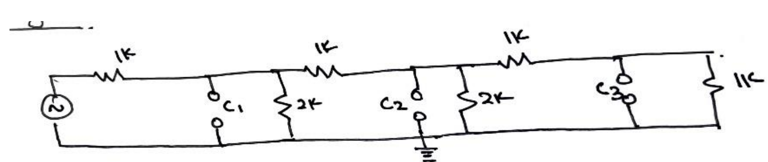


Figure 2: Circuit for SCOC test

- Calculating C_1
  - All Capacitors act as Open Circuits

$$\tau_{C_1} = \left(\frac{1}{\omega_{p1}}\right) = \left(R_{Seen\ by\ C_1} * C_1\right) = (500 * C_1)$$

$$C_1 = 20\ nF$$

- Calculating C_2
  - C_1 act as Short Circuit

$$\tau_{C_2} = \left(\frac{1}{\omega_{p2}}\right) = \left(R_{Seen\ by\ C_2} * C_2\right) = (500 * C_2)$$

$$C_1 = 2\ nF$$

- Calculating C_1
  - C_1 and C_2 act as Short Circuit

$$\tau_{C_3} = \left(\frac{1}{\omega_{p3}}\right) = \left(R_{Seen\ by\ C_3} * C_3\right) = (500 * C_3)$$

$$C_1 = 0.2\ nF$$

<u>Circuit (on *Circuit Maker*)</u> :

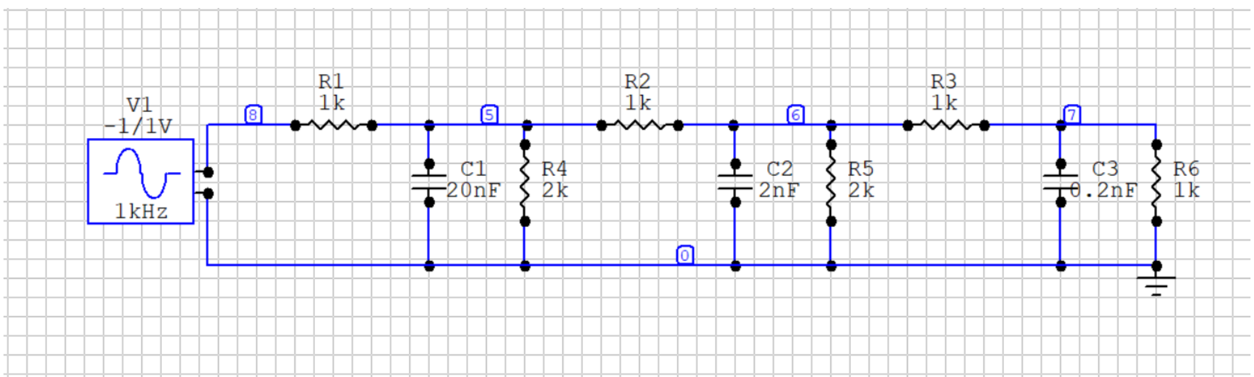


Figure 3. Circuit Maker Circuit

Circuit Bode Plot:

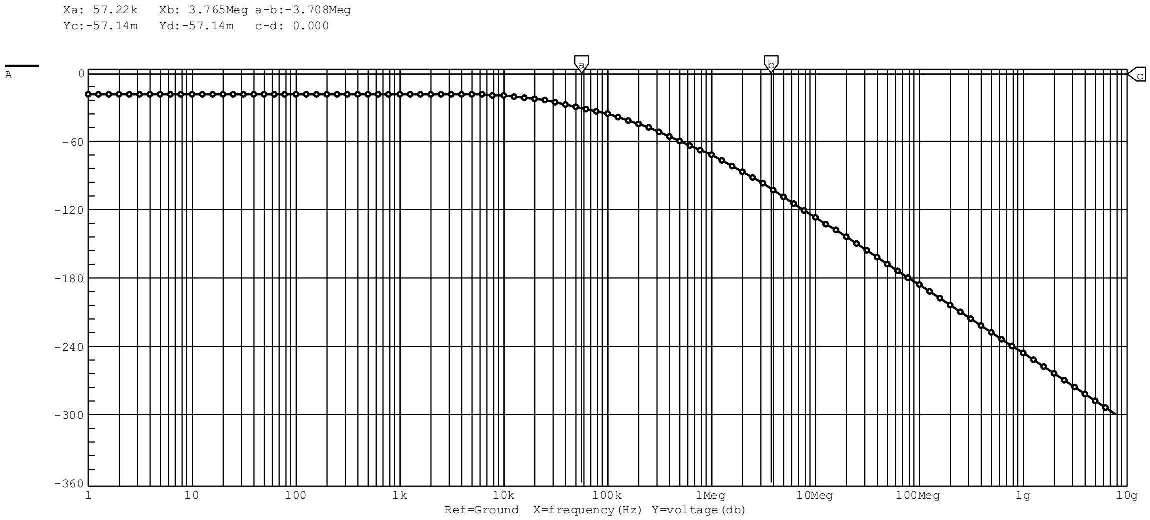


Figure 4 Magnitude Plot of Part 1-A

Circuit Phase (in degrees)

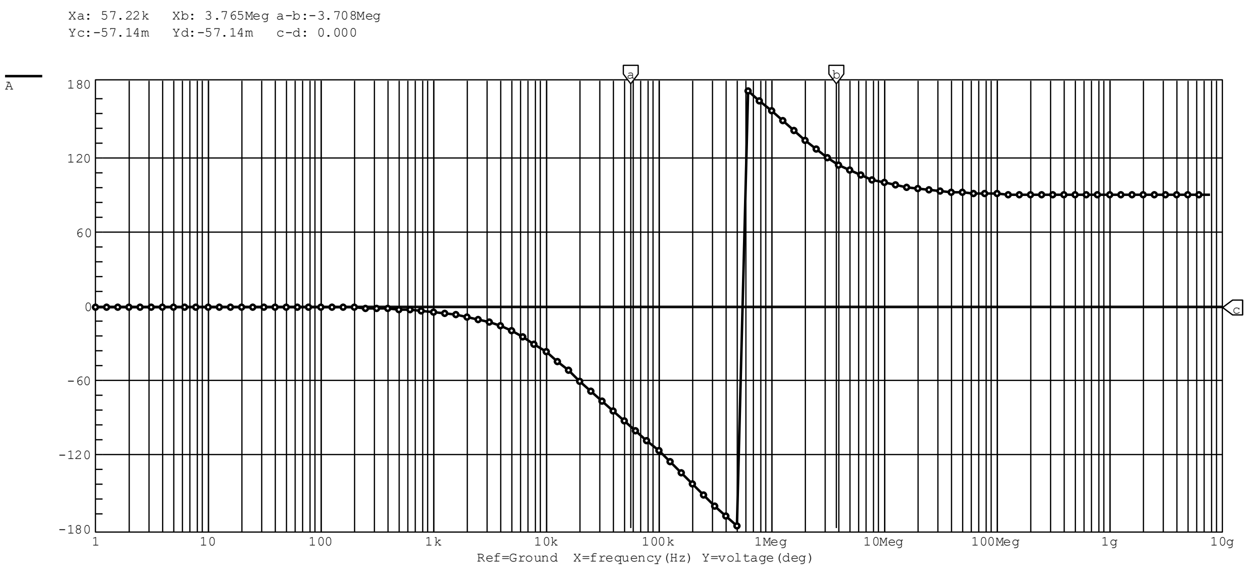
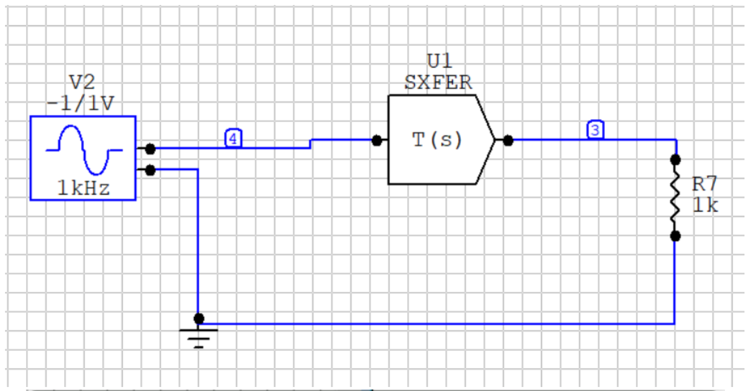


Figure 5 Phase Plot of Part 1-A

- Part B

SXFER Function Block



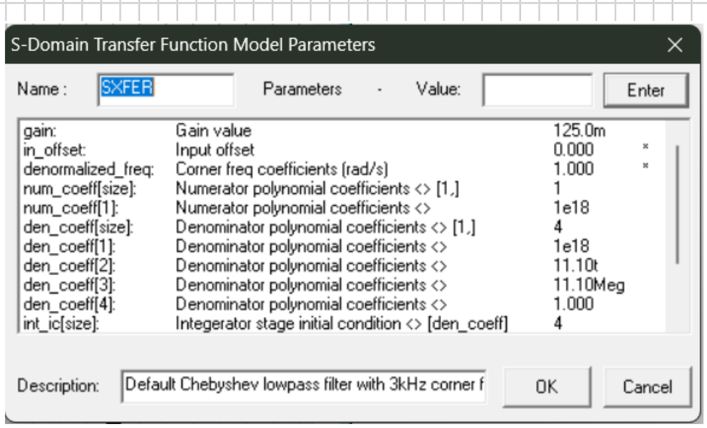


Figure 6 SXFER Circuit

Figure 7 SXFER parameters

Bode Plot for Part 2:

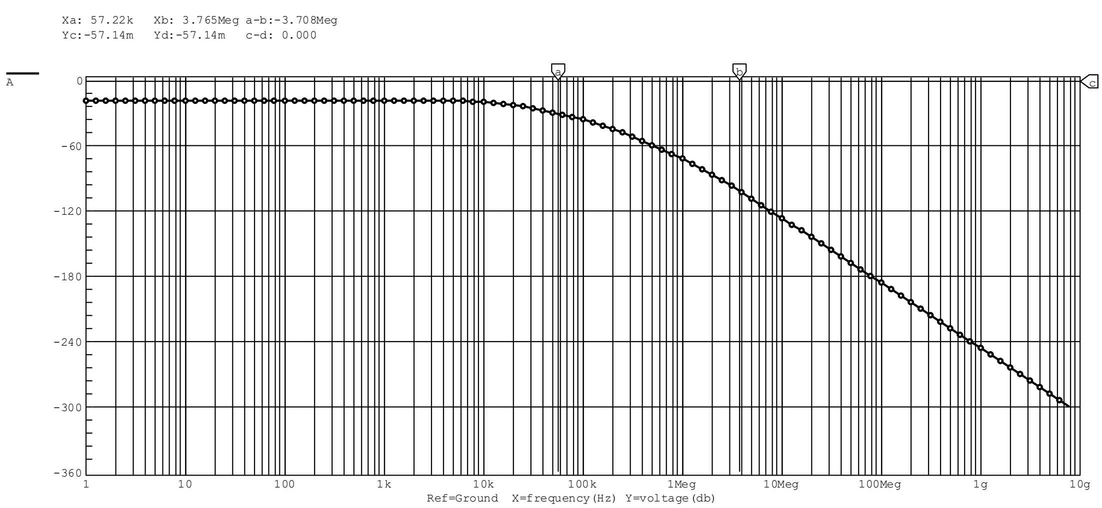


Figure 8 Magnitude Plot for SXFER Function

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Circuit Phase (in degrees)

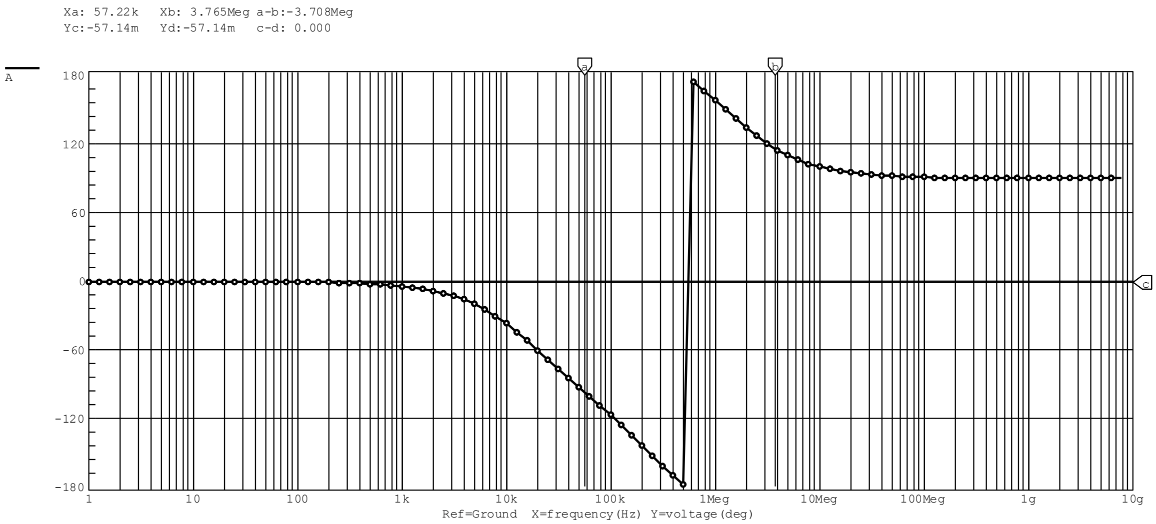

Figure 9 Phase Plot for SXFER

Part 2

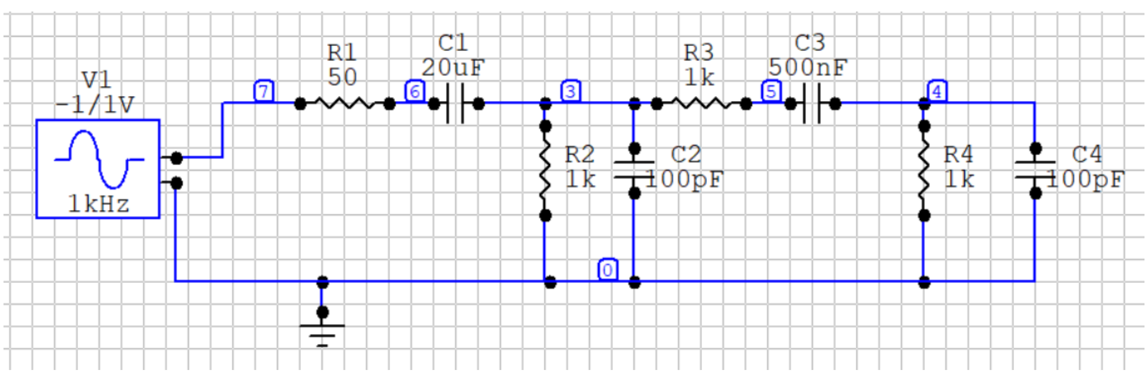

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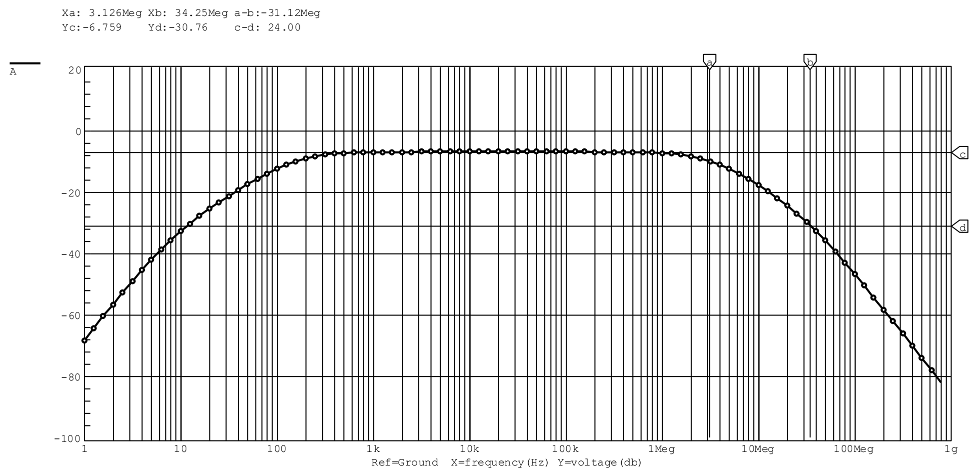
Figure 10 Magnitude plot for fig 10 Circuit



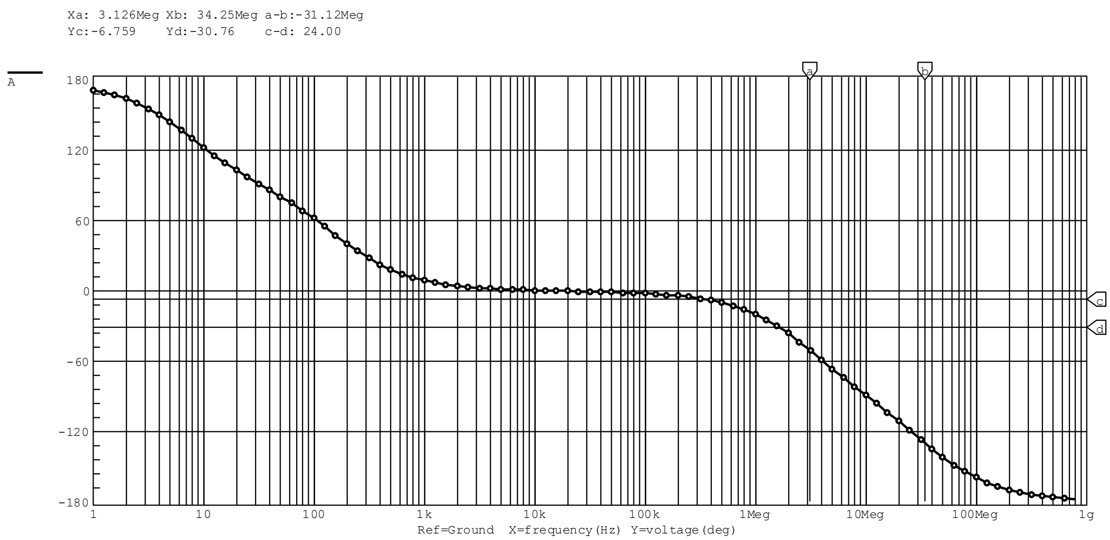


Figure 11 Phase Plot for fig 10 Circuit

Approximating poles graphically,

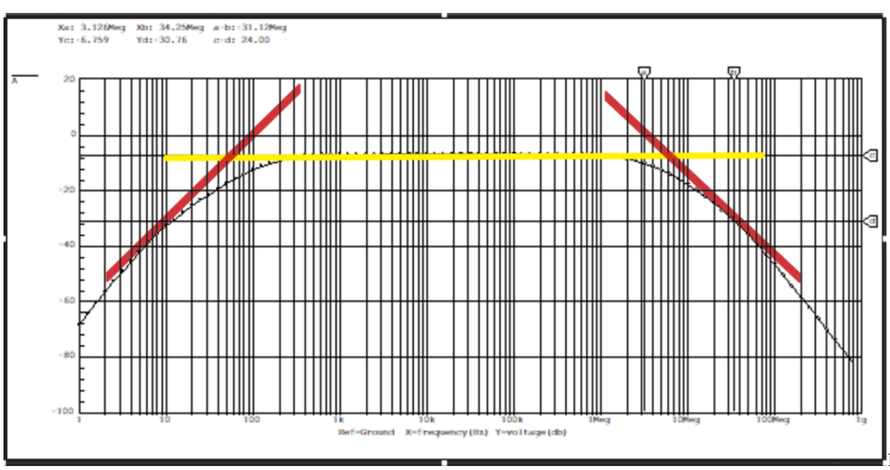


Figure 12 Approximate poles

Frequency (Hz)	Pole (rad/s)
7.69	ω_{p1}
156.21	ω_{p2}
3.0126×10^6	ω_{p3}
35.22×10^6	ω_{p4}

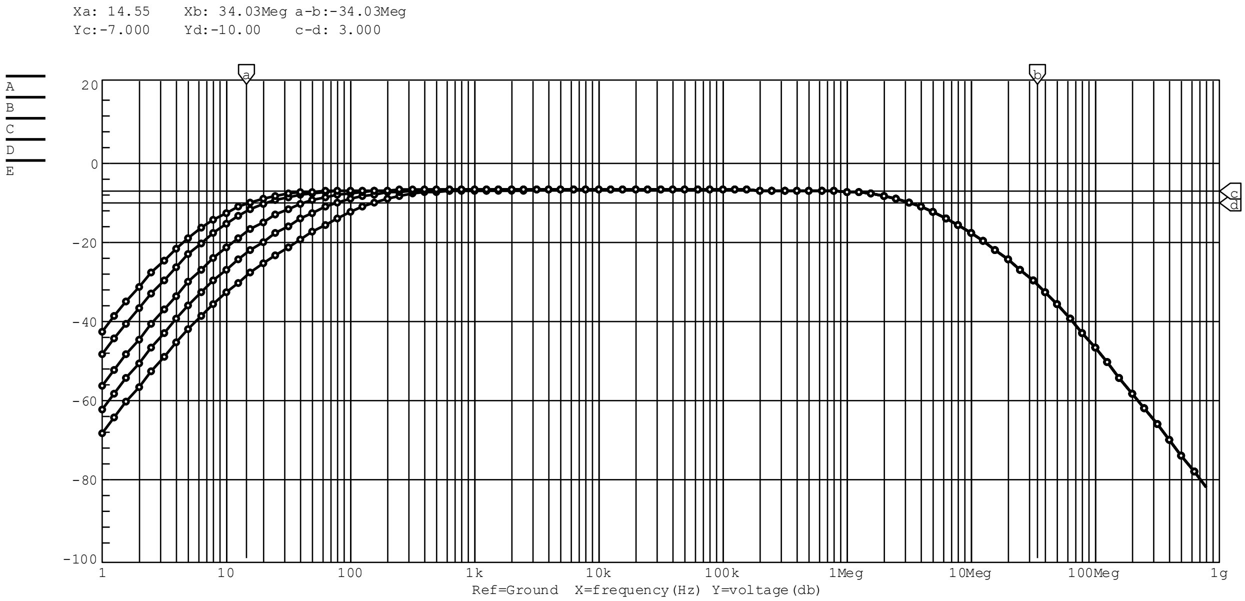


Figure 13 Magnitude plot for All Capacitors

	A: C_3 = 500 nF	B: C_3 = 1 uF	C: C_3 = 2 uF	D: C_3 = 5 uF	E: C_3 = 10 uF
ω_{L3dB} (Hz)	153.5	80.72	43.84	22.54	14.55
ω_{H3dB}(MHz)	3.0126				

Calculated Frequencies:

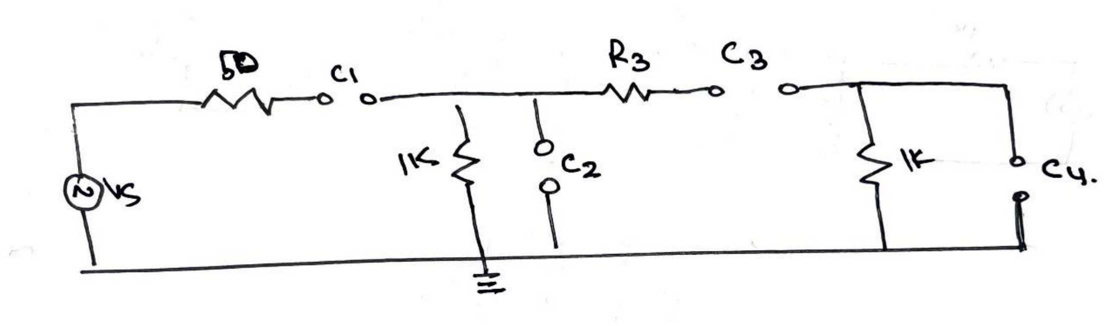


Figure 14 OCSC Diagram for frequency Calculations

ω_{H3dB}:

- Short C_1 and C_3
  - To Calculate ω_{Hp1}, open C_4 and Observe C_2

$$\tau_{C_2} = \left(\frac{1}{\omega_{Hp1}}\right) = \left(R_{Seen\ by\ C_2} * C_2\right) = (511.6 * 100\ pF)$$

$$\omega_{Hp1} = 19.455 \frac{Mrad}{s}$$

  - To Calculate ω_{Hp2}, short C_2 and observe C_4

$$\tau_{C_4} = \left(\frac{1}{\omega_{Hp2}}\right) = \left(R_{Seen\ by\ C_4} * C_4\right) = (45.45 * 100\ pF)$$

$$\omega_{Hp2} = 220 \frac{Mrad}{s}$$

Calculated Frequency are similar to approximated values therefore,

$$\omega_{H3dB} = \frac{1}{\sqrt{\left(\tau_{C_2}\right)^2 + \left(\tau_{C_4}\right)^2}} = 3.10\ MHz$$

ω_{L3dB}:

- Open C_2 and C_4

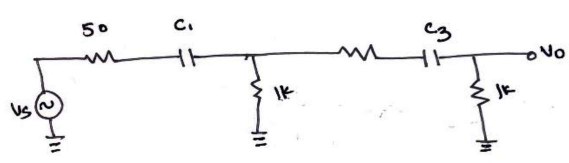


Figure 15 Lower Frequency Calculation

  - To Calculate ω_{Lp1}, open C_3 and Observe C_1

$$\tau_{C_1} = \left(\frac{1}{\omega_{Lp1}}\right) = \left(R_{Seen\ by\ C_1} * C_1\right) = (1050 * 20\mu F)$$

$$\omega_{Lp1} = 47.619\frac{rad}{s}$$

- To Calculate ω_{Lp2}, short C_1 and observe C_3

C_3 = 500 nF

$$\tau_{C_3} = \left(\frac{1}{\omega_{Lp2}}\right)_{500\ nF} = \left(R_{Seen\ by\ C_3} * C_3\right) = (2.048\ \times 10^3 \times 500\ nF)$$

$$\left(\omega_{Lp2}\right)_{500\ nF} = 976.7\frac{rad}{s}$$

$$(\omega_{L3dB})_{500\ nF} = \sqrt{(47.619)^2 +\ (976.7)^2} =\ 155.6\ Hz$$

C_3 = 1 uF

$$\tau_{C_3} = \left(\frac{1}{\omega_{Lp2}}\right)_{1\ \mu F} = \left(R_{Seen\ by\ C_3} * C_3\right) = (2.048\ \times 10^3 \times 1\ \mu F)$$

$$\left(\omega_{Lp2}\right)_{1\ \mu F} = 488.372\frac{rad}{s}$$

$$(\omega_{L3dB})_{500\ nF} = \sqrt{(47.619)^2 +\ (490.7)^2} =\ 78.1 Hz$$

C_3 = 2 uF

$$\tau_{C_3} = \left(\frac{1}{\omega_{Lp2}}\right)_{2\ \mu F} = \left(R_{Seen\ by\ C_3} * C_3\right) = (2.048\ \times 10^3 \times 2\ \mu F)$$

$$\left(\omega_{Lp2}\right)_{500\ nF} = 244.186\frac{rad}{s}$$

$$(\omega_{L3dB})_{500\ nF} = \sqrt{(47.619)^2 +\ (244.186)^2} =\ 39.595 Hz$$

C_3 = 5 uF

$$\tau_{C_3} = \left(\frac{1}{\omega_{Lp2}}\right)_{5\ \mu F} = \left(R_{Seen\ by\ C_3} * C_3\right) = (2.048\ \times 10^3 \times 5\ \mu F)$$

$$\left(\omega_{Lp2}\right)_{5\ \mu F} =\ 97.674\frac{rad}{s}$$

$$(\omega_{L3dB})_{500\,nF} = \sqrt{(47.619)^2 + (97.674)^2} = 17.294\ Hz$$

C₃ = 10 uF

$$\tau_{C_3} = \left(\frac{1}{\omega_{Lp2}}\right)_{10\,\mu F} = \left(R_{Seen\ by\ C_3} * C_3\right) = (2.048 \times 10^3 \times 10\ \mu F)$$

$$(\omega_{Lp2})_{10\,\mu F} = 48.837 \frac{rad}{s}$$

$$(\omega_{L3dB})_{500\,nF} = \sqrt{(47.619)^2 + (48.837)^2} = 10.856\ Hz$$

Percent Error :

3 dB error percentage can be calculated by

$$\%\ error = \frac{|calculated - observed|}{observed} \times 100\ \%$$

	$\mathbf{500\ nF}$	$\mathbf{1\ \mu F}$	$\mathbf{2\ \mu F}$	$\mathbf{5\ \mu F}$	$\mathbf{10\ \mu F}$
$(\omega_{L3dB})_{\boldsymbol{observed}}$	153.5 Hz	80.72 Hz	43.84 Hz	22.54 Hz	14.55 Hz
$(\omega_{L3dB})_{\boldsymbol{calculated}}$	155.6 Hz	78.1 Hz	39.59 Hz	17.294 Hz	10.856 Hz
% error	1.36807818	3.245788	9.694343	23.27418	25.38832

Since Changing the values of C_3 does not affect the value of $\omega_{\boldsymbol{H}3dB}$, therefore it stays same in all cases.

	$\mathbf{500\ nF}$	$\mathbf{1\ \mu F}$	$\mathbf{2\ \mu F}$	$\mathbf{5\ \mu F}$	$\mathbf{10\ \mu F}$
$(\omega_{\boldsymbol{H}3dB})_{\boldsymbol{observed}}$	3.0126 MHz				
$(\omega_{\boldsymbol{H}3dB})_{\boldsymbol{calculated}}$	3.10 MHz				
% error	2.90114851				

Part 3

- **Part A**

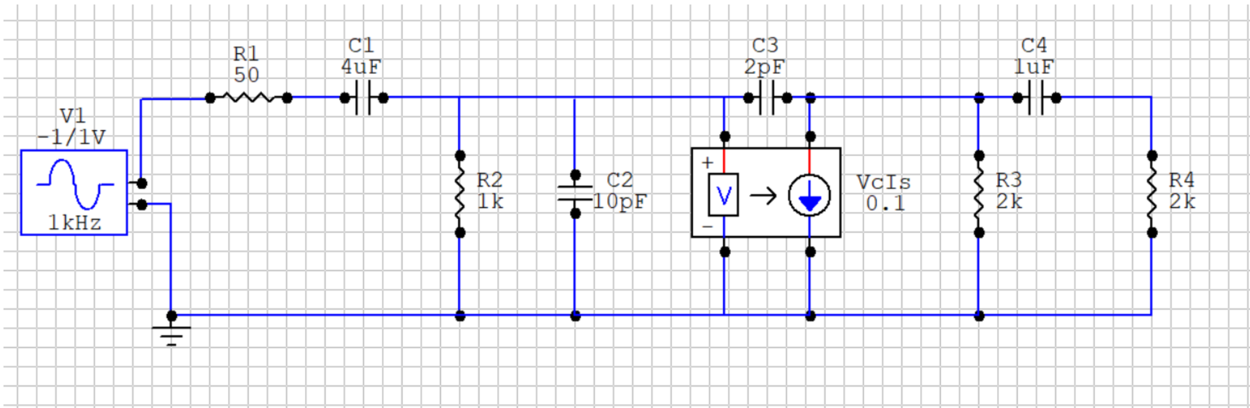


Figure 16 Part 3 Circuit

Miller Gain of the Circuit can be calculated as $k = -\frac{V_o}{V_1}$, by the given information of circuit having 4 poles and band pass filter.

$$V_2 = kV_1, k = -100$$

Miller Theorem, states that

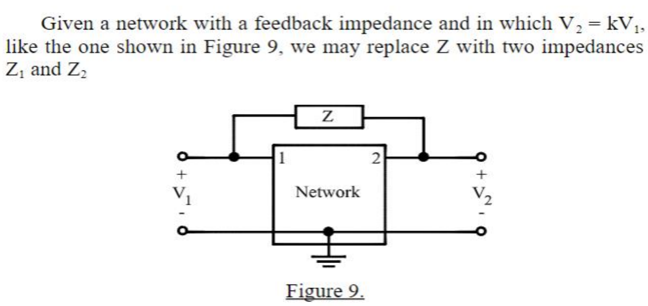

Given a network with a feedback impedance and in which $V_2 = kV_1$, like the one shown in Figure 9, we may replace Z with two impedances Z_1 and Z_2

Figure 17 Miller Theorem

Hence, we can rearrange 2 pF capacitor as:

$$C_1 = 2\,pF \times \left(1 - (-100)\right) = 202\,pF$$

$$C_2 = 2\,pF\ \times \frac{-100 - 1}{-100} = 2.02\,pF$$

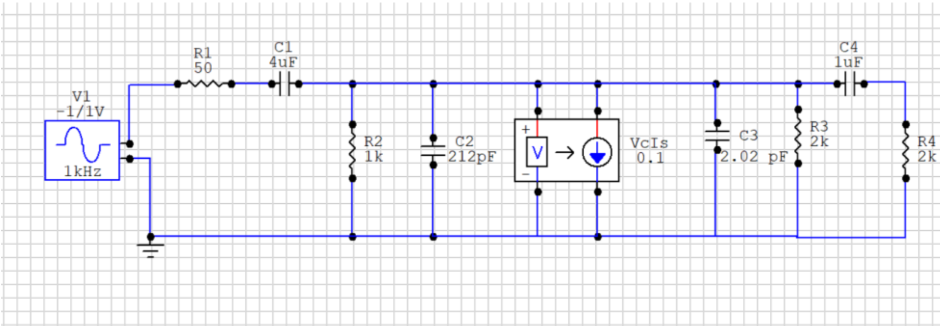


Figure 18 Part 3 equivalent Circuit

Midband Gain,

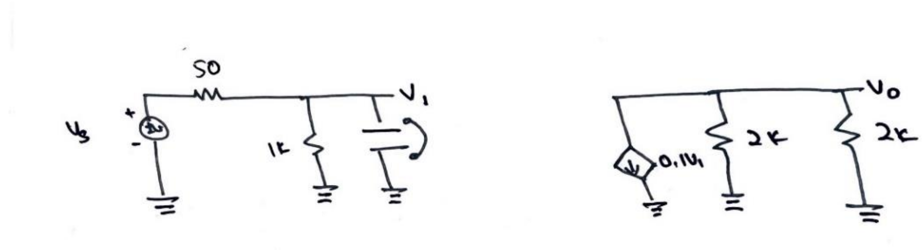


Figure 19 Midband Diagram

$$V_0 = (0.1)(V_1)(1000)$$

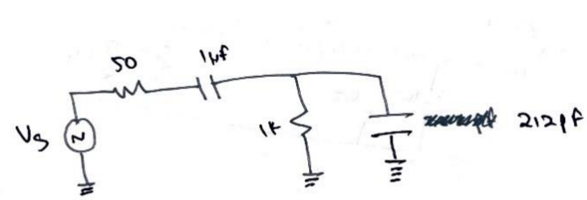
$$V_0 = (0.1)(V_s)\left(\frac{1000}{1050}\right)100$$

$$\frac{V_0}{V_s} = -95.2380$$

Pole Frequencies,

Short Circuit – Open Circuit Test

- **Input**



Since $\mathbf{C_1 > C_2}$

Open C_2 and observe C_1 ,

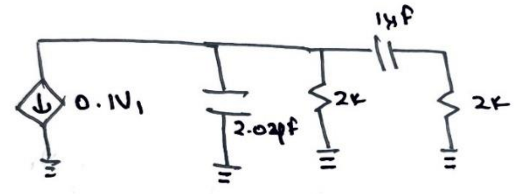
$$\tau_{C1} = (4\ \mu F)(1050) = 4.20\ ms$$

Next,

Short C_1 and observe C_2 ,

$$\tau_{C2} = (212\ \mu F)(46.62) = 10.1\ ns$$

- **Output**



"The dependent source, as far as the output is concerned, can be treated as an independent source"

Since **$C_4 > C_3$**

Open C_3 and observe C_4 ,

$$\tau_{C4} = (1\ \mu F)(4000) = 4\ ms$$

Next,

Short C_4 and observe C_3,

$$\tau_{C3} = (2.02\ \mu F)(1000) = 2.02\ ns$$

Calculated Pole Frequencies:

$\boldsymbol{\omega_{Lp1}}$	$(\mathbf{2}\pi \times 4.20 \times 10^{-3})^{-1} = 37.89\ Hz$
$\boldsymbol{\omega_{Lp2}}$	$(\mathbf{2}\pi \times 4 \times 10^{-3})^{-1} = 39.89\ Hz$
$\boldsymbol{\omega_{Hp1}}$	$(\mathbf{2}\pi \times 10.1 \times 10^{-9})^{-1} = 15.76\ MHz$
$\boldsymbol{\omega_{Hp2}}$	$(\mathbf{2}\pi \times 4 \times 10^{-3})^{-1} = 78.79\ MHz$

$$(\omega_{L3dB}) = \sqrt{(37.89)^2 + (39.89)^2} = 55.02\ Hz$$

$$\omega_{H3dB} = \frac{1}{\sqrt{(15.76)^{-2} + (78.79)^{-2}}} = 15.45\ MHz$$

- **Part B**

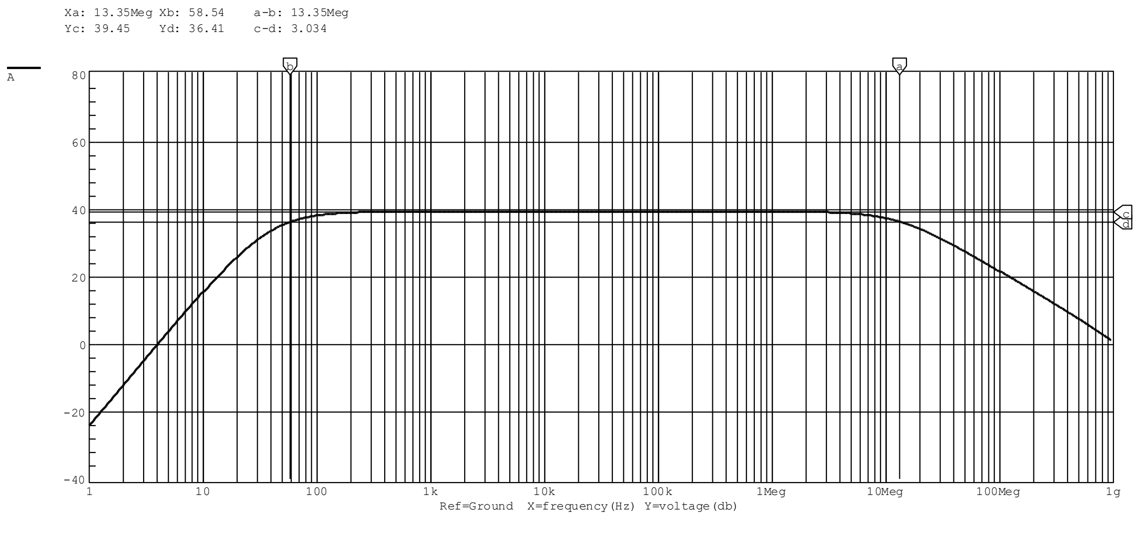


Figure 20 Magnitude Plot of Part 3

AC Simulation Phase Plot

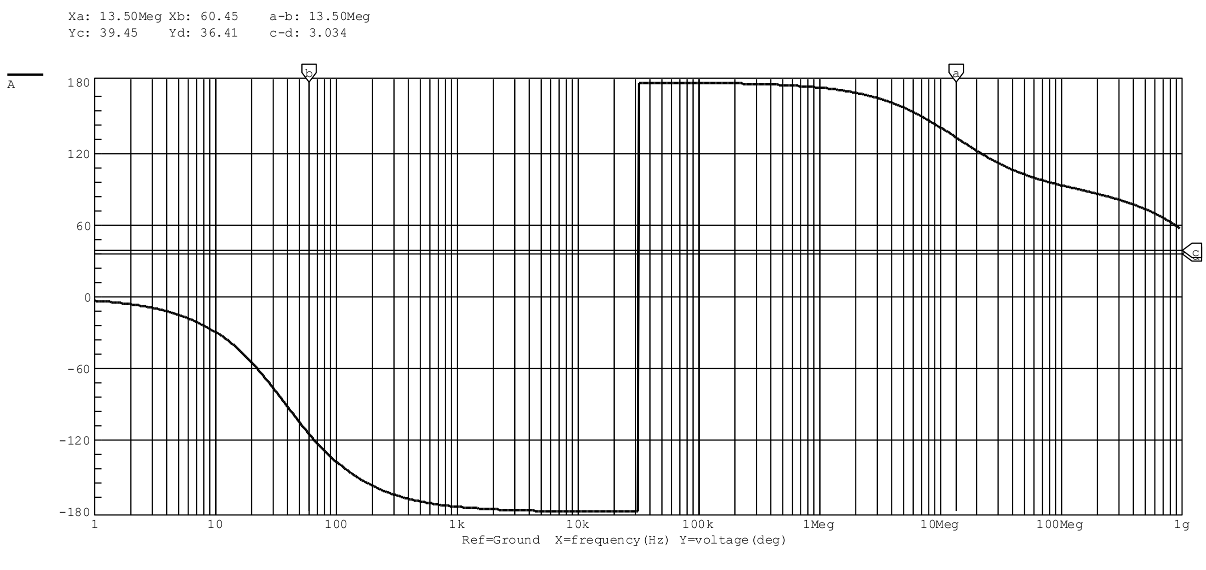


Figure 21 Phase Plot of Part 3

AC Simulation Observed Poles

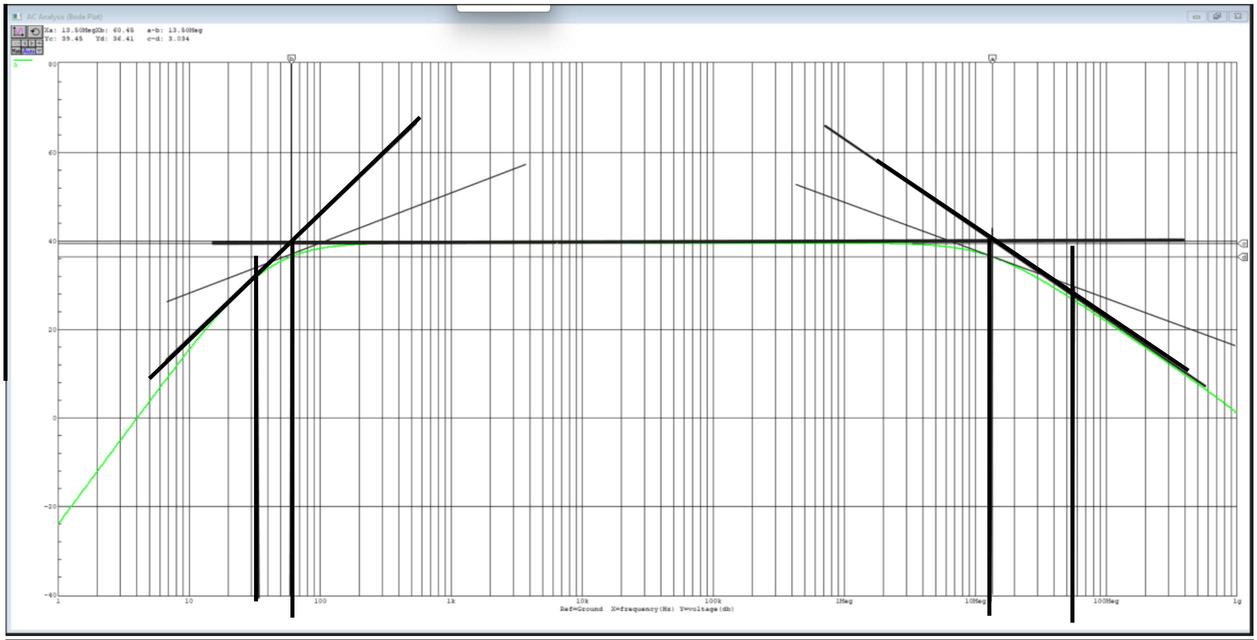


Figure 22 Recorded Values of Transfer Function

	Observed Frequency	Calculated Frequency	% Error
ω_{L3dB}	58.54 Hz	55.02 Hz	6.012983
ω_{H3dB}	13.35 MHz	15.45 MHz	15.7303
ω_{Lp1}	25.5 Hz	37.89 Hz	48.5882
ω_{Lp2}	50.1 Hz	39.89 Hz	20.37924
ω_{Hp1}	18.2 MHz	15.76 MHz	13.40659
ω_{Hp2}	61.1 *M*Hz	78.79 MHz	28.9525

Conclusion

In Part 1, We conclude the values of C_1 , C_2 , C_3 using OCSC Time Constants and obtain an AC Simulation of the circuit using Circuit Maker. We Confirm the values of Capacitors using SXFER function block and we obtain similar plots.

In Part 2, We used method of OC and SC time constants. We ran an AC simulation of circuit on Circuit Maker and obtained the values of poles which were found to be similar. Furthermore, increasing the values of C_3 changed the lower poles but the higher poles remained constants. The Values obtained from AC analysis were compared to calculated values and conclusions were drawn.

In Part 3, Using Miller theorem and OC and SC time constants, We converted the circuit in pi model and hence calculated the poles for the transfer function. Plotted the 3-dB points on AC analysis simulations.

Reference

1. ELEC 301 Course Notes
2. CircuitMaker User's Manual
3. PSIM User's Manual
4. Notes on ELEC 301 Connect
5. A. Sedra and K.Smith, "Microelectronic Circuits", 5 th (or higher) Ed., Oxford University Press, New York.