ELECENG 3EJ4: Electronic Devices and Circuits II

Lab 5: Active Filter Circuits

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Questions for part 1

Q1. (1)

$$T(s) = \frac{V_o(s)}{V_{in}(s)}$$

$$V_+ = V_- = V_o(s)\frac{R_3}{R_3+R_2}$$

$$\frac{V_{in}-V_+}{R_1} = \frac{V_+}{\frac{1}{sC_1}}$$

$$\frac{V_{in} - V_o\frac{R_1}{R_2+R_3}}{R_1} = V_o\frac{R_3}{R_3+R_2}sC_1$$

$$T(s) = \frac{V_o(s)}{V_{in}(s)} = \frac{R_3+R_2}{R_3(R_1sC_1+1)}$$

Low frequency gain:

$$T_{s=0} = 1+\frac{R_2}{R_3} = 1+\frac{100k}{200k} = 1+0.5$$

$$= 1.5\ \frac{V}{V}$$

$$= 3.52\ dB$$

-3dB frequeny:

$$f_c = \frac{1}{2\pi R_1C_1} = \frac{1}{2\pi(100k)(1n)} = 1.591kHz$$

(2) For the simulation, when Vin = 100mV, Vout = 0.150000077195281V = 150mV

1	0.150000077	-0.036069295

Av = 150mV/100mV = 1.5 V/V

$20\log_{10}(1.5) = 3.52dB$

At the cutoff frequency, the gain drops by 3dB from its maximum:

3.52dB - 3dB = 0.52dB

$20\log_{10}(Vo/0.1) = 0.52dB = 0.106V$

1577.683204	0.106318853	-44.74587498

Therefore the simulated cutoff frequency is 1577.68 Hz.

For the measured values, when Vin = 100mV, Vout =0.149974317219689 = 149.97mV

1	0.149974317

Av = 149.97mV/100mV = 1.4997 V/V

$20\log_{10}(1.4997) = 3.52dB$

3.52dB - 3dB = 0.52dB

$20\log_{10}(Vo/0.1) = 0.52dB = 0.106V$

1621.81	0.10600621	-44.7501

Therefore the measured cutoff frequency is 1621.81 Hz.

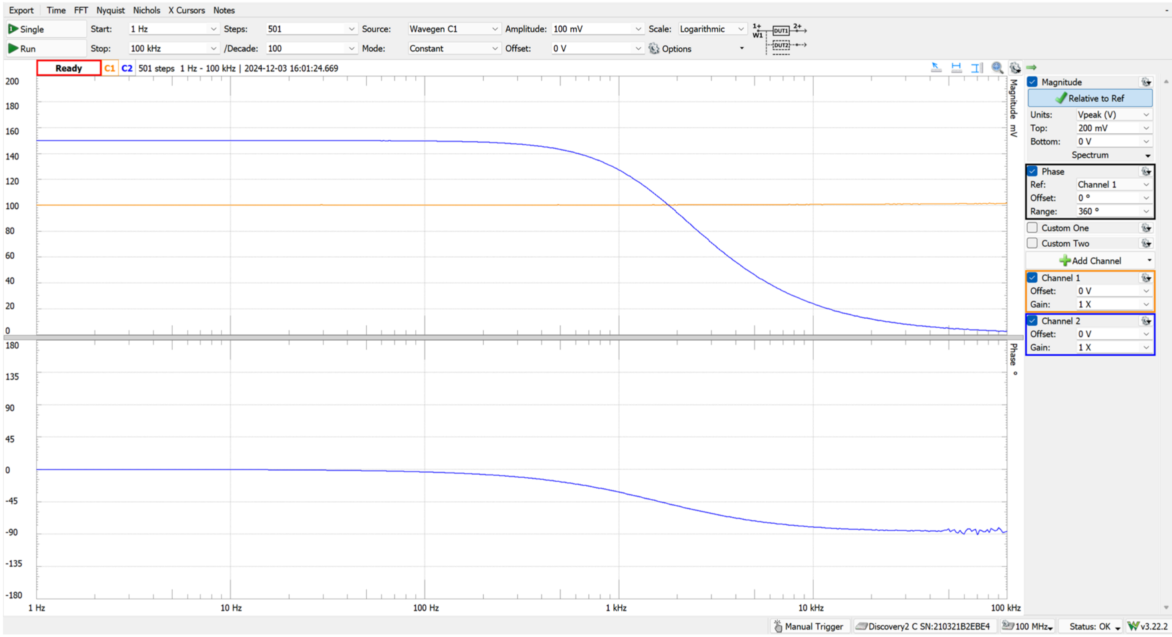


Figure 1 - Wavegen graph for circuit 1

The values for the low-frequency gain and the -3dB frequency are very similar for the calculated, simulated, and measured values. The only visible difference is for the cutoff frequency of the measured values which is 1621.81Hz compared to the theoretical 1691Hz in the calculations. This difference can be attributed to regular error when constructing a circuit compared to the ideal theoretical values.

Questions for part 2

Q2.

$$T(s) = \frac{V_o(s)}{V_{in}(s)}$$

KCL at node VA

$$\frac{V_A - V_{in}}{R_1} + \frac{V_A}{R_2 + sC_2} - \frac{V_A - V_{out}}{sC_1} = 0$$

$$V_- = \frac{R_3}{R_3 + R_4} V_{out} = \frac{1}{2} V_{out}$$

$$V_- = V_+$$

$$T(s) = \frac{2\frac{1}{sC_1}\left(\frac{1}{sC_2}\right)}{R^2 + R\left(2\frac{1}{sC_1} - \frac{1}{sC_2}\right) + \frac{1}{sC_1}\frac{1}{sC_2}}$$

$$= \frac{2\left(\frac{1}{s1n}\right)\left(\frac{1}{s2.2n}\right)}{(100k)^2 + 100k\left(2\frac{1}{s1n} - \frac{1}{s2.2n}\right) + \frac{1}{1n} + \frac{1}{2.2}}$$

$$= \frac{90.9 \times 10^6}{s^2 + 15.45 \times 10 s + 45.45 \times 10^6}$$

Low frequency gain

$$\frac{90.9 \times 10^6}{0 + 0 + 45.45 \times 10^6} = 2 \frac{V}{V}$$

$$20 \log_{10} 2 = 6.02 \text{ dB}$$

From the simulations, the low frequency gain is 6.02dB and from the measurements, the low frequency gain is 6.03dB

1	6.020586918

1	6.028227333

These values are both very similar and match the value of 6.02dB calculated above.

Q3.

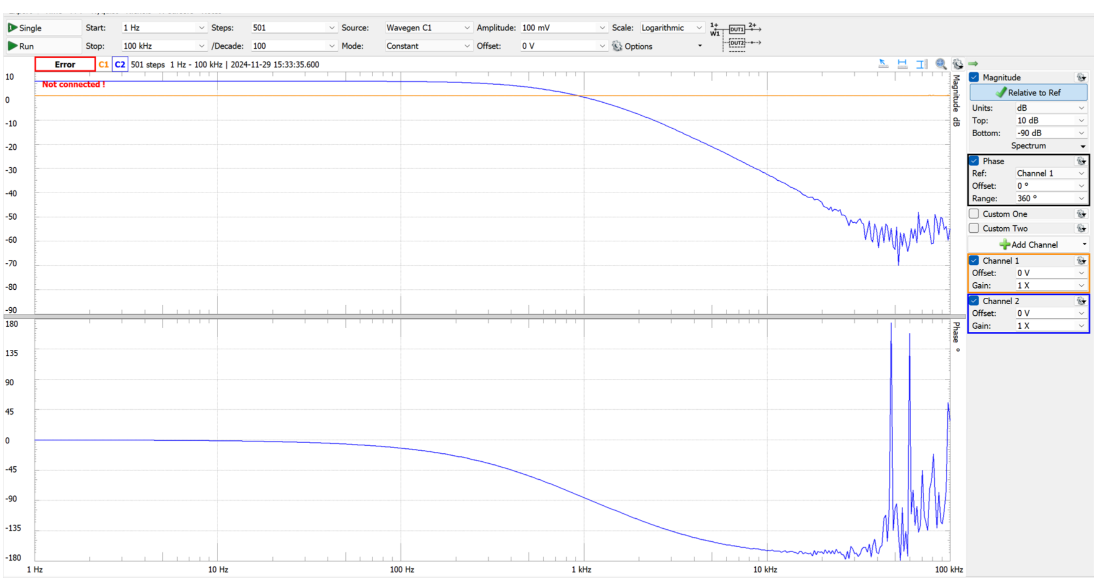


Figure 2 - Wavegen graph for circuit 2

(1) pole frequency

$w_o = 45.45 \times 10^6$

$f_o = \frac{w_o}{2\pi}$

$= \frac{\sqrt{45.45 \times 10^6}}{2\pi}$

$= 1072.97\ Hz$

(2) cutoff frequency

$T(jw_c) = \frac{90.9 \times 10^6}{\sqrt{(45.45 \times 10^6 - w_c^2)^2 + (15.45 \times 10^3)^2 w_c^2}} = \sqrt{2}$

$w_c^2 = 1.2777 \times 10^7$

$w_c = 3574.52$

$f_c = \frac{3574.52}{2\pi} = 568.9\ Hz$

(3) pole quality factor

$\frac{w_o}{Q} = 15.45 \times 10^3$

$Q = \frac{\sqrt{45.45 \times 10^6}}{15.45 \times 10^3} = 0.436$

(4) peak value

$w \geq 0, \quad w_{max} = w_o$

$|T(s)|_{max} = 2\ V/V$

$= 6.02\ dB$

(5) frequency f_{max}

$f_{max} = \frac{w_{max}}{2\pi} = \frac{0}{2\pi} = 0\ Hz$

The calculated cutoff gain is the low frequency gain found in Q2 - 3dB:
6.02dB - 3dB = 3.02dB

In the simulated data, this gain occurs at cutoff frequency 565.56Hz and in the measured data, this gain occurs at the cutoff frequency 562.34Hz.

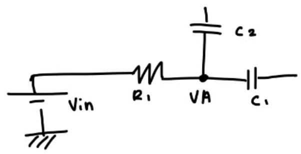
565.5555225	3.036726579	-59.17249618
562.3413252	3.039332111	-58.21252754

These values are both very similar to the theoretical cutoff frequency of 568.9Hz found in the calculations above.

Questions for part 3

Q4.

$$T(s) = \frac{V_o(s)}{V_{in}(s)}$$



center frequency

$$w_o = \sqrt{\frac{1}{C_1R_1C_2R_2}}$$

$$= \sqrt{\frac{1}{(240k)^2\,(1n)^2}}$$

$$= 4166.67 \text{ rad/s}$$

$$f_o = \frac{w_o}{2\pi} = 663.15 \text{ Hz}$$

At node V_A:

$$\frac{V_A - V_{in}}{R_1} + V_A s C_2 + \frac{V_A - V_o}{\frac{1}{sC_1}} = 0$$

$$T(s) = \frac{-\frac{s}{R_1C_1}}{s^2 + s\left(\frac{1}{C_1R_2} + \frac{1}{C_2R_2}\right) + \frac{1}{C_1R_1C_2R_2}}$$

center frequency gain

$$T(4166.67) = -6.02 \text{ dB}$$

Given this transfer function, the center frequency is 663.15Hz and the center frequency gain is -6.02dB. These values match the simulated values (center frequency = 663.4Hz, center frequency gain = -6.021dB) and the measured values (center frequency = 660.69Hz, center gain= -6.027dB).

663.4102514	-6.020589659	-180.0370809

660.693448	-6.027333909	-178.1949268

Q5.

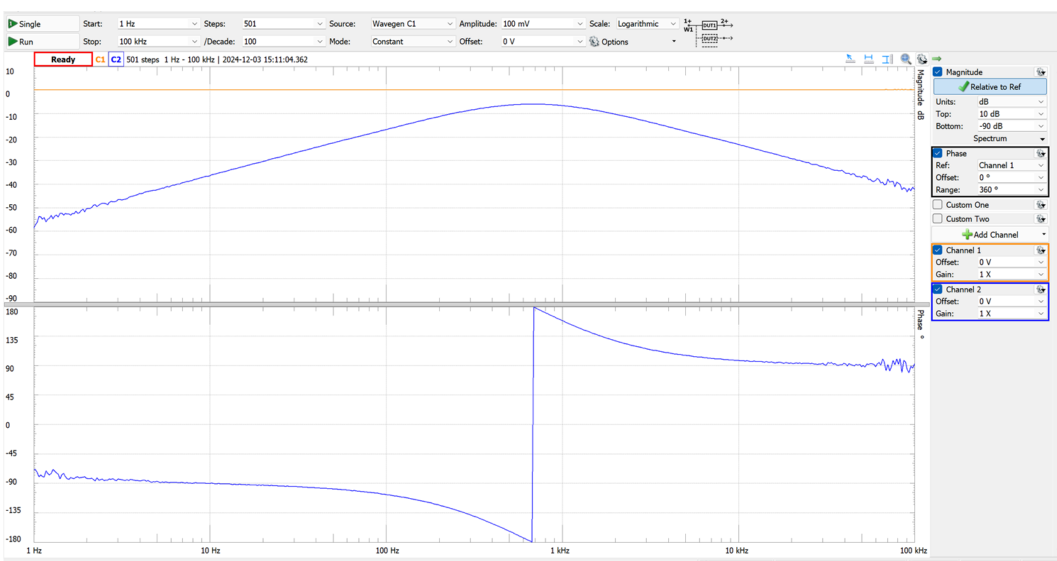


Figure 3 - Wavegen graph for circuit 3

(1) center frequency

$$f_0 = \frac{w_0}{2\pi} = 663.15 \text{ Hz}$$

(2) pole quality factor

$$\frac{W_0}{Q} = \frac{2}{RC}$$

$Q = 0.5$

(4) bandwidth

$BW = W_2 - W_1$

$= 10059.22 - 1725.89$

$= 8333.33 \text{ rad/s}$

(3) -3 dB frequencies

$$\frac{-\frac{s}{R_1C_1}}{s^2 + s\left(\frac{1}{C_1R_2} + \frac{1}{C_2R_2}\right) + \frac{1}{C_1R_1C_2R_2}} = -9.03\text{dB}$$

$w_{p_1} = 2\pi f_{p_1}$, $w_{p_2} = 2\pi f_{p_2}$

for f_{p_1}: $f_c\left(\sqrt{1+\frac{1}{4Q^2}} - 2Q\right)$

$f_{p_1} = 274.67$

for f_{p_2} : $f_c\left(\sqrt{1+\frac{1}{4Q^2}} + 2Q\right)$

$f_{p_2} = 1600.98$

$w_1 = 1725.89 \text{ rad/s}$

$w_2 = 10059.22 \text{ rad/s}$

The parameters above can be compared to their simulated and measured values.
The simulated and measured center frequencies and center frequency gains are shown in the question above.

Simulated -3dB frequencies and magnitudes:

272.6738966	-9.075976901	-134.708069
1614.064152	-9.081884151	-225.357865

Measured -3db frequencies and magnitudes:

281.8382931	-9.016123147	-135.1636738
1659.586907	-9.047336754	134.8613341

Simulated bandwidth:
1614.0641Hz - 272.6739 = 1341.294Hz = 8428 rad/s

Measured bandwidth:
1659.587Hz - 281.838Hz = 1377.75Hz = 8651 rad/s