Faculty of Enigeering

Cairo University

Analog Electronics Project # 3

Design an Opamp - RC Bandpass Filter

Presented for **ELC 3060** Cadence Project

Presented to:

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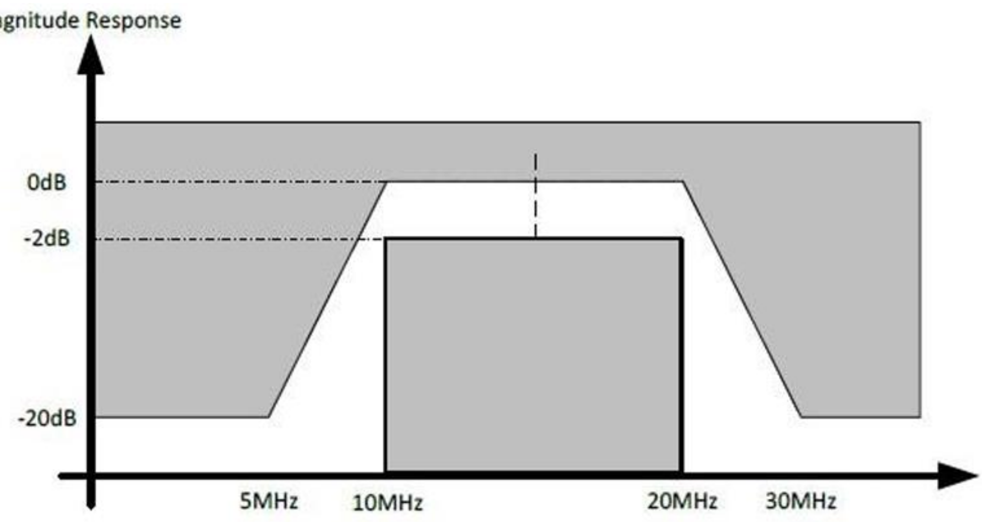


RC BPF

Hand Analysis

Obtain Transfer Function

Givens: $f_1 = 10\ MHz\ , f_2 = 20\ MHz\ , f_3 = 5\ MHz\ , f_4 = 30\ MHz.$

We Find That $f_1 f_2 \neq f_3 f_4$ so, we can change f_3 value across the white area.

Assume $f_1 f_2 = f_3 f_4\ \rightarrow\ 20 \times 10 = f_{3_{new}} \times 30 \rightarrow \therefore \boldsymbol{f_{3_{new}} = \frac{20}{3}\ MHz}$

$\omega_o = \sqrt{\omega_1 \omega_2} = 2\pi\sqrt{f_1 f_2} \rightarrow \therefore \boldsymbol{\omega_o = 88.86\ M\ rad/sec},\ \boldsymbol{f_o = 14.142\ MHz}$

Pass Band Attenuation: $\boldsymbol{A_p = 2\ dB}$, Stop Band Attenuation: $\boldsymbol{A_s = 20\ dB}$

Normalized Pass Band Frequency $\boldsymbol{\Omega_p = 1}$, Normalized Stop Band Frequency $\boldsymbol{\Omega_s = \frac{f_4 - f_3}{f_2 - f_1} = \frac{7}{3}}$

Using Chebyshev (I) Approximations:

$A_p = 2\ dB = 10\log\left(1 + \varepsilon^2 \Omega_p^{2n}\right) = 10\log(1 + \varepsilon^2) \rightarrow \therefore \boldsymbol{\varepsilon = 0.76478}$

$A_s = 20\ dB = 20\log(\varepsilon) + 6(n-1) + 20n\log(\Omega_s) \rightarrow \therefore \boldsymbol{n \approx 3}$ (3rd Order LPF)

LPF Poles:

$S_k = \sigma_k + j\omega_k = -\sinh(\beta)\sin\left(\frac{2k-1}{2n}\pi\right) + j\cosh(\beta)\cos\left(\frac{2k-1}{2n}\pi\right)\ , \boldsymbol{\beta = \frac{1}{n}\sinh^{-1}\left(\frac{1}{\varepsilon}\right) = 0.361}$

$k\ :\ 1 \rightarrow 2n\ (\text{All poles})\ , k\ :\ 1 \rightarrow n\ (\text{poles in LHP to achieve Stability})$ so, $k\ :\ 1 \rightarrow 3$ (LHP Poles)

$S_1 = -0.18445 + 0.9231j\ ,\ S_2 = -0.3689 + 0j\ ,\ S_3 = -0.18445 - 0.9231j$

LPF Transfer Function:

$$T(S)_{LPF} = \frac{1}{(S_n - S_1)(S_n - S_2)(S_n - S_3)} = \frac{0.3689 \times 0.8861}{(S_n + 0.3689)(S_n^2 + 0.3689\ S_n + 0.8861)} = \frac{0.3269}{(S_n + 0.3689)(S_n^2 + 0.3689\ S_n + 0.8861)}$$

BPF Transfer Function:

$BW = \omega_2 - \omega_1 = 62.832\ M\ rad/sec$ Replace $S_n = \frac{\omega_o}{BW}\left(\frac{S}{\omega_o} + \frac{\omega_o}{S}\right) = 1.592 \times 10^{-8}\ S + \frac{125.67 \times 10^6}{S}$

$$\boldsymbol{T(S)_{BPF} = \frac{8.102 \times 10^{22}\ S^3}{S^6 + 4.634 \times 10^7\ S^5 + 2.771 \times 10^{16}\ S^4 + 8.127 \times 10^{23}\ S^3 + 2.188 \times 10^{32}\ S^2 + 2.888 \times 10^{39}\ S + 4.919 \times 10^{47}}}$$

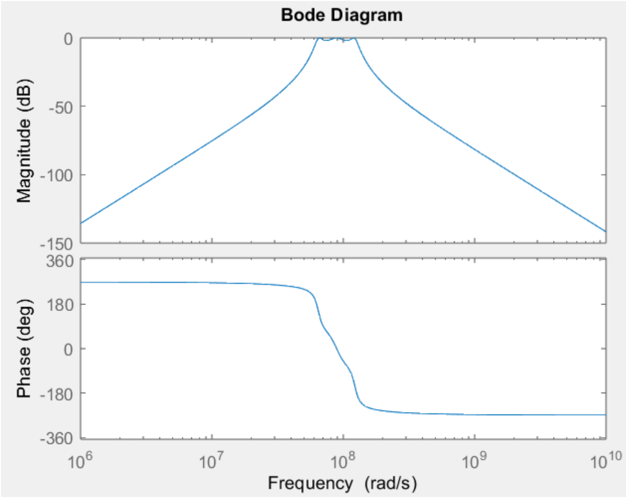
BPF Poles:

```
  1.0e+08 *

 -0.0759 + 1.2229i
 -0.0759 - 1.2229i
 -0.1159 + 0.8809i
 -0.1159 - 0.8809i
 -0.0399 + 0.6430i
 -0.0399 - 0.6430i
```

```
BPF_TF_Simplified =

                                   8.102e22 s^3
  ---------------------------------------------------------------------------------
  s^6 + 4.634e07 s^5 + 2.771e16 s^4 + 8.127e23 s^3 + 2.188e32 s^2 + 2.888e39 s + 4.919e47
```




```
%% LPF Transfer Functions
p1_LPF = -0.18445+0.9231i;
p2_LPF = -0.18445-0.9231i;
p3_LPF = -0.3689+0i;
zeros1_LPF = [];
poles1_LPF = [p1_LPF p2_LPF p3_LPF];
gain1_LPF = 0.3269;
LPF_TF = zpk(zeros1_LPF,poles1_LPF,gain1_LPF);
%% BPF Transfer Functions
s = tf('s');
Sn = (1.592*(1e-8)*s) + ((125.67*(1e6))/s);
BPF_TF = 0.3269 / (((Sn)+0.3689)*((Sn)^2 +0.3689*(Sn)+0.8861));
BPF_TF_Simplified = minreal(BPF_TF);
bode(BPF_TF_Simplified);
BPF_Poles = pzmap(BPF_TF_Simplified);
```

Note: BPF TF has 6 Poles and 3 Zeros (6th Order BPF). So, we use 3 Stages 2nd Order BPF, And an Additional Stage to Normalize the TF with its Gain (8.102×10^{22}).

We Use the Topology used in Project **#1 The Universal Biquadratic Filter**

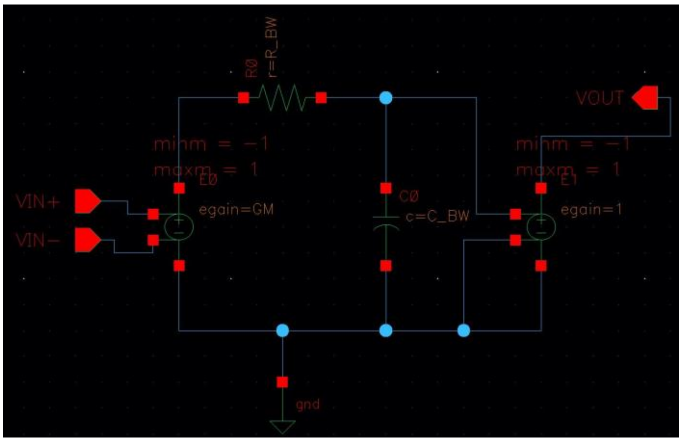


Figure 1: Opamp Model

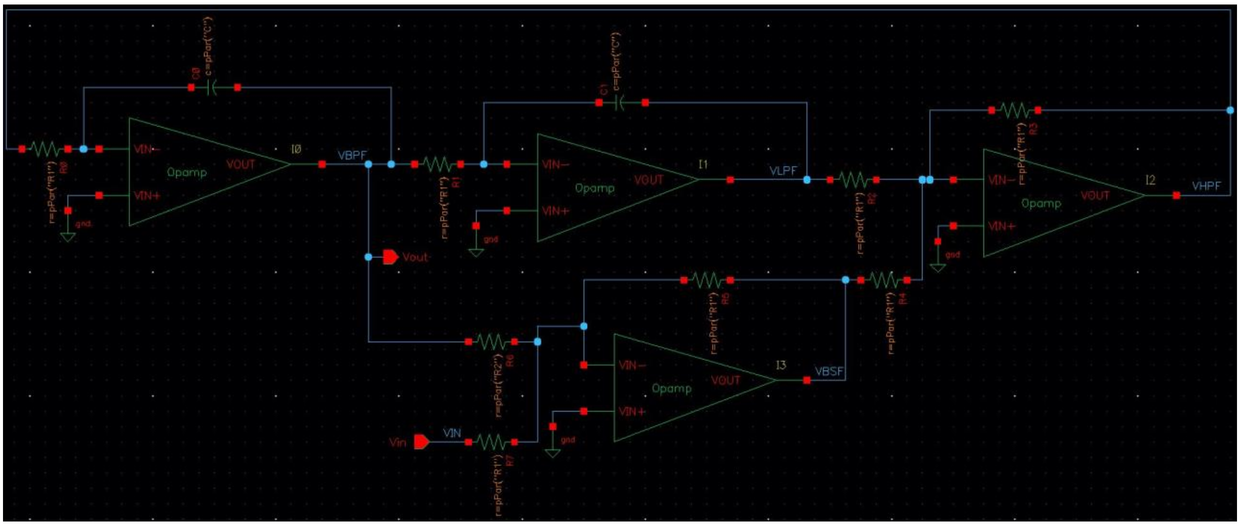


Figure 2: 2nd Order BPF Model

$$\therefore H_{BPF} = \frac{V_{BPF}}{V_{in}} = \frac{-H_o}{\frac{1}{Q}+SCR+\frac{1}{SCR}} = \frac{-H_o\frac{S}{CR}}{S^2+\frac{S}{QCR}+\frac{1}{C^2R^2}} = \frac{-\frac{S}{CR}}{S^2+\frac{S}{QCR}+\frac{1}{C^2R^2}},\ H_o = 1$$

Design Equations

2nd Order BPF Stages	Design Equations & Component Values
1st Stage	$S_{1,2} = (-0.0759 \pm 1.2229j) \times 10^{8}$ $H_{1st\ Stage} = \frac{-122.53\times10^{6}\ S}{S^{2}+15.18\times10^{6}\ S+1.50125\times10^{16}}$ $\frac{1}{(R_1C_1)^2} = 1.50125 \times 10^{16}$, Let $R_{1_{1st\ Stage}} = 1\ k\Omega \rightarrow C_{1_{1st\ Stage}} = 8.1616\ pF$ $\frac{1}{Q_1R_1C_1} = 15.18 \times 10^{6} \rightarrow Q_1 = 8.0722 \rightarrow R_{2_{1st\ Stage}} = QR_{1_{1st\ Stage}} = 8.0722\ k\Omega$
2nd Stage	$S_{3,4} = (-0.1159 \pm 0.8809j) \times 10^{8}$ $H_{2nd\ Stage} = \frac{-88.85\times10^{6}\ S}{S^{2}+23.18\times10^{6}\ S+7.8942\times10^{15}}$ $\frac{1}{(R_2C_2)^2} = 7.8942 \times 10^{15}$, Let $R_{1_{2nd\ Stage}} = 1\ k\Omega \rightarrow C_{1_{2nd\ Stage}} = 11.255\ pF$ $\frac{1}{Q_2R_2C_2} = 23.18 \times 10^{6} \rightarrow Q_2 = 3.833 \rightarrow R_{2_{2nd\ Stage}} = QR_{1_{2nd\ Stage}} = 3.833\ k\Omega$
3rd Stage	$S_{5,6} = (-0.0399 \pm 0.643j) \times 10^{8}$ $H_{3rd\ Stage} = \frac{-64.424\times10^{6}\ S}{S^{2}+7.98\times10^{6}\ S+4.1504\times10^{15}}$ $\frac{1}{(R_3C_3)^2} = 4.1504 \times 10^{15}$, Let $R_{1_{3rd\ Stage}} = 1\ k\Omega \rightarrow C_{1_{3rd\ Stage}} = 15.5223\ pF$ $\frac{1}{Q_3R_3C_3} = 7.98 \times 10^{6} \rightarrow Q_3 = 8.07313 \rightarrow R_{2_{3rd\ Stage}} = QR_{1_{3rd\ Stage}} = 8.073\ k\Omega$
Additional Stage	$A_{1st\ Stage} \times A_{2nd\ Stage} \times A_{3rd\ Stage} \times A_{Added\ Stage} = A_{BPF}$ $(-122.53 \times 10^{6}) \times (-88.85 \times 10^{6}) \times (-64.424 \times 10^{6}) \times A_{Added\ Stage} = 8.102 \times 10^{22}$ $A_{Added\ Stage} = -0.11552$ **(Add Inverting Amplifier to Achieve BPF TF Gain)** $A_{Added\ Stage} = -0.11552 = -\frac{R_2}{R_1}$, Let $R_1 = 10\ k\Omega \rightarrow R_2 = 1.1552\ k\Omega$

Full Schematic

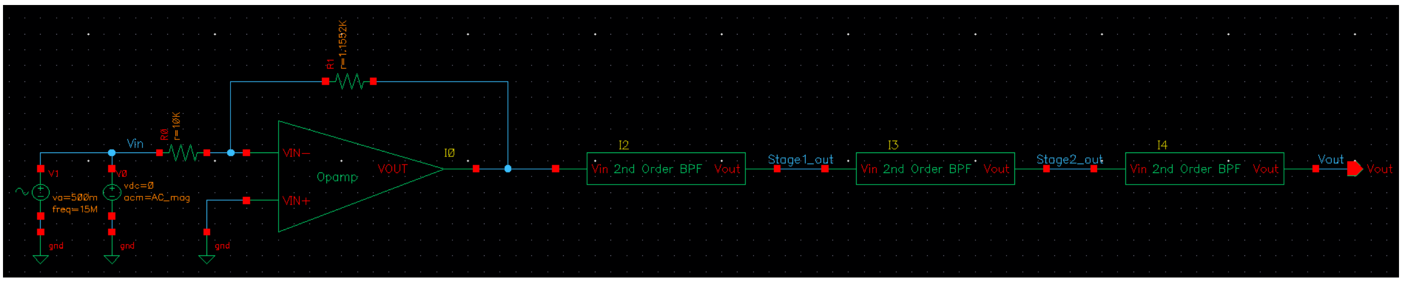
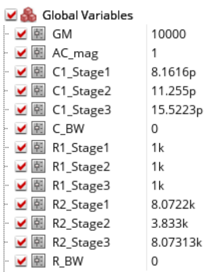


Figure 3: 6th Order BPF Schematic Satsify the Required Specs

AC Analysis

Nominal Components Values:



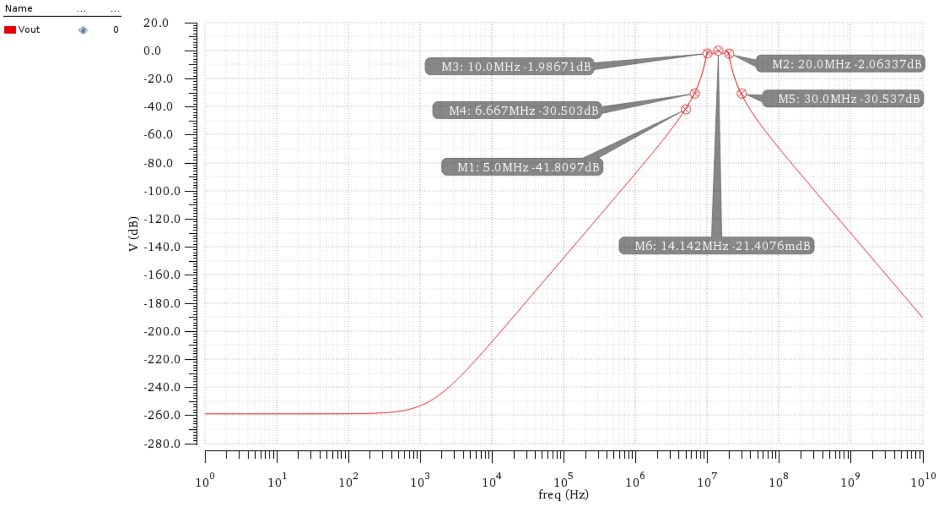


Figure 4: Magnitude Plot in dB20 Scale

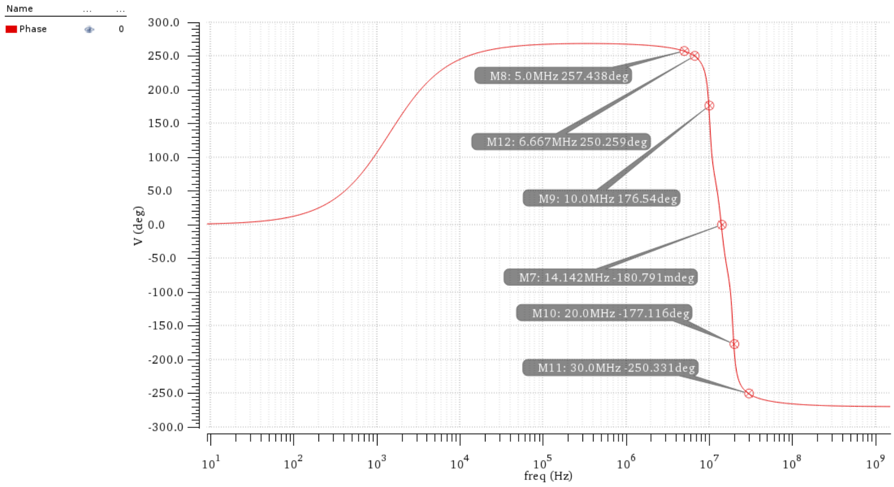


Figure 5: Phase Plot in degrees

Comments: Magnitude Response Meets the Filter Specification + Expectations.

As $A_p \geq -2\ dB\ @\ 10\ MHz, 20\ MHz$ & $A_s \leq -20\ dB\ @\ 5\ MHz\ , 30\ MHz$ and $A_{\omega_o} \approx 0\ dB$

PZ Analysis

R_BW=0

Poles(Hz)

	Real	Imaginary	Qfactor
Pole_1	-6.357e+05	1.023e+07	8.063e+00
Pole_2	-6.357e+05	-1.023e+07	8.063e+00
Pole_3	-1.845e+06	1.402e+07	3.832e+00
Pole_4	-1.845e+06	-1.402e+07	3.832e+00
Pole_5	-1.209e+06	1.946e+07	8.062e+00
Pole_6	-1.209e+06	-1.946e+07	8.062e+00

Zeros(Hz)

	Real	Imaginary	Qfactor
Zero_1	-1.027e+03	0.000e+00	5.000e-01
Zero_2	-1.412e+03	0.000e+00	5.000e-01
Zero_3	-1.950e+03	0.000e+00	5.000e-01

Network function gain(magnitude)= 8.086e+22

Figure 6: PZ Summary

Comments: The poles are close to the calculated poles (when converted to Hertz and divided by 2π). The zeros also have values, but they're relative small that we ignore them (S_z Approaches Zero for an ideal BPF Section).

Noise Analysis

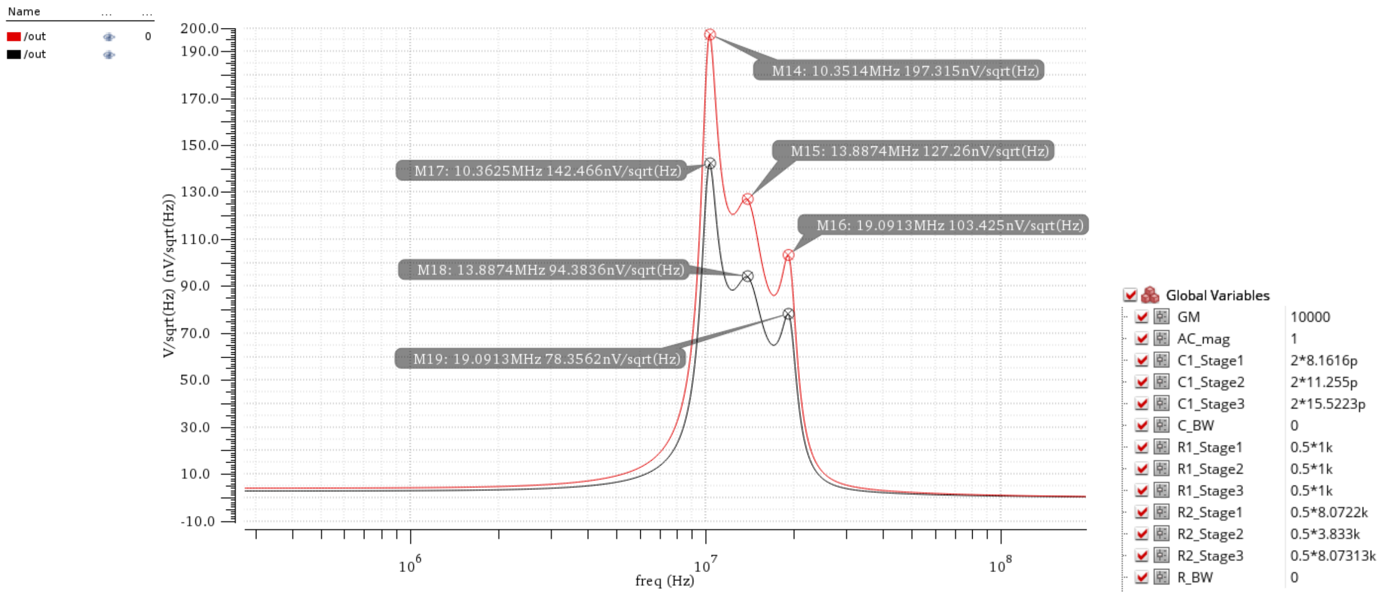


Figure 7: Output Referred Noise Before (Red Curve) and After (Black Curve) Reduce All Resistors by Factor 2

Comments:

- To Keep Same Transfer Function When Reduce all Resistors by Factor 2 (Multiply all Resistors by 0.5 and all Capacitance by 2)
- We find that noise decrease by decreasing the value of Resistors as $\overline{V_n^2} = 4KTR\,\Delta f$.
- Power Consumption will Increase by decreasing the value of Resistors as $P = \frac{V^2}{R}$
- Area Will Increase as Capacitance will Increase to double.

Transient Analysis

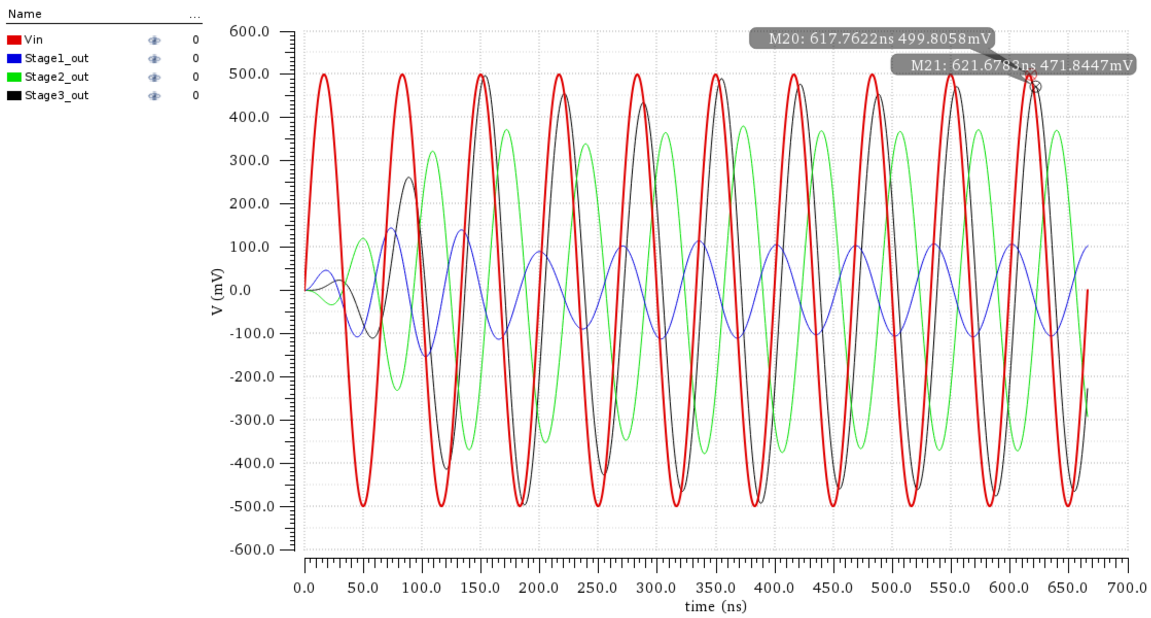


Figure 8: Transient Response for Vin (Red Curve), Stage 1 Out (Blue Curve), Stage 2 Out (Green Curve) & Stage 3 Out (Black Curve)

Comments: Firstly, the Output wasn't Equal the Input due to the Transient Interval in the Beginning and then the Output Became Close to the Input but with Delay.

Delay $= 621.6783\ ns - 617.7622\ ns = 3.9161\ ns.$

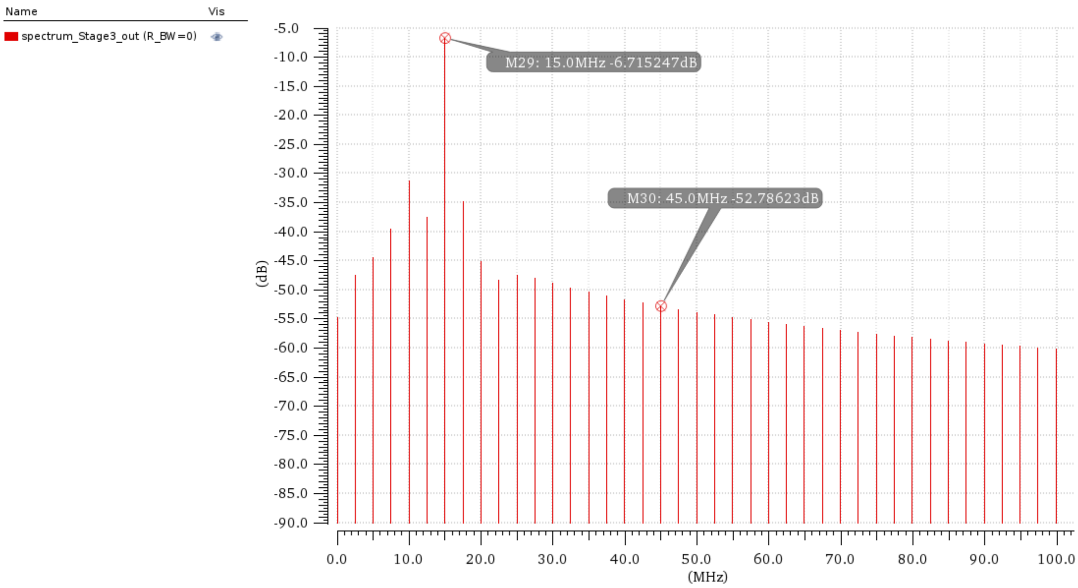


Figure 9: Vout (Stage 3 out) DFT

Comments: Third Harmonic Distortion (dB) = Magnitude at f_o – Magnitude at $3f_o$

$$HD_3 = -6.715247 + 52.78623 = 46.071\ dB$$

Varying Cap $\pm 15\%$

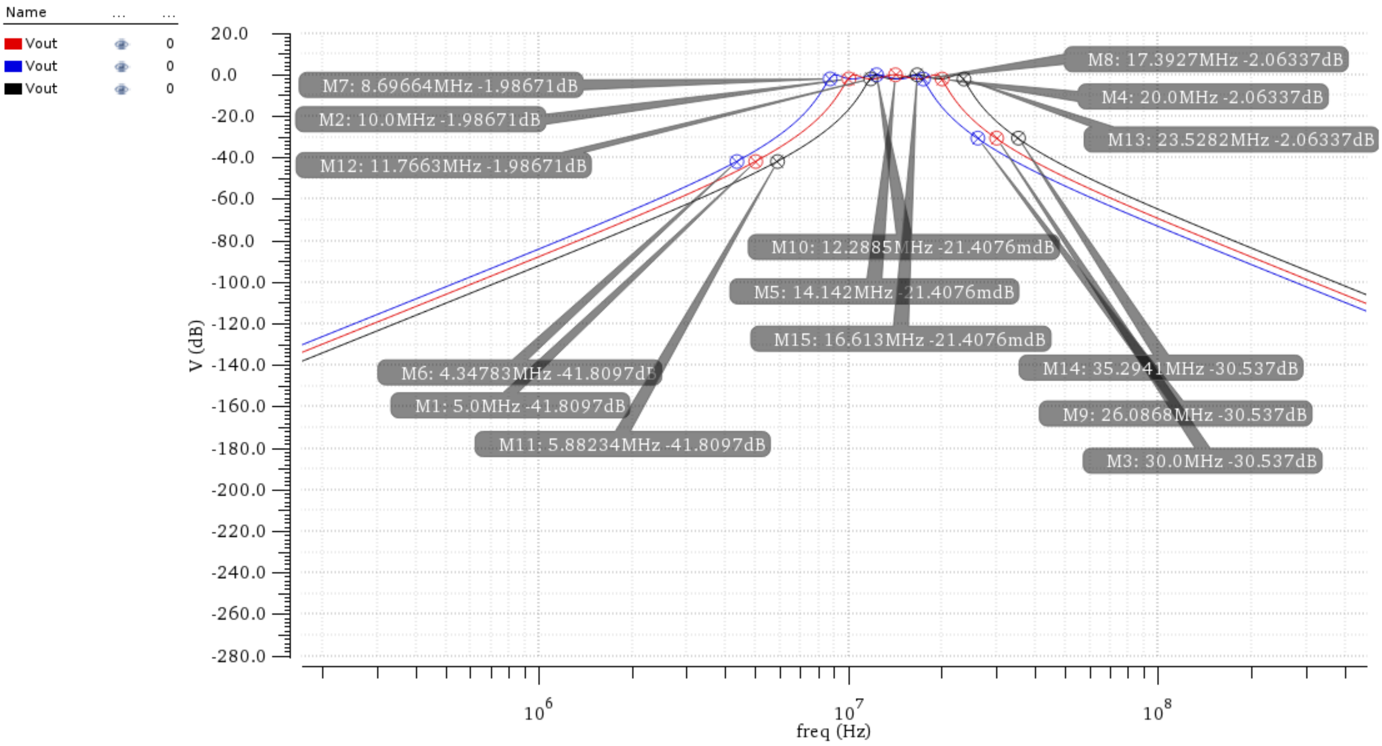


Figure 10: Vout Nominal Cap (Red Curve), +15% Cap (Blue Curve) & -15% Cap (Black Curve)

Comments: By Varying the Capacitance Value by +15% the Center Frequency will decrease (Shifting to Left) and By Varying the Capacitance Value by -15% the Center Frequency will Increase (Shifting to Right). And the Attenuation wasn't Affected. Meanwhile, the center frequency reference Ω_s has been shifted as each pair of poles is virtually moved over the ellipsoidal map of Chebyshev poles $\frac{\sigma_k^2}{\sinh^2\beta} + \frac{\omega_k^2}{\cosh^2\beta} = 1$

C1_Stage1	1.15*8.1616p
C1_Stage2	1.15*11.255p
C1_Stage3	1.15*15.5223p

R_BW=0

Poles(Hz)

	Real	Imaginary	Qfactor
Pole_1	-5.528e+05	8.897e+06	8.063e+00
Pole_2	-5.528e+05	-8.897e+06	8.063e+00
Pole_3	-1.604e+06	1.219e+07	3.832e+00
Pole_4	-1.604e+06	-1.219e+07	3.832e+00
Pole_5	-1.051e+06	1.692e+07	8.062e+00
Pole_6	-1.051e+06	-1.692e+07	8.062e+00

Zeros(Hz)

	Real	Imaginary	Qfactor
Zero_1	-8.935e+02	0.000e+00	5.000e-01
Zero_2	-1.228e+03	0.000e+00	5.000e-01
Zero_3	-1.696e+03	0.000e+00	5.000e-01

Network function gain(magnitude)= 5.317e+22

Figure 11: PZ Summary Effect of Capacitance Change by +15%

C1_Stage1	0.85*8.1616p
C1_Stage2	0.85*11.255p
C1_Stage3	0.85*15.5223p

R_BW=0

Poles(Hz)

	Real	Imaginary	Qfactor
Pole_1	-7.478e+05	1.204e+07	8.063e+00
Pole_2	-7.478e+05	-1.204e+07	8.063e+00
Pole_3	-2.170e+06	1.649e+07	3.832e+00
Pole_4	-2.170e+06	-1.649e+07	3.832e+00
Pole_5	-1.422e+06	2.289e+07	8.062e+00
Pole_6	-1.422e+06	-2.289e+07	8.062e+00

Zeros(Hz)

	Real	Imaginary	Qfactor
Zero_1	-1.209e+03	0.000e+00	5.000e-01
Zero_2	-1.661e+03	0.000e+00	5.000e-01
Zero_3	-2.294e+03	0.000e+00	5.000e-01

Network function gain(magnitude)= 1.317e+23

Figure 12: PZ Summary Effect of Capacitance -15%

Comments: By Increasing the Cap. Value by 15% Both real and imaginary parts decrease making the pole closer to the origin while maintaining the quality factor constant. The same goes for reducing the Cap. Value by 15% where the real and imag. Parts increase and the pole is more distant from the origin while having the same quality factor.

VARYING CAP ±2% IN 1ST STAGE

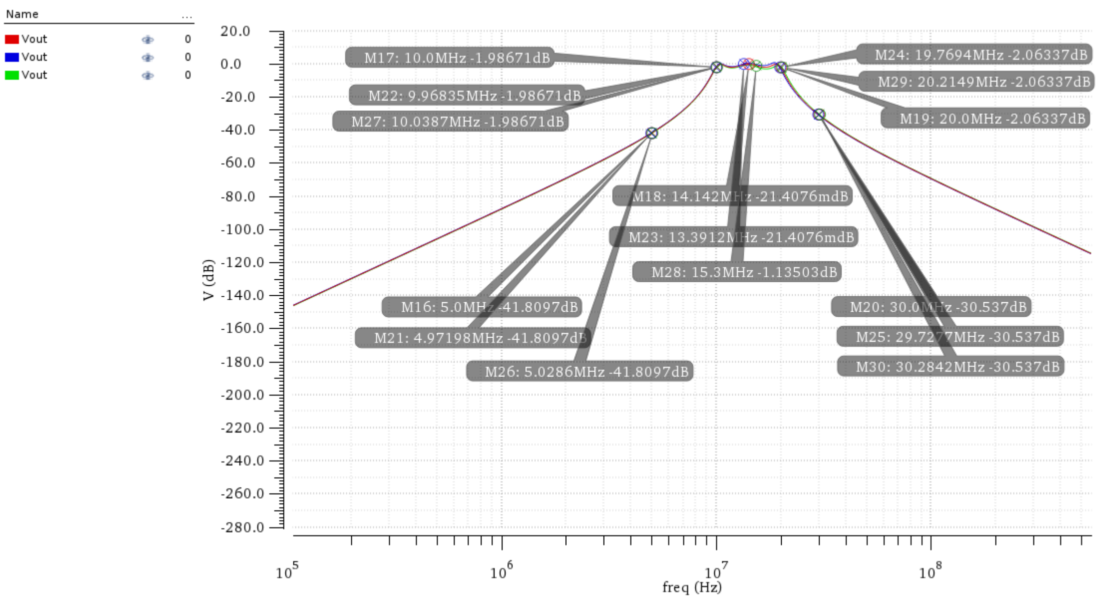


Figure 13: Vout Nominal Cap (Red Curve), +2% 1st Cap (Blue Curve) & -2% 1st Cap (Green Curve)

Comments: By Varying the Capacitance of the 1st Stage by $\pm 2\ \%$ And as Q_1 considered moderate for a BPF it should be robust enough to handle ±2% changes in capacitance there is very small variations between V_{out} Curves and very close to each other.

C1_Stage1	1.02*8.1616p
C1_Stage2	11.255p
C1_Stage3	15.5223p

R_BW=0

Poles(Hz)

	Real	Imaginary	Qfactor
Pole_1	-6.357e+05	1.023e+07	8.063e+00
Pole_2	-6.357e+05	-1.023e+07	8.063e+00
Pole_3	-1.845e+06	1.402e+07	3.832e+00
Pole_4	-1.845e+06	-1.402e+07	3.832e+00
Pole_5	-1.185e+06	1.908e+07	8.062e+00
Pole_6	-1.185e+06	-1.908e+07	8.062e+00

Zeros(Hz)

	Real	Imaginary	Qfactor
Zero_1	-1.027e+03	0.000e+00	5.000e-01
Zero_2	-1.412e+03	0.000e+00	5.000e-01
Zero_3	-1.912e+03	0.000e+00	5.000e-01

Network function gain(magnitude)= 7.927e+22

Figure 14: PZ Summary Effect Capacitance Change by +2% for 1st Stage

C1_Stage1	0.98*8.1616p
C1_Stage2	11.255p
C1_Stage3	15.5223p

R_BW=0

Poles(Hz)

	Real	Imaginary	Qfactor
Pole_1	-6.357e+05	1.023e+07	8.063e+00
Pole_2	-6.357e+05	-1.023e+07	8.063e+00
Pole_3	-1.845e+06	1.402e+07	3.832e+00
Pole_4	-1.845e+06	-1.402e+07	3.832e+00
Pole_5	-1.234e+06	1.986e+07	8.062e+00
Pole_6	-1.234e+06	-1.986e+07	8.062e+00

Zeros(Hz)

	Real	Imaginary	Qfactor
Zero_1	-1.027e+03	0.000e+00	5.000e-01
Zero_2	-1.412e+03	0.000e+00	5.000e-01
Zero_3	-1.990e+03	0.000e+00	5.000e-01

Network function gain(magnitude)= 8.251e+22

Figure 15: PZ Summary Effect Capacitance Change by -2% for 1st Stage

Comments:

- By Varying the Capacitance of the 1st Stage by $\pm 2\ \%$ this will affect the poles and the zeros of this Stage only and the other stages will remain the same as before.
- Small Variations at Pole_5, Pole_6, Zero_3.

VARYING GAIN 1000 & 100

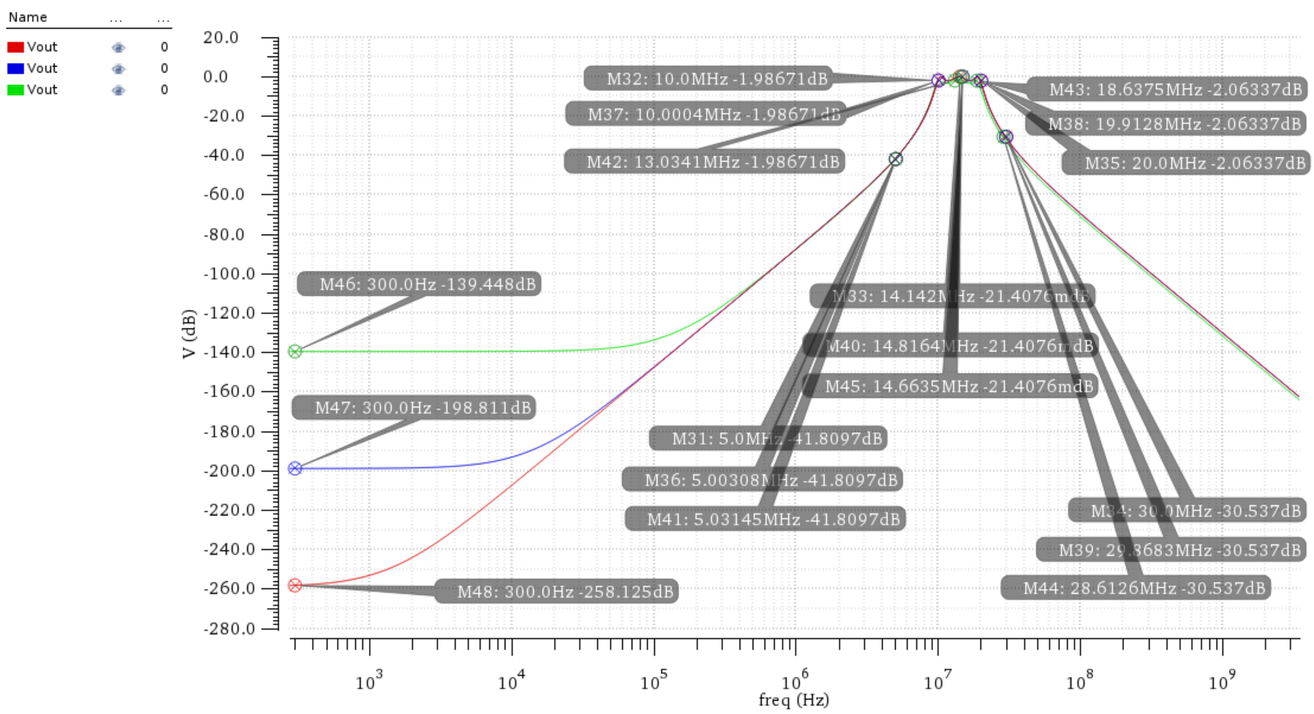


Figure 16: Vout G = 10000 (Red Curve), G = 1000 (Blue Curve) & G = 100 (Green Curve)

Comments: By Decreasing the Gain From 10000 to 1000 to 100 there is a 60dB difference between each consecutive reduction response at the beginning but all of them converge identically starting from the pass band of the filter. The static gain error increases at decreasing the gain which affects each stage but this error is mitigated at higher frequencies

Global Variables
GM 1000

R_BW=0

Poles(Hz)

	Real	Imaginary	Qfactor
Pole_1	-6.992e+05	9.985e+06	7.157e+00
Pole_2	-6.992e+05	-9.985e+06	7.157e+00
Pole_3	-1.874e+06	1.369e+07	3.686e+00
Pole_4	-1.874e+06	-1.369e+07	3.686e+00
Pole_5	-1.330e+06	1.899e+07	7.157e+00
Pole_6	-1.330e+06	-1.899e+07	7.157e+00

Zeros(Hz)

	Real	Imaginary	Qfactor
Zero_1	-1.015e+05	0.000e+00	5.000e-01
Zero_2	-1.400e+05	0.000e+00	5.000e-01
Zero_3	-1.931e+05	0.000e+00	5.000e-01

Network function gain(magnitude)= 6.673e+22

Figure 17: PZ Summary Effect by Change Gain = 1000

Global Variables
GM 100

R_BW=0

Poles(Hz)

	Real	Imaginary	Qfactor
Pole_1	-6.414e+05	1.021e+07	7.974e+00
Pole_2	-6.414e+05	-1.021e+07	7.974e+00
Pole_3	-1.847e+06	1.399e+07	3.819e+00
Pole_4	-1.847e+06	-1.399e+07	3.819e+00
Pole_5	-1.220e+06	1.941e+07	7.973e+00
Pole_6	-1.220e+06	-1.941e+07	7.973e+00

Zeros(Hz)

	Real	Imaginary	Qfactor
Zero_1	-1.024e+04	0.000e+00	5.000e-01
Zero_2	-1.413e+04	0.000e+00	5.000e-01
Zero_3	-1.948e+04	0.000e+00	5.000e-01

Network function gain(magnitude)= 7.945e+22

Figure 18: PZ Summary Effect by Change Gain = 100

Comments: By Varying the Gain From 10000 to 1000 to 100 the poles and zeros moves away from the Origin.

VARYING BW 10 MHZ & 1 MHZ, GAIN = 1000

$BW = 10\ MHz = \frac{1}{2\pi R_1 C_1}$, Let $\boldsymbol{R_1 = 10\ k\Omega \rightarrow C_1 = 1.592\ pF}$

$BW = 1\ MHz = \frac{1}{2\pi R_2 C_2}$, Let $\boldsymbol{R_2 = 10\ k\Omega \ \rightarrow C_2 = 15.92\ pF}$

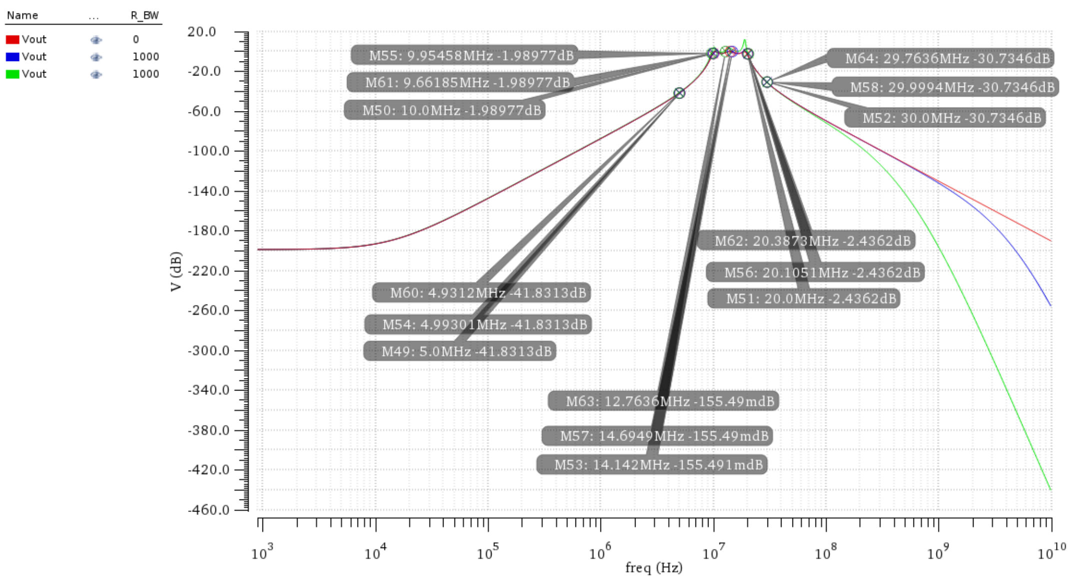


Figure 19: Vout at BW = infinity (Red Curve), BW = 10 MHz (Blue Curve) & BW = 1 MHz (Green Curve)

Comments: By Varying the BW from Infinity to 10 MHz to 1 MHz there is Notice a small Ripples Variations around the center Frequency due to non – ideality in the Op-amp and also small variation in V_{out} Curves except at the end there is High difference.

The needed center Frequency of each stage of the realized BPF are $f_{o1} = 10.25\ MHz$ $f_{o2} = 14.142\ MHz$, $f_{o3} = 19.5\ MHz$, When its required change BW to 10 MHz only one of the Center Frequencies is nearly included to the Op-amp BW while the other two falls to the Stop Band of the Op-amp.

The BW limitation of the op-amp mitigates the effect in pole-pairs for each section which creates an overall shift in the performance so the as the BW is limited the higher stopband is more rejected due to falling in the stopband of the op-amp which adds extra attenuation.

As for the ripples in the passband @ 1MHz, this is because the pass-band also falls in the op-amp stop band as well

Global Variables

GM	1000
C_BW	1.592p
R_BW	10k

Poles(Hz)

	Real	Imaginary	Qfactor
Pole_1	-6.151e+05	1.020e+07	8.308e+00
Pole_2	-6.151e+05	-1.020e+07	8.308e+00
Pole_3	-1.799e+06	1.399e+07	3.920e+00
Pole_4	-1.799e+06	-1.399e+07	3.920e+00
Pole_5	-1.125e+06	1.940e+07	8.634e+00
Pole_6	-1.125e+06	-1.940e+07	8.634e+00
Pole_7	-3.321e+09	0.000e+00	5.000e-01
Pole_8	-3.330e+09	0.000e+00	5.000e-01
Pole_9	-3.336e+09	0.000e+00	5.000e-01
Pole_10	-4.452e+09	0.000e+00	5.000e-01
Pole_11	-4.723e+09	0.000e+00	5.000e-01
Pole_12	-4.728e+09	0.000e+00	5.000e-01
Pole_13	-8.972e+09	0.000e+00	5.000e-01
Pole_14	-1.001e+10	0.000e+00	5.000e-01
Pole_15	-1.001e+10	0.000e+00	5.000e-01
Pole_16	-1.001e+10	0.000e+00	5.000e-01
Pole_17	-1.002e+10	0.000e+00	5.000e-01
Pole_18	-1.003e+10	0.000e+00	5.000e-01
Pole_19	-1.004e+10	0.000e+00	5.000e-01

Zeros(Hz)

	Real	Imaginary	Qfactor
Zero_1	-1.023e+04	0.000e+00	5.000e-01
Zero_2	-1.411e+04	0.000e+00	5.000e-01
Zero_3	-1.944e+04	0.000e+00	5.000e-01
Zero_4	-1.002e+10	0.000e+00	5.000e-01
Zero_5	-1.002e+10	0.000e+00	5.000e-01
Zero_6	-1.003e+10	0.000e+00	5.000e-01
Zero_7	1.964e+10	8.302e+09	-5.428e-01
Zero_8	1.964e+10	-8.302e+09	-5.428e-01
Zero_9	9.949e+09	2.225e+10	-1.225e+00
Zero_10	9.949e+09	-2.225e+10	-1.225e+00
Zero_11	-1.776e+10	2.225e+10	8.016e-01
Zero_12	-1.776e+10	-2.225e+10	8.016e-01
Zero_13	-2.748e+10	8.286e+09	5.222e-01
Zero_14	-2.748e+10	-8.286e+09	5.222e-01
Zero_15	-3.924e+09	2.870e+10	3.691e+00
Zero_16	-3.924e+09	-2.870e+10	3.691e+00

Network function gain(magnitude)= 1.737e+16

Figure 20: PZ Summary Effect by Change BW = 10 MHz

Global Variables

GM	1000
C_BW	15.92p
R_BW	10k

Poles(Hz)

	Real	Imaginary	Qfactor
Pole_1	-3.810e+05	1.015e+07	1.333e+01
Pole_2	-3.810e+05	-1.015e+07	1.333e+01
Pole_3	-1.359e+06	1.398e+07	5.168e+00
Pole_4	-1.359e+06	-1.398e+07	5.168e+00
Pole_5	-2.901e+05	1.915e+07	3.302e+01
Pole_6	-2.901e+05	-1.915e+07	3.302e+01
Pole_7	-3.162e+08	0.000e+00	5.000e-01
Pole_8	-3.253e+08	0.000e+00	5.000e-01
Pole_9	-3.287e+08	0.000e+00	5.000e-01
Pole_10	-4.602e+08	0.000e+00	5.000e-01
Pole_11	-4.772e+08	0.000e+00	5.000e-01
Pole_12	-4.817e+08	0.000e+00	5.000e-01
Pole_13	-8.972e+08	0.000e+00	5.000e-01
Pole_14	-1.003e+09	0.000e+00	5.000e-01
Pole_15	-1.004e+09	0.000e+00	5.000e-01
Pole_16	-1.006e+09	0.000e+00	5.000e-01
Pole_17	-1.018e+09	0.000e+00	5.000e-01
Pole_18	-1.024e+09	0.000e+00	5.000e-01
Pole_19	-1.033e+09	0.000e+00	5.000e-01

Zeros(Hz)

	Real	Imaginary	Qfactor
Zero_1	-1.014e+04	0.000e+00	5.000e-01
Zero_2	-1.393e+04	0.000e+00	5.000e-01
Zero_3	-1.911e+04	0.000e+00	5.000e-01
Zero_4	-1.011e+09	0.000e+00	5.000e-01
Zero_5	-1.015e+09	0.000e+00	5.000e-01
Zero_6	-1.020e+09	0.000e+00	5.000e-01
Zero_7	3.491e+09	1.324e+09	-5.348e-01
Zero_8	3.491e+09	-1.324e+09	-5.348e-01
Zero_9	1.985e+09	3.491e+09	-1.012e+00
Zero_10	1.985e+09	-3.491e+09	-1.012e+00
Zero_11	-3.942e+08	4.344e+09	5.531e+00
Zero_12	-3.942e+08	-4.344e+09	5.531e+00
Zero_13	-2.774e+09	3.490e+09	8.036e-01
Zero_14	-2.774e+09	-3.490e+09	8.036e-01
Zero_15	-4.281e+09	1.324e+09	5.234e-01
Zero_16	-4.281e+09	-1.324e+09	5.234e-01

Network function gain(magnitude)= 1.541e+14

Figure 21: PZ Summary Effect by Change BW = 1 MHz

Comments: By Varying the BW from Infinity to 10 MHz to 1 MHz, New Poles Appeared Due to Non – Ideality of the Op-amp.

The END Thank You