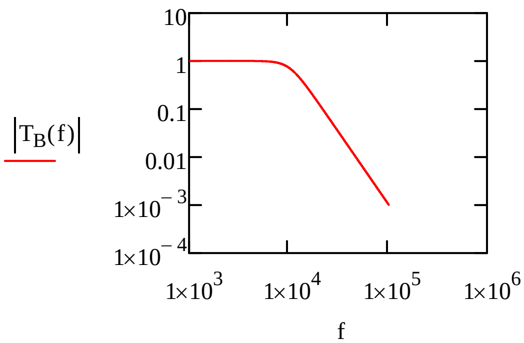
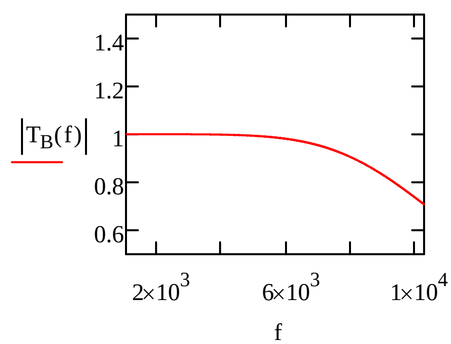
1. Design a 3rd order Butterworth low-pass filters having a dc gain of unity and a cutoff frequency, fc, of 10.28 kHz.

$f_c := 10.28\text{kHz}$ $\quad K := 1$ $\quad$ The transfer function is given on page 72 $\quad j := \sqrt{-1}$

$$T_B(f) := K \cdot \frac{1}{j \cdot \frac{f}{f_c} + 1} \cdot \frac{1}{\left(j \cdot \frac{f}{f_c}\right)^2 + j \cdot \frac{f}{f_c} + 1}$$

This is the product of a 1st order LPF & 2nd order LPF.





To implement this with a circuit cascade the circuit on page 82 with that on page 83. For each the dc gain is unity (K) which means that RF is zero (a wire) and the resistor from the inverting input to ground is infinity (nothing there).

Start by picking two of the capacitors to be 0.01μF. For the Butterworth filter ωc & ωo are the same.

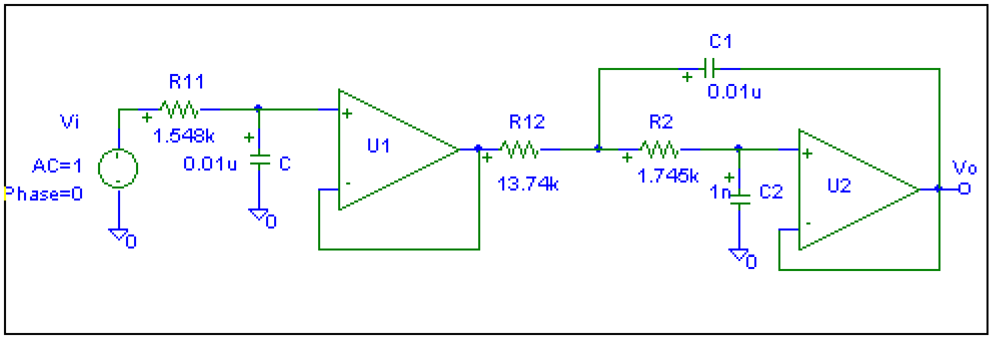
So for the circuit on page 82 This is a 1st order LPF $\quad C := 0.01\mu F \quad R_1 := \frac{1}{2 \cdot \pi \cdot f_c \cdot C} \quad R_1 = 1.548 \times 10^3 \Omega$

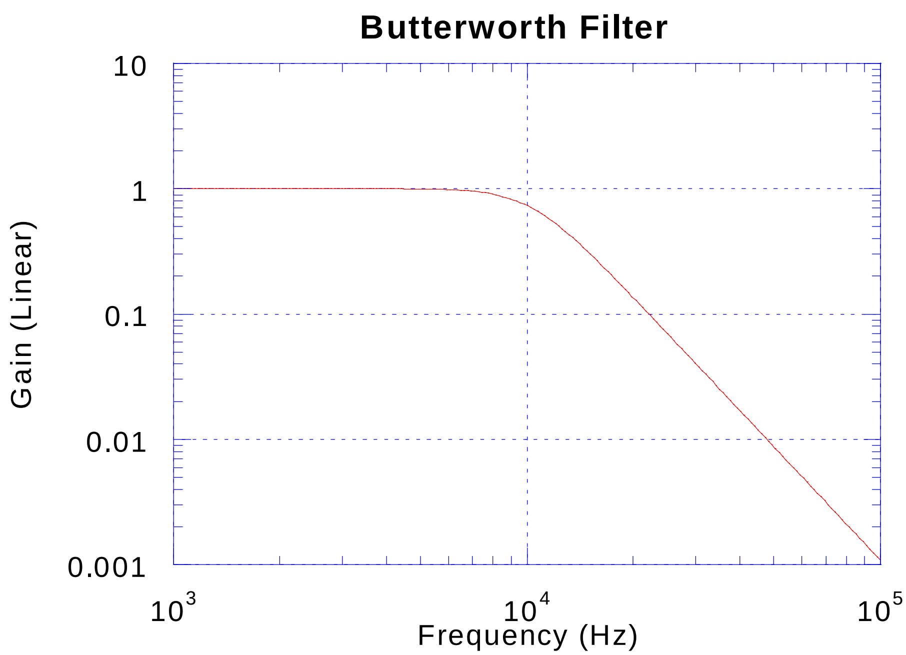
For the circuit shown on page 83, the 2nd order LPF, pick then Eq. 6.84 applies with Q=1 and ωo=ωc $\quad C_1 := 0.01\mu F \quad C_2 := 0.1C_1 \quad Q := 1 \quad \omega_o := 2 \cdot \pi \cdot f_c$

$$R_1 := \frac{1}{2 \cdot Q \cdot \omega_o \cdot C_2} \cdot \left(1 + \sqrt{1 - 4 \cdot Q^2 \frac{C_2}{C_1}}\right) \qquad R_2 := \frac{1}{2 \cdot Q \cdot \omega_o \cdot C_2} \cdot \left(1 - \sqrt{1 - 4 \cdot Q^2 \frac{C_2}{C_1}}\right)$$

$R_1 = 1.374 \times 10^4 \Omega \quad R_2 = 1.745 \times 10^3 \Omega \quad C_1 = 1 \times 10^{-8} F \quad C_2 = 1 \times 10^{-9} F$

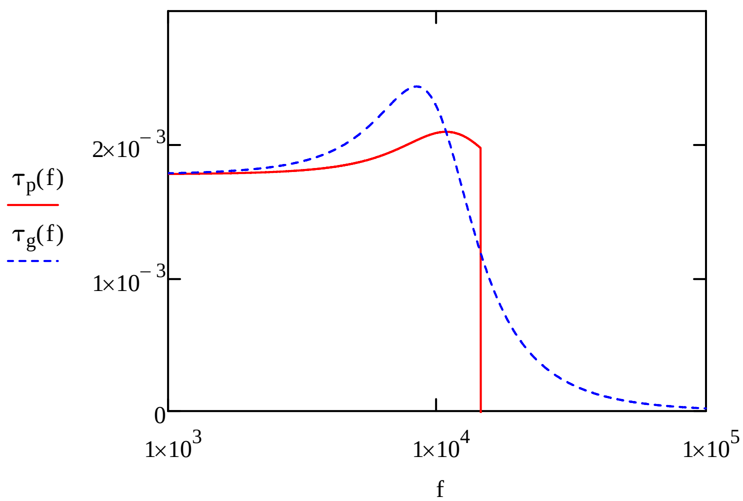
Now that all of the component values have been determined it's time to simulate it with SPICE





The next step is to head to the lab and build the circuits. Use 741s, LF351s, LF347s. The resistors for your use are 5%. The caps are 20 %. Try to find 3 caps reasonably close to the design values.

$$\varphi(f) := \frac{180}{\pi} \cdot \arg\left(T_B(f)\right) \qquad \tau_p(f) := \frac{-1}{2\cdot\pi} \cdot \frac{\varphi(f)}{f} \qquad \tau_g(f) := \frac{-1}{2\cdot\pi} \cdot \left(\frac{d}{df}\varphi(f)\right)$$



2. Design a 3rd order unity dc gain Chebyshev LPF with a -3 frequency of 10.28 kHz and 0.5 db ripple in the pass band.

$db := 0.5$ $\quad f_3 := 10.28kHz$ $\quad K := 1$ $\quad n := 3$ $\quad t_3(x) := 4\cdot x^3 - 3\cdot x$ $\quad j := \sqrt{-1}$

$$\varepsilon := \sqrt{10^{\frac{db}{10}} - 1}$$

Eq. 6.47 must be solved to obtain the relationship between ωc & ω3 which requires that Eq. 6.46 be solved which is a cubic polynomial g(x)

$$g(x) := 4\cdot x^3 - 3\cdot x - \frac{1}{\varepsilon}$$

Since t3(0)=0 To solve this form the vector v

$$v := \begin{pmatrix} \frac{-1}{\varepsilon} \\ -3 \\ 0 \\ 4 \end{pmatrix}$$

This is done with the Insert Matrix selection from the toolbar. The roots are now obtained with the polyroots(.) function. With MathCad the index on arrays in a matrix begin with 0.

Since this is a cubic polynomial it will have at least one real root and its the one required.

$u := \text{polyroots}(v)$ $\quad u = \begin{pmatrix} -0.584 - 0.522i \\ -0.584 + 0.522i \\ 1.167 \end{pmatrix}$ $\quad x := u_{2,0}$ $\quad x = 1.167$

$f_c := \frac{f_3}{x}$ $\quad f_c = 8.805\times 10^3 \frac{1}{s}$

The transfer function is Eq. 6.56 which requires h, a2, a1, & b1

$h := \tanh\left(\frac{1}{n}\cdot \operatorname{asinh}\left(\frac{1}{\varepsilon}\right)\right)$ $\quad \varepsilon = 0.349$ $\quad h = 0.531$ $\quad \theta_1 := \frac{1}{3}\cdot\frac{\pi}{2}$

$a_2 := \frac{h}{\sqrt{1 - h^2}}$ $\quad a_1 := \sqrt{\frac{1}{1-h^2} - \left(\sin\left(\theta_1\right)\right)^2}$ $\quad b_1 := \frac{1}{2}\cdot\sqrt{1 + \frac{1}{\left(h\cdot\tan\left(\theta_1\right)\right)^2}}$

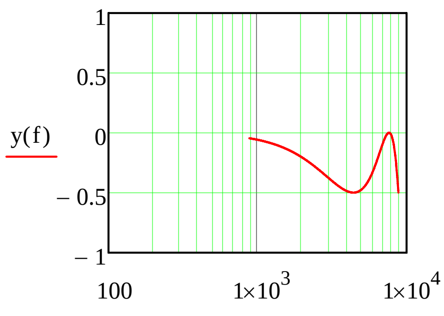
$a_2 = 0.626$ $\quad a_1 = 1.069$ $\quad b_1 = 1.706$

The transfer function then becomes

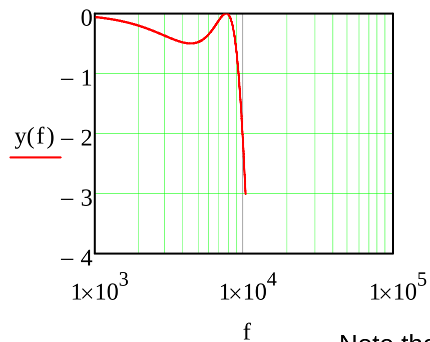
$$T_C(f) := K\cdot\frac{1}{\frac{j\cdot f}{a_2\cdot f_c} + 1}\cdot\frac{1}{\left[\left(\frac{j\cdot f}{a_1\cdot f_c}\right)^2 + \frac{1}{b_1}\cdot\frac{j\cdot f}{a_1\cdot f_c} + 1\right]}$$

$$y(f) := 20\cdot\log\left(\left|T_C(f)\right|\right)$$

For a check of the solution the magnitude of the transfer function in db will be plotted vs f



Equiripple box



3 db box

Note that it is 3 dB down at 10.28 kHz

Now the circuit must be designed. This requires a 1st order lpf cascaded with a 3rd order lpf. This can be done by cascading the circuit shown in Fig. 6.9.a (page 83) with Fig. 6.11 (page 83).

For the 1st order filter, since the dc gain is unity, K=1, pick RF=0 (a wire) and R1 infinity.

Pick $C_1 := 0.01\mu F$

$$R_1 := \frac{1}{2 \cdot \pi \cdot a_2 \cdot f_c \cdot C_1} \qquad R_1 = 2.885 \times 10^3 \Omega$$

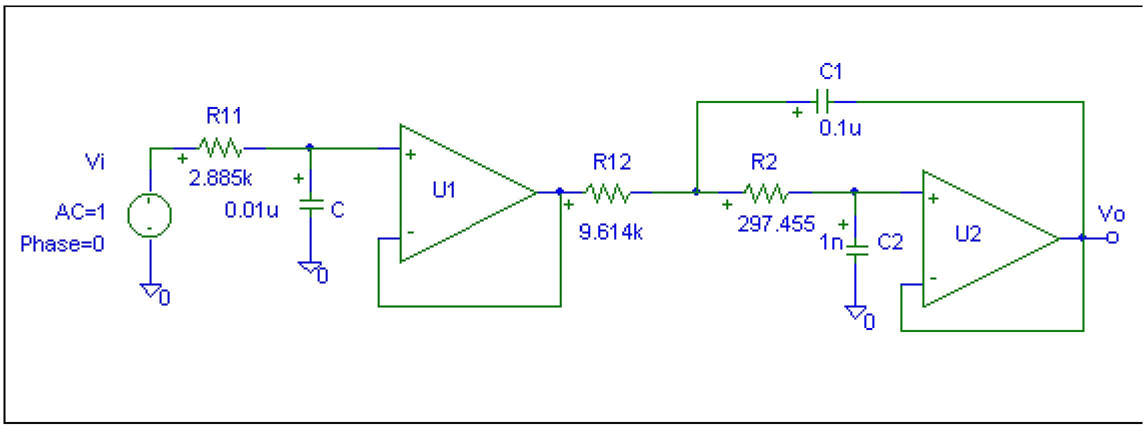
For the 2nd order filter, K=1, pick RF=0 & R3 open ckt.

$f_o := f_c \cdot a_1$ $\qquad \omega_o := 2 \cdot \pi \cdot f_o$ $\qquad Q := b_1$

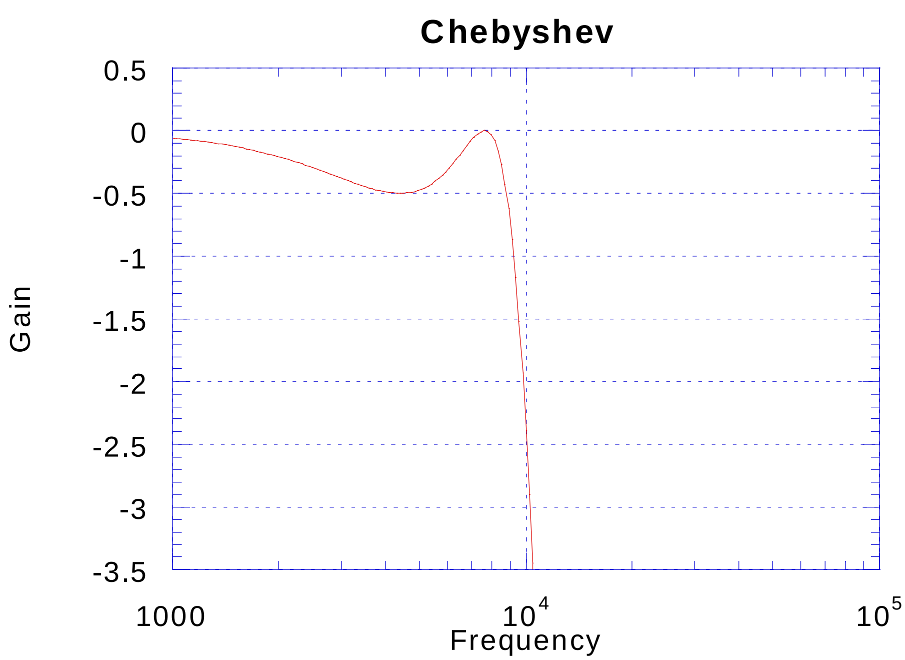
Pick $C_1 := 0.1\mu F$ $\qquad C_2 := 0.01 \cdot C_1$

$$R_1 := \frac{1}{2 \cdot Q \cdot \omega_o \cdot C_2} \cdot \left(1 + \sqrt{1 - \frac{4 \cdot Q^2 \cdot C_2}{C_1}}\right) \qquad R_1 = 9.614 \times 10^3 \Omega \qquad C_1 = 1 \times 10^{-7} F$$

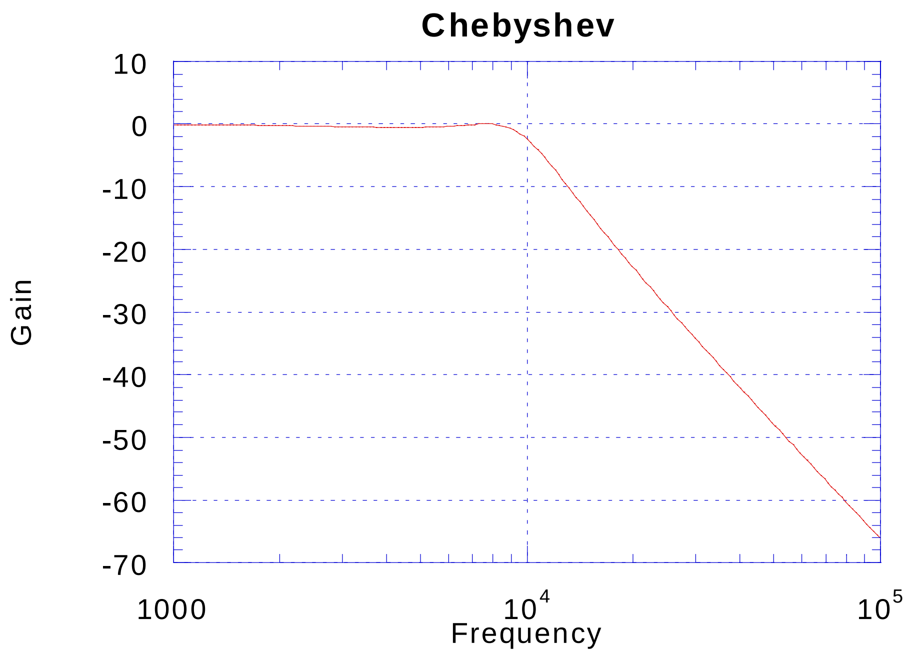
$$R_2 := \frac{1}{2 \cdot Q \cdot \omega_o \cdot C_2} \cdot \left(1 - \sqrt{1 - \frac{4 \cdot Q^2 \cdot C_2}{C_1}}\right) \qquad R_2 = 297.455 \Omega \qquad C_2 = 1 \times 10^{-9} F$$



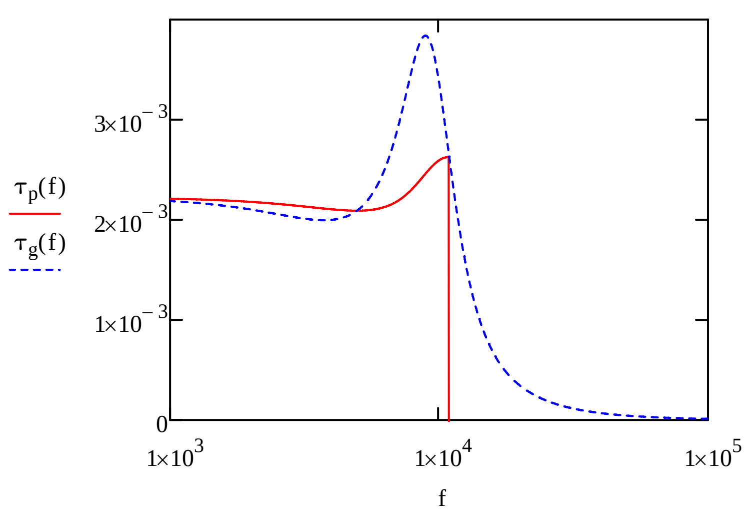
C1
0.1u
R11
2.885k
Vi
AC=1
Phase=0
0.01u
C
U1
R12
9.614k
R2
297.455
1n
C2
U2
Vo
0



Chebyshev
Gain
0.5
0
-0.5
-1
-1.5
-2
-2.5
-3
-3.5
1000
10^4
10^5
Frequency



$$\varphi(f) := \frac{180}{\pi}\cdot \arg\left(T_C(f)\right) \qquad \tau_p(f) := \frac{-1}{2\cdot\pi}\cdot\frac{\varphi(f)}{f} \qquad \tau_g(f) := \frac{-1}{2\cdot\pi}\cdot\left(\frac{d}{df}\varphi(f)\right)$$

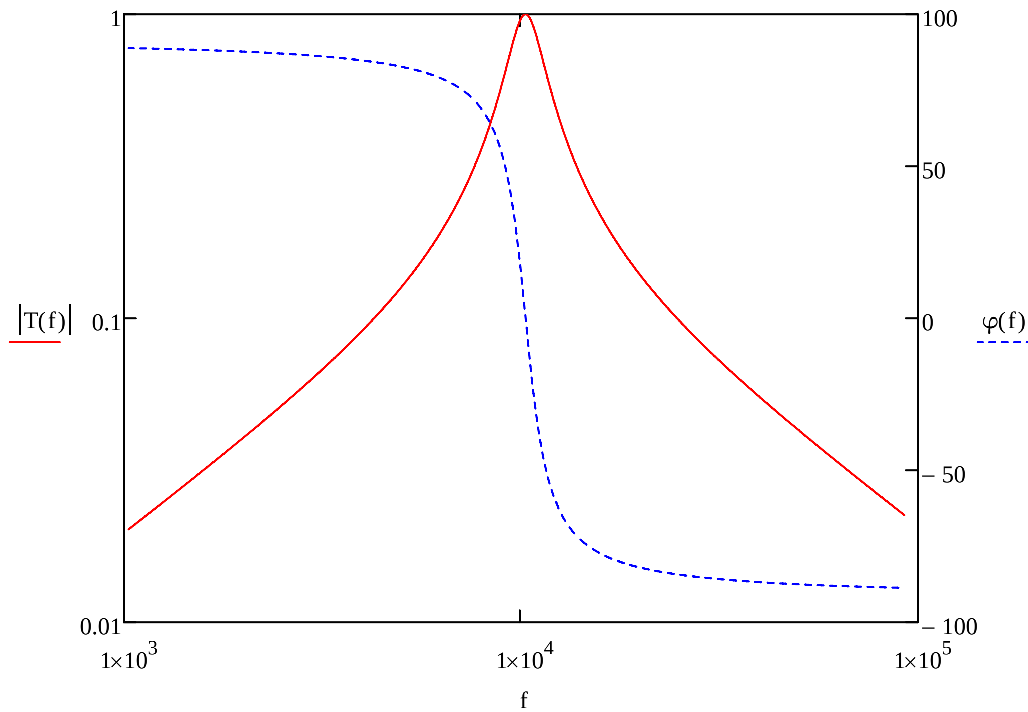


Page 86, Fig 6-14

Second Order Sallen Key BPF

$f_c := 10.28 \cdot kHz$ $\quad K := 1$ $\quad Q := 5$ $\quad f_o := f_c$ $\quad j := \sqrt{-1}$

$$T(f) := K \cdot \frac{\frac{1}{Q} \cdot j \cdot \frac{f}{f_o}}{\left(j \cdot \frac{f}{f_o}\right)^2 + \frac{1}{Q} \cdot j \cdot \frac{f}{f_o} + 1} \qquad \varphi(f) := \frac{180}{\pi} \cdot \arg(T(f))$$



$R_4 := 3 \cdot k\Omega$ $\quad R_5 := 3 \cdot k\Omega$ $\quad C_1 := 10 \cdot nF$ $\quad C_2 := 10 \cdot nF$ $\quad \omega_o := 2 \cdot \pi \cdot f_o$

$R_1 := 1.8 \cdot k\Omega$ $\quad R_2 := 1.8 \cdot k\Omega$ $\quad R_3 := 1.8 \cdot k\Omega$ $\quad K_o := 1 + \frac{R_5}{R_4}$

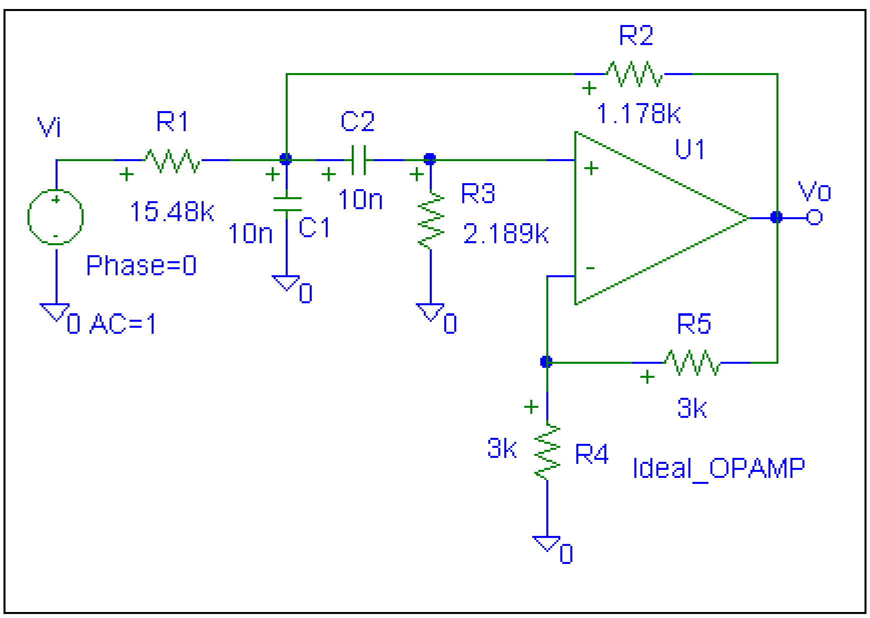
Given

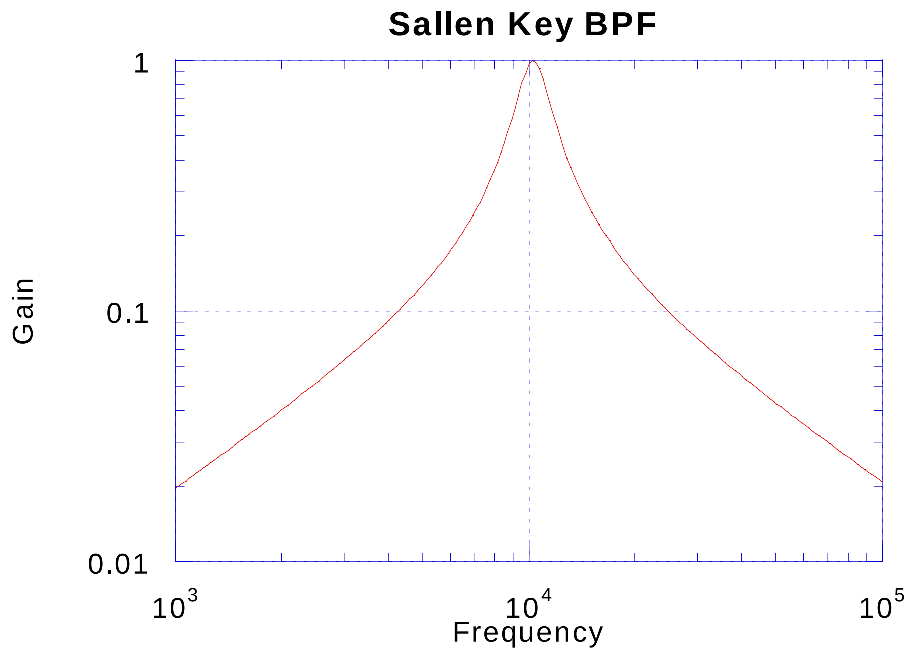
$$K = \frac{R_2}{R_1 + R_2} \cdot \frac{K_o \cdot R_3 \cdot C_2}{\left(\frac{R_1 \cdot R_2}{R_1 + R_2}\right) \cdot (C_1 + C_2) + R_3 \cdot C_2 \cdot \left[1 - \frac{K_o \cdot R_1}{(R_1 + R_2)}\right]}$$

$$\omega_o = \frac{1}{\sqrt{\frac{R_1 \cdot R_2}{R_1 + R_2} \cdot R_3 \cdot C_1 \cdot C_2}}$$

$$Q = \frac{\sqrt{\frac{R_1 \cdot R_2}{R_1 + R_2} \cdot R_3 \cdot C_1 \cdot C_2}}{\left(\frac{R_1 \cdot R_2}{R_1 + R_2}\right)(C_1 + C_2) + R_3 \cdot C_2 \cdot \left(1 - \frac{K_o \cdot R_1}{R_1 + R_2}\right)}$$

$$\text{Find}(R_1, R_2, R_3) = \begin{pmatrix} 1.548 \times 10^4 \\ 1.178 \times 10^3 \\ 2.189 \times 10^3 \end{pmatrix} \Omega$$

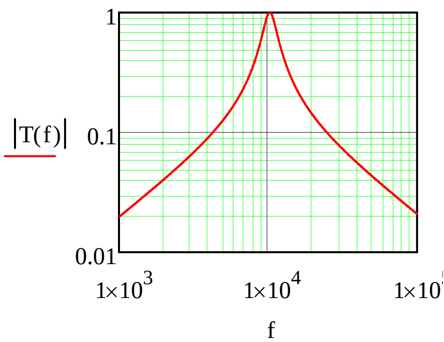


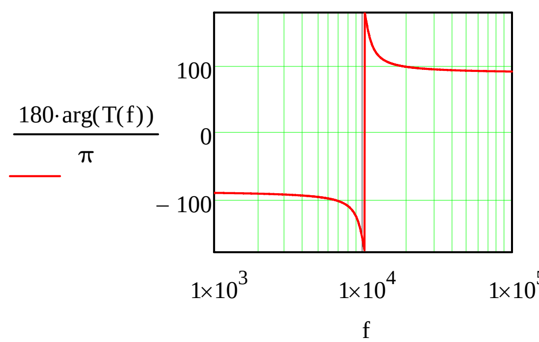

Sallen Key BPF
Gain
1
0.1
0.01
10^3
10^4
10^5
Frequency

Second Order Infitite Gain Multiple Feedback BPF, page 87, Exp 6

$f_o := 10.28 \cdot kHz \quad Q := 5 \quad K := 1 \quad \omega_o := 2 \cdot \pi \cdot f_o \quad j := \sqrt{-1}$

$$T(f) := -K \frac{\frac{1}{Q} \cdot j \cdot \frac{f}{f_o}}{\left(j \cdot \frac{f}{f_o}\right)^2 + \frac{1}{Q} \cdot j \cdot \frac{f}{f_o} + 1}$$





$C_1 := 0.01 \cdot \mu F \quad C_2 := C_1 \quad R_1 := 10 \cdot k\Omega \quad R_2 := 240 \cdot \Omega \quad R_3 := 20 \cdot k\Omega$

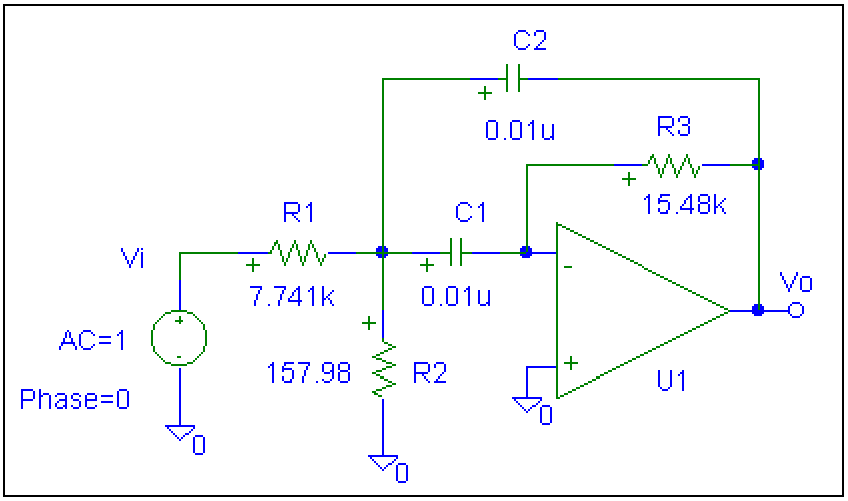
Given

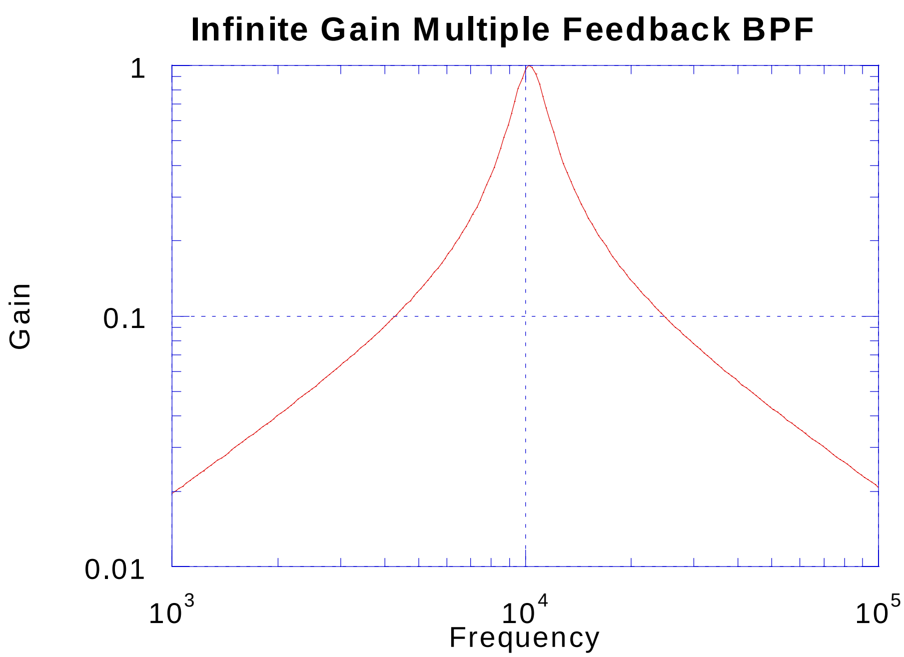
$$\frac{R_3 \cdot C_1}{R_1 \cdot (C_1 + C_2)} = K$$

$$\frac{1}{\sqrt{\frac{R_1 \cdot R_2 \cdot R_3 \cdot C_1 \cdot C_2}{R_1 + R_2}}} = \omega_o$$

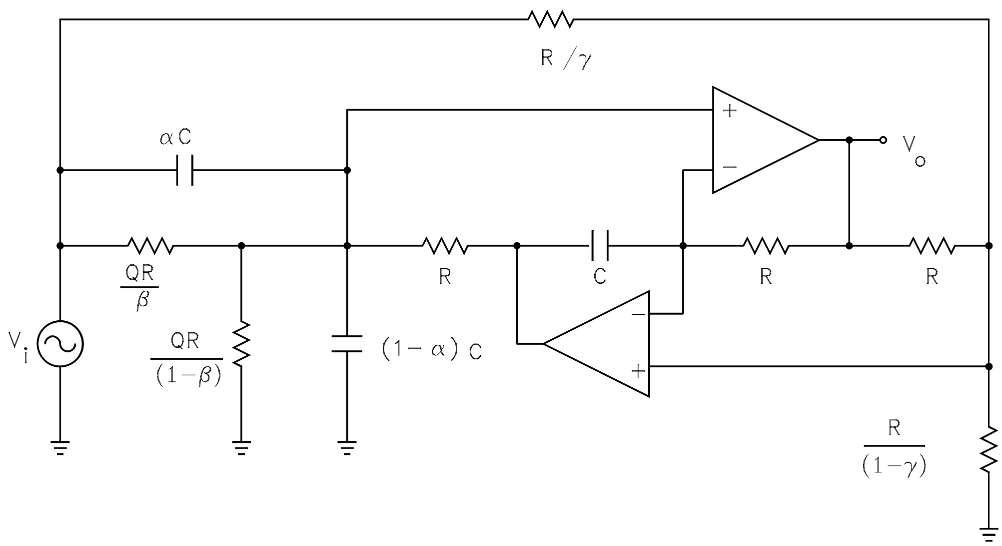
$$\frac{\sqrt{\frac{R_3 \cdot C_1 \cdot C_2 \cdot (R_1 + R_2)}{(R_1 \cdot R_2)}}}{C_1 + C_2} = Q$$

$$\mathrm{Find}(R_1, R_2, R_3) = \begin{pmatrix} 7.741 \times 10^3 \\ 157.98 \\ 1.548 \times 10^4 \end{pmatrix} \Omega$$


C2
0.01u
R3
15.48k
R1
C1
Vi
7.741k
0.01u
Vo
AC=1
157.98
R2
U1
Phase=0
0
0
0


Infinite Gain Multiple Feedback BPF
1
0.1
0.01
Gain
10^3
10^4
10^5
Frequency

General Bi Quadratic Filter



$$T(s) = \left[\frac{\left(\frac{s}{\omega_o}\right)^2\cdot(2\cdot\alpha-\gamma)+\frac{1}{Q}\cdot\left(\frac{s}{\omega_o}\right)\cdot(2\cdot\beta-\gamma)+\gamma}{\left(\frac{s}{\omega_o}\right)^2+\frac{1}{Q}\cdot\frac{s}{\omega_o}+1}\right]$$

$f_o := 10.28\text{kHz}$ $\quad N := 2000$ $\quad i := 0 .. N-1$ $\quad f_{start} := 1\text{kHz}$ $\quad j := \sqrt{-1}$

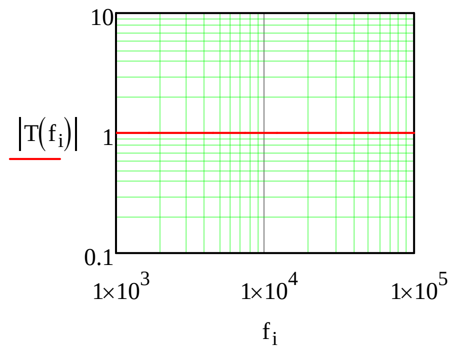
$f_{stop} := 100\text{kHz}$

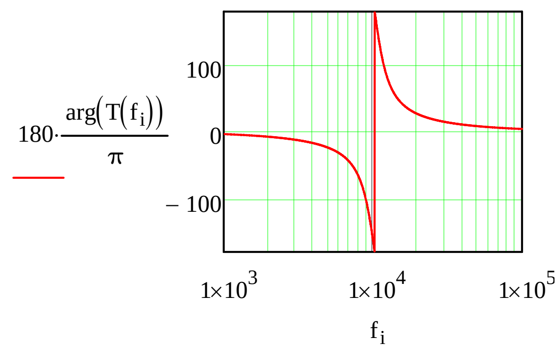
$$f_i := f_{start}\cdot\left(\frac{f_{stop}}{f_{start}}\right)^{\frac{i}{N-1}}$$

Allpass

$Q := 3$ $\quad \alpha := 1$ $\quad \beta := 0$ $\quad \gamma := 1$

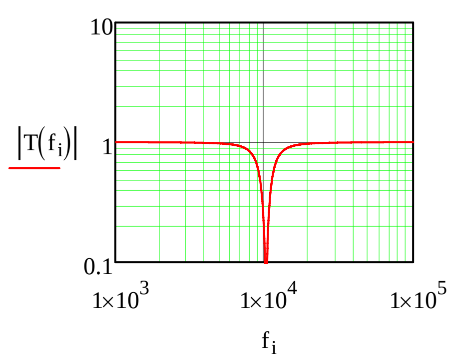
$$T(f) := \frac{\left(\frac{f}{f_o}\cdot j\right)^2\cdot(2\cdot\alpha-\gamma)+\frac{1}{Q}\cdot\left(\frac{j\cdot f}{f_o}\right)\cdot(2\cdot\beta-\gamma)+\gamma}{\left(j\,\frac{f}{f_o}\right)^2+\frac{1}{Q}\cdot\frac{j\cdot f}{f_o}+1}$$

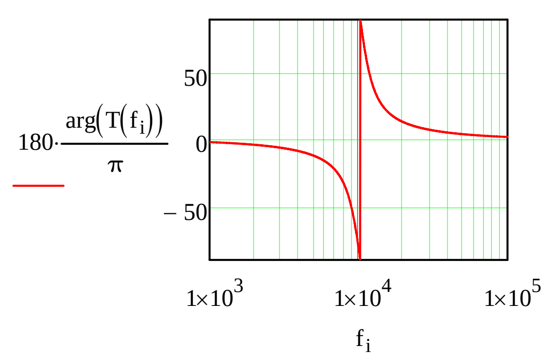




Notch $\alpha := 1$ $\beta := 0.5$ $\gamma := 1$ $Q := 3$ $f_o := 10.28\text{kHz}$

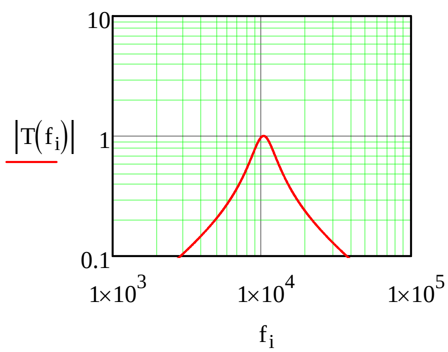
$$T(f) := \frac{\left(\frac{f}{f_o}\cdot j\right)^2\cdot(2\cdot\alpha-\gamma)+\frac{1}{Q}\cdot\left(\frac{j\cdot f}{f_o}\right)\cdot(2\cdot\beta-\gamma)+\gamma}{\left(j\,\frac{f}{f_o}\right)^2+\frac{1}{Q}\cdot\frac{j\cdot f}{f_o}+1}$$

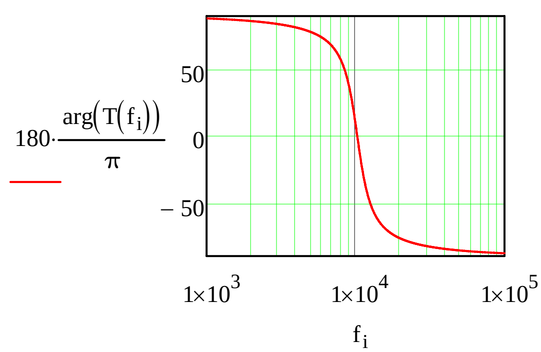




Bandpass $\alpha := 0$ $\beta := 0.5$ $\gamma := 0$ $f_o := 10.28\text{kHz}$ $Q := 3$

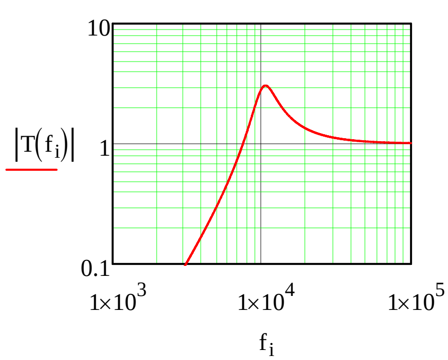
$$T(f) := \frac{\left(\frac{f}{f_o}\cdot j\right)^2\cdot(2\cdot\alpha-\gamma)+\frac{1}{Q}\cdot\left(\frac{j\cdot f}{f_o}\right)\cdot(2\cdot\beta-\gamma)+\gamma}{\left(j\,\frac{f}{f_o}\right)^2+\frac{1}{Q}\cdot\frac{j\cdot f}{f_o}+1}$$

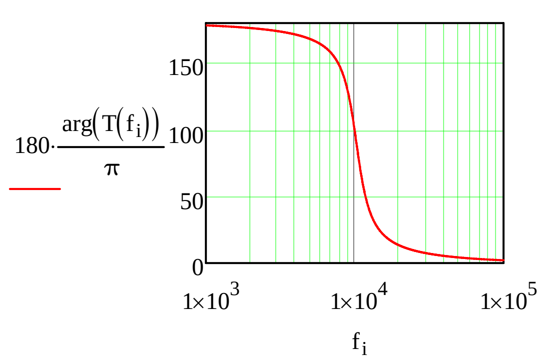




Highpass $\alpha := 0.5$ $\beta := 0$ $\gamma := 0$ $f_o := 10.28\text{kHz}$ $Q := 3$

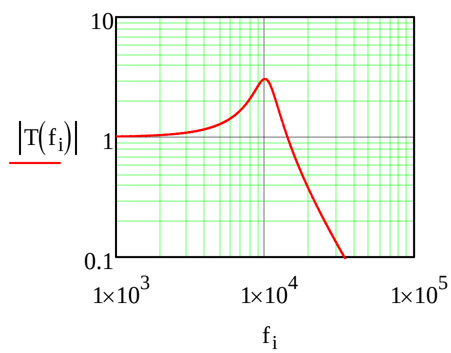
$$T(f) := \frac{\left(\frac{f}{f_o}\cdot j\right)^2\cdot(2\cdot\alpha-\gamma)+\frac{1}{Q}\cdot\left(\frac{j\cdot f}{f_o}\right)\cdot(2\cdot\beta-\gamma)+\gamma}{\left(j\,\frac{f}{f_o}\right)^2+\frac{1}{Q}\cdot\frac{j\cdot f}{f_o}+1}$$

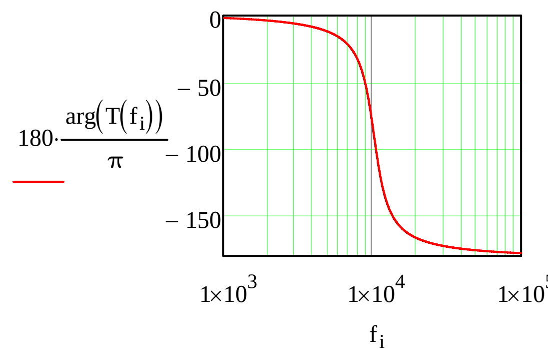




Lowpass $\alpha := 0.5$ $\beta := 0.5$ $\gamma := 1$ $f_o := 10.28\text{kHz}$ $Q := 3$

$$T(f) := \frac{\left(\frac{f}{f_o}\cdot j\right)^2\cdot(2\cdot\alpha-\gamma)+\frac{1}{Q}\cdot\left(\frac{j\cdot f}{f_o}\right)\cdot(2\cdot\beta-\gamma)+\gamma}{\left(j\,\frac{f}{f_o}\right)^2+\frac{1}{Q}\cdot\frac{j\cdot f}{f_o}+1}$$





Third Order Elliptic Filter with 0.5 db ripple unity dc gain with stop band to cutoff ratio of 1.5

with a min attenuation in the stop band of 21.9 dB from page 79 in the lab manual

$$T(s) = \frac{1}{\frac{s}{0.76695\omega_c}+1}\cdot\frac{\left(\frac{s}{1.6751\cdot\omega_c}\right)^2+1}{\left(\frac{s}{1.0720\cdot\omega_c}\right)^2+\frac{1}{2.3672}\cdot\frac{s}{1.0720\cdot\omega_c}+1}$$

this requires that a first order filter be cascaded with a bi quad

for a notch at fp this means

$f_c := 10.28\text{kHz}$ $\gamma := 1$ $\beta := \frac{1}{2}$ $f_o := 1.072 \cdot f_c$

$$\alpha := \frac{\gamma + \left(\frac{1.072}{1.6751}\right)^2}{2} = 0.705$$

$Q := 2.3672$

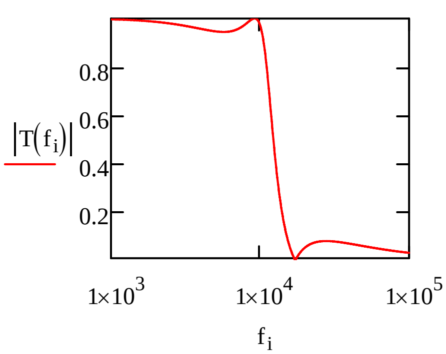
$$T_2(f) := \frac{\left(\frac{f}{f_o} \cdot j\right)^2 \cdot (2 \cdot \alpha - \gamma) + \frac{1}{Q} \cdot \left(\frac{j \cdot f}{f_o}\right) \cdot (2 \cdot \beta - \gamma) + \gamma}{\left(j \frac{f}{f_o}\right)^2 + \frac{1}{Q} \cdot \frac{j \cdot f}{f_o} + 1}$$

for the first order filter

$f_1 := 0.7669 \cdot f_c$

$$T_1(f) := \frac{1}{1 + j \cdot \frac{f}{f_1}}$$

$T(f) := T_1(f) \cdot T_2(f)$

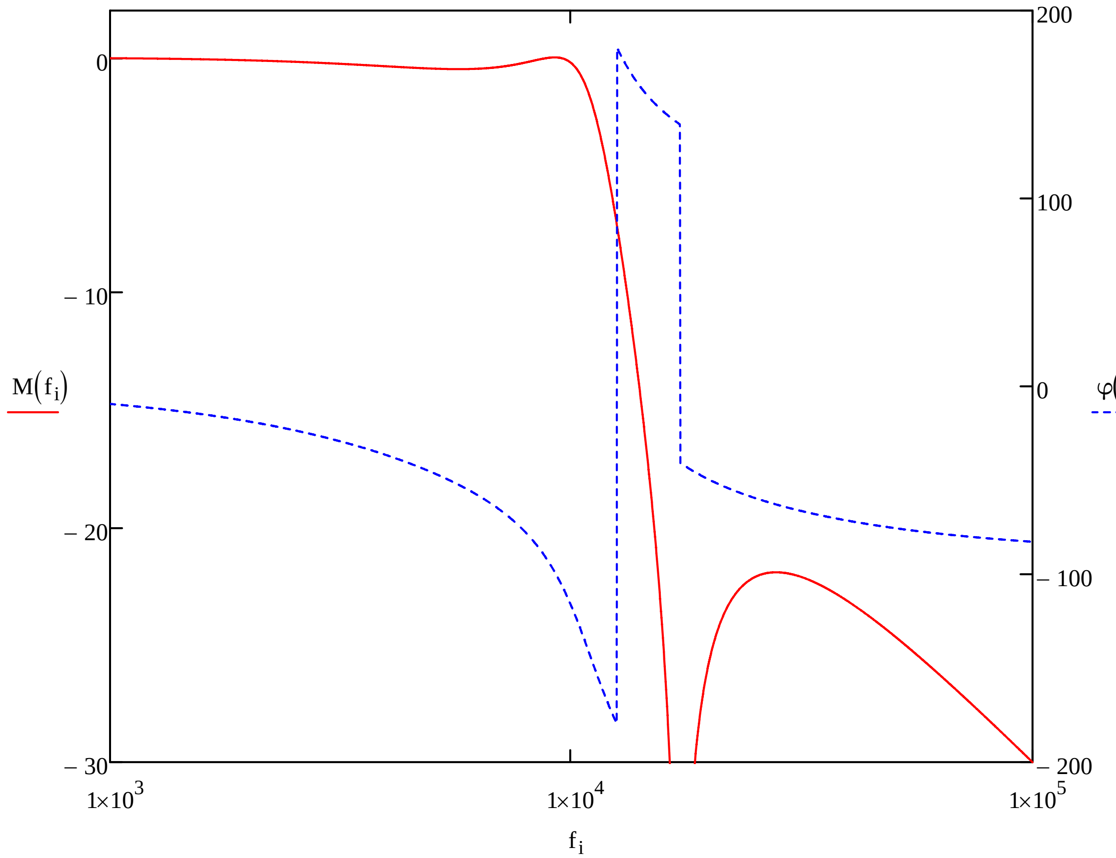


$$\varphi(f) := \frac{180}{\pi} \cdot \arg(T(f))$$

$$\tau_g(f) := -\frac{1}{2 \cdot \pi} \cdot \left(\frac{d}{df} \varphi(f)\right)$$

$$\tau_p(f) := -\frac{\varphi(f)}{2 \cdot \pi \cdot f}$$

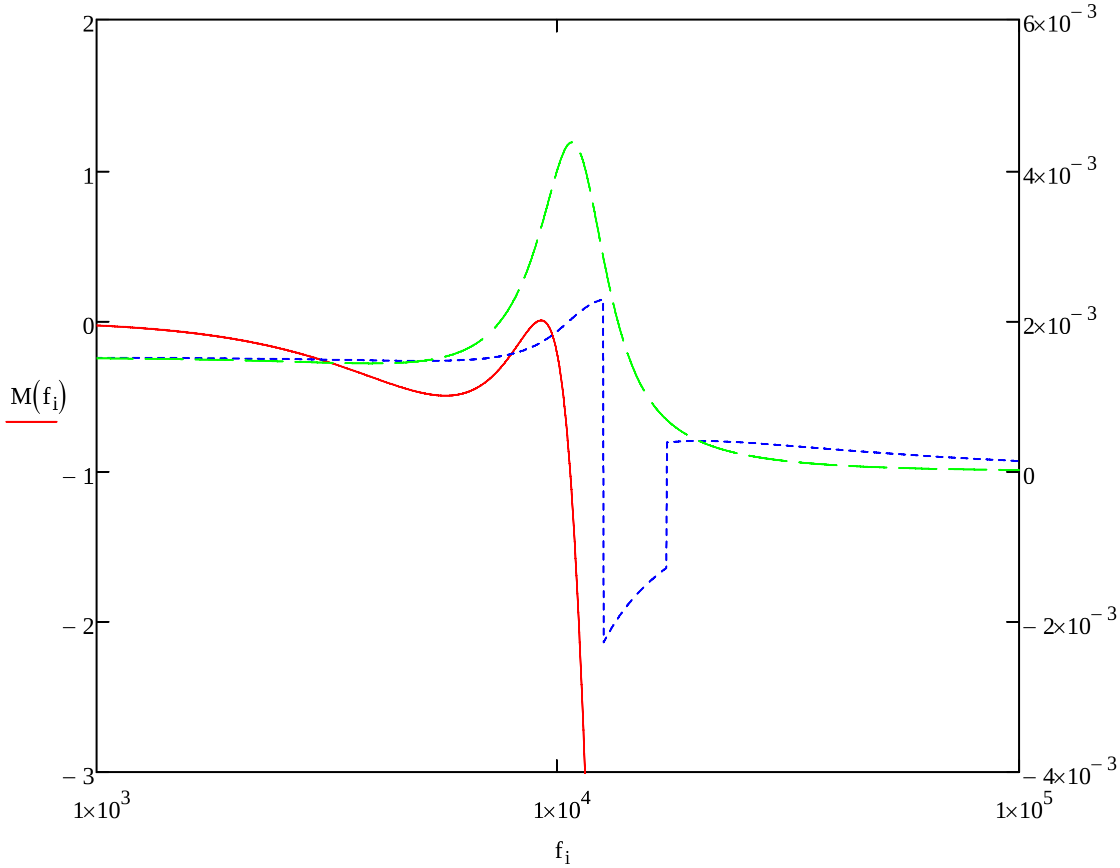
$$M(f) := 20 \cdot \log(|T(f)|)$$



$$\varphi(f) := \frac{180}{\pi} \cdot \arg(T(f))$$

$$\tau_p(f) := -\frac{\varphi(f)}{2 \cdot \pi \cdot f}$$

$$\tau_g(f) := -\frac{1}{2 \cdot \pi} \cdot \left(\frac{d}{df}\varphi(f)\right)$$



Third Order Bessel Filter

$f_3 := 10.28\mathrm{kHz}$

$$f_c := \frac{f_3}{1.7557}$$

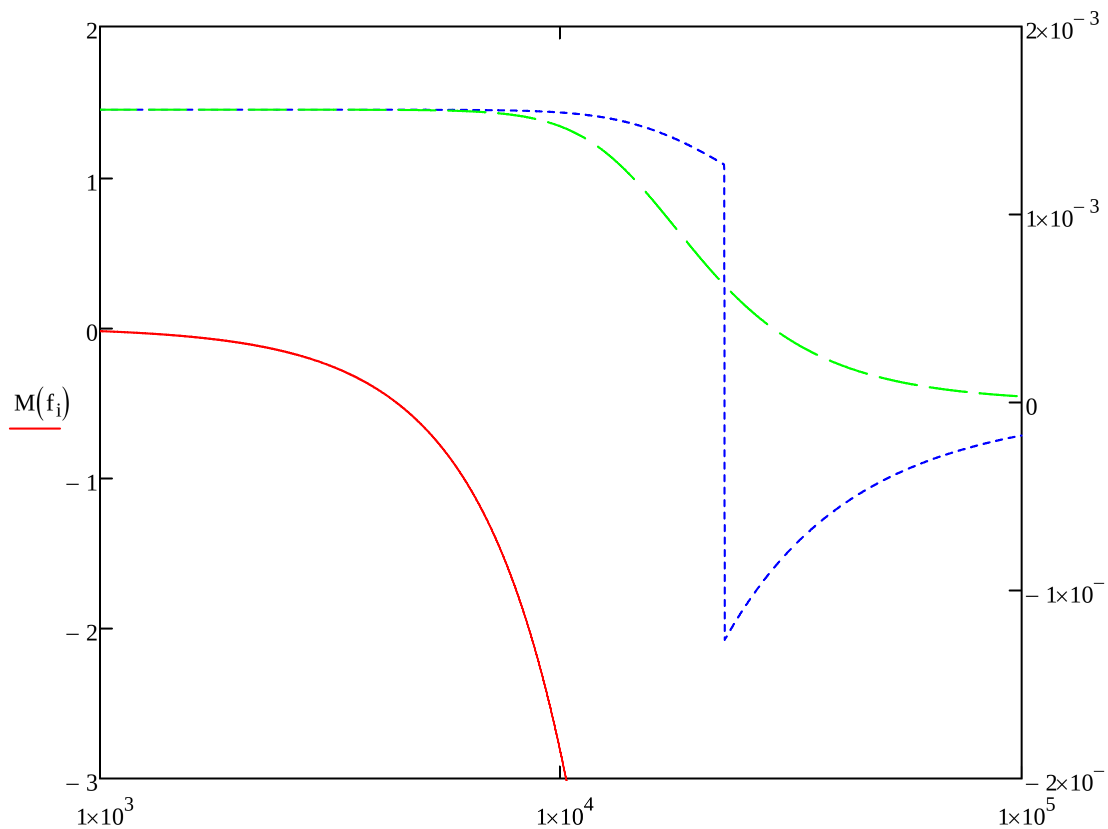
$a_2 := 2.3222$ $a_1 := 2.5415$ $b_1 := 0.69105$

$$T(f) := \frac{1}{j\cdot\frac{f}{a_2\cdot f_c}+1}\cdot\frac{1}{\left(j\cdot\frac{f}{a_1\cdot f_c}\right)^2+\frac{1}{b_1}\cdot j\cdot\frac{f}{a_1\cdot f_c}+1}$$

$$M(f) := 20\cdot\log(|T(f)|) \qquad \varphi(f) := \frac{180}{\pi}\cdot\arg(T(f))$$

$$\varphi(f) := \frac{180}{\pi}\cdot\arg(T(f)) \qquad \tau_p(f) := -\frac{\varphi(f)}{2\cdot\pi\cdot f}$$

$$\tau_g(f) := -\frac{1}{2\cdot\pi}\cdot\left(\frac{d}{df}\varphi(f)\right)$$



f_i

$n = 3$ $\quad \frac{f_3}{f_c} = 1.7557$ $\quad a_1 := 2.5415$ $\quad b_1 := 0.69105$

$a_2 := 2.3222$

$$T(s) = \frac{1}{\frac{s}{a_2 \cdot \omega_c} + 1} \cdot \frac{1}{\left(\frac{s}{a_1 \cdot \omega_c}\right)^2 + \frac{1}{b_1} \cdot \frac{s}{a_1 \cdot \omega_c} + 1}$$

1st Order LPF
2nd Order LPF

$f_3 := 10.28\text{kHz}$ $\quad f_c := \frac{f_3}{1.7557}$ $\quad \omega_c := 2 \cdot \pi \cdot f_c$

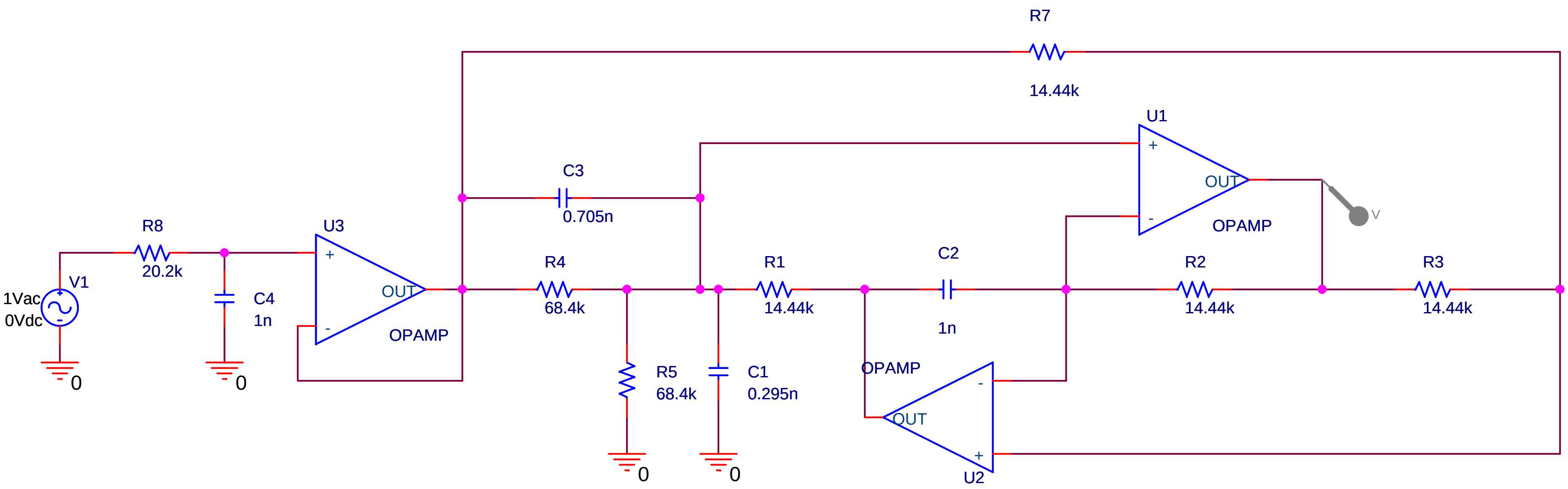
$C_3 := 1\text{nF}$ $\quad R_3 := \frac{1}{a_2 \cdot \omega_c \cdot C_3} = 1.171 \times 10^4 \, \Omega$

Use Sallen Key

$C_1 := 0.01\mu\text{F}$ $\quad C_2 := 0.1 \cdot C_1$

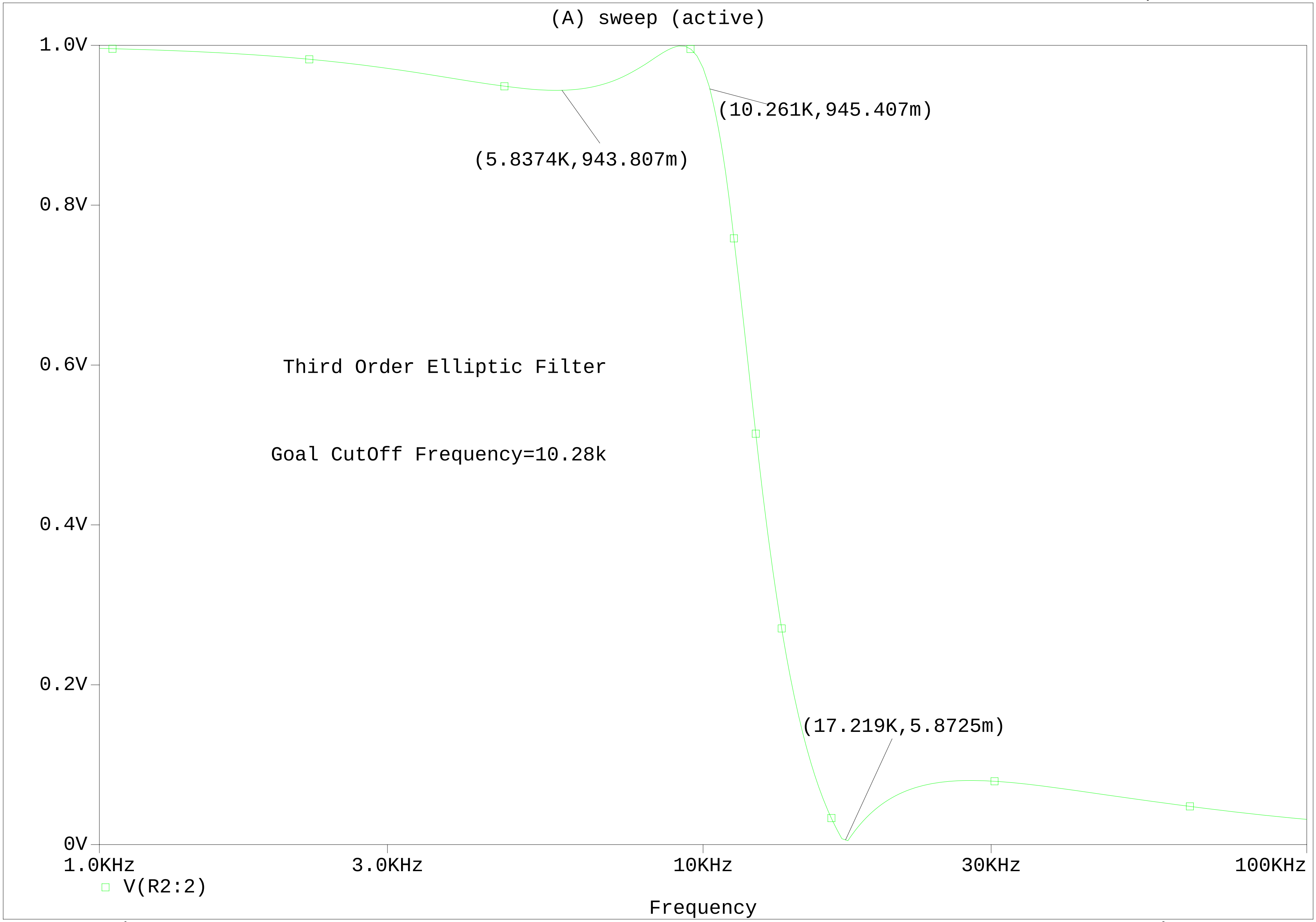
$$R_1 := \frac{1}{2 \cdot b_1 \cdot a_1 \cdot \omega_c \cdot C_2} \cdot \left(1 + \sqrt{1 - 4 \cdot {b_1}^2 \cdot \frac{C_2}{C_1}}\right) = 1.47 \times 10^4 \, \Omega$$

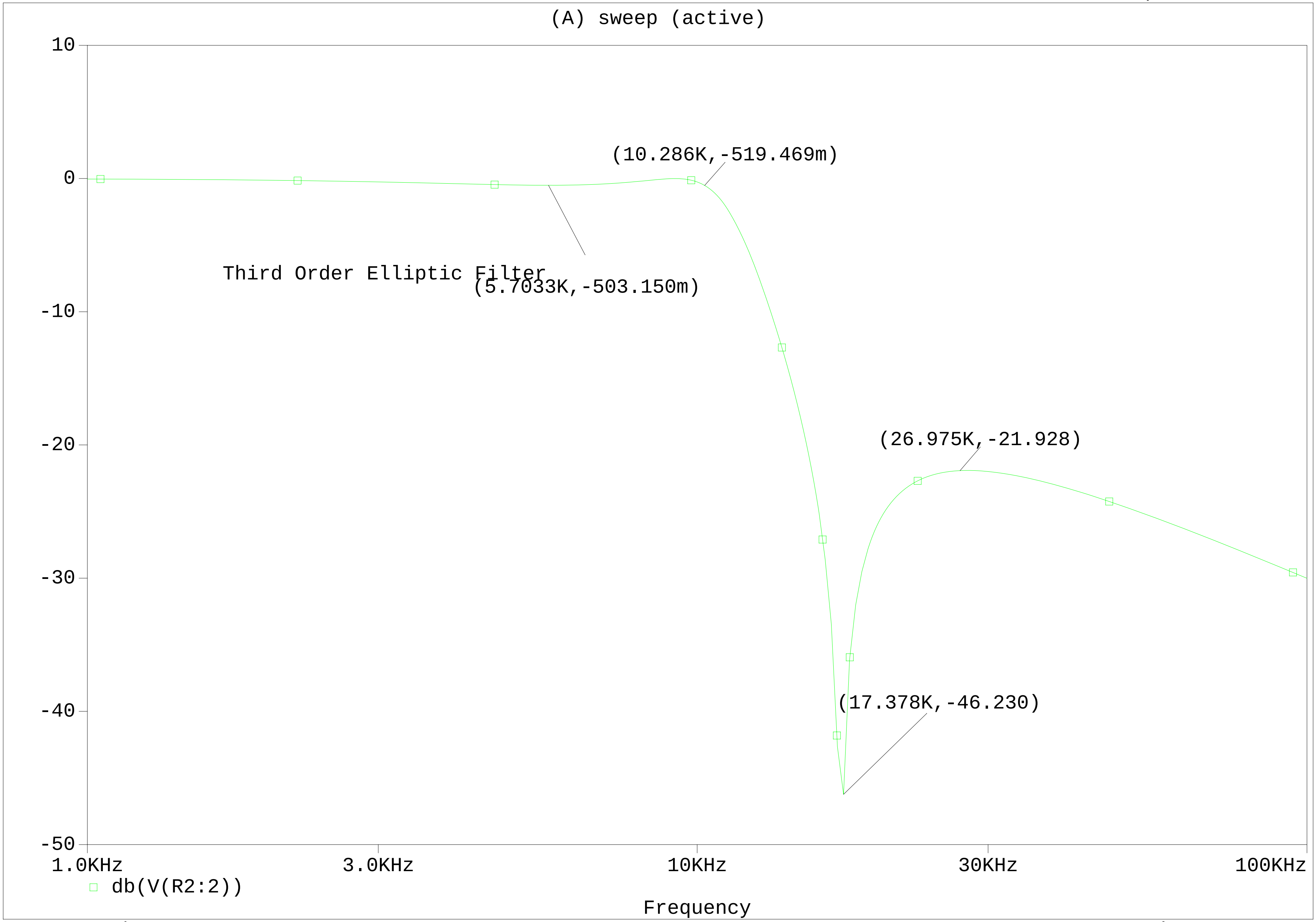
$$R_2 := \frac{1}{2 \cdot b_1 \cdot a_1 \cdot \omega_c \cdot C_2} \cdot \left(1 - \sqrt{1 - 4 \cdot {b_1}^2 \cdot \frac{C_2}{C_1}}\right) = 778.221 \, \Omega$$

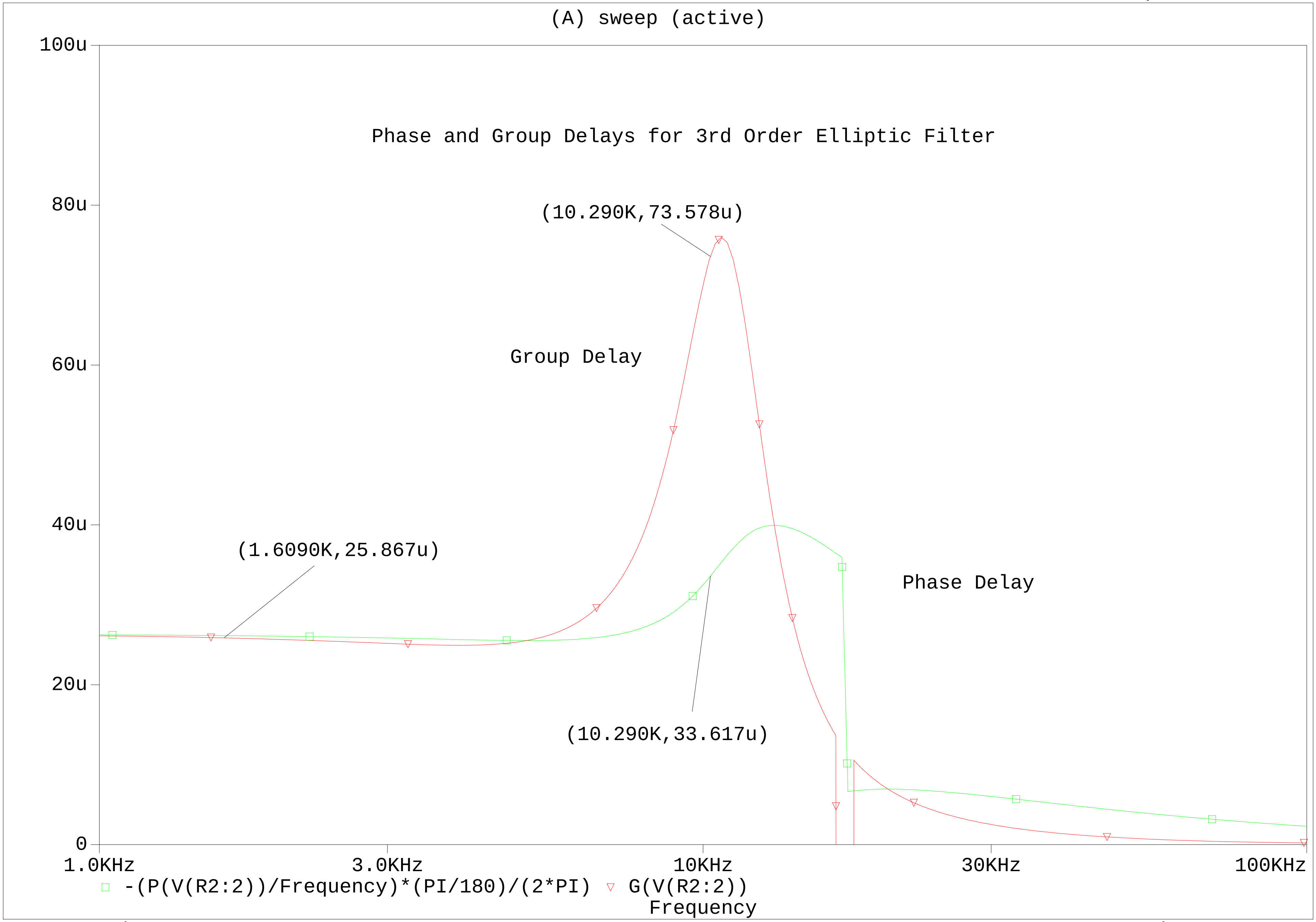


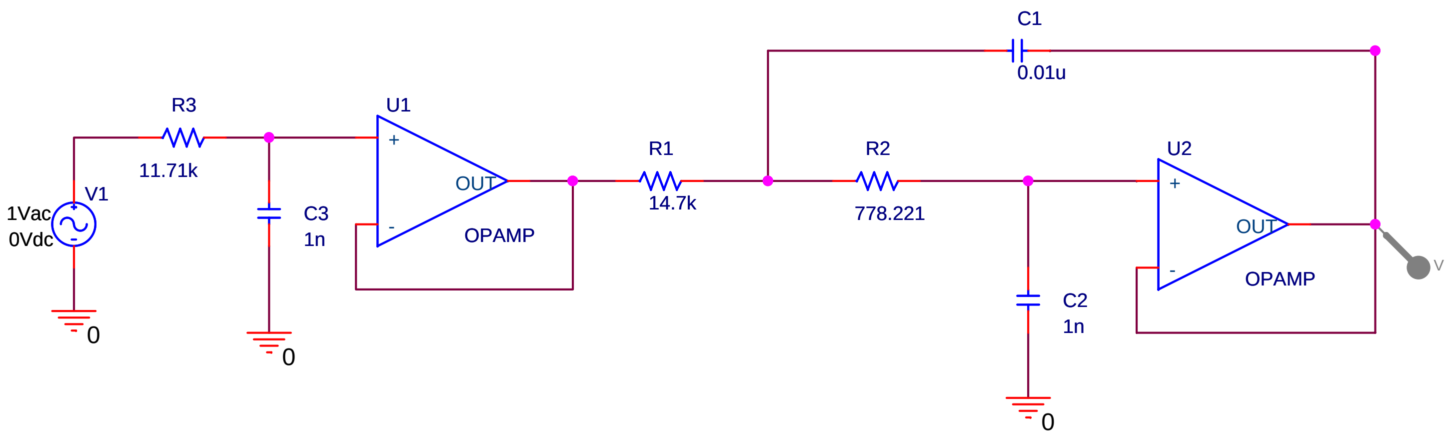
Third Order Elliptic Filter

Title	Third Order Elliptic Filter		
Size A	Document Number Active Filters		Rev 1
Date:	Tuesday, March 11, 2008	Sheet 1 of 1	


(A) sweep (active)
1.0V
0.8V
0.6V
0.4V
0.2V
0V
(10.261K,945.407m)
(5.8374K,943.807m)
Third Order Elliptic Filter
Goal CutOff Frequency=10.28k
(17.219K,5.8725m)
1.0KHz
3.0KHz
10KHz
30KHz
100KHz
V(R2:2)
Frequency

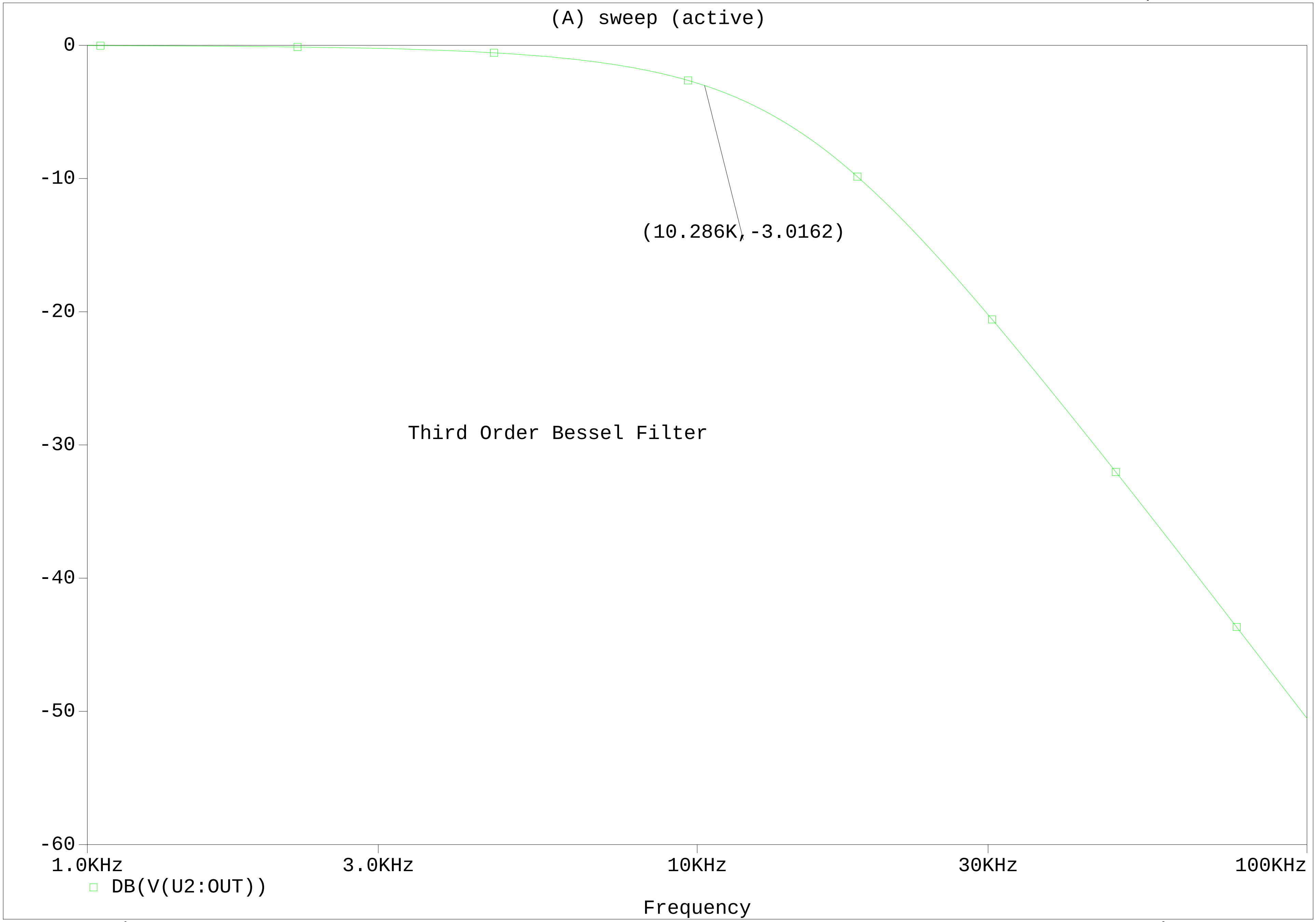

(A) sweep (active)
10
0
-10
-20
-30
-40
-50
(10.286K,-519.469m)
Third Order Elliptic Filter
(5.7033K,-503.150m)
(26.975K,-21.928)
(17.378K,-46.230)
1.0KHz
3.0KHz
10KHz
30KHz
100KHz
db(V(R2:2))
Frequency

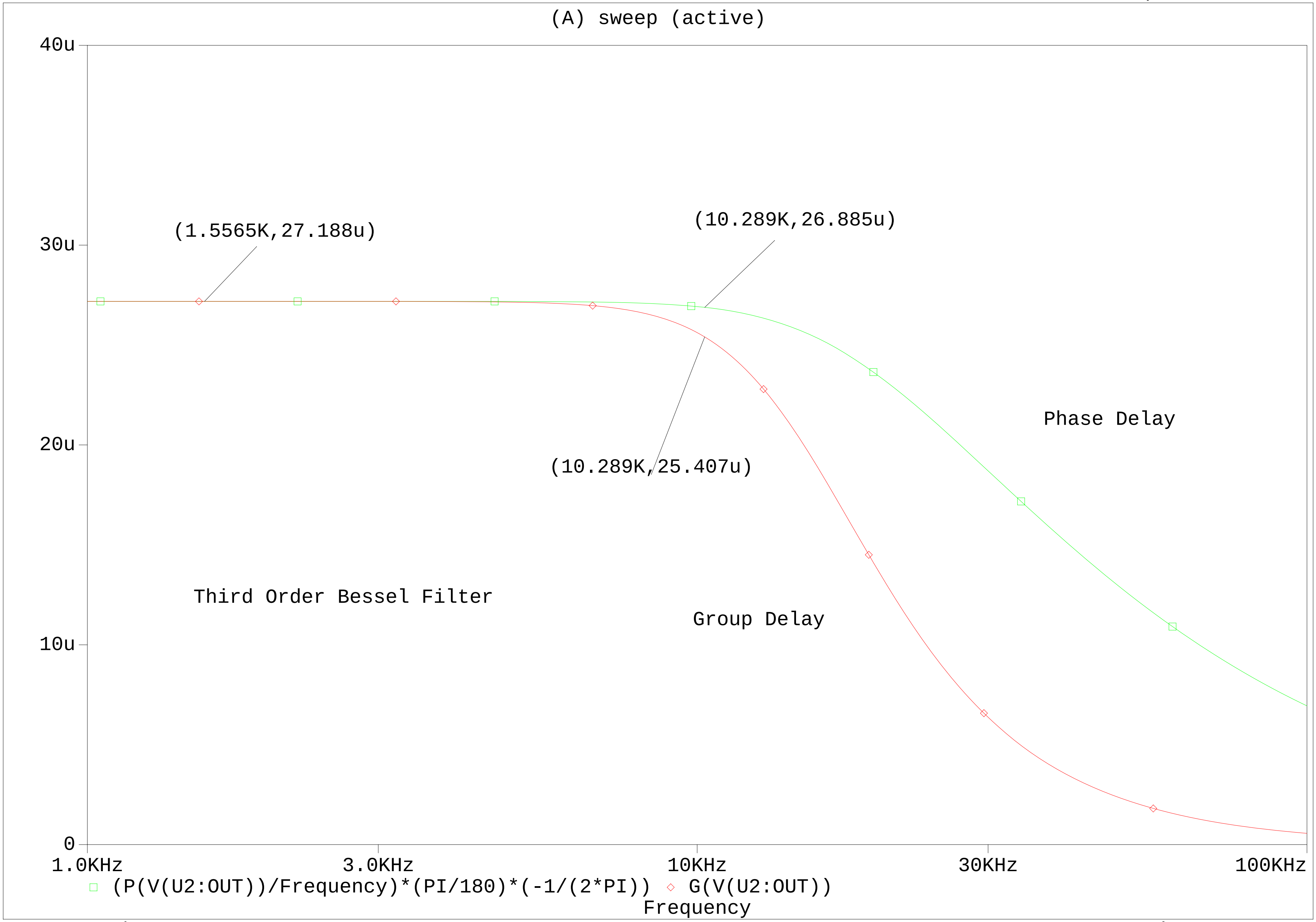

(A) sweep (active)
Phase and Group Delays for 3rd Order Elliptic Filter
(10.290K,73.578u)
Group Delay
(1.6090K,25.867u)
Phase Delay
(10.290K,33.617u)
100u
80u
60u
40u
20u
0
1.0KHz
3.0KHz
10KHz
30KHz
100KHz
-(P(V(R2:2))/Frequency)*(PI/180)/(2*PI)
G(V(R2:2))
Frequency



Third Order Bessel Filter

Title	Third Order Bessel Filter	
Size A	Document Number Active Filters	Rev 1
Date:	Wednesday, March 12, 2008	Sheet 1 of 1


(A) sweep (active)
0
-10
-20
-30
-40
-50
-60
(10.286K,-3.0162)
Third Order Bessel Filter
1.0KHz
3.0KHz
10KHz
30KHz
100KHz
DB(V(U2:OUT))
Frequency


(A) sweep (active)
40u
30u
20u
10u
0
(1.5565K,27.188u)
(10.289K,26.885u)
(10.289K,25.407u)
Phase Delay
Third Order Bessel Filter
Group Delay
1.0KHz
3.0KHz
10KHz
30KHz
100KHz
(P(V(U2:OUT))/Frequency)*(PI/180)*(-1/(2*PI))
G(V(U2:OUT))
Frequency

Georgia Institute of Technology

School of Electrical and Computer Engineering

ECE 3042 Microelectronic Circuits Laboratory Verification Sheet

NAME:____ SECTION:____________________________

GT NUMBER:___________________________________ GTID:________________________________

Experiment 6: Op-Amp Active Filters

Procedure	Time Completed	Date Completed	Verification (Must demonstrate circuit)	Points Possible	Points Received
1. Third-Order Butterworth LPF				16	
2. Third-Order Chebyshev LPF				16	
3. Second-Order Band-Pass				16	
4. Second-Order Notch				16	
5. First-Order All-Pass				16	
6. Second-Order All-Pass				20	

Enter your critical frequency below:

f_{crit}	

To be permitted to complete the experiment during the open lab hours, you must complete at least **three** procedures during your scheduled lab period or spend your entire scheduled lab session attempting to do so. A signature below by your lab instructor, Dr. Brewer, or Dr. Robinson permits you to attend the open lab hours to complete the experiment and receive full credit on the report. Without this signature, you may use the open lab to perform the experiment at a 50% penalty.

SIGNATURE:_____________________________________ DATE:______________________________________

ECE 3042 Check-off Requirements for Experiment 6

Make sure you have made all required measurements before requesting a check-off. For all check-offs, you must demonstrate the circuit or measurement to a lab instructor. All screen captures must have a time/date stamp.

Do not follow the procedures in the lab manual. Only Bode magnitude plots are required—it is not necessary to measure the phase. Do not follow the lab report format for this experiment. Instead, display two Bode plots and their associated tables per page.

1. Third-Order Butterworth Low-Pass Filter
   - ✓ Bode gain magnitude plot over frequency range of 100Hz to 100khz.
   - ✓ Measurement of dc gain and -3dB frequency.
   - ✓ Table comparing these measured values to the design specifications. Show percent error.
2. Third-Order Chebyshev Low-Pass Filter
   - ✓ Bode gain magnitude plot over frequency range of 100Hz to 100khz.
   - ✓ Measurement of dc gain, dB ripple, and -3dB frequency.
   - ✓ Table comparing these measured values to the design specifications. Show percent error.
3. Second-Order Bandpass Filter
   - ✓ Bode gain magnitude plot over frequency range of 100Hz to 100khz.
   - ✓ Measurement of center frequency f_o, -3dB bandwidth BW, and Q. Q is given by f_o /BW.
   - ✓ Table comparing these measured values to the design specifications. Show percent error.
4. Second-Order Notch Filter
   - Implement filter with the general biquad circuit from the class notes. Save this filter—it can be modified to obtain the second-order all-pass transfer function.
   - ✓ Bode gain magnitude plot over frequency range of 100Hz to 100khz.
   - ✓ Measurement of center frequency f_o, -3dB bandwidth BW, and Q. Q is given by fo/BW.
   - ✓ Table comparing these measured values to the design specifications. Show percent error.
5. First-Order All-Pass Filter
   - ✓ Bode gain magnitude plot over frequency range of 100Hz to 100khz.
   - ✓ Measurement of dc gain.
   - ✓ Scope screen capture showing measured f_{crit}, the frequency at which the phase shift between input and output is 90 deg. Connect input to ch1 and output to ch2. Display measured Vpp for each channel, the frequency, and the phase.
   - ✓ Table comparing these measured values to the design specifications. Show percent error.
6. Second-Order All-Pass Filter
   - ✓ Bode gain magnitude plot over frequency range of 100Hz to 100khz.
   - ✓ Measurement of dc gain.
   - ✓ Scope screen capture showing measured f_{crit}, the frequency at which the phase shift between input and output is 180 deg. Connect input to ch1 and output to ch2. Display measured Vpp for each channel, the frequency, and the phase.
   - ✓ Table comparing these measured values to the design specifications. Show percent error.