

Project
Design and Simulation of Band Reject Filter

In Fulfillment
of the Requirements
of ELEC 441

451
/ 50

Names &
ID # of
project
partners

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3. FILTER DESIGN FROM SPECIFICATION

A band-reject filter is designed with the following specifications:

- The stop-band extends from 1 kHz to 10 kHz
- The peak-peak ripple in the pass-band not to exceed 1.0 dB
- The magnitude characteristics at 2 kHz is to be at least 30 dB from its peak value at DC

3.1 Theoretical Transfer Function

The overall band-stop transfer function $T(s)$, is obtained by a transformation of a normalized low-pass transfer function $H_{N,LP}(s)$. This low-pass filter is designed to meet the specification. Because of the equal ripple property, a Chebyshev filter is used. The following parameters are extracted out of the specifications

$$\omega_{p1} = 2\pi * 1 \frac{\text{krad}}{s} = 6.283 \frac{\text{krad}}{s}$$

$$\omega_{p2} = 2\pi * 10 \frac{\text{krad}}{s} = 62.832 \frac{\text{krad}}{s}$$

$$\omega_{a1} = 2\pi * 2 \frac{\text{krad}}{s} = 12.566 \frac{\text{krad}}{s}$$

$$\omega_0 = \sqrt{\omega_{p1}\omega_{p2}} = 19.869 \frac{\text{krad}}{s}$$

$$B = \omega_{p2} - \omega_{p1} = 2\pi * 9 \frac{\text{krad}}{s}$$

$$\omega_{a2} = \frac{\omega_0^2}{\omega_{a1}} = \frac{(19.869 \text{ krad/s})^2}{4\pi \text{ krad/s}} = 31.416 \text{ krad/s}$$

$$\omega_s = \frac{\omega_{p2} - \omega_{p1}}{\omega_{a2} - \omega_{a1}} = 3$$

To determine the order n of the normalized low-pass Chebyshev filter, we use the relation

$$D = \frac{10^{0.1A_a} - 1}{10^{0.1A_p} - 1} = 3.858 * 10^3$$

$$n = \frac{\cosh^{-1}(\sqrt{D})}{\cosh^{-1}(\omega_s)} = 2.73 \xrightarrow{\text{yields}} n = 3$$

From the table of Chebyshev pole locations [1] the coefficients for 1 dB equal ripple is obtained

3.2 Cascaded Second Order Active Filter

3.2.1 Calculation and Circuit Design

The second order transfer functions $T_1(s)$, $T_2(s)$, and $T_3(s)$ are used to create the overall RC active filter network. The Fleischer-Tow universal biquad, shown in Figure 3, is used to implement the filters in cascade.

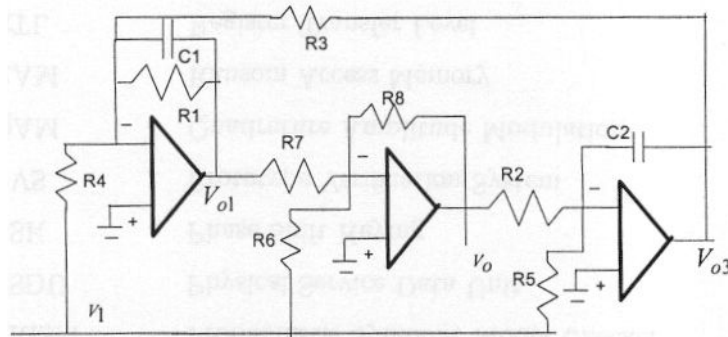


Figure 3 Fleischer-Tow universal biquad structure [2]

The expression for the transfer function is [2]:

$$\frac{V_o}{V_1} = -\frac{\frac{R_8}{R_6} s^2 + \frac{1}{R_1 C_1} \left[\frac{R_8}{R_6} - \frac{R_1 R_8}{R_4 R_7} \right] s + \frac{R_8}{R_3 R_5 R_7 C_1 C_2}}{s^2 + \frac{1}{R_1 C_1} s + \frac{R_8}{R_2 R_3 C_1 C_2 R_7}} = -\frac{b_2 s^2 + b_1 s + b_0}{s^2 + a_1 s + a_0}$$

The values of resistors and capacitors for $T_1(s)$ are derived as follow:

$$b_1 = 0, \frac{b_0}{b_2} = a_0$$

$$\frac{R_8}{R_6} - \frac{R_1 R_8}{R_4 R_7} = 0$$

$$b_2 = 1$$

$$\frac{R_8}{R_6} = 1$$

$$\frac{b_0}{b_2} = \frac{R_6}{R_3 R_5 R_7 C_1 C_2}$$

$$a_0 = \frac{R_8}{R_2 R_3 R_7 C_1 C_2}$$

$$\frac{R_8}{R_2 R_3 R_7 C_1 C_2} = \frac{R_6}{R_3 R_5 R_7 C_1 C_2}$$

Table 2 Component values for active cascaded Op-Amp

	T1(s)		T2(s)		T3(s)	
	Calc.	Pract.	Calc.	Pract.	Calc.	Pract.
R1 [kΩ]	8.74	9.1	38.715	39.0	39.18	39.0
R2 [kΩ]	50.33	51.0	49.73	51.0	5.09	5.1
R3 [kΩ]	50.33	51.0	5.033	5.1	50.33	51.0
R4 [kΩ]	8.74	9.1	38.715	39.0	39.18	39.0
R5 [kΩ]	50.33	51.0	5.033	5.1	50.33	51.0
R6 [kΩ]	1.00	1.00	1.00	1.00	1.00	1.00
R7 [kΩ]	1.00	1.00	1.00	1.00	1.00	1.00
R8 [kΩ]	1.00	1.00	1.00	1.00	1.00	1.00
C [nF]	1	1	10	10	1	1

X not practical values

The circuitry with the three second order stages is shown in Figure 4. Due to the operational amplifiers every stage has a low impedance output and can be cascaded without further components or restrictions.

values that you get in the lab bins are the practical values

3.2.2 Simulation and Comparison

show new TF. express

A numerical simulation using MATLAB and the practical component values results in the frequency response shown in Figure 5. The pass-band frequencies changed only slightly compared to the theoretical curve in Figure 2. However, the higher stop-band frequency at $2\pi \cdot 8000 = 50.265 \text{ krad/s}$ does not meet the -30 dB specification anymore. The attenuation dropped to approximately -25 dB.

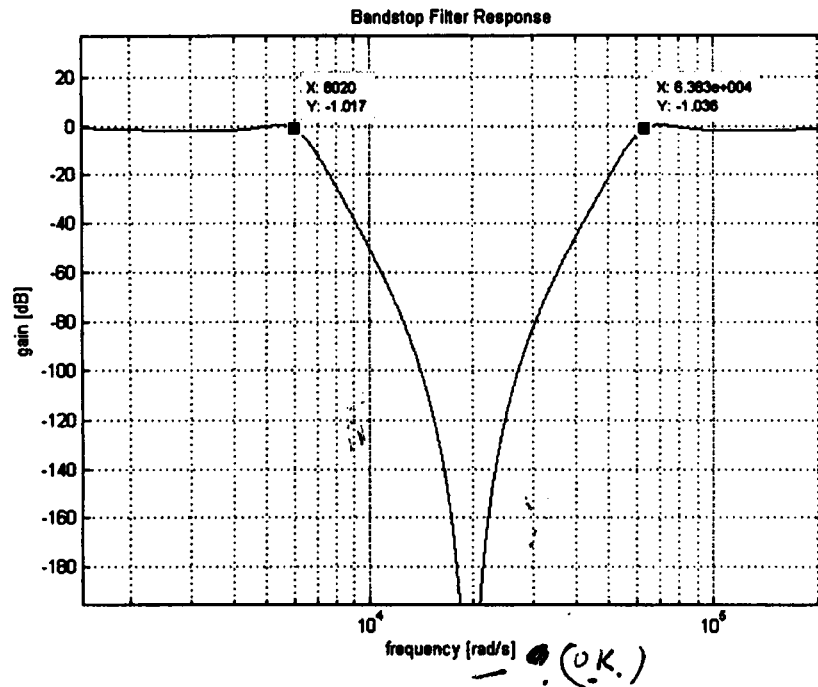
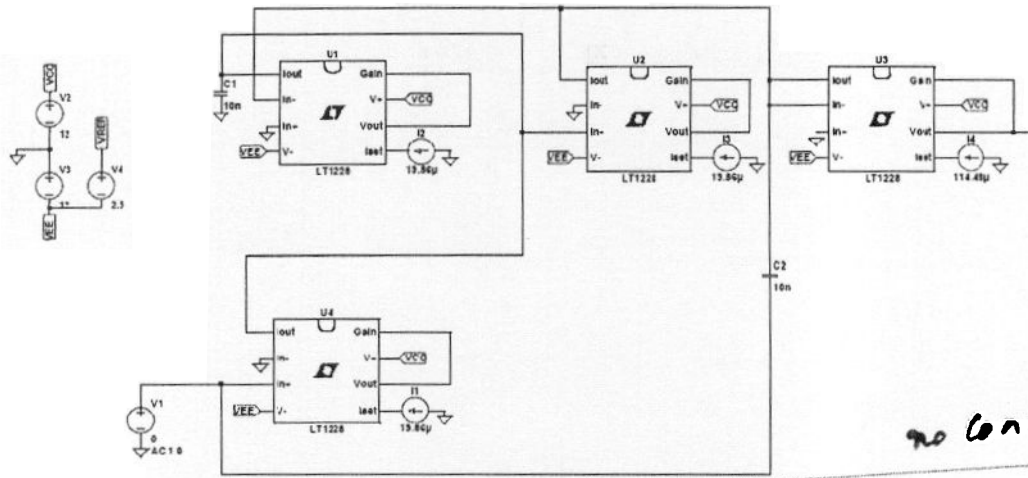


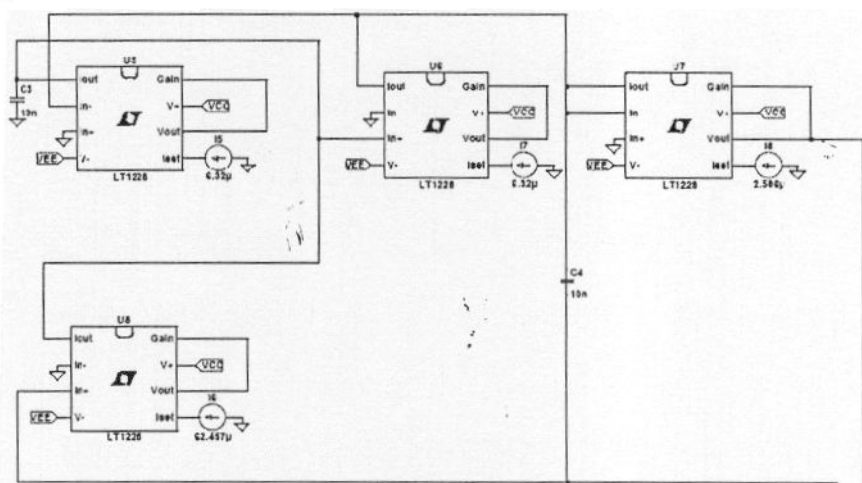
Figure 5 MATLAB Simulation of cascaded filter with practical values

A model of the operational amplifier LT1354 is used to design the circuit in Figure 4. This circuitry is tested with the LTspice simulation program. The LT1354 has a high gain bandwidth of 12 MHz and a slew rate of 400V/us to avoid Q-enhancement [4]. As expected, the MATLAB and LTspice simulations differ only slightly. However, the attenuation at $\omega_{a2} = 2\pi \cdot 8000 \text{ rad/s}$ drops to less than 10 dB. The -30 dB point is shifted to lower frequencies and becomes approximately $f_{a2} = 5.5 \text{ kHz}$. This shifting happens most probably because of a combination of the sensitivity of the circuit to component value changes and the finite bandwidth and gain of the LT1354 amplifier. The response of the circuit is shown in Figure 6.



no connection with the rest?

AC 1.0 100 20000



Did you use a buffer?

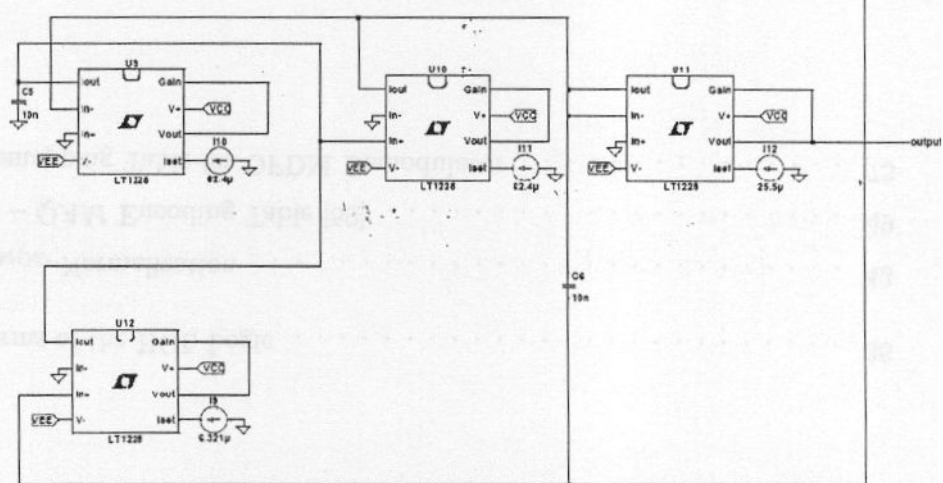


Figure 8 Schematic of OTA-C BSF

$$m = \frac{R_a}{R_p} = 1$$

$$R_3 = R_{c3} = \sqrt{m \frac{L_2}{C}} = 4.2177k\Omega$$

$$R_4 = R_{c4} = \sqrt{\frac{L_2 C_2}{C^2}} = 50.3296k\Omega$$

Capacitor and Inductor to calculate R_2, R_{c2} are missing in the series and shunt branch, therefore $R_2 = R_{c2} = \infty$. The last series branch calculation is the same as the first series branch. The Table 4 shows the overall values of the operational simulation circuit.

Table 4 Theoretical and practical values for operational simulation circuit

component	series branch 1		parallel branch 1		series branch 2	
	Theoretical	Practical	Theoretical	Practical	Theoretical	Practical
Ra(kΩ)	1	1	1		1	1
Rp(kΩ)	1	1	1		1	1
Ro(kΩ)	1	1	open	open	1	1
R3(kΩ)	2.9562	3	4.2177	4.3	2.9562	3
Rc3(kΩ)	2.9562	3	4.2177	4.3	2.9562	3
R4(kΩ)	50.3296	51	50.3296	51	50.3296	51
Rc4(kΩ)	50.3296	51	50.3296	51	50.3296	51

numerical simul with practical comp. values

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