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## Application Note

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### Design Notes for a 2-Pole Filter

by  
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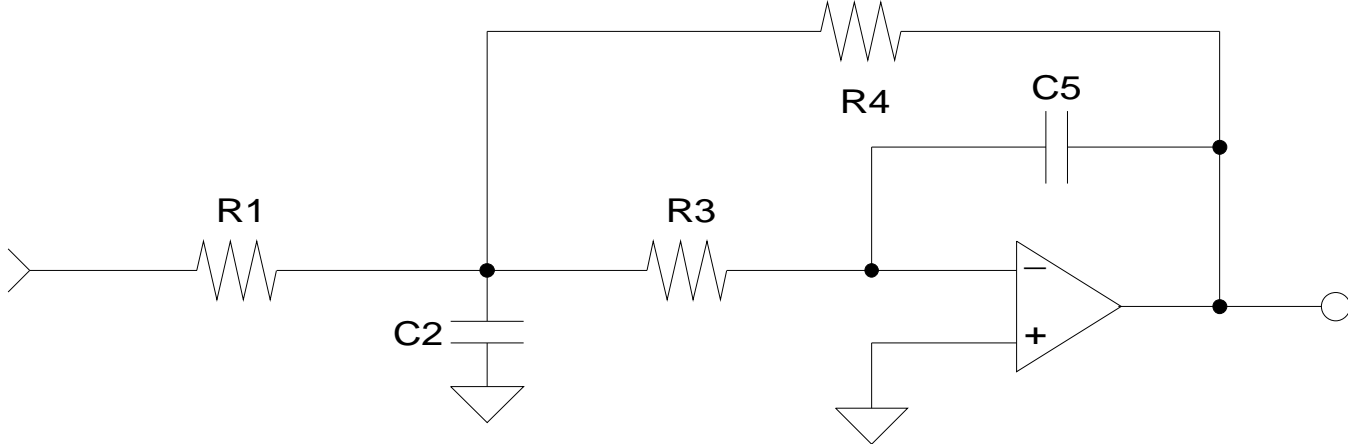


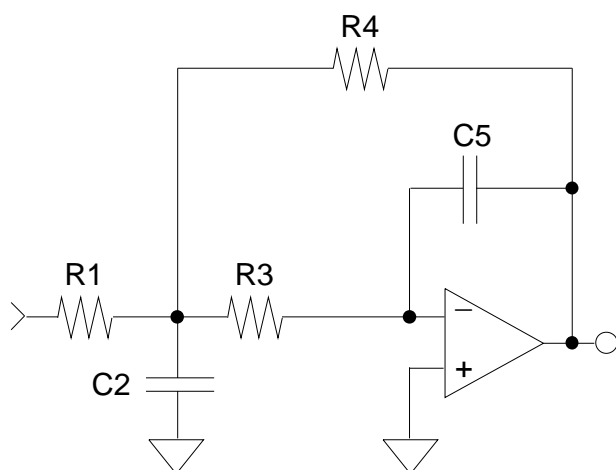
Figure 1. 2-Pole Low-Pass Filter

#### Introduction

The recommended application of the CS4327, discussed in the CS4327 data sheet, requires a second-order analog filter to reduce the out-of-band noise produced by the delta-sigma modulator. The circuit shown in Figure 1 is the second-order analog filter implemented on the CS4327 evaluation board, CDB4327. This application note outlines the design steps required to determine filter component values.

#### Design Steps

**Step 1:** Determine the required pass band gain,  $H_0$ .  
The output level for the CDB4327 is 2V<sub>rms</sub> to be compatible with standard consumer audio levels. This required  $H_0$  equal to -2. Notice that  $H_0$  is also negative due to the inverting op-amp configuration.



**Figure 2. Multiple-Feedback Low-Pass Filter**

**Step 2:** Select the desired filter type, Butterworth, Bessel, etc. and the corner frequency,  $F_c$ , for the final design. The filter response and corner frequency determine the audio band phase and amplitude response. The filter type determines the pole-locations and therefore  $\alpha$  and  $\beta$ . Table 1 lists the normalized pole locations for several filter types.

FILTER TYPE	$\alpha$	$\beta$
Butterworth	0.7071	0.7071
Bessel	1.1030	0.6368
0.01 dB Chebyshev	0.6743	0.7075
0.1 dB Chebyshev	0.6104	0.7106

**Table 1. Normalized Pole Locations**

**Step 3:** Select standard values for  $C_5$  and  $C_2$ . Notice in Step 4 that  $K$  ( $C_5/C_2$ ) and  $H_0$  must be selected such that  $\sqrt{\zeta^2 - K(1 - H_0)}$  is real.

**Step 4:** Given  $F_c$ ,  $H_0$ ,  $C_2$ ,  $C_5$ ,  $\alpha$  and  $\beta$ , calculate  $R_1$ ,  $R_2$  and  $R_3$  using the following equations.  $H_0$  will be a negative number due to the inverting op-amp.

$$\zeta = \frac{\alpha}{\sqrt{\alpha^2 + \beta^2}}$$

$$\omega_0 = 2\pi F_c \sqrt{\alpha^2 + \beta^2}$$

$$K = \frac{C_5}{C_2}$$

$$R_3 = \frac{1}{\omega_0 C_2 [\zeta \pm \sqrt{\zeta^2 - K(1 - H_0)}}$$

$$R_4 = \frac{\zeta \pm \sqrt{\zeta^2 - K(1 - H_0)}}{\omega_0 C_5}$$

$$R_1 = \frac{R_4}{(-H_0)}$$

**Step 5:** It is recommended that  $R_1$  be a minimum of 10 kohm to meet the CS4327 load requirements. However, values larger than 10 kohm can lead to small capacitor values (ten's of picofarads) where stray capacitance can be an appreciable amount of the total circuit capacitance. It may be necessary to adjust the capacitor values chosen in Step 3 to minimize the effects of stray capacitance and meet the minimum load requirement.

**Step 6:** The resistor values calculated in Step 4 are generally not standard values. Select standard values which are nearest the calculated values. This should not create a large change in the filter characteristics since metal film resistors are available in approximately 2.5% increments which allows for component selection near the calculated values.

### Design Example

The following example shows the steps required to duplicate the CDB4327 filter.

Step 1: The desired output level is 2 V<sub>rms</sub> which requires a pass band gain, H<sub>o</sub>, of -2.

Step 2: A two-pole Butterworth with a corner frequency of 50 kHz was selected for this application. This filter attenuates the signal at 20 kHz by approximately 0.1 dB and has nearly ideal phase linearity within the audio band. Though popular for audio applications, a Bessel response will achieve negligible phase improvement at the expense of degraded amplitude response for this application.

$$F_c = 50 \text{ kHz}$$

$$\alpha = .7071$$

$$\beta = .7071$$

Step 3: Select standard values for C<sub>5</sub> and C<sub>2</sub>.

$$C_5 = 150 \text{ pF}$$

$$C_2 = 1000 \text{ pF}$$

Step 4: Given F<sub>c</sub>, H<sub>o</sub>, C<sub>2</sub>, C<sub>5</sub>, α and β, calculate R<sub>1</sub>, R<sub>3</sub> and R<sub>4</sub>.

$$R_1 = 9.875 \text{ kohm}$$

$$R_3 = 3.42 \text{ kohm}$$

$$R_4 = 19.75 \text{ kohm}$$

Step 5: Verify that R<sub>1</sub> is greater than or equal to 10 kohm.

$$R_1 = 10 \text{ kohm}$$

Step 6: Select standard values which are nearest the calculated values.

$$R_1 = 10 \text{ kohm}$$

$$R_3 = 3.4 \text{ kohm}$$

$$R_4 = 20 \text{ kohm}$$

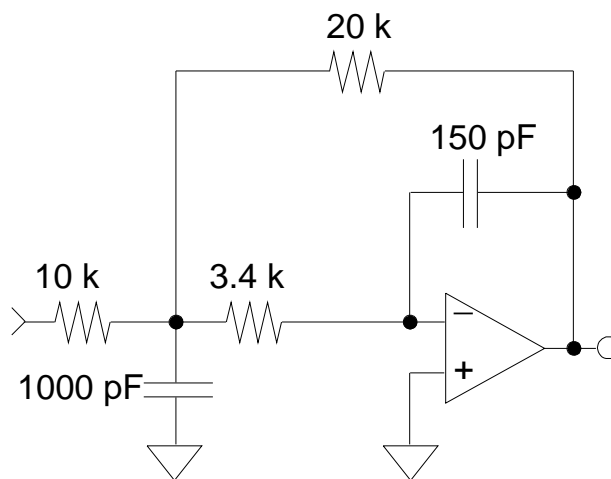


Figure 4. Filter Design

### References

- [1] C. L. Lindquist, "Active Network Design with Signal Filtering Applications", Steward & Sons
- [2] A. B. Williams, "Electronic Filter Design Handbook", McGraw-Hill
- [3] "Reference Data for Radio Engineers" (Fourth Edition), International Telephone and Telegraph Corporation
- [4] CS4327 Data sheet DS190PP1, Crystal Semiconductor
- [5] CDB4327 Data sheet DS190DB1, Crystal Semiconductor