A Cirrus Logic Company

Application Note

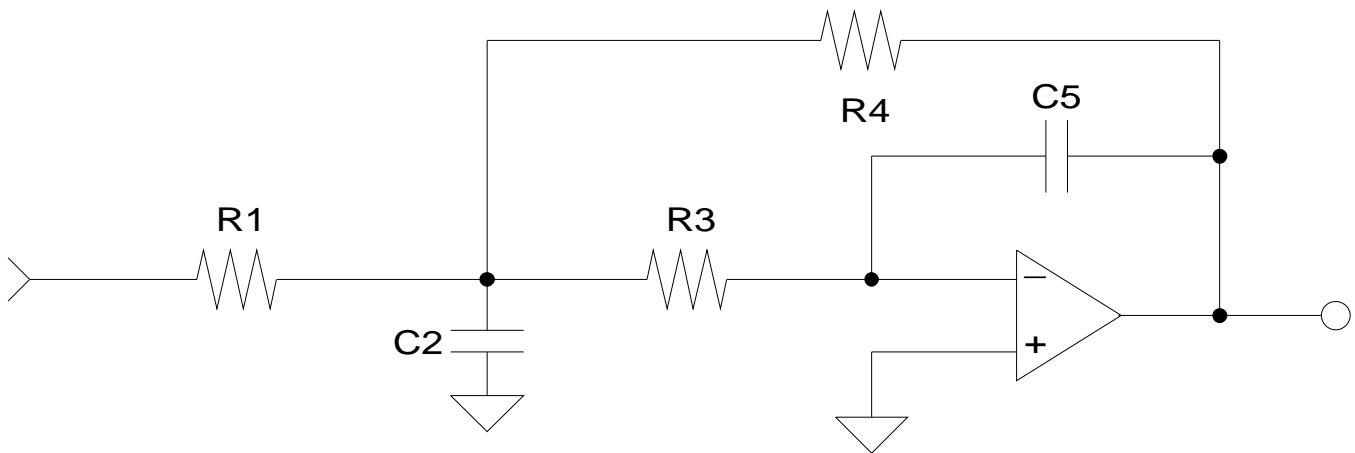## Design Notes for a 2-Pole Filter

by

Steven Green

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_O.
The output level for the CDB4327 is 2Vrms to be compatible with standard consumer audio levels. This required Ho equal to -2. Notice that H_O is also negative due to the inverting op-amp configuration.
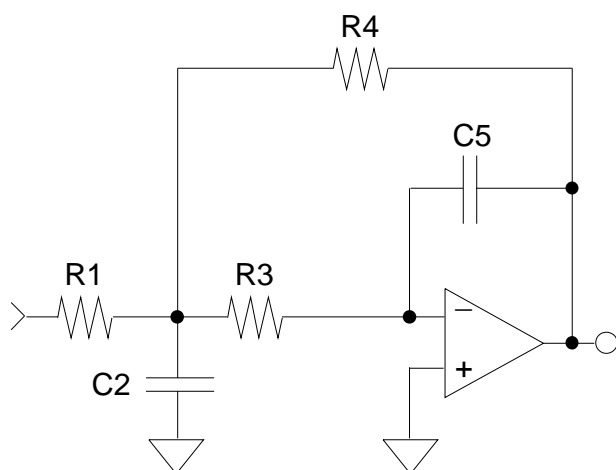
Figure 2. Multiple-Feedback Low-Pass Filter

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 α and β. Table 1 lists the normalized pole locations for several filter types.

FILTER TYPE	α	β
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_o must be selected such that $\sqrt{\zeta^2 - K(1 - H_o)}$ is real.

Step 4: Given F_c, H_o, C_2, C_5, α and β, calculate R_1, R_2 and R_3 using the following equations. H_o will be a negative number due to the inverting op-amp.

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

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

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

$$R_3 = \frac{1}{\omega_o C_2 [\zeta \pm \sqrt{\zeta^2 - K(1 - H_o)}]}$$

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

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

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 Vrms which requires a pass band gain, H_o, 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 kHz

α = .7071

β, = .7071

Step 3: Select standard values for C_5 and C_2.

C_5 = 150 pF

C_2 = 1000 pF

Step 4: Given F_c, H_o, C_2, C_5, α and β, calculate R_1, R_3 and R_4.

R_1 = 9.875 kohm

R_3 = 3.42 kohm

R_4 = 19.75 kohm

Step 5: Verify that R_1 is greater than or equal to 10 kohm.

R_1 = 10 kohm

Step 6: Select standard values which are nearest the calculated values.
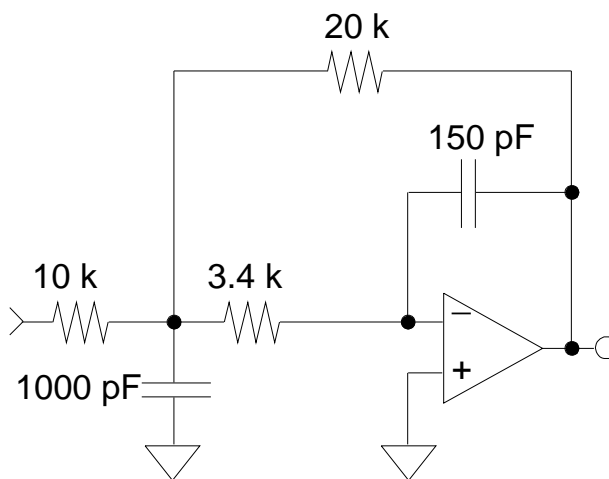
R_1 = 10 kohm

R_3 = 3.4 kohm

R_4 = 20 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