

Application Note

**Design Notes for a 2-Pole Filter
with Differential Input**

by
Steven Green

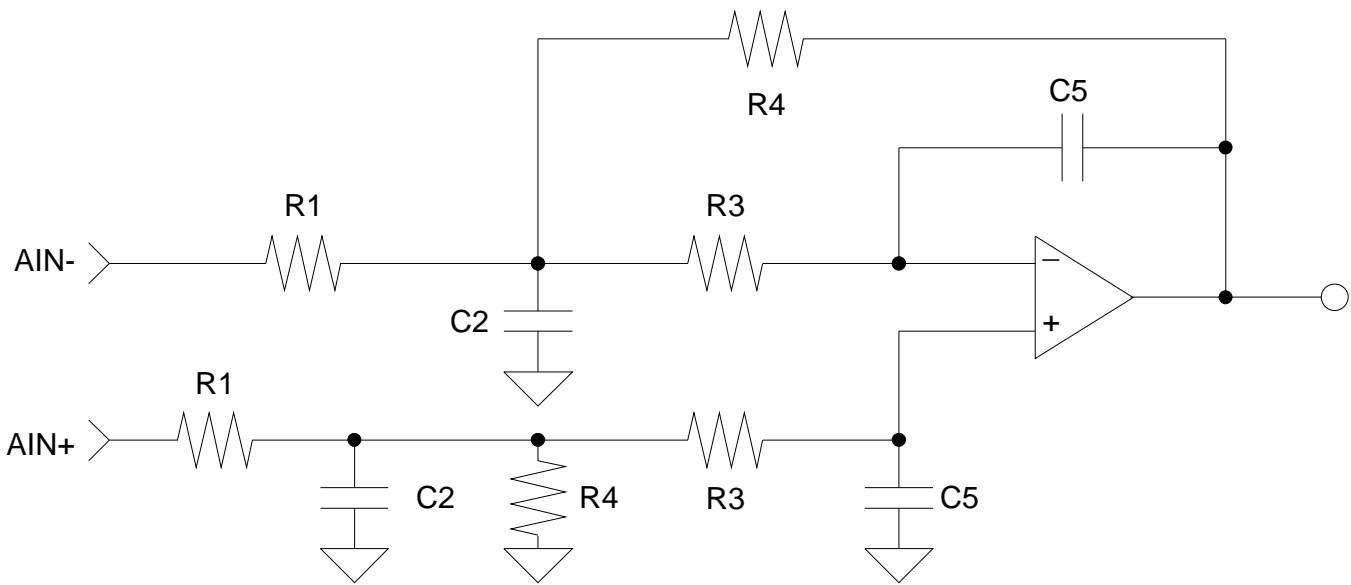


Figure 1. 2-Pole Low-Pass Filter with Differential Input

Introduction

The CS4329 evaluation board required an analog circuit capable of removing common-mode errors and lowering the out-of-band noise produced by the delta-sigma modulator. The circuit in Figure 1 includes a differential input and a two-pole analog filter to achieve these design requirements. This application note outlines the design steps required to select component values.

Notice the similarities between Figure 1 and the multiple-feedback low-pass filter shown in Figure 2. The 2-Pole Low-Pass Filter with Differential Input is easily designed using the design equations for the multiple-feedback low-pass filter. Also, notice the similarities between Fig. 1 and Fig. 3. The differential input function is accomplished by simply duplicating the component values generated in the filter design.

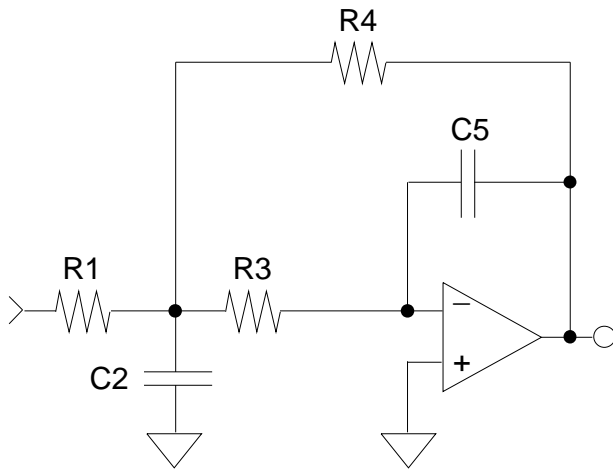


Figure 2. Multiple-Feedback Low-Pass Filter

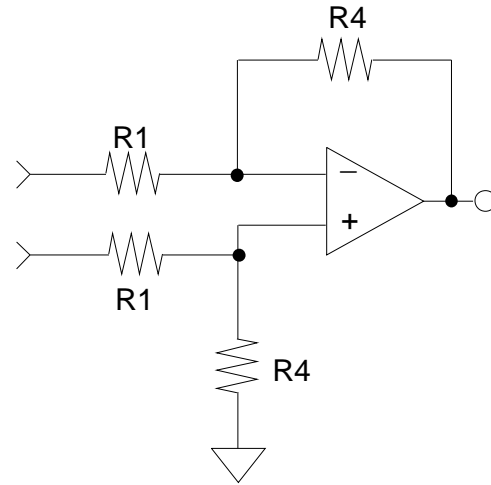


Figure 3. Differential Input Circuit

Design Steps

Step 1: Determine the required pass band gain, H_o . The circuit parameters require that the magnitude of H_o be greater than or equal to one. H_o is also negative due to the inverting op-amp configuration.

Note: For the CS4329, the single-ended output will be $2V_{rms}$ for $H_o = -1$.

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 pass 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	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 convenient 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 , alpha and beta, calculate R_1 , R_2 and R_3 using the following equations.

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

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

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

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

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

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

Step 5: It is recommended that R_1 be a minimum of 10 kohm to meet the CS4329 load requirements. Values much larger than 10 kohm can lead to small capacitor values where it is desirable to keep the capacitor values large to minimize the effects of stray capacitance. It may be necessary to adjust the capacitor values chosen in Step 3 to achieve this 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.

Step 7: The conversion from the singled-ended circuit to the differential circuit requires duplicating the values of R_1 , C_2 , R_3 , R_4 and C_5 in the non-inverting input as shown in Figure 1.

Design Example

The following example shows the steps required to duplicate the CDB4329 filter.

Step 1: The required output level is 2 Vrms, therefore the required pass band gain, H_o , is -1.

Step 2: A two-pole Butterworth with a corner frequency of 50 kHz attenuates the signal at 20 kHz by approximately 0.1 dB and has nearly ideal phase linearity within the audio band. A Bessel response would achieve negligible phase improvement at the expense of degraded amplitude response.

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

$$\alpha = .7071$$

$$\beta = .7071$$

Step 3: Select convenient values for C_5 and C_2 .

$$C_5 = 220 \text{ pF}$$

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

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

$$R_1 = 13.77 \text{ kohm}$$

$$R_3 = 3.343 \text{ kohm}$$

$$R_4 = 13.77 \text{ kohm}$$

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

$$R_1 = 13.77 \text{ kohm}$$

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

$$R_1 = 13.7 \text{ kohm}$$

$$R_3 = 3.32 \text{ kohm}$$

$$R_4 = 13.7 \text{ kohm}$$

Step 7: The conversion from the singled-ended to the differential circuit requires duplicating the values of R_1 , C_2 , R_3 , R_4 and C_5 in the non-inverting input as shown in Figures 4 and 5.

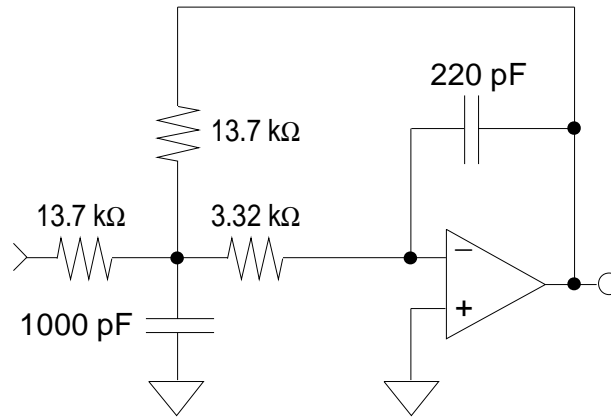


Figure 4. Filter Design

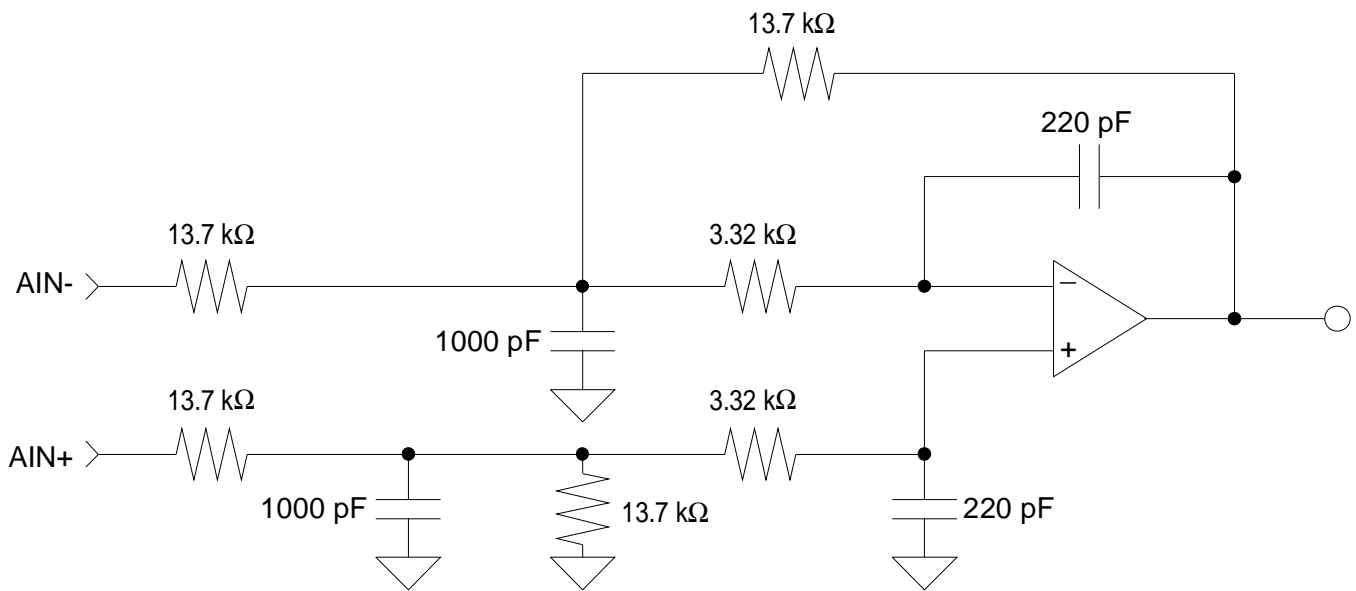


Figure 5. CDB4329 2-Pole Filter with Differential Input

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