Application Brief

Active Filter Design for Differential ADCs

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Introduction

This application note aims to refine the process for converting a Multiple Feedback (MFB) filter for a traditional operational amplifier into a differential filter suitable for use with a fully differential amplifier (FDA). When using an FDA as an active filter, most online filter designers and tools simply do not include fully differential amplifiers in the analysis. There are multiple key benefits of utilizing a fully-differential amplifier to drive the inputs of these ADCs, including being able to convert single-ended signals into differential with DC coupling, adding gain and active filtration in one stage, independent output common mode control, improved second-order harmonic performance, and more.

For a more complete analysis of the various filter types (Butterworth, Bessel, and so on), transfer functions, supporting equations, and more, please consider evaluating the references listed at the end of this article.

MFB Operational Amplifier Implementation

At the simplest, an MFB filter can be designed for a traditional operational amplifier, and then simply flipped or mirrored onto the negative terminal and duplicated on both sides of the feedback network. To generate an op amp MFB model for conversion, use *Texas Instrument's Filter Design Tool*. Figure 1 demonstrates this principle with the core 5 basic components in the following.

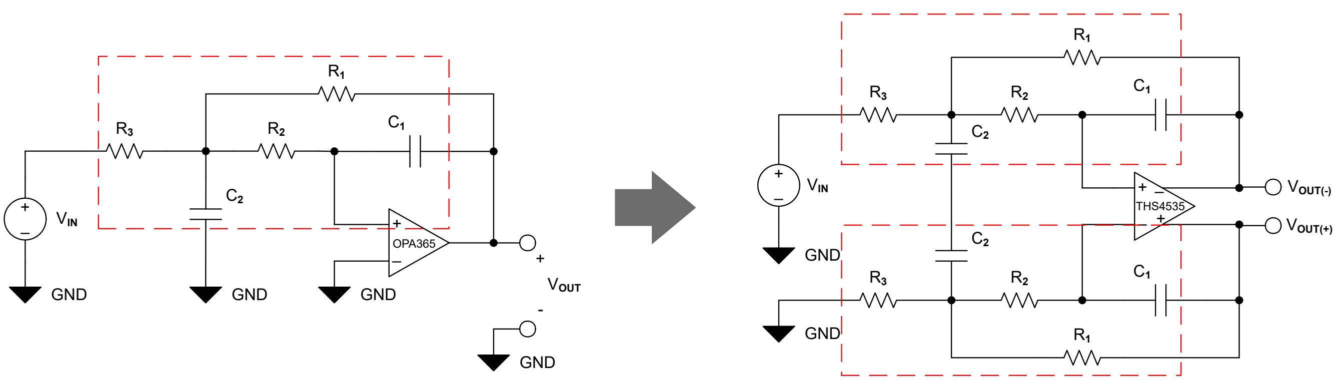

Figure 1. Operational Amplifier to Differential Amplifier MFB Filter

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Note

If the design being developed has a source impedance or requires a termination resistor, remember to add a resistor to the inverting input of the FDA to match the impedance of the non-inverting input. For more information on this topic, please refer to the references at the end of this article.

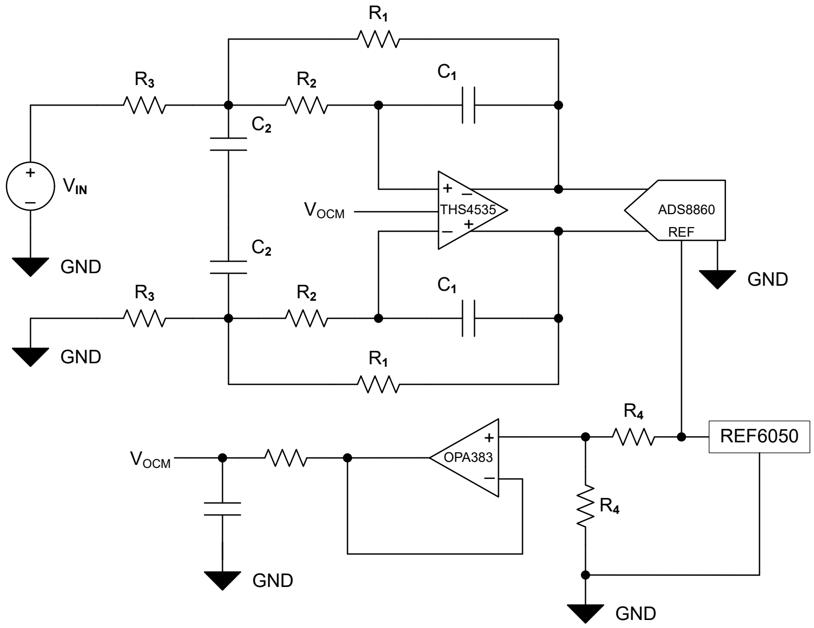

Figure 2. Differential Amplifier MFB Filter Driving an ADC

Both capacitors labeled C2 can be combined in series into one passive component with a value of the following:

$$\frac{1}{2}C_2 \tag{1}$$

where

$$C_{total} = \frac{1}{C_2} + \frac{1}{C_2} = \frac{1}{2}C_2 \tag{2}$$

This is shown in Figure 6.

Simulation Implementation and Results

Table 1 outlines an example design requirement for one of the most common filter applications – an anti aliasing filter to drive a 1 MSPS SAR ADC.

Table 1. Design Requirements

Parameter	Target Value
Filter Type	2nd Order Low Pass Butterworth (Q = 0.707)
Cut Off Frequency	500kHz
Target Gain	1V/V
FDA	THS4535
ADC Sampling Rate	1MSPS
Target ADC	ADS8860

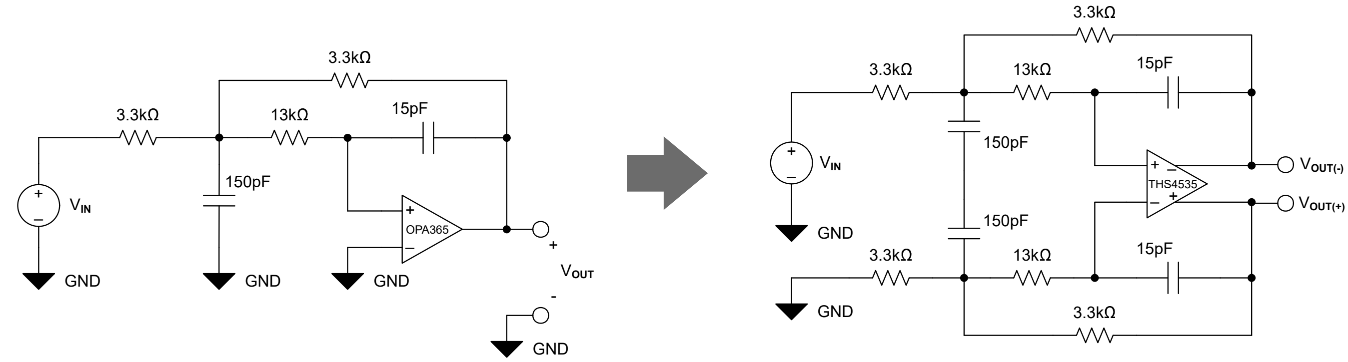

Figure 3. 500kHz, Gain = 1V/V, Low Pass Filter Schematic

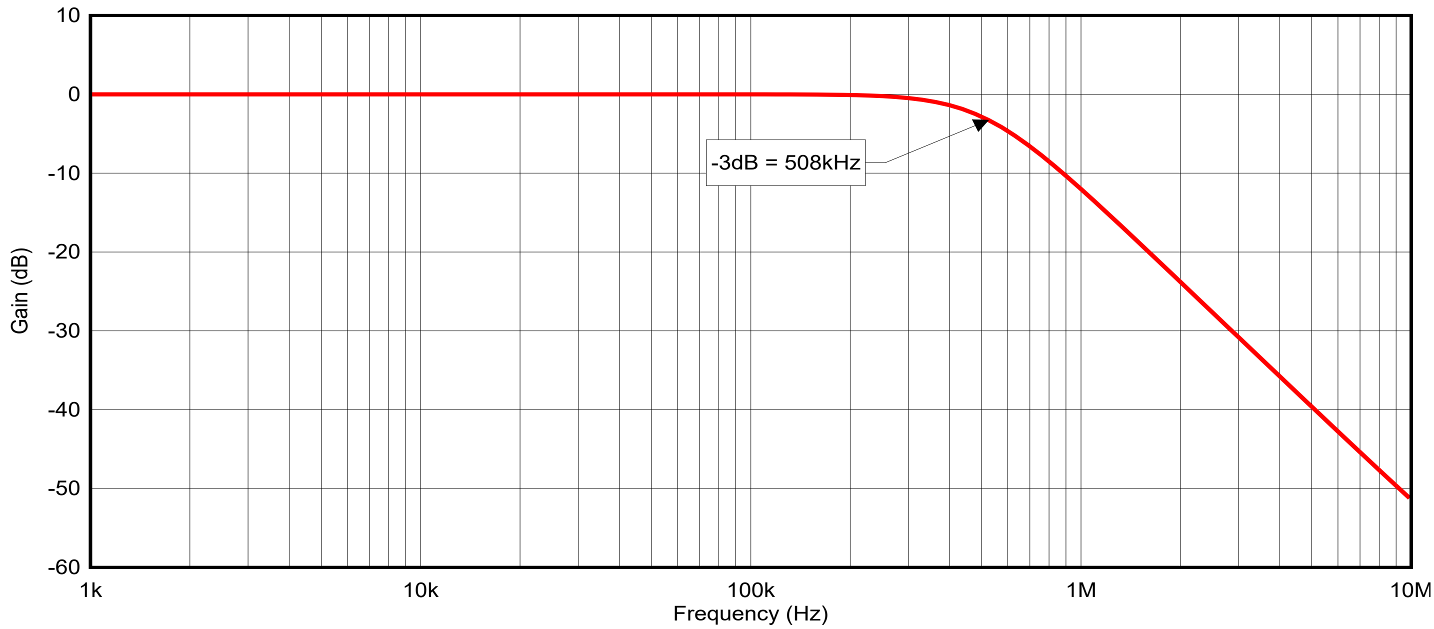

Figure 4. 500kHz, Gain = 1V/V, Low Pass Filter Op Amp Frequency Response

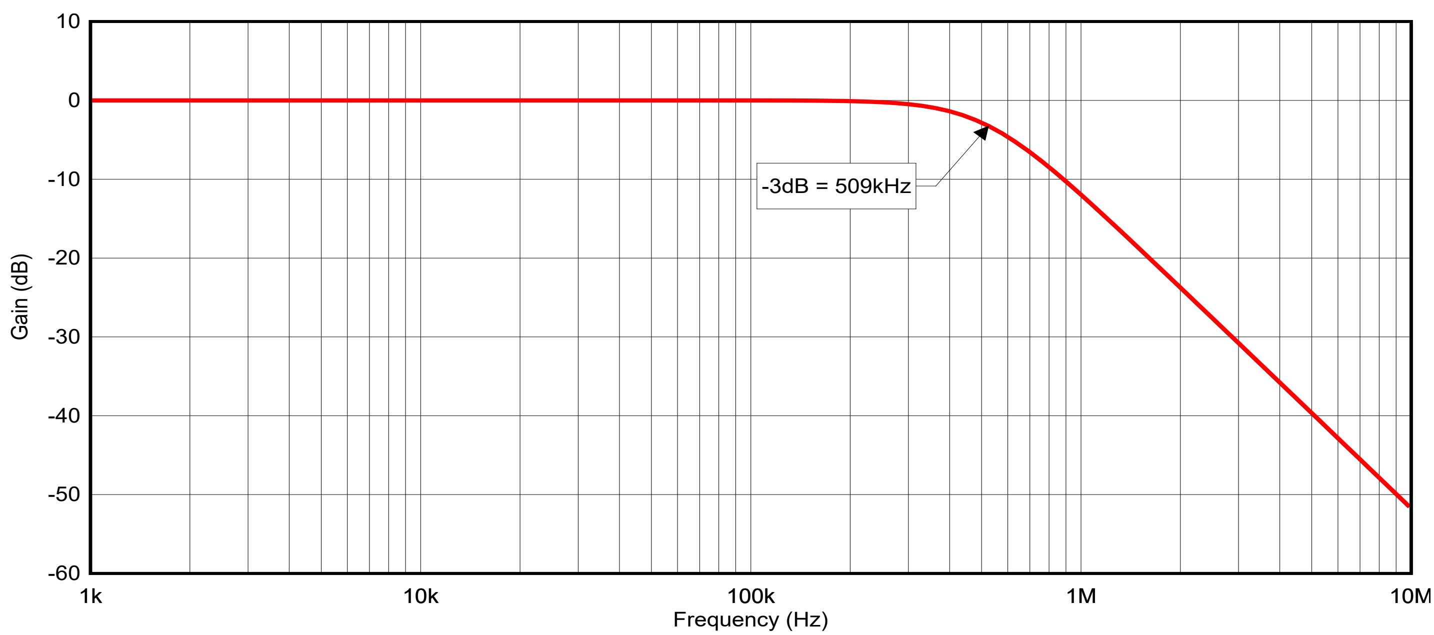

Figure 5. 500kHz, Gain = 1V/V, Low Pass Filter FDA Frequency Response

[Table 2](#) outlines an additional design example with a gain of 2V/V to demonstrate single to differential conversion, addition of gain, and active filtration.

Table 2. Design Requirements

Parameter	Target Value
Filter Type	2nd Order Low Pass Butterworth (Q = 0.707)
Cut Off Frequency	500kHz
Target Gain	2V/V
FDA	THS4535
ADC Sampling Rate	1 MSPS
Target ADC	ADS8860

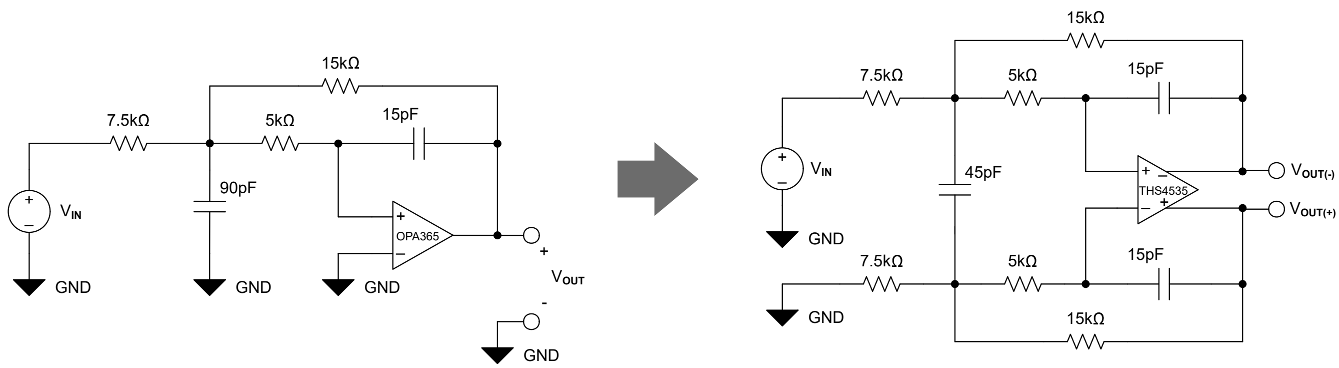

Figure 6. 500kHz, Gain = 2V/V, Low Pass Filter Schematic

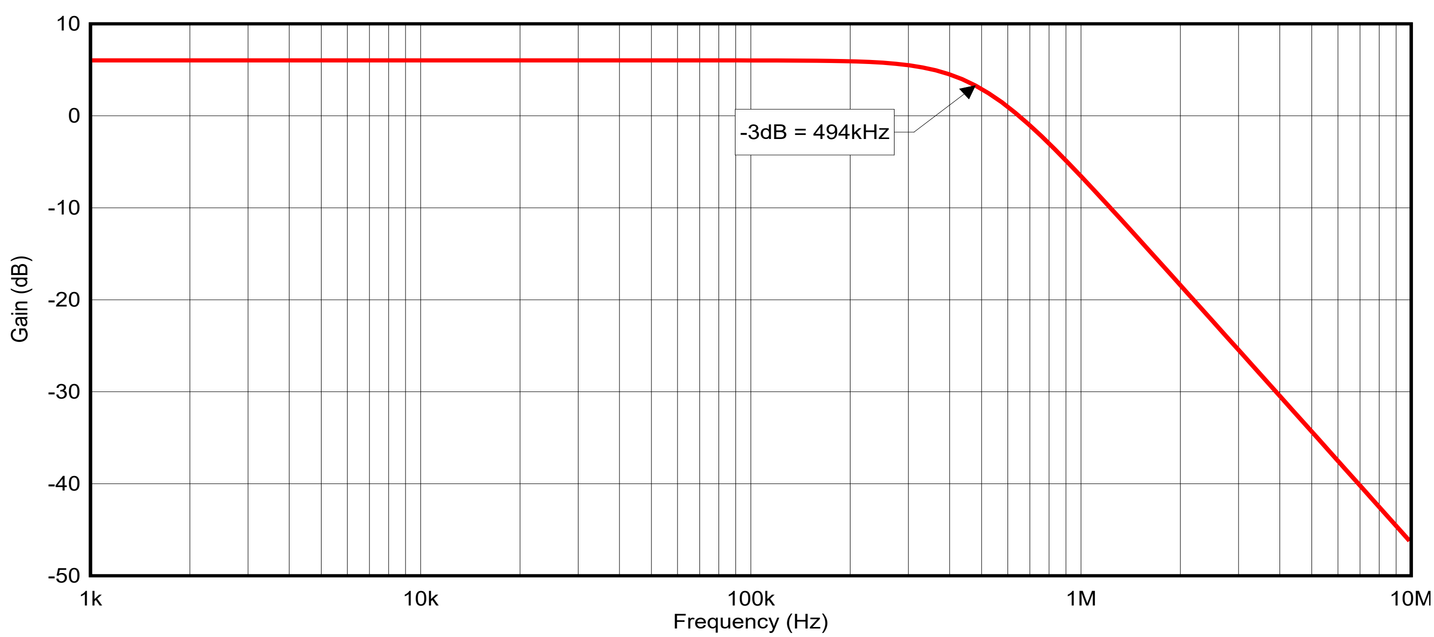

Figure 7. 500kHz, Gain = 2V/V, Low Pass Filter Op Amp Frequency Response

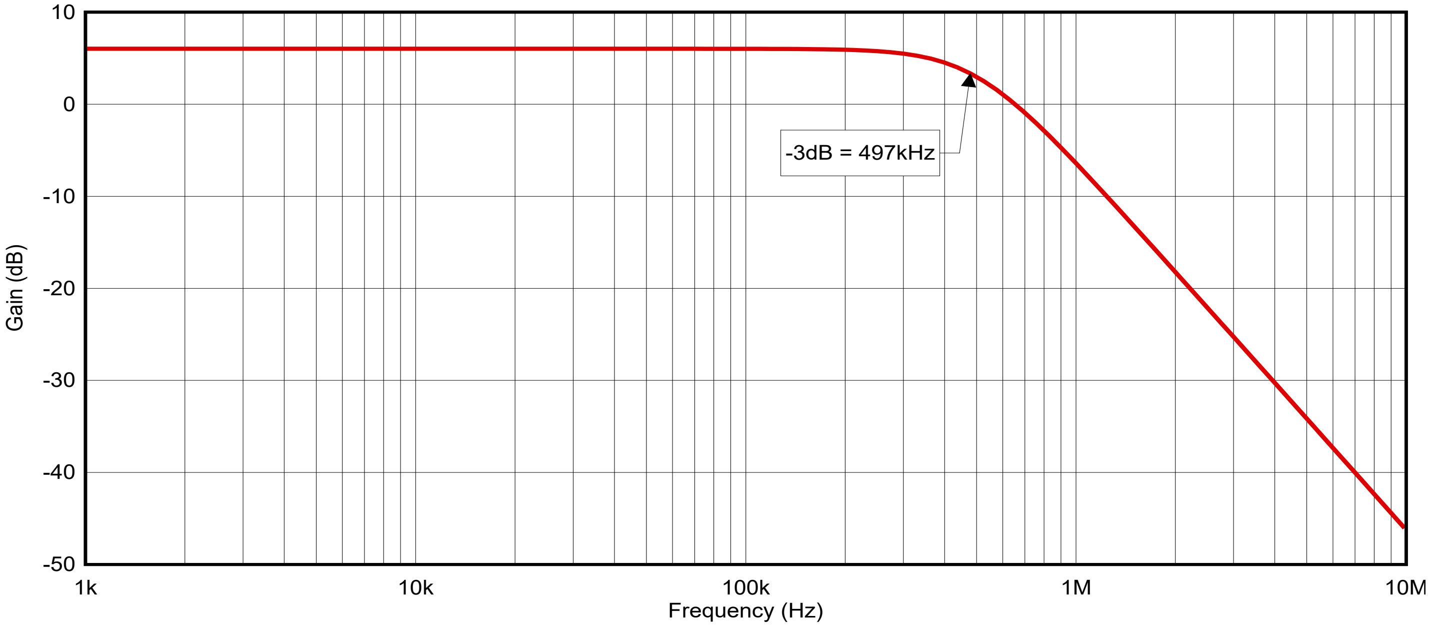

Figure 8. 500kHz, Gain = 2V/V, Low Pass Filter FDA Frequency Response

Sallen-Key Implementation

Sallen-Key filters are not typically used with fully differential amplifiers, and therefore not considered in this document due to the dependency on a feedback path to both the inverting and noninverting terminal of a traditional op amp. In this configuration, the impedances on each terminal are mismatched – if this were replicated onto an FDA, the impedance mismatch would cause high distortion and other circuit abnormalities. Therefore, this is generally recommended to utilize an MFB filter topology as described previously for fully differential amplifiers.

References

1. Texas Instruments, *Texas Instrument's Filter Design Tool*
2. Texas Instruments, *Using the infinite-gain, MFB filter topology in fully differential active filters*, analog applications journal.
3. Texas Instruments, *Design a front-end to drive a differential ADC*, video
4. Texas Instruments, *Active Low-Pass Filter Design*, application note.
5. Texas Instruments, *AN-1393 Using High Speed Differential Amplifiers to Drive Analog-to-Digital Converters*, application note.
6. Texas Instruments, *Single-Ended Input to Differential Output Circuit Using a Fully-Differential Amplifier*, analog engineer's circuit.
7. Texas Instruments, *THS4551 Low-Noise, Precision, 150-MHz, Fully Differential Amplifier*, data sheet.

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