Application Note AN2320

Offset Compensation for High Gain AC Amplifiers

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Abstract
A simple solution is proposed to cancel DC offset in high gain AC amplifiers. This solution is based on external DC feedback-coupling. Included with this Application Note is the supporting PC application to estimate amplifier frequency response results.

Introduction
The typical PSoC™ device application includes signal conditioning and processing from various sources. Often, a weak AC signal needs processed. That signal can be from a microphone, photodiode, magnetic head, PIR sensor and so on. A Programmable Gain Amplifier (PGA) User Module is commonly used for weak signal conditioning. Problems arise when the desired gain is greater than 100. This problem is caused by the PSoC internal amplifier input offset voltage, which may be as much as 10 mV. The amplified offset voltage distorts the symmetry of the AC output signal and decreases the dynamic range of successive signal processing stages (ADC etc.). The generic solution to this problem is to use an additional RC-circuit between two PGAs (see Figure 1).

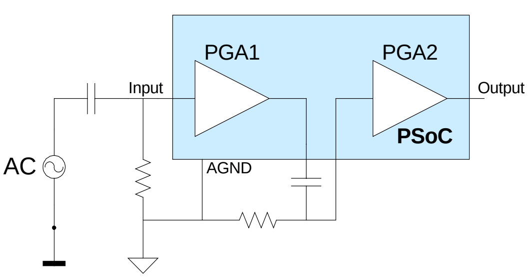

Figure 1. Typical AC Amplifier Circuit

The disadvantage of this generic solution is it requires several PSoC analog I/O pins for analog ground (AGND) output and for the RC-circuit between PGAs. To rectify the disadvantage, this circuit can be modified by adding DC feedback-coupling between the output and input, which frees up the I/O pins for other purposes.

Amplifier with DC Feedback
The modified AC amplifier circuit is shown in Figure 2.

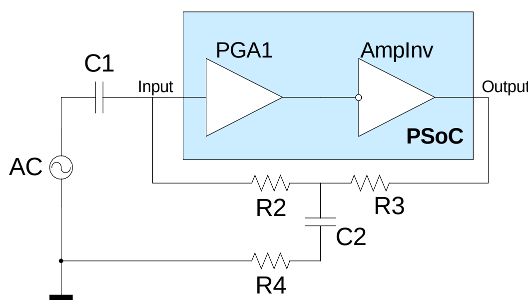

Figure 2. AC Amplifier with Negative Feedback

This circuit uses only two analog I/O pins (instead of the four in the generic solution). PGA2 is replaced by an Inverting Amplifier (AMPINV) User Module to achieve inverted output as opposed to input.

This allows the connection of output to input via the additional RC-circuit to form negative feedback-coupling. Capacitor C2 suppresses the AC component of the feedback signal. The DC component passes from output to input without any changes, which forms 100% DC negative feedback. This permits the output DC voltage to be close to analog ground, independent of the amplifier's input offset voltage.

The circuit in Figure 2 seems to be very simple. Nevertheless, it is not easy to estimate the gain-frequency characteristic of the whole amplifier due to frequency-dependent feedback. For analysis purposes, the amplifier circuit should be slightly modified as shown in Figure 3.

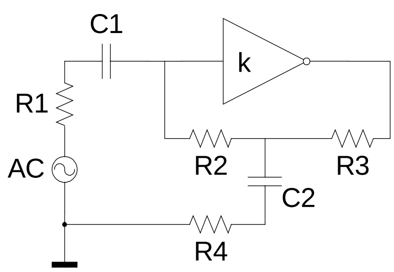

Figure 3. Amplifier Equivalent

The resistor R1 is added, taking into account the AC signal source output resistance. PGA and AMPINV coupled in series are replaced by one equivalent inverting amplifier with gain equal to *k*.

Using Kirchhoff's laws and simple algebra, the frequency-response function for the circuit shown in Figure 3 can be written as follows:

$$K(p) = -\frac{a_2 p^2 + a_1 p}{b_2 p^2 + b_1 p + b_0} \cdot k; \qquad \textbf{(1)}$$

$$a_2 = C_1 C_2 (R_2 R_3 + R_2 R_4 + R_3 R_4);$$
$$a_1 = C_1 (R_2 + R_3);$$
$$b_2 = C_1 C_2 R_3 (R_1 + R_2) + C_1 C_2 R_4 (R_1 + R_2 + R_3 + kR_1);$$
$$b_1 = C_1 (R_1 + R_2 + R_3) + C_2 R_3 + kC_1 R_1 + (1+k) C_2 R_4;$$
$$b_0 = k + 1.$$

Equation (1) describes a combination of high-pass and band-pass filters with the same roll-off frequency.

$$\omega_r^2 = \frac{b_0}{b_2} \qquad \textbf{(2)}$$

The gain at high frequencies is equal to $-k\frac{a_2}{b_2}$.

In order to facilitate the estimation of frequency-gain response characteristics at middle frequencies, a simple PC application was developed. This application tabulates and plots a frequency response curve according to Equation (1). The interface is shown in Figure 4.

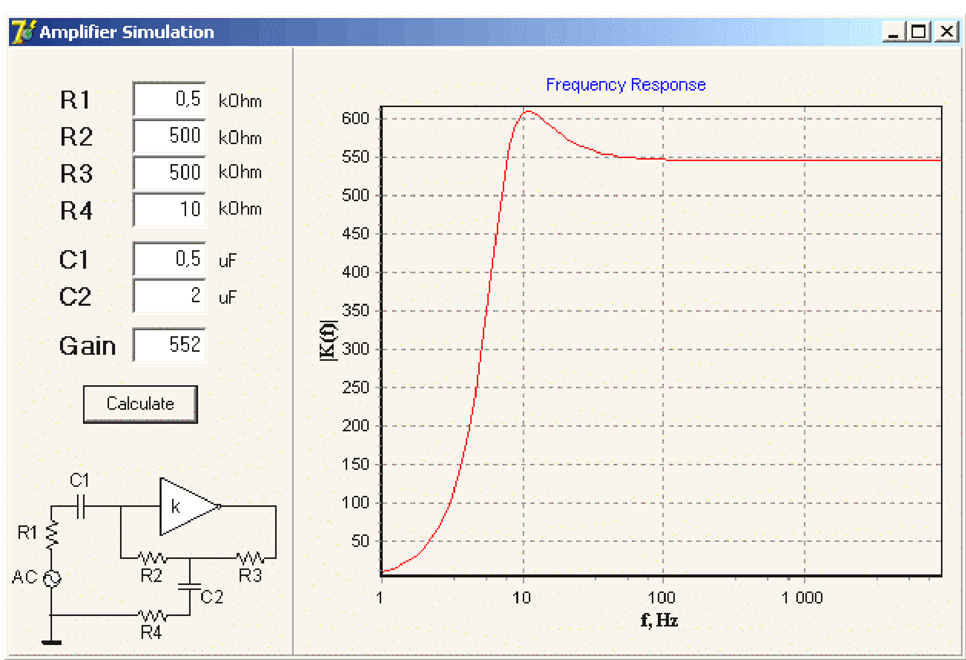

Figure 4. PC Application

To estimate frequency-response characteristics, the component values are entered and the "Calculate" button clicked. All resistances are expressed in kilohms, capacitors in microfarads. The "Gain" value is equal to the product of the gains of the PGA and AMPINV (see Figure 2).

There are no restrictions for selecting component values. Even so, the roll-off frequency, Equation (2), should be set relatively low, less than 1-2 kHz in order to ensure stability of the circuit. To decrease the resonant peak on the frequency plot, R_4 should be increased.

DC Feedback via Modulator

The amplifier with feedback that is shown in Figure 2 uses two analog I/O pins for input and output. Occasionally, all analog pins are required for signal input purposes. In this case, the digital I/O pin can be used to form the feedback loop. The analog signal is transferred via a digital pin using the analog-to-digital modulator on the type C switched capacitor block. For details on modulator functions, refer to Application Note AN2041 "Understanding Switched Capacitor Analog Blocks" available on the www.cypress.com web site. The subsequent device block schematic is shown in Figure 5.

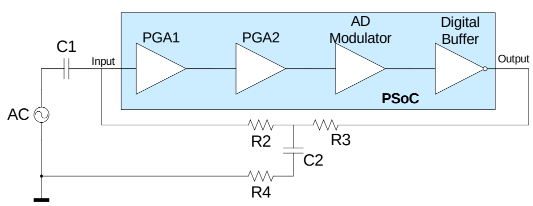

Figure 5. DC Feedback Using Modulator

The analog signal from the PGA output is routed to the AD Modulator. The modulator converts the analog signal into a series of digital pulses. The average value of these digital pulses is equal to the analog input signal. The SCBlock User Module parameters to form the AD Modulator are shown in Figure 6.

SCBLOCK_1

User Module Parameters	Value
FCap	16
ClockPhase	Norm
ASign	Pos
ACap	16
ACMux	AnalogOutBus_1
BCap	0
AnalogBus	Disable
CompBus	ComparatorBus_1
AutoZero	Off
CCap	0
ARefMux	ComparatorBus_1
FSW1	On
FSW0	Off
BMux	TrefGND
Power	High

Figure 6. Parameters for AD Modulator

The AD Modulator produces digital pulses on corresponding analog column comparator bus. To route this digital signal to the output pin, the Digital Buffer (DigiBuf) User Module is used. For the PSoC CY8C24x94 device family, the comparator bus can directly drive the global output bus without the Digital Buffer using the Comparator Bus to Global Outputs Enable register (CMP_GO_EN).

If the digital signal is used for feedback, then inversion can be performed by either the INVAMP or the digital row LUT (see Figure 7).

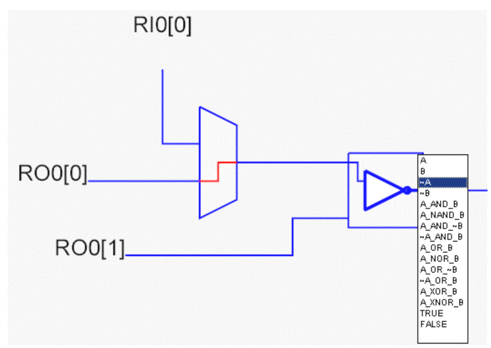

Figure 7. LUT Configuration

Important Tip: The incremental and sigma-delta ADC use the analog modulator as a one-bit, analog-to-digital converter. Therefore, the ADC's modulator can be used to form the compensation feedback signal. You just need to route the ADC's comparator bus signal to the digital buffer input.

Conclusion

Described in this note is an AC amplifier with feedback can not only be used to cancel DC offset, but also as an active hardware filter. This is due to its transfer function, Equation (1), which corresponds to the second order analog filter. By modifying the feedback chain, the frequency-gain characteristic can be modified to form another filter type, for example, a band-pass filter.

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