Analog Engineer's Circuit

Low-Noise and Long-Range PIR Sensor Conditioner Circuit with MSP430™ Smart Analog Combo

TEXAS INSTRUMENTS

James Evans

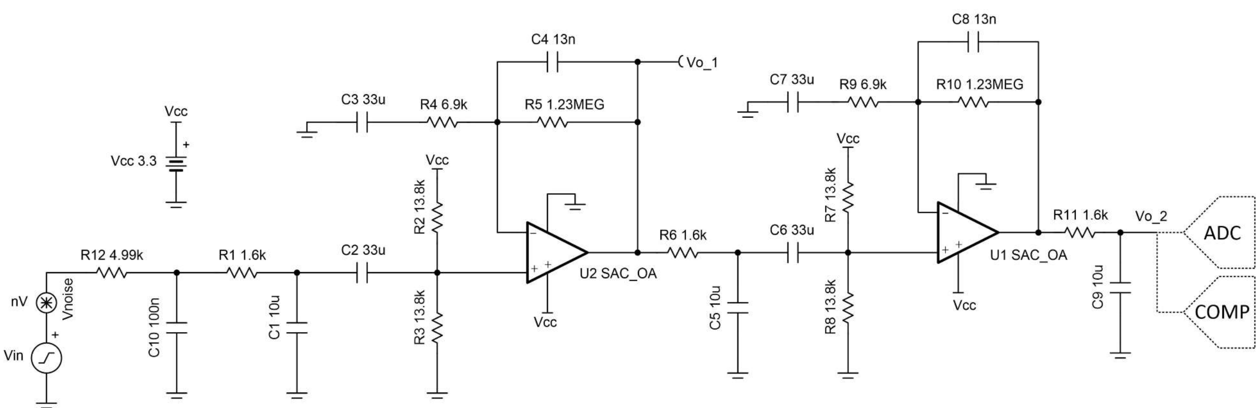
Design Goals

AC Gain	Filter Cut-Off Frequency		Supply	
90dB	f_L	f_H	V_{cc}	V_{ee}
	0.7Hz	10Hz	3.3V	0V

Design Description

Some MSP430™ microcontrollers (MCUs) contain configurable integrated signal chain elements such as op-amps, DACs, and programmable gain stages. These elements make up a peripheral called the Smart Analog Combo (SAC). For information on the different types of SACs and how to leverage configurable analog signal chain capabilities, visit *MSP430 MCUs Smart Analog Combo Training*. To get started with your design, download the *Low-Noise Long-Range PIR Sensor Conditioner Circuit Design Files*.

This design leverages two of the four integrated op-amp blocks (SACs) in the MSP430FR2355 MCU. Two SAC_L3 peripherals are configured as cascaded op-amps in general-purpose mode to amplify and filter the signal from a passive infrared (PIR) sensor. The circuit includes multiple low-pass and high-pass filters to reduce noise at the output of the circuit to be able to detect motion at long distances and reduce false triggers. The output of the second-stage op-amp in this circuit can be internally or externally connected to other integrated peripherals in the MSP430FR2355 MCU. For example, the analog-to-digital converter (ADC) window comparator can sample this output periodically (with no CPU intervention) and trigger an interrupt when the signal crosses a threshold, indicating motion or an alert.



Design Notes

- The common-mode voltage and output-bias voltage are set using the resistor dividers between R_2 and R_3 (and R_7 and R_8).
- Two or more amplifier stages must be used to allow for sufficient loop gain.
- Additional low-pass and high-pass filters can be added to further reduce noise.
- Capacitors C_4 and C_8 filter noise by decreasing the bandwidth of the circuit and help stabilize the amplifiers.

- RC filters on the output of the amplifiers (for example, R_6 and C_5) are required to reduce the total integrated noise of the amplifier.
- The maximum gain of the circuit can be affected by the cut-off frequencies of the filters. Adjust the cut-off frequencies to achieve the desired gain.
- For this design, two SAC_L3 peripherals in the MSP430FR2355 MCU are configured as cascaded op-amps in general-purpose mode.
- This design can also be implemented by using the transimpedance amplifier (TIA) and SAC_L1 peripheral in the MSP430FR2311 MCU for the cascaded op-amps, but since the maximum input voltage of the TIA is limited to VCC/2, limit the common-mode voltage and gain accordingly.
- The *Low-Noise Long-Range PIR Sensor Conditioner Circuit Design Files* include a code example demonstrating how to properly configure the SAC_L3 and ADC window comparator peripherals in the MSP430FR2355 MCU.

Design Steps

1. Choose large-valued capacitors C_1, C_5, and C_9 for the low-pass filters. Select these capacitors first because large-valued capacitors have limited standard values to select from compared to standard resistor values.

$$C_1 = C_5 = C_9 = 10\mu F$$

2. Calculate resistor values for R_1, R_6, and R_{11} to form the low-pass filters.

$$R_1 = R_6 = R_{11} = \frac{1}{2\pi \times f_H \times C_1} = \frac{1}{2\pi \times 10Hz \times 10\mu F} = 1.592k\Omega$$

$$\text{Choose} \quad R_1 = R_6 = R_{11} = 1.6k\Omega \quad \left(\text{Standard value}\right)$$

3. Select capacitor values for C_2, C_3, C_6, and C_7 for the high-pass filters.

$$C_2 = C_3 = C_6 = C_7 = 33\mu F$$

4. Calculate the resistor values for R_4 and R_9 for the high-pass filters.

$$R_4 = R_9 = \frac{1}{2\pi \times f_L \times C_2} = \frac{1}{2\pi \times 0.7Hz \times 33\mu F} = 6.89k\Omega$$

$$\text{Choose} \quad R_4 = R_9 = 6.9k\Omega \quad \left(\text{Standard value}\right)$$

5. Set the common-mode voltage of the amplifier to mid-supply using a voltage divider. The equivalent resistance of the voltage divider should be equal to R_4 to properly set the corner frequency of the high-pass filter.

$$R_2 = R_3 = R_7 = R_8 = 2 \times R_4 = 2 \times 6.9k\Omega = 13.8k\Omega$$
$$\text{Choose} \quad R_2 = R_3 = R_7 = R_8 = 13.8k\Omega \quad (\text{Standard value})$$

6. Calculate the gain required by each gain stage to achieve the total gain requirement. Distribute the total gain target of the circuit evenly between both gain stages.

$$\text{Gain} = \frac{90dB}{2} = 45dB = 177.828\frac{V}{V}$$

7. Calculate R_5 to set the gain of the first stage.

$$R_5 = (\text{Gain} - 1) \times R_4 = \left(177.828\frac{V}{V} - 1\right) \times 6.9k\Omega = 1.22M\Omega$$

$$\text{Choose} \quad R_5 = 1.23M\Omega \quad \left(\text{Standard value}\right)$$

8. Calculate C_4 to set the low-pass filter cut-off frequency.

$$C_4 = \frac{1}{2\pi \times f_H \times R_5} = \frac{1}{2\pi \times 10Hz \times 1.23M\Omega} = 12.939nF$$

$$\text{Choose} \quad C_4 = 13nF \quad \left(\text{Standard value}\right)$$

9. Since the gain and cut-off frequency of the first gain stage is equal to the second gain stage, set all component values of both stages equal to each other.

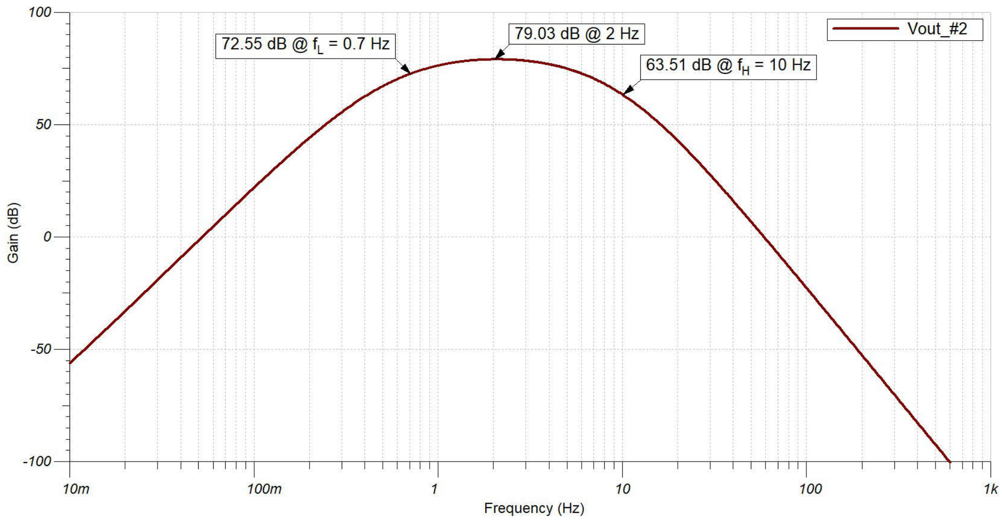
$$R_1 = R_6 = 1.6k\Omega$$
$$R_7 = R_8 = 13.8k\Omega$$
$$R_9 = R_4 = 6.9k\Omega$$
$$R_{10} = R_5 = 1.23M\Omega$$
$$C_8 = C_4 = 13nF$$

10. Calculate R_{11} to set the cut-off frequency of the low-pass filter at the output of the circuit.

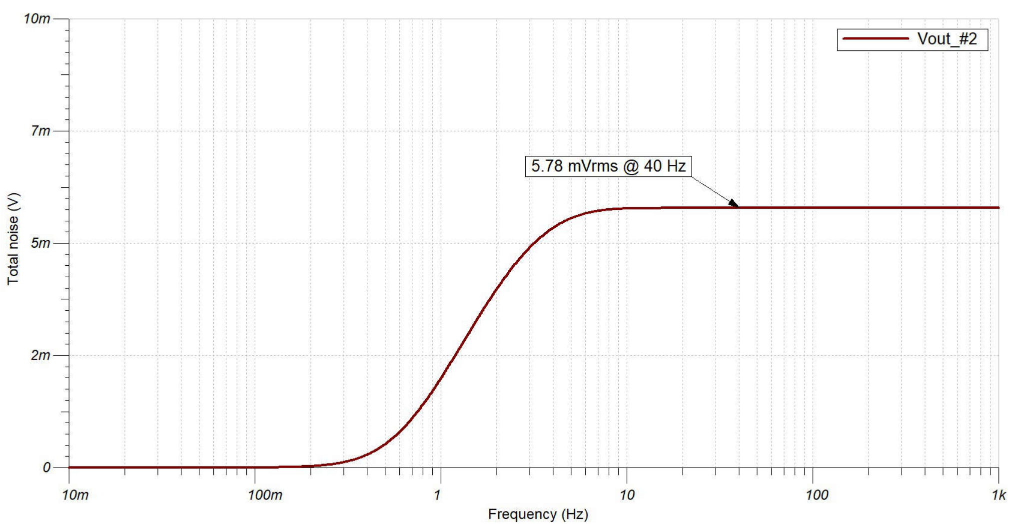
$$R_{11} = \frac{1}{2\pi \times f_H \times C_9} = \frac{1}{2\pi \times 10Hz \times 10\mu F} = 1.592k\Omega$$
$$\text{Choose} \quad R_{11} = 1.6k\Omega \ \left(\text{Standard} \quad \text{value}\right)$$

Design Simulations

AC Simulation Results



Noise Simulation Results



Target Applications

- *Motion detector*
- *Occupancy detection (people tracking and people counting)*
- *Building automation*
- *IP network camera*
- *Lighting sensor*
- *Thermostat*
- *Video doorbell*

References

1. Texas Instruments, *Low-Noise Long-Range PIR Sensor Conditioner Circuit*, design files
2. Texas Instruments, *16MHz integrated analog microcontroller with 3.75-KB FRAM, Op Amp, TIA, comparator with DAC, 10-bit ADC*, product page
3. Texas Instruments, *How to Use the Smart Analog Combo in MSP430TM MCUs*, application report
4. Texas Instruments, *MSP430 MCUs Smart Analog Combo*, training video

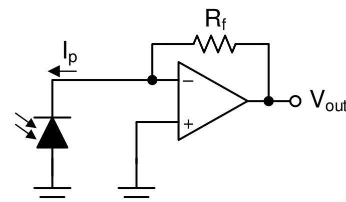
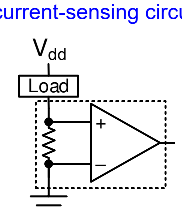
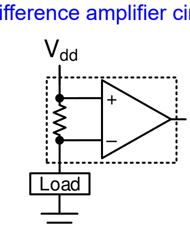
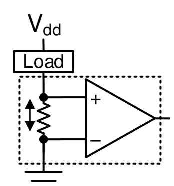
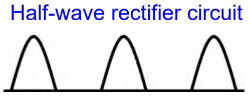
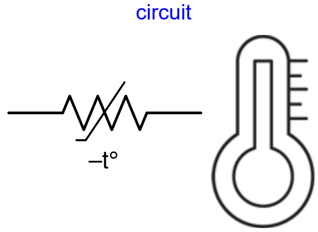
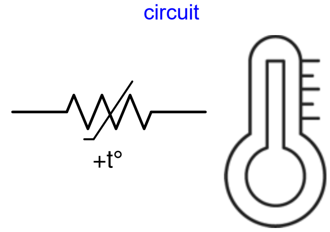
Design Featured Op Amp

MSP430FRxx Smart Analog Combo		
	MSP430FR2311 SAC_L1	MSP430FR2355 SAC_L3
V_{cc}	2.0V to 3.6V	
V_{CM}	-0.1V to V_{CC} + 0.1V	
V_{out}	Rail-to-rail	
V_{os}	±5mV	
A_{OL}	100dB	
I_q	350µA (high-speed mode)	
	120µA (low-power mode)	
I_b	50pA	
UGBW	4MHz (high-speed mode)	2.8MHz (high-speed mode)
	1.4MHz (low-power mode)	1MHz (low-power mode)
SR	3V/µs (high-speed mode)	
	1V/µs (low-power mode)	
Number of channels	1	4
	MSP430FR2311	MSP430FR2355

Design Alternate Op Amp

MSP430FR2311 Transimpedance Amplifier	
V_{cc}	2.0V to 3.6V
V_{CM}	-0.1V to V_{CC}/2V
V_{out}	Rail-to-rail
V_{os}	±5mV
A_{OL}	100dB
I_q	350µA (high-speed mode)
	120µA (low-power mode)
I_b	5pA (TSSOP-16 with OA-dedicated pin input)
	50pA (TSSOP-20 and VQFN-16)
UGBW	5MHz (high-speed mode)
	1.8MHz (low-power mode)
SR	4V/µs (high-speed mode)
	1V/µs (low-power mode)
Number of channels	1
MSP430FR2311	

Related MSP430 Circuits

Low-noise and long-range PIR sensor conditioner circuit 	Bridge amplifier circuit 	Transimpedance amplifier circuit 
Single-supply, low-side, unidirectional current-sensing circuit 	High-side current sensing with discrete difference amplifier circuit 	Low-side, bidirectional current-sensing circuit 
Half-wave rectifier circuit 	Temperature sensing with NTC thermistor circuit 	Temperature sensing with PTC thermistor circuit 

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Revision History

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

Changes from Revision A (February 2020) to Revision B (October 2024) **Page**

- Updated the format for tables, figures, and cross-references throughout the document.................................. 1

Changes from Revision * (December 2019) to Revision A (February 2020) **Page**

- Added *Related MSP430 Circuits* section..1