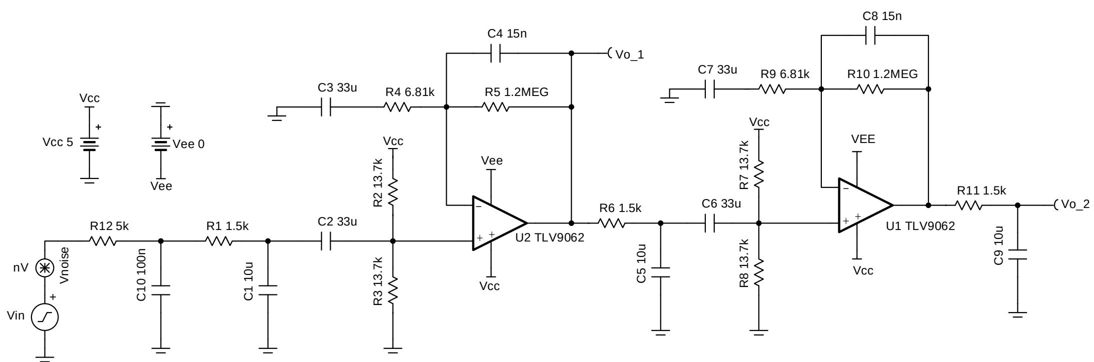
Low-noise and long-range PIR sensor conditioner circuit

Design Goals

AC Gain	Filter Cut Off Frequency		Supply	
90dB	f_L	f_H	V_{cc}	V_{ee}
	0.7Hz	10Hz	5V	0V

Design Description

This two stage amplifier design amplifies and filters 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. This circuit can be followed by a window comparator circuit to create a digital output or connect directly to an analog–to–digital converter (ADC) input.



Design Notes

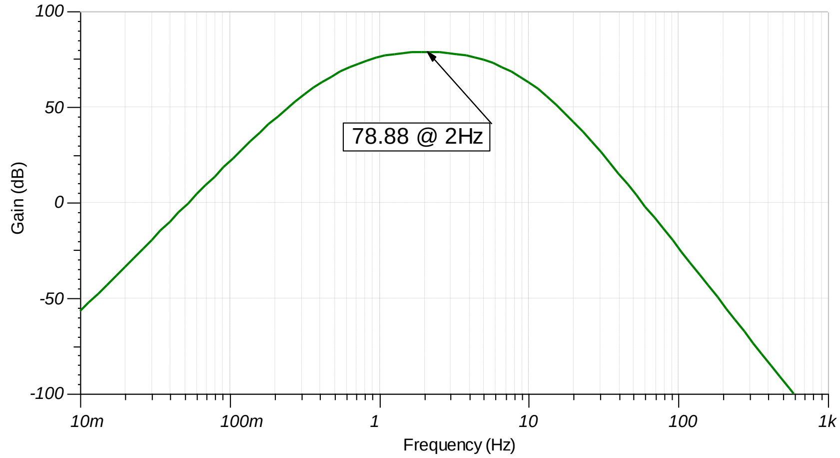
1. The common mode voltage and output bias voltage are set using the resistor dividers between R_2 and R_3 (and R_7 and R_8).
2. Two or more amplifier stages must be used to allow for sufficient loop gain.
3. Additional low–pass and high–pass filters can be added to further reduce noise.
4. Capacitors C_4 and C_8 filter noise by decreasing the bandwidth of the circuit and help stabilize the amplifiers.
5. 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.
6. The maximum gain of the circuit can be affected by the cutoff frequencies of the filters. The cutoff frequencies may need to be adjusted to achieve the desired gain.

Design Steps

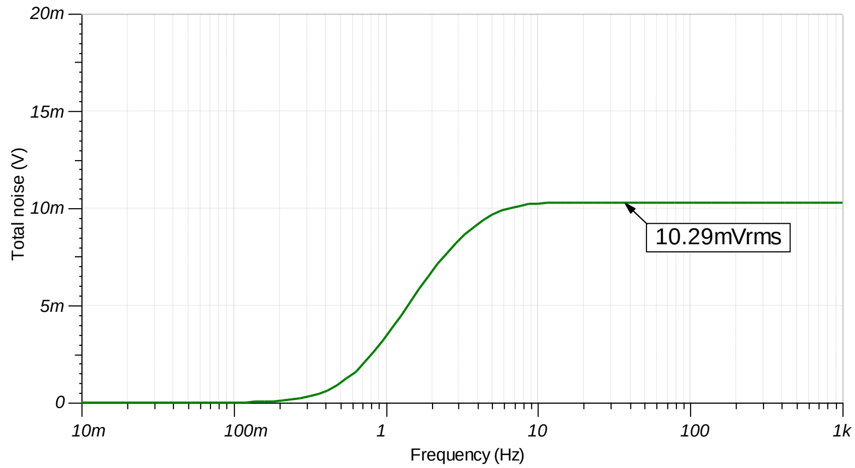
1. Choose large–valued capacitors C_1, C_5, and C_9 for the low–pass filters. These capacitors should be selected first since large–valued capacitors have limited standard values to select from compared to standard resistor values.
   $$C_1 = C_5 = C_9 = 10\mu F$$
2. Calculate resistor values for R_1, R_6, and R_{11} to form the low–pass filters.
   $$R_1 = R_6 = R_{11} = \frac{1}{2\pi \times f_L \times C_1} = \frac{1}{2\pi \times 0.7Hz \times 10\mu F} = 1.592k\Omega$$
   $$\text{Choose } R_1 = R_6 = R_{11} = 1.5k\Omega \text{ (Standard value)}$$
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.
   $$R_4 = R_9 = \frac{1}{2\pi \times f_H \times C_2} = \frac{1}{2\pi \times 10Hz \times 33\mu F} = 6.89k\Omega$$
   $$\text{Choose } R_4 = R_9 = 6.81k\Omega \text{ (Standard value)}$$
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.
   $$R_2 = R_3 = R_7 = R_8 = 2 \times R_4 = 2 \times 6.81k\Omega = 13.62k\Omega$$
   $$\text{Choose } R_2 = R_3 = R_7 = R_8 = 13.7k\Omega \text{ (Standard value)}$$
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.
   $$Gain = \frac{90dB}{2} = 45dB = 177.828\frac{V}{V}$$
7. Calculate R_5 to set the gain of the first stage.
   $$R_5 = (Gain - 1) \times R_4 = (177.828\frac{V}{V} - 1) \times 6.81k\Omega = 1.204M\Omega$$
   $$\text{Choose } 1.2M\Omega$$
8. Calculate C_4 to set the low–pass filter cut off frequency.
   $$C_4 = \frac{1}{2\pi \times R_5 \times f_L} = \frac{1}{2\pi \times 1.2MHz \times 10Hz} = 13.263nF$$
   $$\text{Choose } C_4 = 15nF$$
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.
   $$R_1 = R_6 = 5k\Omega$$
   $$R_7 = R_8 = 13.7k\Omega$$
   $$R_9 = R_4 = 6.81k\Omega$$
   $$R_{10} = R_5 = 1.2M\Omega$$
   $$C_8 = C_4 = 15nF$$
10. Calculate R_{11} to set the cut off frequency of the low–pass filter at the output of the circuit.
   $$R_{11} = \frac{1}{2\pi \times C_9 \times f_L} = \frac{1}{2\pi \times 10\mu F \times 10Hz} = 1.592k\Omega$$
   $$\text{Choose } R_{11} = 1.5k\Omega$$

Design Simulations

AC Simulation Results



Noise Simulation Results



References:

1. Analog Engineer's Circuit Cookbooks
2. SPICE Simulation File SBOC524
3. TI Precision Labs

Design Featured Op Amp

TLV9062	
V_{ss}	1.8V to 5.5V
V_{inCM}	Rail–to–rail
V_{out}	Rail–to–rail
V_{os}	0.3mV
I_q	538µA
I_b	0.5pA
UGBW	10MHz
SR	6.5V/µs
#Channels	1,2,4
www.ti.com/product/tlv9062	

Design Alternate Op Amp

OPA376	
V_{ss}	2.2V to 5.5V
V_{inCM}	V_{ee} to V_{cc}–1.3V
V_{out}	Rail–to–rail
V_{os}	5µV
I_q	760µA/Ch
I_b	0.2pA
UGBW	5.5MHz
SR	2V/µs
#Channels	1, 2, 4
http://www.ti.com/product/opa376	