

Auto-Zero Noise Filtering Improves Instrumentation Amplifier Output

by Maurizio Gavardoni, Product Definer

Maxim Integrated Products Inc

Auto-zero amplifiers offer high-precision voltage offset, drift, gain, and CMRR, but they also produce noise at the auto-zero frequency and its harmonics. Even though the auto-zero frequency lies outside the instrumentation amplifier's (IA's) available bandwidth, the noise can be a problem in some cases – those in which the IA output feeds an ADC, for instance. Yet, a simple filtering technique can reduce auto-zero noise. It features an auto-zero IA with novel indirect current-feedback architecture, and requires a minimum number of external components.

Indirect Current-Feedback Architecture

IAs amplify small differential voltages in the presence of high common-mode voltage. They appear as the interface to strain-gauge bridges for pressure and temperature sensing, and in a variety of current-sensing applications. Many of these systems employ the traditional 3-op amp scheme of Fig. 1. Fortunately, an indirect current-feedback architecture⁽¹⁾ new to IAs (Fig. 2) offers important advantages over the circuit in Fig. 1.

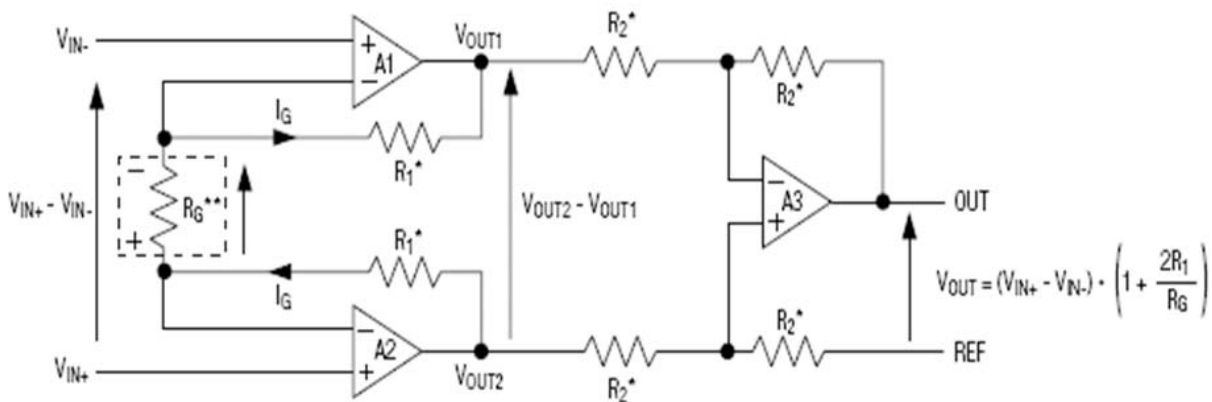


Fig. 1: Gain Is Set In Traditional 3-op amp IA By A Single External Resistor (R_G)

In Fig. 2, two transconductance amplifiers (A and B) reject common-mode input signals while generating output currents in response to the differential input voltages of those amplifiers. The C block is a high-gain amplifier that provides negative feedback via R1 and R2. This feedback forces the differential input voltages of amplifiers A and B to be equal. Thus, the relationship of the IA output to its differential input (V_{IN}) is:

$$V_{OUT} = V_{IN} \times (1 + R_2/R_1)$$

where, $V_{IN} = V_{IN+} - V_{IN-}$

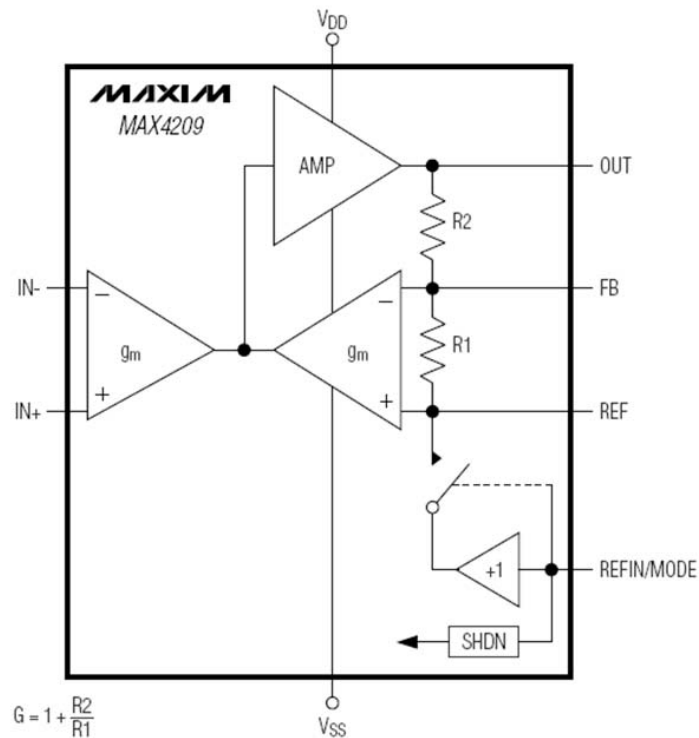


Fig. 2: Indirect Current-Feedback IA Offers Better Gain Accuracy

Two important advantages distinguish this indirect current-feedback architecture from the traditional approach: first, because input common-mode voltages are rejected by the first stage, the IA can operate on a single-supply voltage while sensing at ground or below ground for all levels of gain. Second, the gain accuracy is improved because the amplifier gain is set by the ratio of two internal, matched resistors.

Basics Of Auto-Zero Amplifiers

To correct for input voltage offset, auto-zero amplifiers employ a nulling amplifier parallel to the signal path, plus an internal oscillator that generates the auto-zero frequency, f_c , typically a few tens of kilohertz. The result is a continual nulling operation that consists of an auto-zero phase alternating with an amplification phase (see Fig. 3).

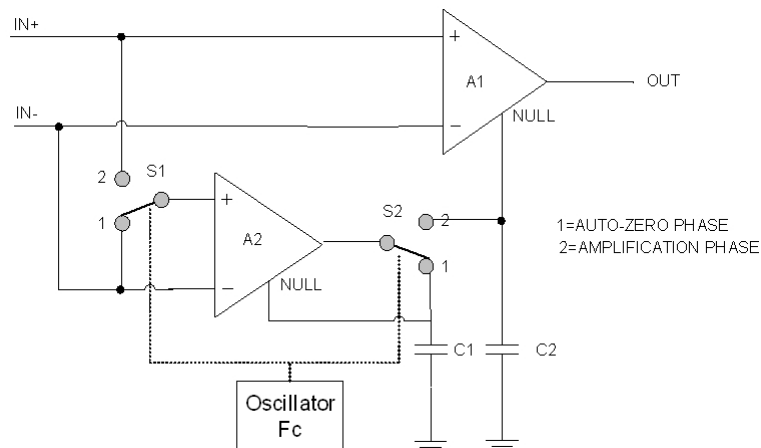


Fig. 3: Simplified Schematic Of Basic Auto-Zero Amplifier

Both switches are set to position 1 as shown during the auto-zero phase, causing capacitor C1 to charge to the voltage offset of nulling amplifier, A2. The voltage offset of main amplifier, A1, (held by C2) is corrected through the NULL pin. During the amplification phase, the switches are set to position 2. C1 holds the voltage offset of the nulling amplifier (which is being corrected by its NULL pin) while the main-amplifier offset is measured by A2 and stored by C2.

The auto-zero amplifier is a sampled data system. As such it produces the sum and difference of the sample frequency (auto-zero frequency, f_c), and the signal frequency, f_s . To avoid aliases, therefore, the signal bandwidth must be limited to less than half of the auto-zero frequency.

The auto-zero technique allows an amplifier to lower its input-voltage offset considerably, to just a few microvolts, and its voltage-offset drift to just a few tenths of $1 \mu\text{V}/^\circ\text{C}$. If the auto-zero frequency is sufficiently higher than the noise corner frequency, then the amplifier also continuously nulls any $1/f$ noise. Theoretically, an auto-zero amplifier has no $1/f$ noise, but chopping action produces an increase in wideband white noise at the output.

Reducing Noise Around The Auto-Zero Frequency

The use of an indirect, current feedback IA lets you leverage the internal auto-zeroing circuitry to achieve very high dc precision. You should then add filtering to remove the IA output noise, particularly for applications in which it feeds an ADC. The output noise consists of a white broadband component plus spurs located at the auto-zero frequency and its harmonics. Filtering is especially important when the difference between the auto-zero frequency and the ADC sample frequency lies within the bandwidth of interest.

The following experiment was conducted using an IA (the MAX4209H) with fixed gain of 100, signal bandwidth of 7.5 kHz, and auto-zero frequency of about 45 kHz. You can implement a simple first-order low-pass filter by placing an external capacitor (C) between the amplifier OUT and FB pins, parallel to the internal resistor R2. The pole of this filter is determined by C and R2 (R2 is 99 k Ω , here). Noise measurements are taken with the circuit of Fig. 4.

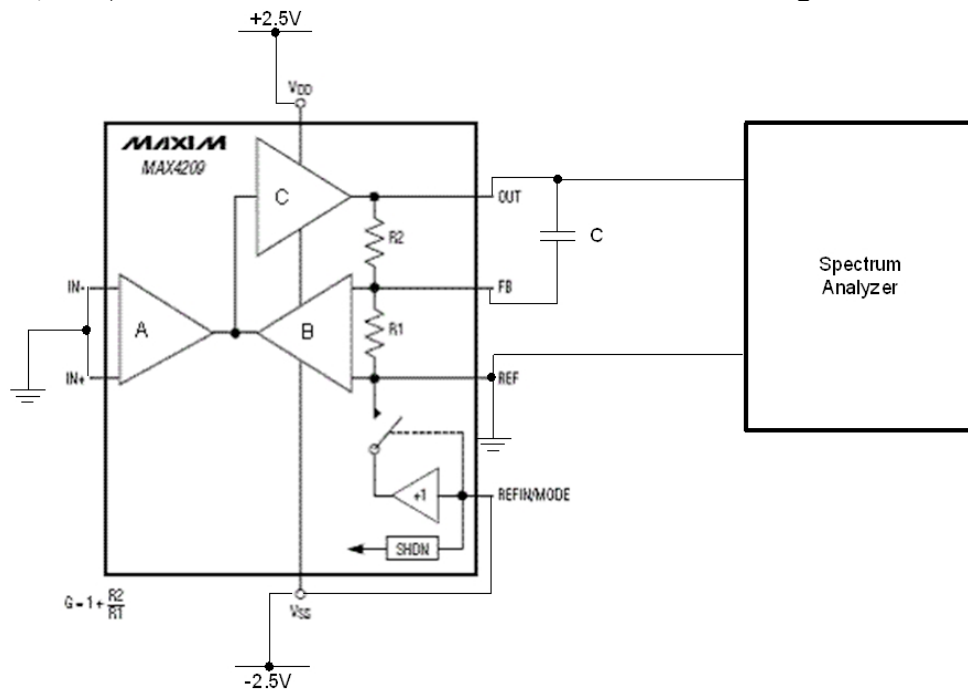


Fig. 4: Measuring IA Output Noise

Input-referred noise plots (Figs. 5 & 6) include three different measurements: no C, C = 1 nF, and C = 10 nF. For the case of no C, the -3 dB bandwidth is limited only by the IC, to 7.5 kHz.

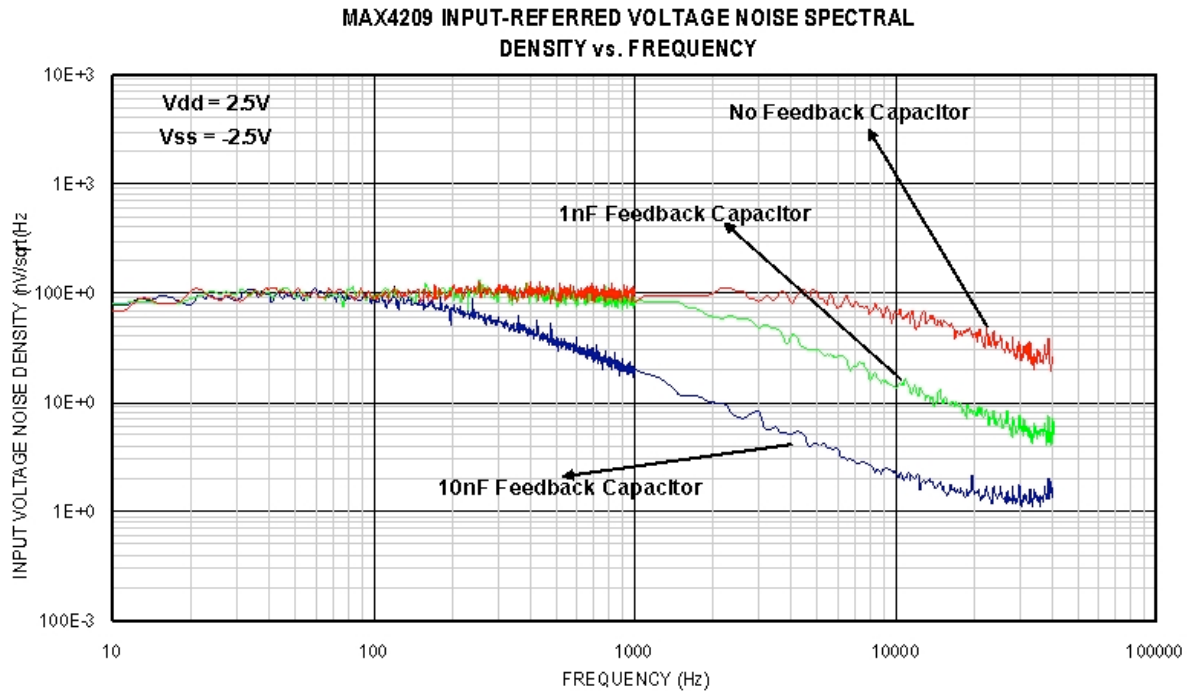


Fig. 5: Input-Referred Noise Density For IA With Different Feedback Capacitance

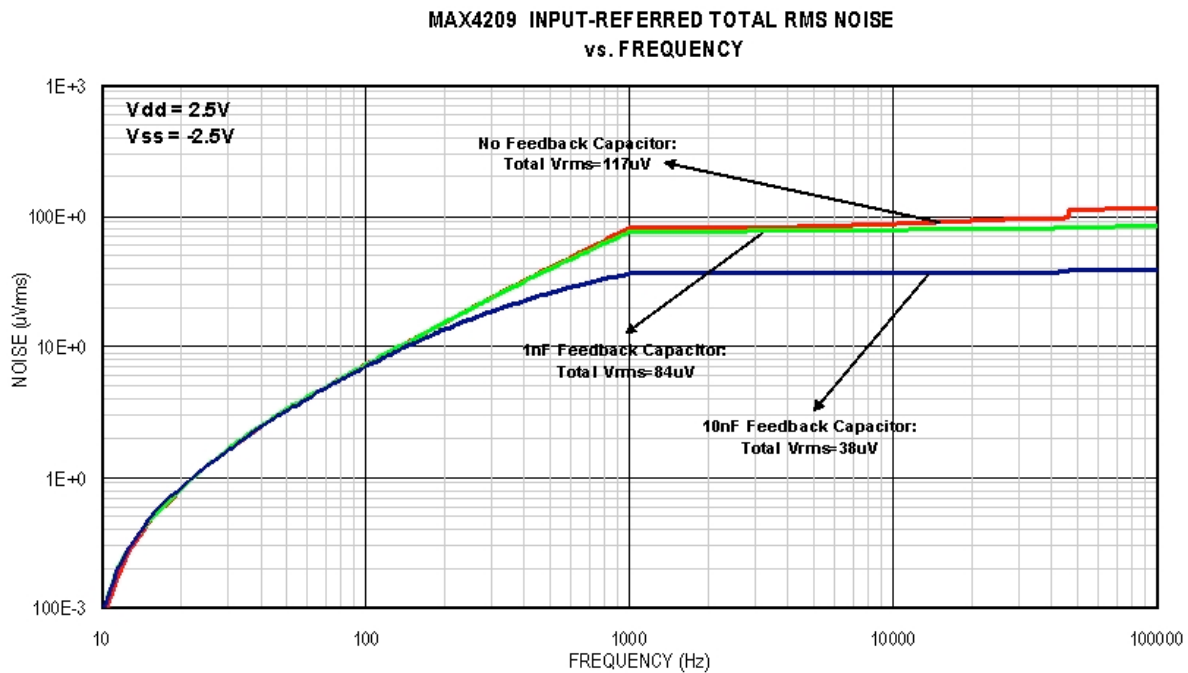


Fig. 6: Input-Referred Total Rms Noise For IA With Different Feedback Capacitance

Depending on the application, you may need to compromise between the desired noise reduction and the limitation on signal bandwidth:

Capacitor (nF)	-3 dB bandwidth (Hz)	Total input-referred noise (μV_{rms})
No cap	7500	117
1	1600	84
10	160	38

This noise reduction may not be sufficient for your application. If you can deploy more than just the feedback capacitor, then a simple low-pass RC filter connected at the amplifier output can provide further noise attenuation. Figs 7 & 8 show the profile of input-referred noise obtained with an output low-pass filter consisting of $R_L = 39 \Omega$ and $C_L = 760 \text{ nF}$. Those values place the RC filter pole at approximately 5 kHz, and provide an attenuation of about 18 dB at the auto-zero frequency of 45 kHz.

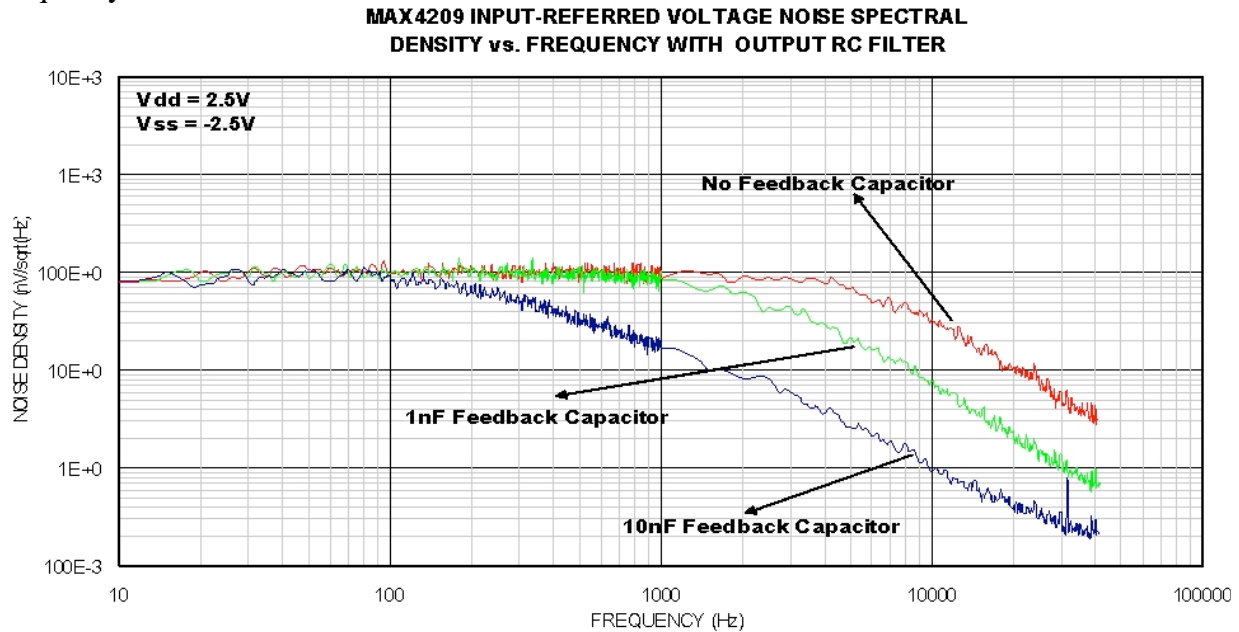


Fig. 7: Input-Referred Noise Density For IA With Added RC Low-Pass Filter

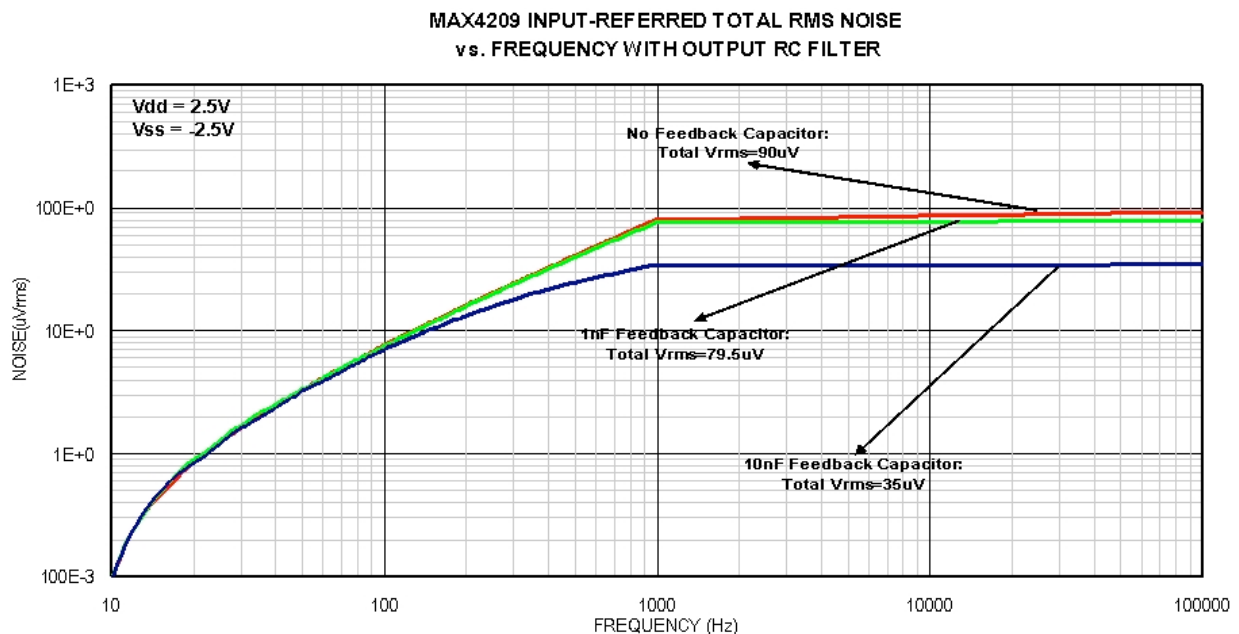


Fig. 8: Input-Referred Total Rms Noise For IA With Added RC Low-Pass Filter

To summarize: applications that resolve small input signals in the presence of high common-mode voltages require IAs that are precise in voltage offset, drift, gain, and CMRR. An auto-zero indirect current-feedback amplifier provides such characteristics, but also produces more output noise. The above shows a simple way to reduce output noise using an indirect current-feedback IA, by adding either one external capacitor or as many as three external components.

Reference

(1). For more information on this new approach see Maxim application note #4034: [Three Is a Crowd for Instrumentation Amplifiers](#)

About The Author

Maurizio Gavardoni is a Product Definer for amplifiers and comparators in the Multimedia Business Unit of Maxim Integrated Products. Before joining Maxim, he worked for ten years as a mixed-signal designer in several ATE companies. He earned Bachelor and Masters Degrees in Electrical Engineering at the University of Milan, Italy.

