Edited by Bill Travis

Input filter prevents instrumentation-amp RF-rectification errors

Charles Kitchin, Lew Counts, and Moshe Gerstenhaber, Analog Devices, Wilmington, MA

Instrumentation amplifiers serve in a variety of applications that need to extract a weak differential signal from large common-mode noise or interference. However, designers often overlook the potential problem of RF rectification inside the instrumentation amplifier. The amplifier's common-mode rejection normally greatly reduces common-mode signals at an instrumentation amplifier's input. Unfortunately, RF rectification still occurs, because even the best instrumentation amplifiers have virtually no common-mode rejection at frequencies higher than 20 kHz. The amplifier's input stage may rectify a strong RF signal and then appear as a dc-offset error. Once the input stage rectifies the signal, no amount of lowpass-filtering at the instrumentation amplifier's output can remove the error. Finally, if the RF interference is intermittent, measurement errors may go undetected. The best practical solution to this problem is to provide RF attenuation ahead of the instrumentation amplifier by using a differential lowpass filter. The filter needs to remove as much RF energy as possible from the input lines, preserve the ac signal's "balance" between each line and ground (common), and maintain a high enough input impedance over the measurement bandwidth to avoid loading the signal source. **Figure 1** provides a basic building block for a wide range of differential RFI filters.

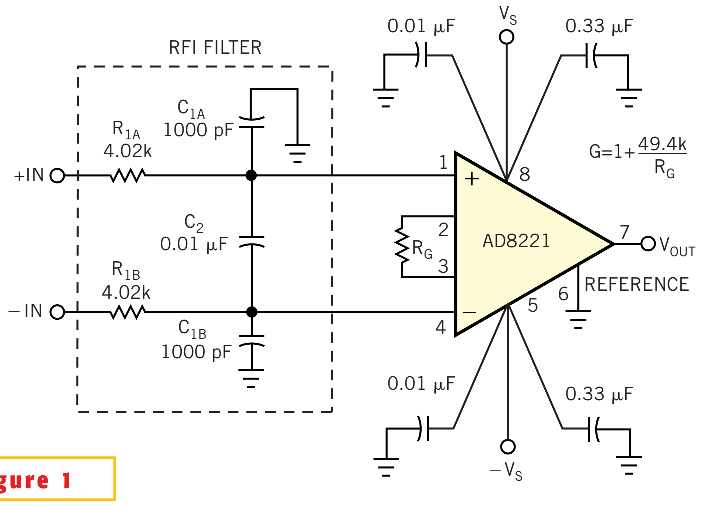

Figure 1

This lowpass-filter circuit prevents RF-rectification errors in instrumentation amplifiers.

The component values are typical of those for the latest generation of instrumentation amplifiers, such as the AD-8221, which has a typical −3-dB bandwidth of 1 MHz and a typical voltage noise level of $7\text{ nV}/\sqrt{\text{Hz}}$. In addition to RFI suppression, the filter also provides additional input-overload protection; resistors R_{1A} and R_{1B} help isolate the instrumentation amplifier's input circuitry from the external signal source. **Figure 2** shows a simplified version of the RFI circuit. It reveals that the filter forms a bridge circuit whose output appears across the instrumentation amplifier's input pins. Because of this connection, any mismatch between the time constants of C_{1A}/R_{1A} and C_{1B}/R_{1B} unbalance the bridge and reduce high-frequency common-mode rejection. Therefore, resistors R_{1A} and R_{1B} and capacitors C_{1A} and C_{1B} should always be equal. C_2 connects across the "bridge output" so that C_2 is effectively in parallel with the series combination of C_{1A} and C_{1B}. Thus connected, C_2 effectively reduces any ac common-mode-rejection errors from mismatching. For example, making C_2 10 times larger than C_1 provides a 20-times reduction in common-mode-rejection errors arising from C_{1A}/C_{1B} mismatch. Note that the filter does not affect dc common-mode rejection.

The RFI filter has differential and common-mode bandwidths. The differential bandwidth defines the frequency response of the filter with a differential input signal applied between the circuit's two inputs, +IN and −IN. The sum of the two equal-value input resistors, R_{1A} and R_{1B}, and the differential capacitance,

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which is C_2 in parallel with the series combination of C_{1A} and C_{1B}, establish this RC time constant. The −3-dB differential bandwidth of this filter is equal to $BW_{DIFF}=[1/(2\pi R(2C_2+C_1))]$. The common-mode bandwidth defines what a common-mode RF signal “sees” between the two inputs tied together and ground. C_2 does not affect the bandwidth of the common-mode RF signal, because this capacitor connects *between* the two inputs, helping to keep them at the same RF-signal level. Therefore, the parallel impedance of the two RC networks (R_{1A}/C_{1A} and R_{1B}/C_{1B}) to ground sets common-mode bandwidth. The −3-dB common-mode bandwidth is equal to $BW_{CM}=1/(2\pi R_1C_1)$.

Using the circuit of **Figure 1**, with a C_2 value of 0.01 μF, the −3-dB differential-signal bandwidth is approximately 1900 Hz. When operating at a gain of 5, the circuit has measured dc-offset shift over a frequency range of 10 Hz to 20 MHz of less than 6 μV referred to the input. At unity gain, there is no measurable dc-offset shift. Some instrumentation amplifiers are more prone to RF rectification than others and may need a more robust filter. A micropower instrumentation amplifier, such as the AD627, with its low-input-stage operating current, is a good example. The simple expedient of increasing the value of the two input resistors, R_{1A}/R_{1B}, that of capacitor C_2, or both can provide further RF attenuation at the expense of reduced signal bandwidth. Some steps for selecting RFI-filter component values follow:

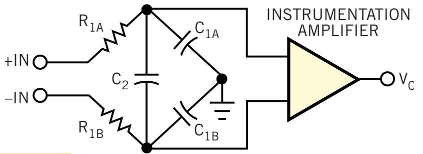
1. Decide on the value of the two series resistors and ensure that the previous circuitry can adequately drive this impedance. With typical values of 2 to 10 kΩ, these resistors should not contribute more noise than that of the instrumentation amplifier itself. Using a pair of 2-kΩ resistors adds Johnson noise of 8 nV/$\sqrt{\text{Hz}}$. This figure increases to 11 nV/$\sqrt{\text{Hz}}$ with 4-kΩ resistors and 18 nV/$\sqrt{\text{Hz}}$ with 10-kΩ resistors.

2. Select an appropriate value for capacitor C_2, which sets the filter’s differential (signal) bandwidth. Set this value as low as possible without attenuating the input signal. A differential bandwidth of 10 times the highest signal frequency is usually adequate.

3. Select values for capacitors C_{1A} and C_{1B}, which set the common-mode bandwidth. For decent ac common-mode rejection, these capacitors should have values 10% or lower of the value of C_2. The common-mode bandwidth should always be less than 10% of the instrumentation amplifier’s bandwidth at unity gain.

You should build the RFI filter using a pc board with a ground plane on both sides. All component leads should be as short as possible. Resistors R_1 and R_2 can be common 1% metal-film units. However, all three capacitors need to be reasonably high-Q, low-loss components. Capacitors C_{1A} and C_{1B} need to be ±5%-tolerance devices to avoid degrading the circuit’s common-mode rejection. Good choices are the traditional 5% silver micas, miniature micas, or the new Panasonic ±2% PPS film capacitors (Digi-key part number PS1H102G-ND).□

Figure 2



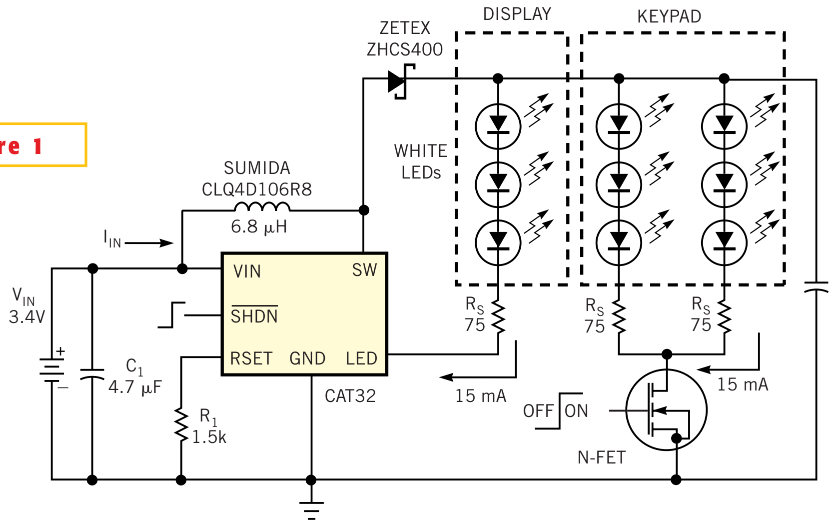
Capacitor C_2 shunts C_{1A}/C_{1B} and reduces ac common-mode-rejection errors arising from component mismatch.

White-LED driver backlights LCD and keypad

Fabien Franc, Catalyst Semiconductor, Sunnyvale, CA

Designers widely use white LEDs to backlight color LCDs and keypads in handheld devices, such as cell phones, MP3 players, GPS navigators, and PDAs. Their spectrum and brightness represent near-ideal light sources. One possible configuration for a phone or a phone/PDA combination is to have a group of three LEDs to light the display and six LEDs for the keypad. **Figure 1** shows a method for driving all the LEDs with a single driver IC from Catalyst Semiconductor (www.catsemi.com), the CAT32. Power comes from a single lithium-ion battery cell. A FET switch can independently turn off the group of six LEDs. The shutdown input, $\overline{\text{SHDN}}$, on the CAT32 turns off all the LEDs. LED brightness is a direct function of the current running through

Figure 1



A single IC boosts the battery voltage to drive a total of nine LEDs.