AN-671
APPLICATION NOTE

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Reducing RFI Rectification Errors in In-Amp Circuits

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INTRODUCTION

Real-world applications must deal with an ever increasing amount of radio frequency interference (RFI). Of particular concern is where signal transmission lines are long and signal strength is low. This is the classic application for an in-amp since its inherent common-mode rejection allows it to extract weak differential signals riding on strong common-mode noise and interference.

One potential problem that is frequently overlooked, however, is that of radio frequency rectification inside the in-amp. When strong RF interference is present, it may become rectified by the IC and then appear as a dc output offset error. Common-mode signals present at an in-amp's input are normally greatly reduced by the amplifier's common-mode rejection.

Unfortunately, RF rectification occurs because even the best in-amps have virtually no common-mode rejection at frequencies above 20 kHz. A strong RF signal may become rectified by the amplifier's input stage and then appear as a dc offset error. Once rectified, no amount of low-pass filtering at the in-amp output will remove the error. If the RF interference is of an intermittent nature, this can lead to measurement errors that go undetected.

DESIGNING PRACTICAL RFI FILTERS

The best practical solution to this problem is to provide RF attenuation ***ahead*** of the in-amp by using a differential low-pass filter. The filter needs to do three things: remove as much RF energy as possible from the input lines, preserve the ac signal 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 number of differential RFI filters. Component values shown were selected for the AD8221, which has a typical –3 dB BW of 1 MHz and a typical voltage noise level of 7 nV/$\sqrt{Hz}$. In addition to RFI suppression, the filter provides additional input overload protection, as resistors R1a and R1b help isolate the in-amp's input circuitry from the external signal source.

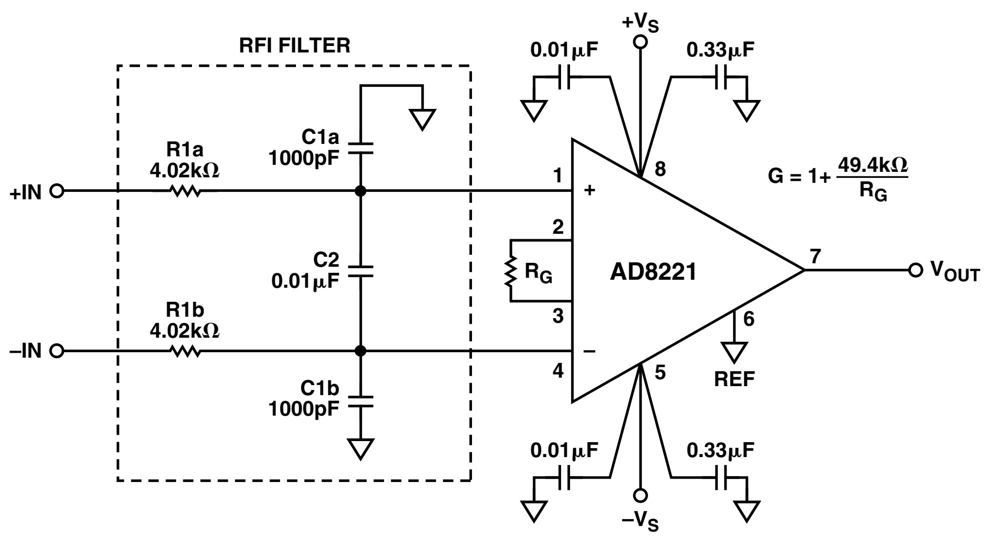

Figure 1. LP Filter Circuit to Prevent RFI Rectification Errors

Figure 2 is a simplified version of the RFI circuit. It reveals that the filter forms a bridge circuit whose output appears across the in-amp's input pins. Because of this, any mismatch between the time constants of C1a/R1a and C1b/R1b will unbalance the bridge and reduce high frequency common-mode rejection. Therefore, resistors R1a and R1b and capacitors C1a and C1b should always be equal.

As shown, C2 is connected across the bridge output so that C2 is effectively in parallel with the series combination of C1a and C1b. Thus connected, C2 very effectively reduces any ac CMR errors due to mismatching. For example, if C2 is made ten times larger than C1, this provides a 20× reduction in CMR errors due to C1a/C1b mismatch. Note that the filter does not affect dc CMR.

The RFI filter has two different bandwidths: differential and common-mode. The differential BW defines the frequency response of the filter with a differential input signal applied between the circuit's two inputs, +IN and –IN. This RC time constant is established by the sum of the two equal-value input resistors (R1a, R1b) together with the differential capacitance, which is C2 in parallel with the series combination of C1a and C1b.

The –3 dB ***differential*** bandwidth of this filter is equal to

$$BW_{DIFF} = \frac{1}{2\pi R(2C2 + C1)}$$

The common-mode bandwidth defines what a common-mode RF signal sees between the two inputs tied together and ground. It's important to realize that C2 does not affect the BW of the common-mode RF signal, as this capacitor is connected *between* the two inputs (helping to keep them at the same RF signal level). Therefore, common-mode BW is set by the parallel impedance of the two RC networks (R1a/C1a and R1b/C1b) to ground.

The –3 dB ***common-mode*** bandwidth is equal to

$$BW_{CM} = \frac{1}{2\pi R1C1}$$

Using the circuit of Figure 1, with a C2 value of 0.01 μF as shown, the –3 dB differential signal BW is approximately 1900 Hz. When operating at a gain of 5, the circuit's measured dc offset shift over a frequency range of 10 Hz to 20 MHz was less than 6 μV RTI. At unity gain, there was no measurable dc offset shift.

The RFI filter should be built using a PC board with ground planes on both sides. All component leads should be made as short as possible. Resistors R1 and R2 can be common 1% metal film units. However, all three capacitors need to be reasonably high Q, low loss components. Capacitors C1a and C1b need to be ±5% tolerance devices to avoid degrading the circuit's common-mode rejection. The traditional 5% silver micas, miniature size micas, or the new Panasonic ±2% PPS film capacitors (Digi-key part # PS1H102G-ND) are recommended.

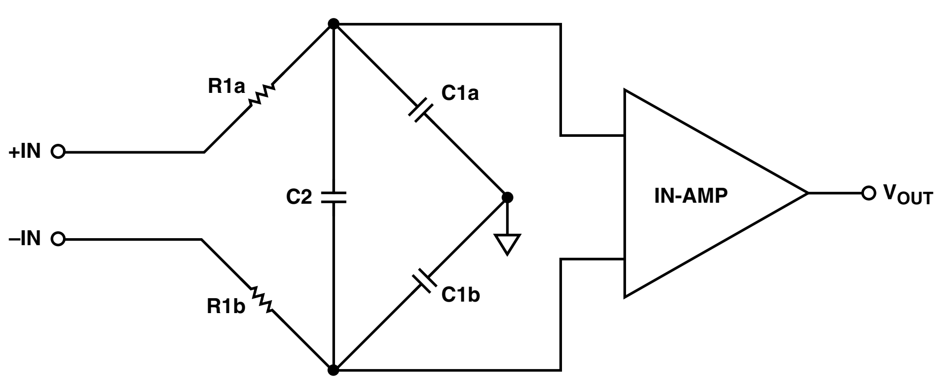

Figure 2. Capacitor C2 Shunts C1a/C1b and Very Effectively Reduces AC CMR Errors Due to Component Mismatching

SELECTING RFI INPUT FILTER COMPONENT VALUES USING A COOKBOOK APPROACH.

The following general rules will greatly ease the design of an RC input filter.

1. First, decide on the value of the two series resistors, while ensuring that the previous circuitry can adequately drive this impedance. With typical values between 2 kΩ and 10 kΩ, these resistors should not contribute more noise than that of the in-amp itself. Using a pair of 2 kΩ resistors will add a Johnson noise of 8 nV/$\sqrt{Hz}$; this increases to 11 nV/$\sqrt{Hz}$ with 4 kΩ resistors and to 18 nV/$\sqrt{Hz}$ with 10 kΩ resistors.
2. Next, select an appropriate value for capacitor C2, which sets the filter's differential (signal) bandwidth. It's always best to set this as low as possible without attenuating the input signal. A differential BW of 10 times the highest signal frequency is usually adequate.
3. Then select values for capacitors C1a and C1b, which set the common-mode bandwidth. For decent ac CMR, these should be 10% the value of C2 or less. The common-mode bandwidth should always be less than 10% of the in-amp's bandwidth at unity gain.

SPECIFIC DESIGN EXAMPLES

1. An RFI Circuit for AD620 Series In-Amps

Figure 3 is a circuit for general-purpose in-amps such as the AD620 series, which have higher noise levels (12 nV/$\sqrt{Hz}$) and lower bandwidths than the AD8221. Accordingly, the same input resistors were used, but capacitor C2 was increased approximately five times, to 0.047 µF, to provide adequate RF attenuation. With the values shown, the circuit's –3 dB BW is approximately 400 Hz; the bandwidth may be increased to 760 Hz by reducing the resistance of R1 and R2 down to 2.2 kΩ. Note that this increased BW does not come free. It requires the circuitry preceding the in-amp to drive a lower impedance load and results in somewhat less input overload protection.

2. An RFI Circuit for Micropower In-Amps

Some in-amps are more prone to RF rectification than others and may need a more robust filter. A micropower in-amp, 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, R1a/R1b, and/or that of capacitor C2, will provide further RF attenuation, at the expense of a reduced signal bandwidth.

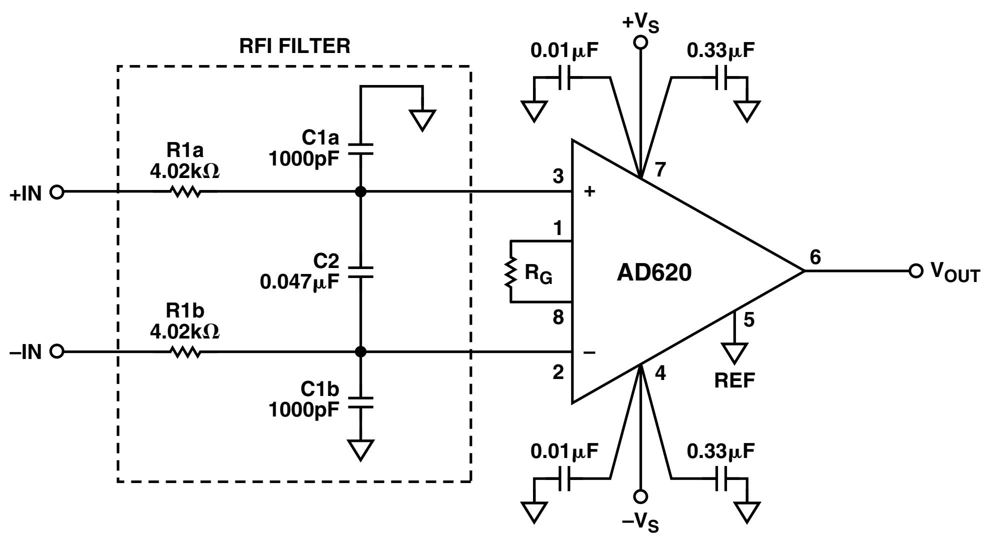

Figure 3. RFI Circuit for AD620 Series In-Amps

Since the AD627 in-amp has higher noise (38 nV/$\sqrt{Hz}$) than general-purpose ICs like the AD620 series devices, higher value input resistors can be used without seriously degrading the circuit's noise performance. The basic RC RFI circuit of Figure 1 was modified to include higher value input resistors and is shown in Figure 4.

The filter bandwidth is approximately 200 Hz. At a gain of 100, the maximum dc offset shift with a 1 V p-p input applied is approximately 400 μV RTI over an input range of 1 Hz to 20 MHz. At the same gain, the circuit's RF signal rejection (RF level at output/RF applied to the input) will be better than 61 dB.

3. An RFI Filter for the AD623 In-Amp

Figure 5 shows the recommended RFI circuit for use with the AD623 in-amp. As this device is less prone to RFI than the AD627, the input resistors can be reduced in value from 20 kΩ to 10 kΩ; this increases the circuit's signal bandwidth and lowers the resistors' noise contribution. Moreover, the 10 kΩ resistors still provide very effective input protection. With the values shown, the bandwidth of this filter is approximately 400 Hz. Operating at a gain of 100, the maximum dc offset shift, with a 1 V p-p input, is less than 1 μV RTI. At the same gain, the circuit's RF signal rejection is better than 74 dB.

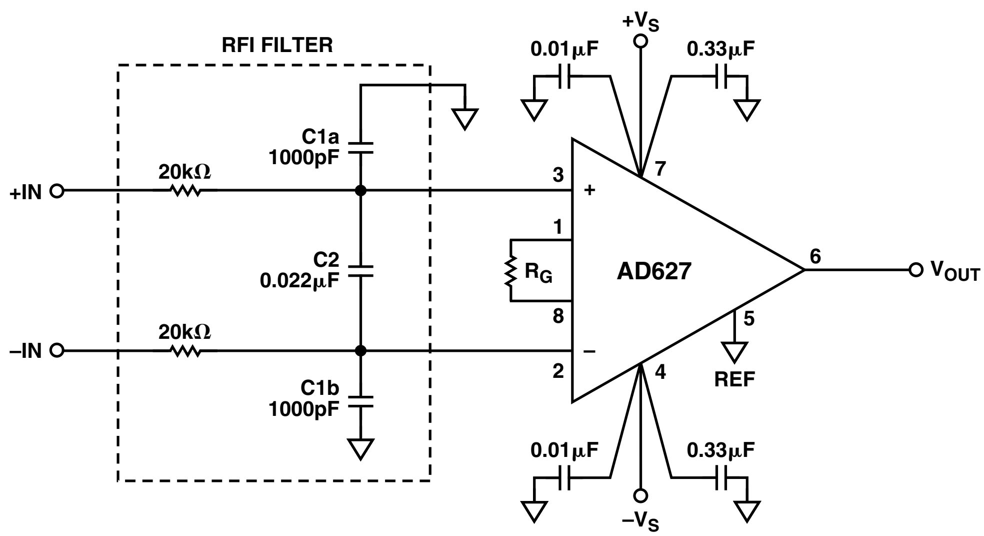

Figure 4. RFI Suppression Circuit for the AD627

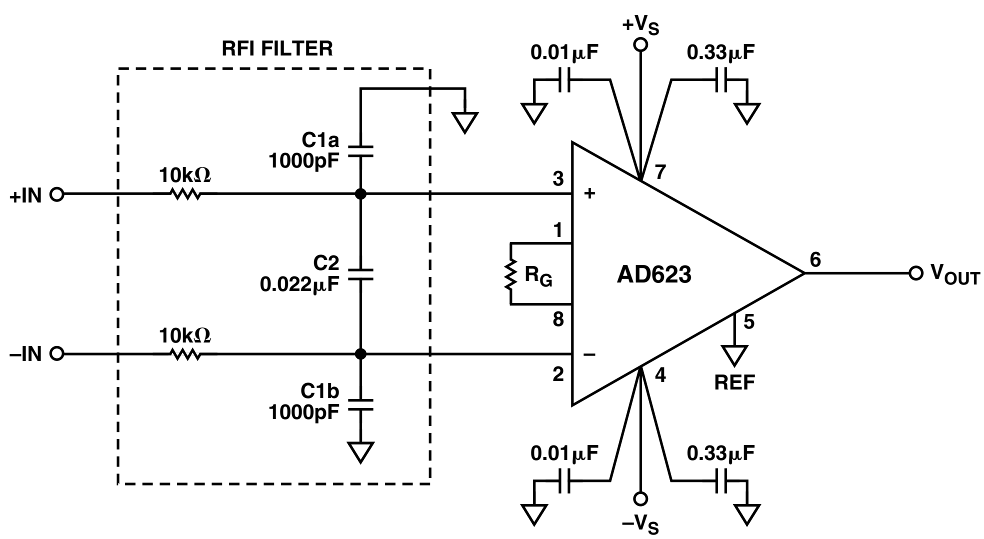

Figure 5. AD623 RFI Suppression Circuit

4. AD8225 RFI Filter Circuit

Figure 6 shows the recommended RFI filter for this in-amp. The AD8225 in-amp has a fixed gain of 5 and a bit more susceptibility to RFI than the AD8221. Without the RFI filter, with a 2 V p-p, 10 Hz to 19 MHz sine wave applied, this in-amp measures about 16 mV RTI of dc offset. The filter used provides a heavier RF attenuation than that of the AD8221 circuit by using larger resistor values: 10 kΩ instead of 4 kΩ. This is permissible because of the AD8225's higher noise level. Using the filter, there was no measurable dc offset error.

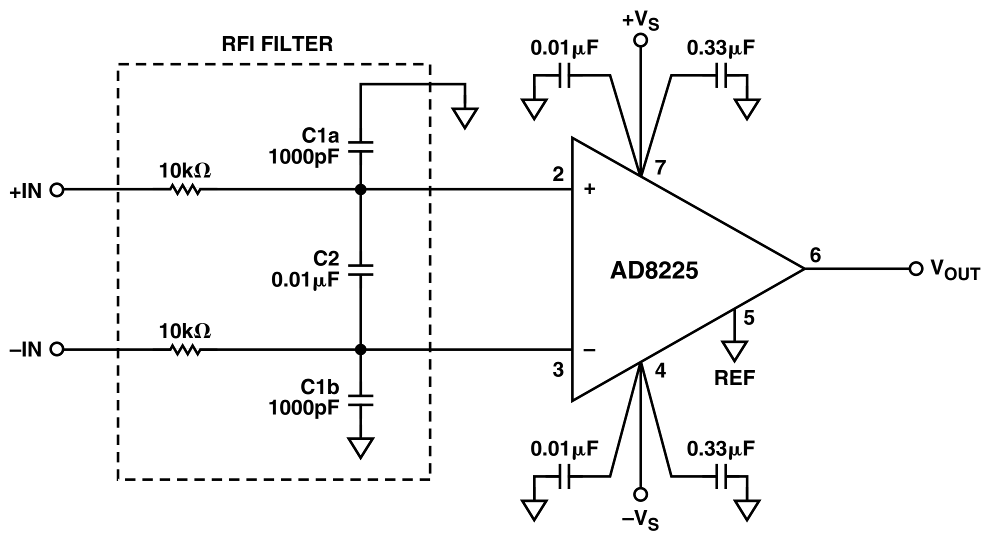

Figure 6. AD8225 RFI Filter Circuit

5. Using Common Mode RF Chokes for In-Amp RFI Filters

As an alternative to using an RC input filter, a commercial common-mode RF choke may be connected in front of an in-amp as shown in Figure 7. A common-mode choke is a two-winding RF choke using a common core. Any RF signals that are common to both inputs will be attenuated by the choke. The common-mode choke provides a simple means for reducing RFI with a minimum of components and provides a greater signal pass band, but the effectiveness of this method depends on the quality of the particular common-mode choke being used. A choke with good internal matching is preferred. Another potential problem with using the choke is that there is no increase in input protection as is provided by the RC RFI filters.

Using an AD620 in-amp with the RF choke specified, at a gain of 1000, and a 1 V p-p common-mode sine wave applied to the input, the circuit of Figure 7 reduces the dc offset shift to less than 4.5 μV RTI. The high frequency common-mode rejection ratio was also greatly reduced, as shown by Table I.

Table I. AC CMR vs. Frequency, Using the Circuit of Figure 7.

Frequency	CMRR
100 kHz	100 dB
333 kHz	83 dB
350 kHz	79 dB
500 kHz	88 dB
1 MHz	96 dB

Because some in-amps are more susceptible to RFI than others, the use of a common-mode choke may sometimes prove inadequate. In these cases, an RC input filter is a better choice.

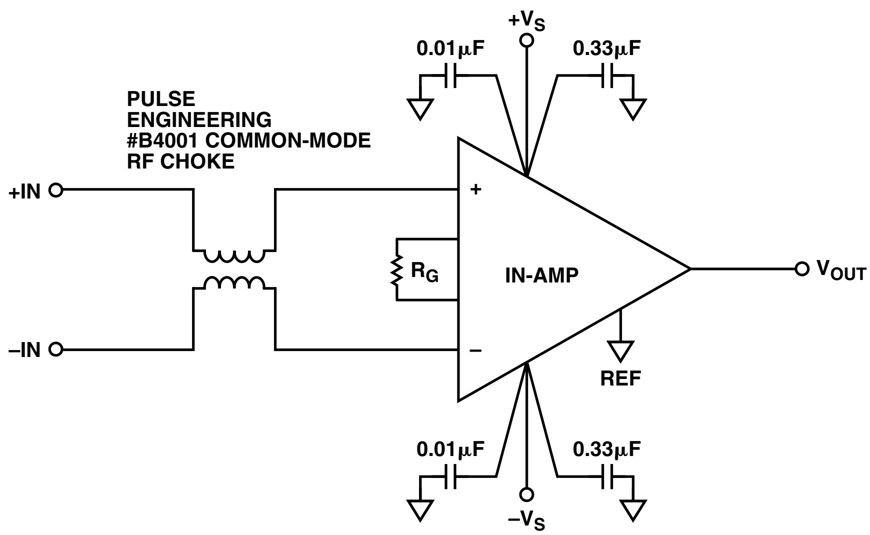

Figure 7. Using a Commercial Common-Mode RF Choke for RFI Suppression

6. RFI Testing

Figure 8 shows a typical setup for measuring RFI rejection. To test these circuits for RFI suppression, connect the two input terminals together using very short leads. Connect a good quality sine wave generator to this input via a 50 Ω terminated cable.

Using an oscilloscope, adjust the generator for a 1 V p-p output at the generator end of the cable. Set the in-amp to operate at high gain (such as a gain of 100). DC offset shift is simply read directly at the in-amp's output using a DVM.

For measuring high frequency CMR, use an oscilloscope connected to the in-amp output by a compensated scope probe, and measure the peak-to-peak output voltage (i.e., feedthrough) versus input frequency. When calculating CMRR versus frequency, remember to take into account the input termination ($V_{IN}/2$) and the gain of the in-amp.

$$CMRR = 20\log\frac{\left(\frac{V_{IN}}{2}\right)}{\left(\frac{V_{OUT}}{Gain}\right)}$$

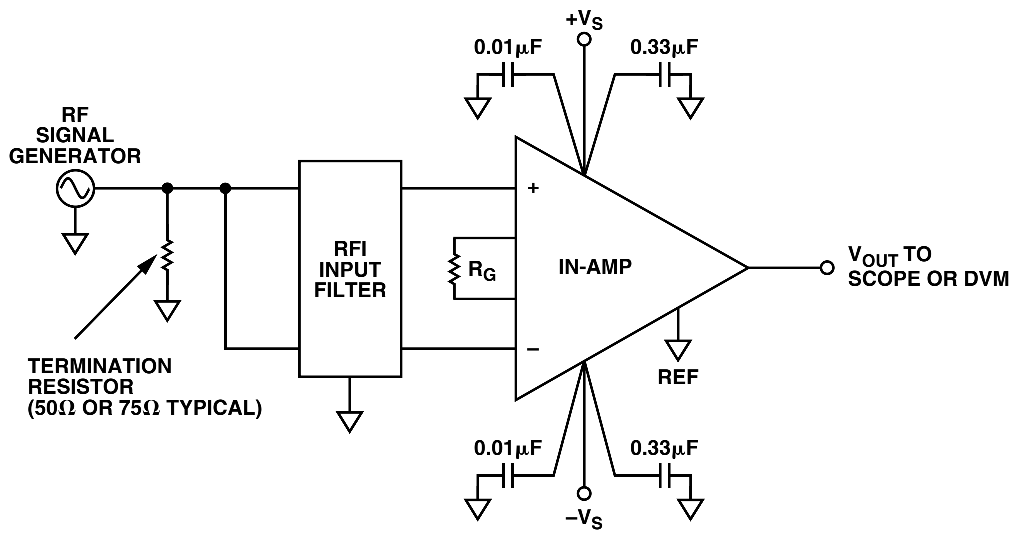

Figure 8. Typical Test Setup for Measuring an In-Amp's RFI Rejection

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