Achieving multiple gain ranges with instrumentation amplifiers

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Question:

I have an instrumentation amplifier but need wider dynamic range than I can get with a single gain. Can I multiplex gain resistors for programmable gain?

Answer:

To maximise dynamic range in precision sensor measurements, it may be necessary to use a programmable gain instrumentation amplifier (PGIA). Because most instrumentation amplifiers (in-amps) use an external gain resistor (R_G) to set the gain, it would seem the desired programmed gains can be achieved with a set of multiplexed gain resistors. Whilst this is possible, there are three major considerations to make before implementing a system this way with a solid-state multiplexer: supply and signal voltage limitations, switch capacitance and on resistance.

Solid-state CMOS switches require a power supply. When the source or drain voltage exceeds the supply, fault current can flow and cause an incorrect output. The voltage at each R_G pin is typically within a diode drop of the voltage at the corresponding input; therefore, the signal voltage range of the switch must be greater than the input range of the in-amp.

Capacitances and resistances

The switch capacitance is similar to hanging a capacitor on one of the R_G pins and leaving the other R_G pin alone. A large enough capacitor could cause peaking or instability, but more overlooked is the effect on the common-mode rejection ratio, or CMRR. In board layout, ground plane is generally removed from beneath the R_G pins, because capacitive imbalance of below 1pF greatly reduces CMRR.

The switch capacitance can be tens of picofarads, causing large errors. Taking the simple case of an in-amp with perfect CMRR, no R_G present and capacitance at only one R_G pin, the CMRR due to the capacitance can be determined by:

$$CMRR(f) = -20 \times \log_{10} (f \times 2\pi \times RF \times C_{RG})$$

For example, if the internal feedback resistance, R_F = 25kΩ and C_{RG} = 10pF, CMRR at 10kHz is only 36dB. This suggests using a low capacitance switch or a balanced switching architecture like the one shown in Figure 2 with single-pole, single-throw (SPST) switches.

And, the on resistance of the switch impacts the gain directly according to the gain equation of the in-amp. If the on resistance is low enough to achieve the desired

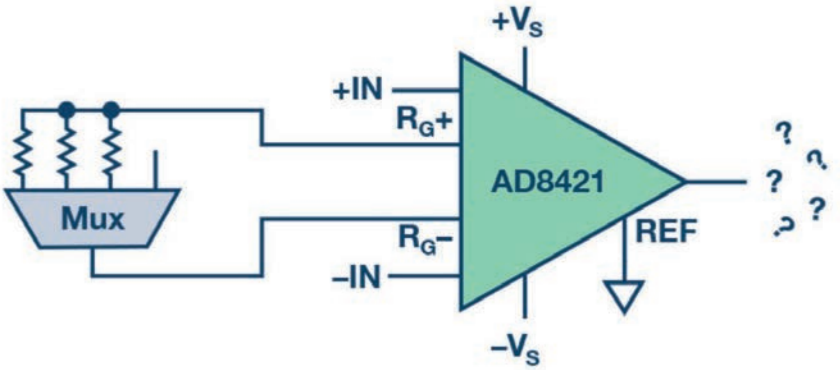

Figure 1: AD8421 PGIA with multiplexer

gain, this might be fine. However, the on resistance of the switch changes with the drain voltage, specified as $R_{FLAT(ON)}$. The change in the switch resistance creates both a gain dependence on the common-mode voltage and a gain non-linearity effect. For example, using an R_G of 1kΩ and a switch with 10Ω $R_{FLAT(ON)}$, there will be a 1% gain uncertainty over the common-mode range. A certain portion of that will translate to the differential signal – for example, a 2Ω change would be 2000ppm non-linearity. This suggests using a low-on-resistance switch, which is contrary to the idea of a low-capacitance switch, because low on-resistance is achieved with large transistor device size whereas low capacitance is achieved with small transistors. The ADG5412F fault-protected, quad SPST switch provides a good solution in many cases. The architecture of these fault-protected switches allows them to provide 10Ω on-resistance that is very flat across the signal range and only 12pF off capacitance.

Alternatives

There are also other ways to implement the programmable gain in-amp function if these circuits don't meet the design requirements. It is highly recommended to choose an appropriate integrated PGIA, designed for high performance, with a smaller footprint and fewer parasitics than discrete solutions and whose specifications include the effects from the internal switches. Some good examples of integrated PGIAs are AD8231, AD8250/AD8251/AD8253 and LTC6915. Additionally, there are solutions with higher levels of integration that include this function, such as AD7124-8 and ADAS3022.

In-amps

In-amps are high-precision components that are as balanced as possible at the silicon level, to reject common-mode. It is possible to build a programmable-gain in-amp using solid-state switches, but it is also very easy to throw off the balance that defines the in-amp and reduce the circuit's precision. The non-ideal effects of the switches need to be considered to make the necessary tradeoffs. Balanced switching architectures and modern switches like ADG5412F are great tools to optimise these designs. Integrated PGIAs are recommended because the effects of the switches are already included in the specifications. EW

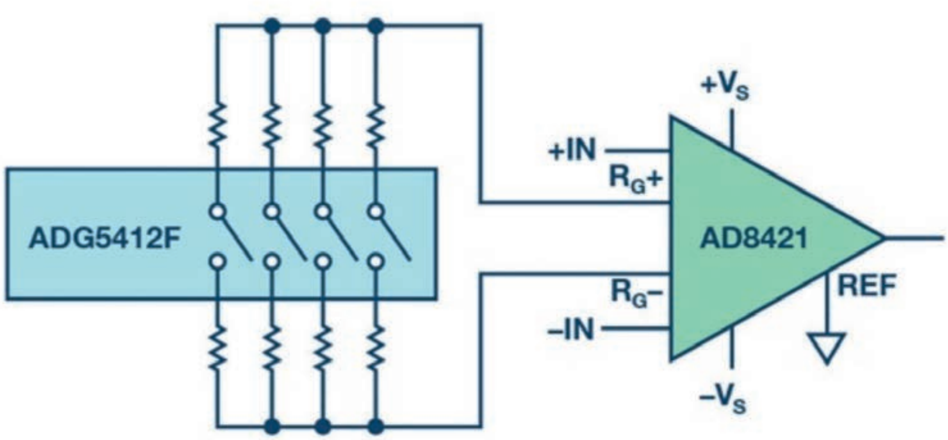

Figure 2: Balanced PGIA with ADG5412F quad SPST and AD8421