Programmable Instrumentation Amplifier Provides Arbitrary Gain Values

Data-acquisition systems often include a programmable-gain amplifier to ensure that different-amplitude signals will be digitized to full resolution by the A/D converter. Large signals require little or no amplification, while low-level signals require high amplification to reduce the effect of converter noise. Two 4-channel differential multiplexers (Fig 1) accomplish this task by selecting different gain levels as required for each of four differential-input channels.

Because channel-select signals drive the multiplexers in parallel, selecting a channel via IC_1 automatically sets the correct gain via IC_2. Figure 1 illustrates a 4-channel differential system. To construct an 8-channel system with as many as eight levels of gain, substitute 8-channel differential multiplexers for IC_1 and IC_2. (And if you provide separate channel-select signals for each multiplexer, you can select any of the gain values for a given channel.) Resistors R_1 through R_7 set the gain values in Figure 1 as follows, where R_T is the sum of R_1 through R_7:

Channel	Switches Closed	Desired Gain	Formula
1	S_{1A}, S_{1B}	1 =	R_T/R_T
2	S_{2A}, S_{2B}	2 =	$R_T/(R_2+R_3+R_4+R_5+R_6)$
3	S_{3A}, S_{3B}	4 =	$RT/(R_3+R_4+R_5)$
4	S_{4A}, S_{4B}	8 =	RT/R_4

Channel 1's gain is necessarily unity, but the other channels can have any reasonable gain value. (The formulas listed apply for any gain numbers, not just the binary values 1, 2, 4, 8 presented here as an example.) To determine the resistor values, begin by assigning an arbitrary value such as 5k to R_4: $R_T/R_4 = 8$, therefore $R_T = 40k$ and $R_3+R_4+R_5 = 10k$. $R_4 = 5k$, therefore $R_3+R_5 = 10k-5k = 5k$. Setting R_3 and R_5 equal yields $R_3 = R_5 = 2.5k$. Similarly, $R_2 = R_6 = 5k$, and $R_1 = R_7 = 10k$.

Note that a 1-to-4 resistor range (2.5k to 10k, suitable for realization as a custom resistor network) implements the gain range of 1 to 8. Note also, that IC_2's $r_{DS(ON)}$ switch resistances contribute virtually no voltage error because they conduct no signal current.

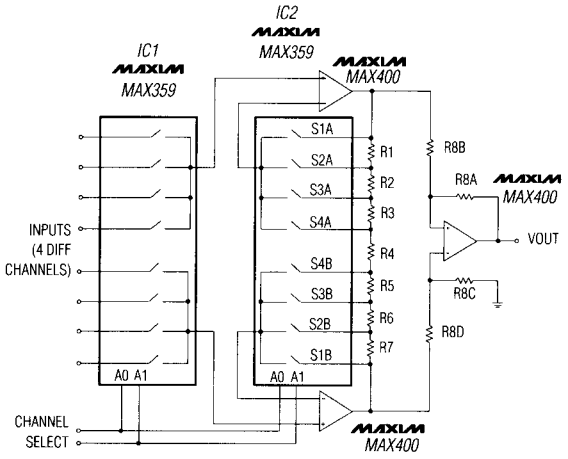

Figure 1. This instrumentation amplifier (IC_2 and the three op amps) automatically sets one of four arbitrary gain levels for each input channel selected by multiplexer IC_1. Resistor values R_1 through R_7 determines the gain levels.

Leakage currents cancel to some degree, so errors due to leakage depend primarily on the differential leakage currents: If S_{1A} has 1nA of leakage and S_{1B} has 0.9nA of leakage, then only the 0.1nA difference current, flowing in the gain-setting resistors, can cause error. To further reduce the effect of leakage-current errors, choose a low-leakage differential multiplexer such as the Maxim MAX329, whose leakage is one-tenth that of the MAX359 shown.

The output stage converts the differential signal path to a single-ended output. For unity gain in the output stage, include four closely matched resistors of the same value (R_{8A-8D}). For other gains, use closely matched ratios R_{8A}/R_{8B} and R_{8C}/R_{8D} that equal the desired value.

The three op amps should combine precision (low I_B, I_{OS}, and V_{OS}, and high A_{VOL}) with as much speed as the application requires. Good common-mode rejection is important, and the amplifiers' common-mode input range should exeed the maximum signal level by at least two volts.

(Circle 4)