Application Brief

Selecting the Right Multiplexer for a Discrete Programmable Gain Amplifier (PGA)

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Introduction

A programmable gain amplifier (PGA) is an electronic amplifier whose gain is controlled by a digital or analog signal. PGAs combine two fundamental building blocks of electronics: multiplexers and amplifiers. The most common use cases for PGAs range from data acquisition systems to motor drives. Typically, PGAs are most useful when an input sensor signal needs to vary across different gain values to then be amplified to carry the signal into the next system component. A multiplexer allows for this switching between the different gain values thereby changing the level of amplifications. This document discusses why a multiplexer is used in a PGA, along with the two critical parameters to account for when choosing the right multiplexer for your PGA: on-capacitance (C_{ON}) and on-resistance (R_{ON}).
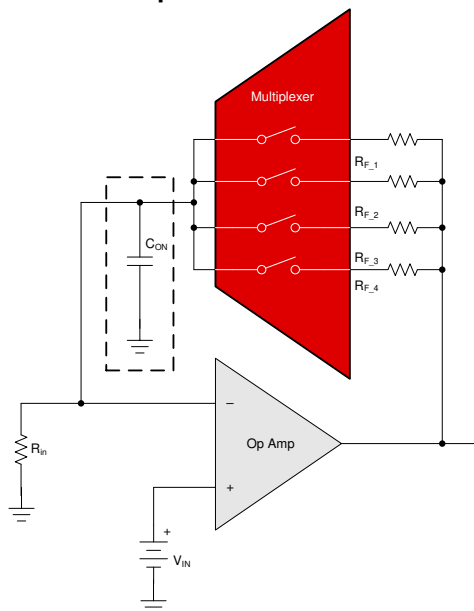
Why Select a Multiplexer?

Figure 1. Circuit Model of Basic Discrete PGA

To achieve different gain values, the feedback resistor (R_f) value, see Figure 1, must vary in accordance with the gain needed, as stipulated by Equation 1 of an non-inverting operational amplifier.

$$\text{Gain} = 1 + \frac{R_f}{R_{in}} \tag{1}$$

This variation can be achieved using a multiplexer. A multiplexer allows for the system designers to switch between different R_f values thereby allowing for multiple gain possibilities. Multiplexers are great cost-effective designs to use inside PGAs because multiplexers are available in a variety of configurations while giving the system designer the flexibility in the gain that needs to be achieved.

Low On-Capacitance

Stability issues can arise from the parasitic on-capacitance interaction with the feedback resistor of the op amp, as Figure 1 shows. The on-capacitance of the multiplexer can cause oscillations in the output signal of the multiplexer, which can negatively impact the integrity of the amplified signal. Therefore, selecting a multiplexer with a low C_{ON} , such as the TMUX1511, can help minimize signal distortion and improve the quality and accuracy of the outputted amplifier signal.

For example, a single channel of a 1:1 switch typically has 40pF of capacitance. Therefore, when all four channels are conducting, the total C_{ON} of the feedback path can be 160pF. However, using a low C_{ON} multiplexer, such as the TMUX1511, with 2.5pF of C_{ON} leads to a total feedback capacitance of only 10pF with all four channels conducting. This significantly lower feedback capacitance makes sure that signal oscillations are minimal and the overall impact on the amplified signal is minimal, as Figure 2 illustrates. For more information, see *Improve Stability Issues with Low C_{ON} Multiplexers* .
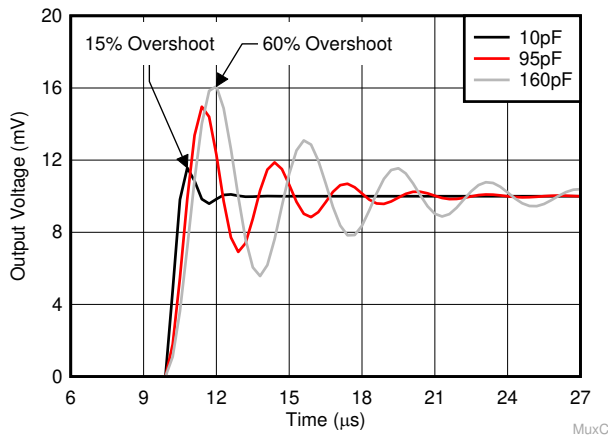
Figure 2. Op Amp Instability

Low On-Resistance

The on-resistance of a multiplexer must be as low as possible to maximize signal integrity through amplification. The higher the R_{ON} and the wider the R_{ON} flatness range, the more distortion the output signal has due to a higher gain error. The gain error of a multiplexer increases as the R_{ON} of the multiplexer increases. For example, the gain error for the circuit in Figure 1 can be calculated using Equation 2.

$$G_{error} = \frac{R_{ON}}{R_{in} + R_f} \times 100 \tag{2}$$

This gain error calculation assumes a non-inverting circuit and does not account for all other attributes that affect gain error, as the calculation is fundamentally focused on R_{ON}. The gain error, as Table 1 shows, increases from 0.18% to 10.90% as R_{ON} increases from 2 Ω to 120 Ω. Additionally, since R_f is in series with R_{ON}, the effects of the changing values of R_{ON} are linear, compared to the

gain. Finally, in computing the gain error in Table 1-1, an enabled signal path and values of $R_{IN} = 100Ω$ and $R_f = 1\ kΩ$ are assumed.

On-Resistance vs On-Capacitance

There is typically a tradeoff between low R_{ON} values versus low C_{ON} values. To achieve a low R_{ON}, the size of the multiplexer die needs to be wider, so that the current can travel through with minimal interruption. However, as the die size increases, so does the on-capacitance. Low on-capacitance is the result of a smaller distance from source to drain on the multiplexer. Therefore, the system designer must make sure that the preferred multiplexer is selected for the design taking into account the effects of C_{ON} vs R_{ON} on the system. The aforementioned TMUX1511 is an example of a multiplexer that has low R_{ON} (2Ω) and low C_{ON} (3.3pF).

Summary

This document discusses why a multiplexer is used in a PGA along with the two critical multiplexer parameters: on-capacitance and on-resistance. Multiplexers are used to switch between different R_f values, which in turn, allows for different gain values for the same op amp. In selecting the right multiplexer, the two critical parameters to be aware of are on-capacitance and on-resistance. The lower the on-capacitance, the lower the signal oscillation and distortion, and the more accurate the output signal. Low on-resistance provides a lower gain error and therefore a more accurate signal. Lastly, the system designer must make sure that the preferred multiplexer is selected for the design taking into account the effects of C_{ON} vs R_{ON} on the system.

Additional Resources

*   Texas Instruments, *TI Precision Labs - Switches and Multiplexers: On-Resistance Flatness and On-Capacitance*, video.
*   Texas Instruments, *TI Precision Labs - Op Amps: Stability*, video.
*   Texas Instruments, *Improve Stability Issues with Low C_{ON} Multiplexers Application Brief*, application brief

Table 1. Gain Error Comparison and Device Comparison

Device	Configuration	Channel Count	R_{ON}	C_{ON}	Gain Error	Mux Friendly Op-Amps
TMUX1511	1:1	4	2Ω	3.3pF	0.18%	OPA2392
TMUX1108	8:1	1	2.5Ω	65pF	0.23 %	OPA2392
TMUX6112	1:1	4	120Ω	4.2pF	10.90 %	TLV9351
TMUX5412	1:1	4	20Ω	8pF	1.8%	TLV9351

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