Application Report

Choosing the Right Multiplexer for MCU Expansion

ABSTRACT

In the analog front end of many systems, reducing the part count, costs, and complexity is becoming paramount as the overall size of our technology is shrinking. In factory, automotive, and medical settings, an increase in the need to minimize the design exists while also maximizing the use of condition monitoring of analog sensing elements such as temperature and humidity sensors. As the number of such sensing elements increases, the available I/O pins on the MCU decreases; which could lead to more sensors than I/O pins. To mitigate this issue, designers have begun to use multiplexers to allow interfacing of multiple signals to one I/O pin. These signals can then be switched depending on the system conditions the designer sets. TI offers a wide variety of switches and multiplexers that can help in accomplishing this MCU expansion. This document discusses the necessity of expanding the GPIO of the MCU and ADC pins and what the specification of interests are when selecting the right multiplexer for your system.

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1 MCU ADC Input Sharing

MCUs are often used to monitor analog inputs by measuring the voltage via the internal ADC of the MCU. Frequently, a buffer may need to be added to source current to the ADC in cases where the analog signal being monitored does not drive enough current for the ADC to register the voltage variations. The amount of these signals an MCU can register is limited by the amount of I/O pins incorporated in their architecture. In a scenario where an MCU has only a single ADC input available but 4 sensing elements that require monitoring, the input count would fall 3 short of the system requirements. This scenario can be resolved with a multiplexing stage between the MCU and the sensors, as Figure 1-1 shows. This eliminates the need for a second processor or investing in a larger, pricier MCU or extra buffers that may be needed saving time, money, and reducing system size and complexity.

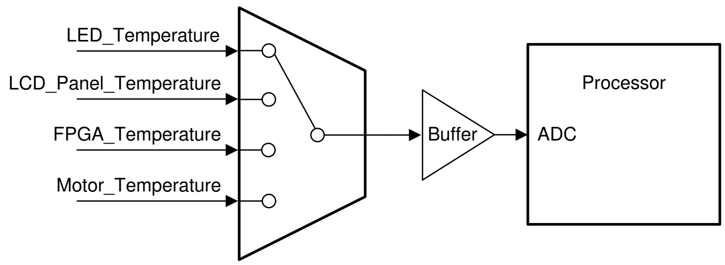

Figure 1-1. Expansion of 1 MCU ADC Input to 4 Sensor Outputs for Monitoring Using a Multiplexer

When selecting a proper multiplexer for your design it is important to first understand the equivalent circuit of the multiplexer, using passive components. Ideally, these switches will appear to be invisible to the circuit, as if they are not there. The reality is, as with any component, there is an accumulation of parasitic capacitances and resistances associated with the device in its use in real world applications. Figure 1-2 shows a simplified circuit model of a FET switch when the switch path is selected.

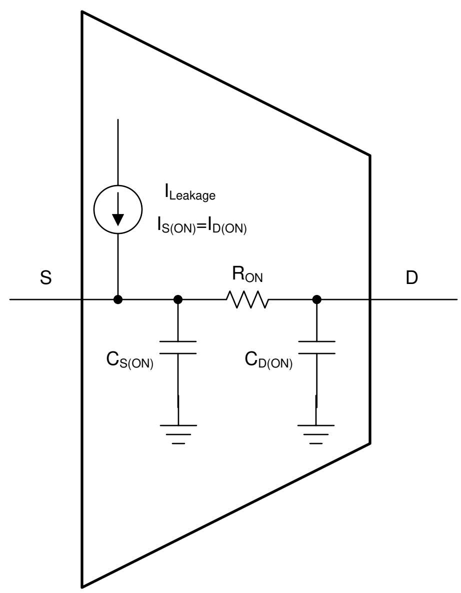

Figure 1-2. Simplified Circuit Model of FET Switch When Signal Switch is Selected

The parasitic on-resistance (R_{ON}) and on-capacitance (C_{SON}/C_{DON}) create a low pass filter through the chip. Although the load impedance heavily impacts the bandwidth of the multiplexers, minimizing the R_{ON} and C_{ON} can help limit bandwidth limitations associated with the switch itself. The leakage current introduced can contribute to DC errors and should be limited as much as possible for high accuracy applications. Some of the important considerations when selecting a multiplexer for expanding the MCU are the voltage range of the input signals, on-resistance, on-capacitance, on-leakage, and charge injection. These are explained in further detail in the *Multiplexer Specifications* section.

2 MCU GPIO Expansion

Similarly, MCU expansion can be used in generic GPIO pins on the MCU, where the ADC is not necessary to utilize. Here, there may be a need to monitor digital triggers or digital signals or send a plethora of digital cues. This may take a toll on the total GPIO count while requiring fairly limited processing. Multiplexing across these digital I/Os, as shown in Figure 2-1, can reduce the number of GPIOs required to do this.

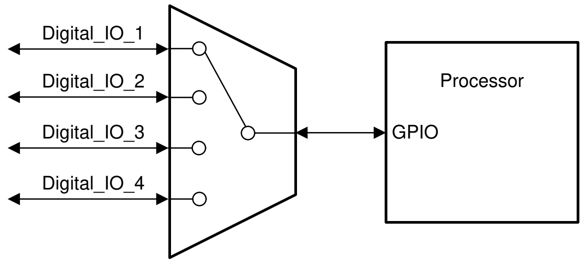

Figure 2-1. Expansion of 1 MCU GPIO to Four Digital I/Os Using A Multiplexer

It is important to note that TI multiplexers are passive FET switches that simply allow any signal through as long as they meet the recommended operation conditions listed in the datasheet. While many of multiplexers and switches from TI are defined as *analog multiplexers and signal switches*, this does not limit their ability to pass through digital signals. That is to say, digital signals can pass through these analog multiplexers as well, as long as they meet the recommended operation conditions for the switch in use. The important considerations to take into account when picking a multiplexer when implementing GPIO expansion is the On-Capacitance, Leakage Current and Signal Voltage Range. For more information see the *Multiplexer Specifications* section.

3 Multiplexer Specifications

Several multiplexer specifications are defined in the following list:

- Signal voltage range – Signal voltage ranges will vary depending on the output of the sensor and whether differential voltages with negative input swings or single-ended outputs are evident. Not all multiplexing devices can handle negative voltages, so finding a device that shows the signal switch input/output voltage whose lower limitations are below 0 V would be required for negative signal applications. This is often defined as either V_s, V_d, or $V_{i/o}$. Devices such as the TMUX6136 support a wide range of input signals ranging from –16.5 V to 16.5 V while still maintaining a low R_{ON} and C_{ON}.
- On-resistance (R_{ON}) – This is the resistance across the signal switch when the switch is turned on. A lower R_{ON} device, such as the TMUX1136, is especially useful in systems where the signal will not be amplified since the voltage will not drop across the signal switch and a close-to-original sensor input signal will be retained. If the design calls for an op amp or buffer in front of the built-in ADC of the MCU, a lower R_{ON} will decrease the gain error. Gain errors are heavily dependent on the load but minimizing the R_{ON} can still be beneficial. Furthermore, larger R_{ON} values create an offset voltage error when leakage current flows through the multiplexer. Simulations in Figure 3-1 illustrate the benefits of a low R_{ON}, modeling the TMUX1136 on the left. Here a 10-MHz signal is passed, with a 1-kΩ, 5-pF load. The 1.8-Ω R_{ON} of the TMUX1136 allows for proper signal pass-through and ensures that the signal integrity is maintained closely. An increase in the propogation delay due to a higher RC time constant is observed along with a decay in the overall signal.

  Figure 3-1 illustrates that a lower on-resistance (TMUX1136 on left) enables lower distortion and errors in signal transmission.

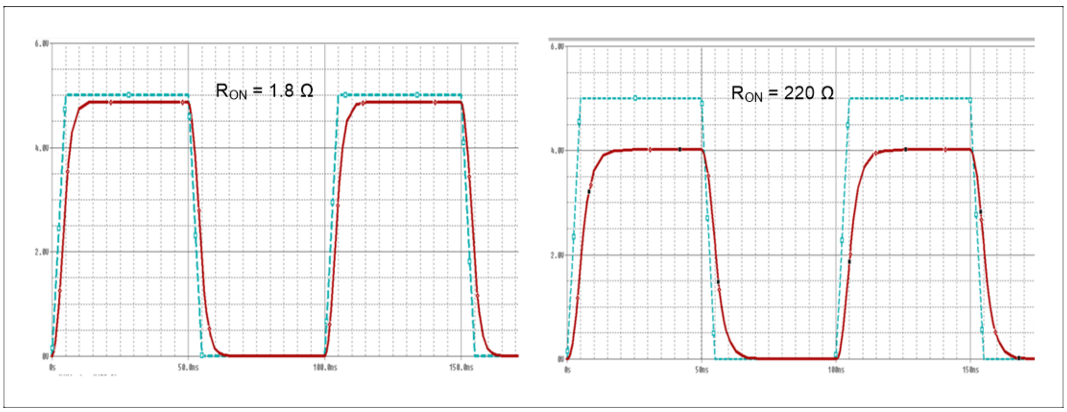

Figure 3-1. Comparison of On-Resistance Impact on Signal

- On-capacitance (C_{ON}) – This is the capacitance relative to ground seen by the system when the signal switch of the multiplexer is conducting. A low C_{ON} device, such as TMUX1308 , allows for quicker response time, optimizing the sampling rate that can be achieved as well as widening the bandwidth. When using an op amp or buffer in front of the built-in ADC of the MCU, a lower C_{ON} will have less negative effects on stability. Figure 3-2 illustrates the effects of on-capacitance on digital signals. The 15-pF device on the left is a simulation of the TMUX1308 signal switch capabilities at 10 MHz. A lower on-capacitance will minimize the RC time constant, allowing for the signal to maintain its integrity. The benefits of a low C_{ON} is described more in more detail in the *Improving Stability Issues with Low CON Multiplexers Application Note.*

  Figure 3-2 illustrates that a lower on-capacitance (TMUX1308 on left) provides less smoothing of the original (cyan) signal.

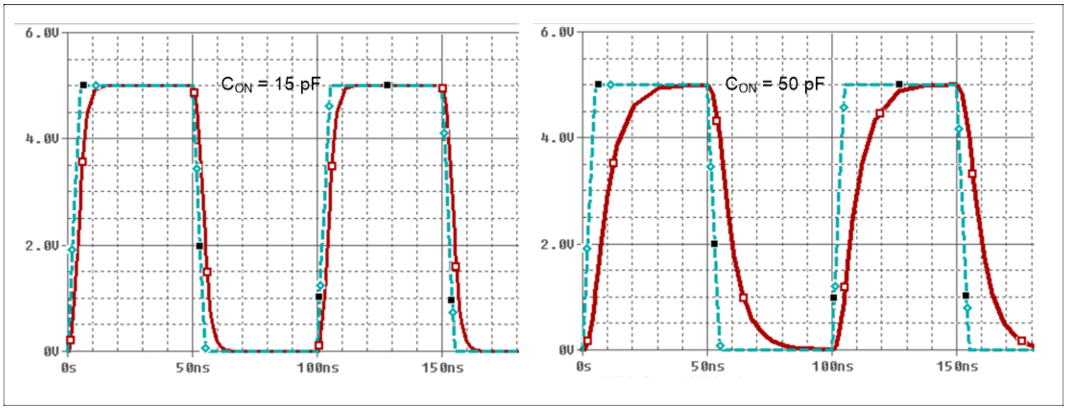

Figure 3-2. Comparison of On-Capacitance Impact on Signal

- On-leakage current ($I_{S(ON)}$ / $I_{D(ON)}$) – This is the leakage current measured across the signal switch while the switch is in the ON state. This should be a very small value as a high leakage current could corrupt data or load a bus that should be isolated. The voltage error associated with the leakage current is represented by the equation $V_{error} = (R_{ON} + R_{source}) \times I_{ON}$, where R_{source} is the internal resistance of your voltage source. When switching between high-impedance sources such as accelerometers, optical and chemical sensors, the R_{ON} can be ignored in this equation, leaving the voltage error approximation to be $I_{ON} \times R_{source}$. When supplied with a 5-V supply, the TMUX1108 and TMUX1109 see typical R_{ON} and leakage current values of 2.5 Ω and 3 pA, respectively. This helps to reduce the voltage error and are great devices for use in high-precision applications.

- Charge injection (Q_C) – This is the measurement of unwanted coupling from the control pin into the signal switch. The charge induced by switching the inputs high or low will be seen on the signal switch. Charge injection is measured in Coulombs (C). While the charge injection occurs the signal on the data path will not be reliable, slowing down your sampling rate. This is illustrated for clearer understanding in Figure 3-3.

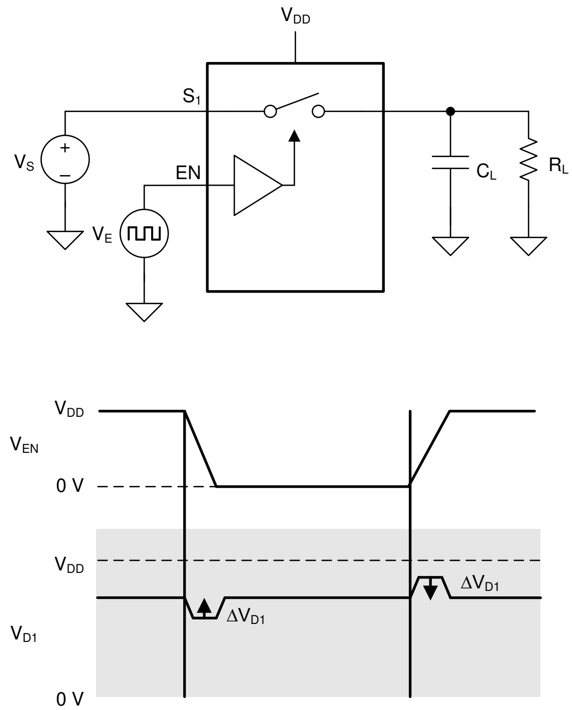

Figure 3-3. Charge Injection

4 References

Table 4-1 lists the hero devices for MCU GPIO or ADC expansion.

Table 4-1. Hero Devices for MCU GPIO or ADC Expansion

Device	Config	#Ch	Input Signal Voltage Range	R_{ON} (Ω)	On-Leakage	Charge Injection (pC)	C_{ON} (pF)	BW (MHz)
TMUX1136	2:1	2	0–5.5 V	1.8	10 pA (typ)	–6 (typ)	20	250
TMUX6136	2:1	2	0–33 V or ±16.5 V	120	8 pA (typ)	–0.4 (typ)	5.5	670
TMUX1109	4:1	2	0–5.5 V / ±2.75 V	2.5	3 pA (typ)	–1 (typ)	35	155
TMUX1308	8:1	1	0–5.5 V	59	0.8 µA (typ)	–6.5 (typ)	15	500
MUX36S16	16:1	1	0–36 V or ±18 V	125	3 pA (typ)	0.31 (typ)	13.5	500