Application Note

Designing with Multiple Multiplexers in Series: A Guide to Cascading Multiplexers

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ABSTRACT

Passing a signal through multiple multiplexers, often called cascading, is a useful way to create new and creative designs for complex system needs. While using this technique does allow for more flexibility in design it is important to note the effects of multiplexer parasitics as more multiplexers are added to the bus. This document will expand on the effects of accumulate On-Resistance, On-Capacitance and On-Leakage when cascading multiplexers while also showing both simulated and bench results of the impact on insertion loss. A table of recommended devices for cascading applications is highlighted at the end of the document.

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1 Introduction

Passing a signal through two or more multiplexers in series, often called cascading, can be used as a creative way to realize unique system designs that otherwise are not possible. While there are a wide range of circumstances that can see a designer implement cascading multiplexer in a system, there are two main instances where this implementation is used the most.

The most common situation where cascading multiplexers are used is in configuration expansion, where smaller multiplexers create a larger multiplexer with a greater number of inputs feeding into the eventual single output. Alternatively the opposite flow can also be done where many outputs feed into a single input as well. An example is highlighted below in Figure 1-1 where 3 SPDT (2:1) multiplexers are used to create a 4:1 multiplexer.

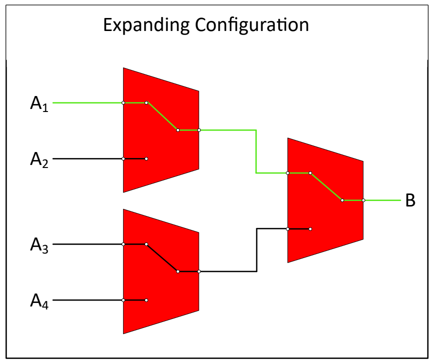

Figure 1-1. Expanding Configuration With Cascading Multiplexers

The other most common instance where a multiplexer can be cascaded is commonly called a ‘cross-point switch’. A cross-point switch is a switch that allows any input to find a path to any other input or output without interferences from any other signal path. For example, on the right in Figure 1-2 we see a type of cross-point switch called a switch array that is created by cascading many multiplexers. Here, A_{in} can be connected to any of A_{out}, B_{out} or C_{out}, depending on the logic of each multiplexer. At the same time, B_{in} can also be connected to any of the three outputs, given the correct logic implementation on your multiplexers, without having to be shorted to A_{in} at the same time. In this example, while a small array can be created by simply shorting the outputs of a couple multiplexers together and utilizing control logic efficiently without cascading (Left image in Figure 1-2), as you increase the size of the array, you can use smaller multiplexers for flexibility in PCB-routing and logic control while also limiting certain parasitics, which we explore in more depth through this report.

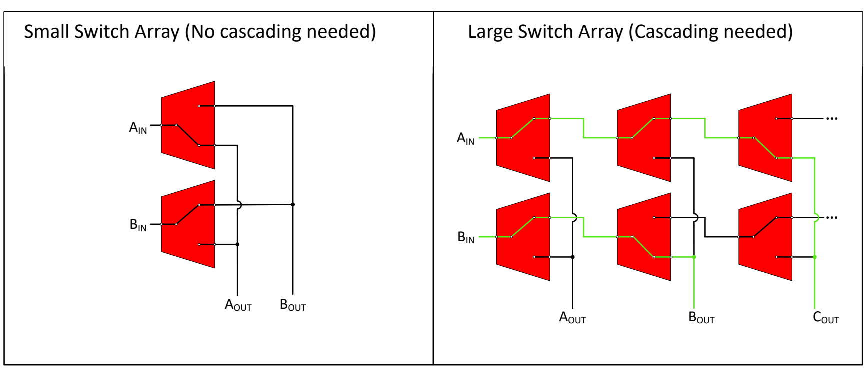

Figure 1-2. Creating Switch Arrays With Multiplexers

With cascading multiplexers, there are a few behavioral specifications that accumulate as more multiplexer stages are added. How these affect the system varies depending on how these multiplexers are being used in a given system. We’ll examine these specifications in the following section.

2 Parameters Affected when Cascading Multiplexers

On-Resistance ($R_{(ON)}$)

The On-resistance($R_{(ON)}$) of a multiplexer is the measured resistance from the input to the output of a multiplexer. In simulation, this can be modeled as simply a resistor in series. This resistance plays a role in many mux characteristics such as the insertion-loss, propagation delay and bandwidth. As $R_{(ON)}$ increases, performance in these specifications decreases. The typical preference is to pick a multiplexer with a lower $R_{(ON)}$ when cascading multiplexers since $R_{(ON)}$ adds linearly as you increase the multiplexer count. Figure 2-1 shows how the insertion-loss increases linearly as you pass a signal through 2 multiplexers. Note how after the 1st mux you lose 1X of your 5V signal and after the 2nd mux 2X loss. This pattern continues through the n^{th} mux in series.

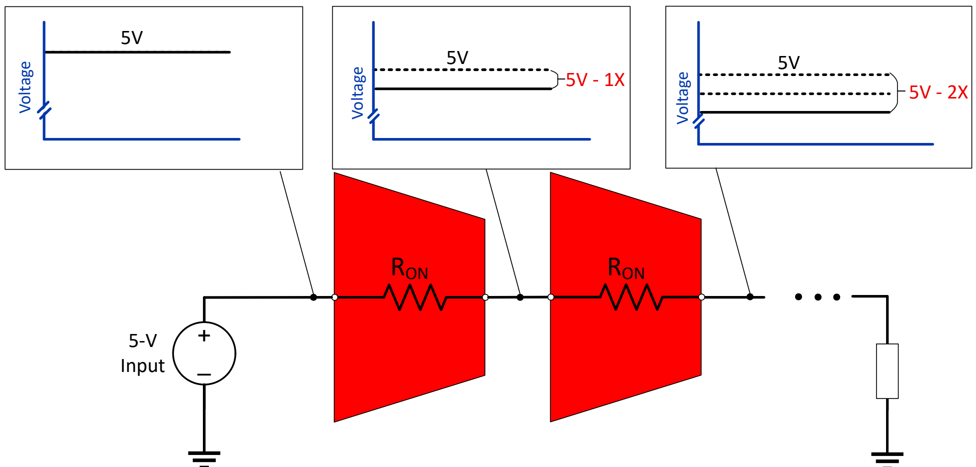

Figure 2-1. Effects of On-Resistance when Cascading Multiplexers

A key distinction to make here is the effect of the load on $R_{(ON)}$. Regardless of the loading, losses accumulate linearly; however, when feeding the output of a multiplexer into a high impedance node the losses due to $R_{(ON)}$ are suppressed by the load. This means when cascading into a high-impedance load, there is less impact from $R_{(ON)}$ as the loss per cascade stage is minimized. Conversely, when the system has a smaller resistive load, a lower $R_{(ON)}$ mux is preferred as you'll accumulate more losses per mux the higher the $R_{(ON)}$ of the multiplexer is. Figure 2-2 highlights the advantage of using a low $R_{(ON)}$ multiplexer, such as the TMUX1574, in cascaded mux applications.

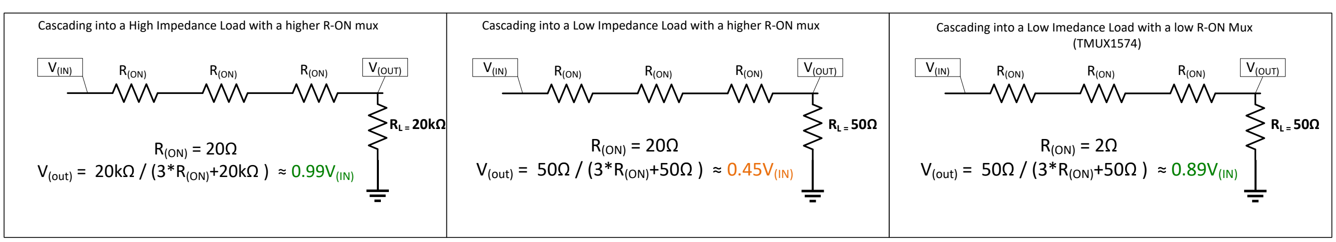

Figure 2-2. Effects of Resistive Load and On-Resistance when Cascading Multiplexers

The center and right images above highlight the advantages of using a low $R_{(ON)}$ multiplexer (right),such as the TMUX1574, versus a higher $R_{(ON)}$ multiplexer (center) when the system resistive load is small. The far left image shows how the $R_{(ON)}$ of the multiplexer has less impact when fed into a high impedance load. The large load suppresses the On-Resistance so the losses due to $R_{(ON)}$ aren't seen as significantly.

On-Leakage

Similar to On-resistance, as you add more stages to your cascaded mux system, the on-leakage current linearly increases as well. So by the 2nd stage, on-leakage doubles; by the third, on-leakage triples; and so forth. In a high precision data acquisition system, you'll often find that the sensor outputs have low output impedance, making any offset coming from the leakage a significant factor in the overall resolution and accuracy of the system. When cascading multiplexers in these high precision environments, select a multiplexer such as a multiplexer from the TMUX11xx family of precision devices that minimizes leakage and maintains signal integrity.

Figure 2-3 shows an example using TMUX1108 (1ch 8:1) and TMUX1119 (1ch 2:1), which are two devices from the TMUX11xx family of precision multiplexers. Cascading these multiplexers allows for a single input to be used for both measuring multiple sensors (A_x inputs) and also calibrating the inputs to a V_{ref} voltage. This design can be implemented into high precision environments systems to reduce overall system size by expanding functionality of the ADC inputs.

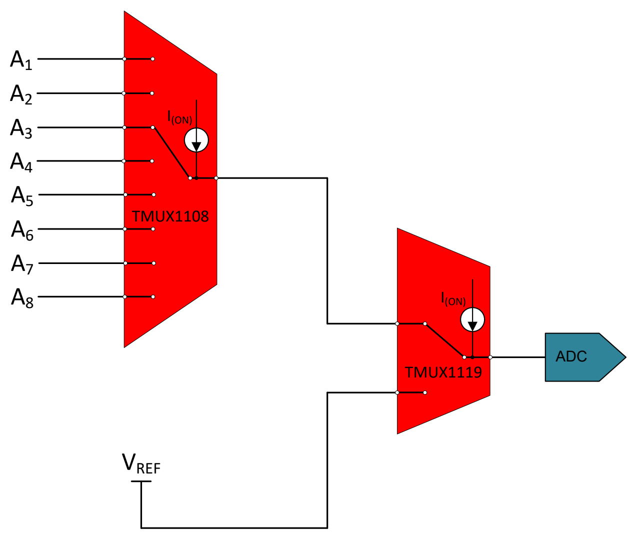

Figure 2-3. Cascading Precision Multiplexers

Bandwidth

The bandwidth of a multiplexer is the frequency range of signals that can pass through the multiplexer with no more than a -3dB loss relative to the DC gain. This equates to approximately 70% of the signal remaining, relative to the insertion loss at DC. The loss is associated with the frequency of the input signal. A key distinction needs to be made and understood here between the -3dB point and the -3dB loss point. Figure 2-4 below shows a couple examples to help with the understanding this definition. Here, the DC gain shifts where the -3dB loss point is measured from. This point won't always be at -3dB but rather 3dB less than the insertion loss at DC.

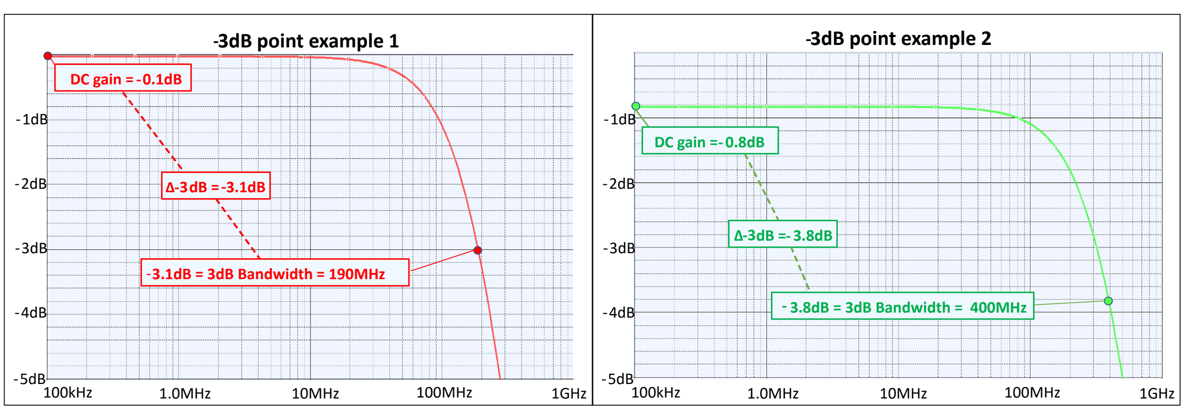

Figure 2-4. -3dB Bandwidth Examples

Notice how the bandwidth of example 2 (400MHz) is higher than example 1 (190MHz) but the overall loss (-3.8dB) is greater than example 1 (-3.1dB). See what the loss is at the given operating frequency since the bandwidth alone won't tell you this. Typically, a multiplexer with a bandwidth close to or equal to the working frequency won't be a good fit for minimizing losses in the system. A good strategy is to select a multiplexer with 1.5x – 2x the Nyquist frequency (twice your operating frequency) for sine waves and 5x-7x the fundamental (operating) frequency for square waves. This helps maintain that more of the signal gets retained when passing through the mux.

To help simulate the bandwidth, a multiplexer can be effectively modeled as a low-pass filter with some input capacitance by using On-Resistance and On-Capacitance as shown in Figure 2-5. These values can be pulled from the data sheet. For ease of modeling, the On-Capacitance is split in two on each side of the resistor representing On-Resistance.

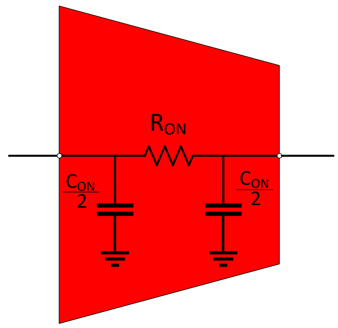

Figure 2-5. Simplified Multiplexer Model

As more multiplexer stages are added to create the cascading network, this creates a higher-order filter. As higher order filters are created, more higher frequency components are filtered out from the input signal. Figure 2-6 shows simulated results for how the -3dB bandwidth decreases when a 2nd and 3rd multiplexer stages are added. Since a high-impedance load is used we can estimate the DC loss is close to 0dB and can draw the -3dB loss point at approximately -3dB.

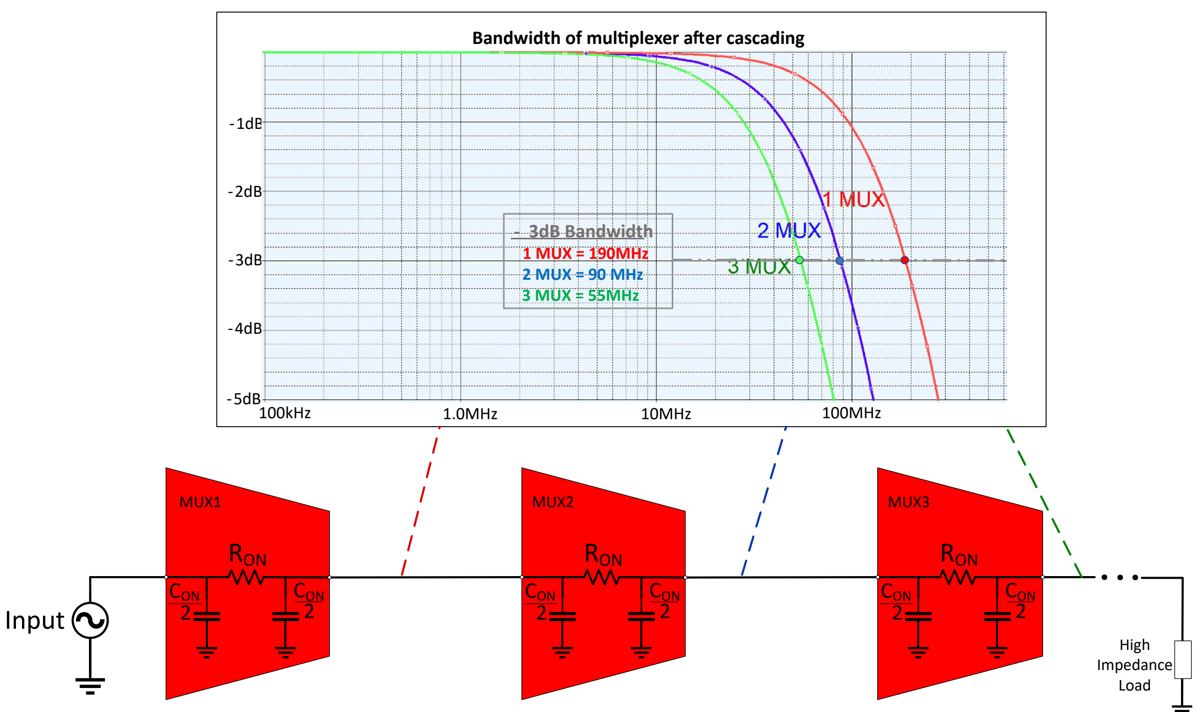

Figure 2-6. On-Resistance Effects on -3dB Bandwidth (High Impedance Load)

Figure 2-6 shows that the decay of the signal isn't linearly proportionate to the number of multiplexers in the cascaded stage. Instead, the decay becomes less significant as more multiplexers are added. Figure 2-7 (high impedance load) and Figure 2-8 (low impedance load) show simulation results as we increase from a single mux up to 8 multiplexers in series. As previously mentioned, the multiplexers act as a filter and exhibit similar properties. Therefore, expect that as we approach higher-orders we see a sharper slope in the roll off. This in turn suppresses the higher frequencies and limits the bandwidth. While the -3dB bandwidths between low and high impedance loads are similar, the overall loss gets greater in low-impedance load systems as more multiplexers are added due to the On-Resistance contributions previously mentioned in the section covering On-Resistance (R(ON)). This stands out more when operating near DC levels. For example, at 100kHz with a high-impedance load, by the 8th mux, the gain remains at nearly 0dB, equating to most of the signal being retained. At the same frequency with a low impedance nearly 20% of the signal is lost by the 8th multiplexer.

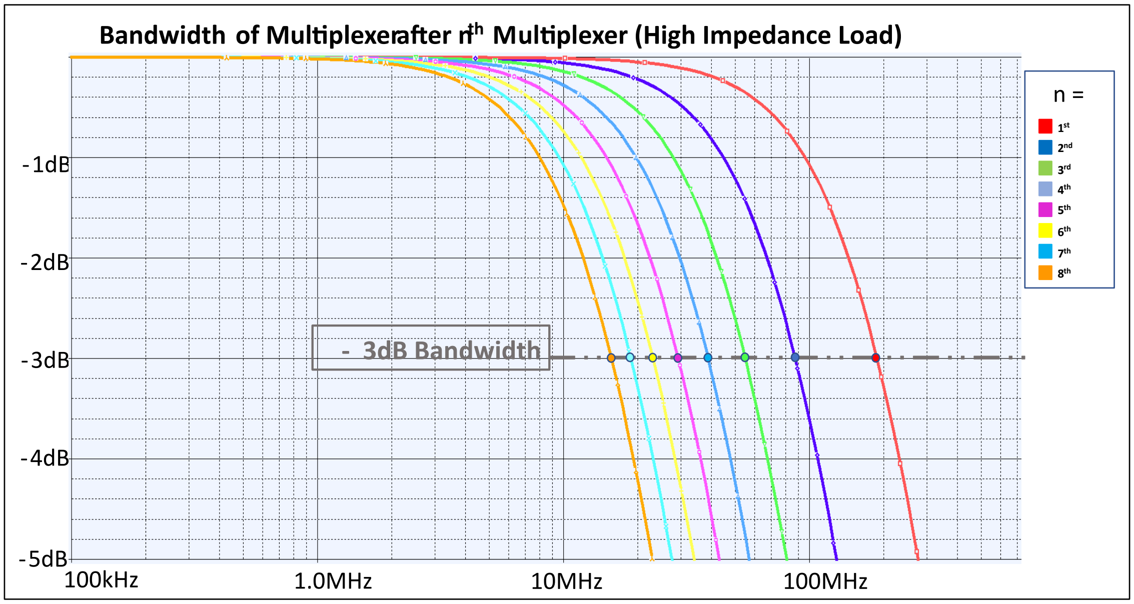

Figure 2-7. -3dB Bandwidth of n^{th} Multiplexer (High Impedance Load)

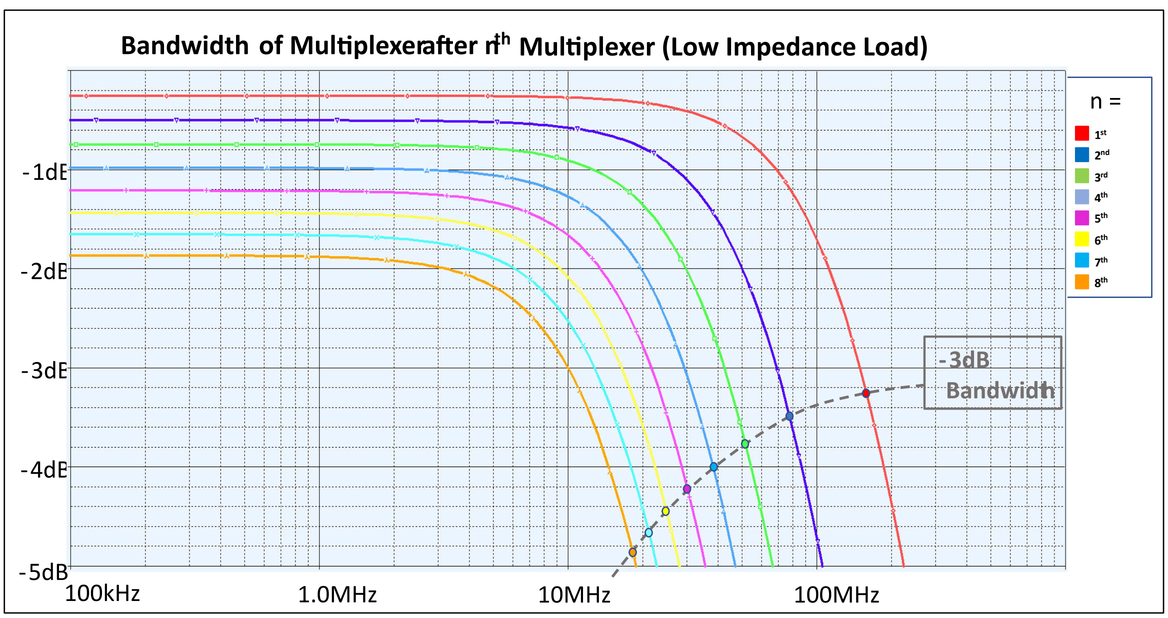

Figure 2-8. -3dB Bandwidth of n^{th} Multiplexer (Low Impedance Load)

Experimental Results

While simulations are useful tools to gauge the general behavior of a system, we recommend to perform lab tests for more complex setups before finalizing a design. We compare our simulated results here with bench results to see how closely the results resemble each other. Below, in Figure 2-9, a vector network analyzer was used to examine the DC insertion loss (in reality this is the <100kHz insertion loss) and -3dB bandwidth when a signal is passed through 1 multiplexer, 2 multiplexers and 3 multiplexers. A 200mV peak-to-peak input signal with a 50-ohm load was used. We see that the bandwidth results look similar to the simulated results. In both the simulation and bench results, adding the 2nd multiplexer reduced the bandwidth by nearly half while the impact of the 3rd multiplexer wasn't as severe. The bench test actually performed better after the 3rd multiplexer was added, retaining more of the bandwidth than the simulated results. So while a simulation can help with ball-park estimations, bench results are not only more accurate but can actually reveal more optimistic limits.

In systems with low impedance loads, recognize the impact of On-Resistance, which accumulates linearly and increases insertion loss. Figure 2-9 shows the linear decay that each stage of cascading network adds to the DC insertion loss. Each stage continues to accumulate the same loss, in this case approximately -25dB per stage, resulting in a -75dB loss by the output of the third stage, which matches the same trend that we see in Figure 2-8.

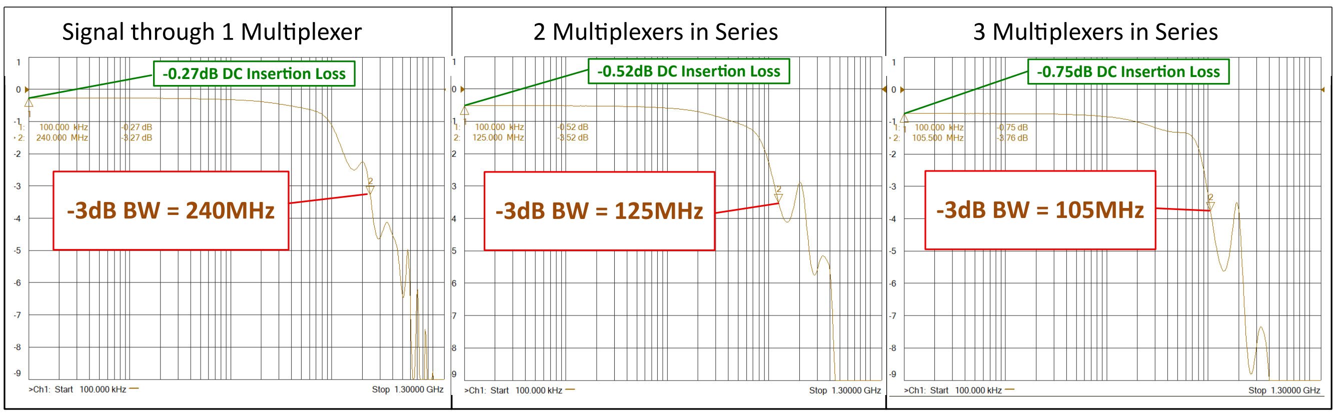

Figure 2-9. Experimental Results of 3 Multiplexers in Series

3 Summary

Using multiple multiplexers in series (cascading) allows for flexibility and versatility to create unique designs but also requires extra parametric checks before finalizing a design. Selecting a lower leakage multiplexer is an important factor in high precision applications as the leakage adds linearly. A low On-Resistance multiplexer is more desirable in applications with a lower load, such a 50-ohm coax load, to help reduce the insertion loss per multiplexer. The overall bandwidth of the system must always be evaluated as the bandwidth decays as more cascading stages are added. The loss is greatest in the first stage, where the bandwidth was reduced by nearly half. In most cascaded multiplexer applications, we recommend to do a bench level analysis of the cascaded networks compatibility with the specific system as use cases, system requirements and environments vary.

Table 3-1. Recommended Devices to Use When Cascading Mutliplexers

Hero Devices					
		Applications			
Device	**Channel and Configuration**	**High Speed**	**Low Leakage Precision**	**Small Load**	**High Voltage**
TMUX136	2ch SPDT (2:1)	6GHz Bandwidth		2Ω On-Resistance	
TMUX1574	4ch SPDT (2:1)	2GHz Bandwidth		2Ω On-Resistance	
TMUX1108	1ch 8:1		3pA On-Leakage	2.5Ω On-Resistance	
TMUX121	2ch SPDT (2:1)	3GHz Bandwidth		3Ω On-Resistance	
TMUX7612	4ch SPST (1:1)		3.7pA On-Leakage	1.35Ω On-Resistance	50V

4 References

- Texas Instruments, *Multiplexers and Signal Switches Glossary* application note.
- Texas Instruments, *Selecting the Correct Texas Instruments Signal Switch* application note.