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Passive Scope Probes: Understanding How They Work Can Help Us Get the Most Out of Them (Introducing the Teradyne Modular Probe Interface (MPi))

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INTRODUCTION

The Teradyne Modular Probe Interface board (MPi) is a peripheral assembly available to connect to your system that provides support for passive and active oscilloscope probes. The MPi helps to maintain bandwidth and signal integrity by providing the 1MΩ input impedance that the probe expects, while driving a signal across the 50 Ohm impedance of a lengthy system cable to the measurement instrument. The MPi acts as a buffer where the probe expects the scope to exist, but also can provide power and a bypass path for active probes.

The inclusion of an MPi in your test system allows for the VXI and PXI form factor oscilloscopes in the Teradyne instrument families to replace a typical bench top oscilloscope. The rest of this paper explores the design of a probe, how each designed component helps to maintain signal integrity at the measurement end, and how to solve the problem of having a far physical distance between a probe and an oscilloscope front panel.

THE PROBLEM STATEMENT

Suppose you have a situation where you are using your Teradyne Ai-760 Series or ZT-Series oscilloscope and would like to probe a signal on a unit under test. However, there is a considerably large distance between the instrument front panel in your system and the unit that you need to probe. When you attempt to probe a simple 1kHz 200mV square wave with a lengthy system cable in between, you get a distorted and inaccurate signal. You need some way to compensate for the length of cable necessary while keeping your signal intact.

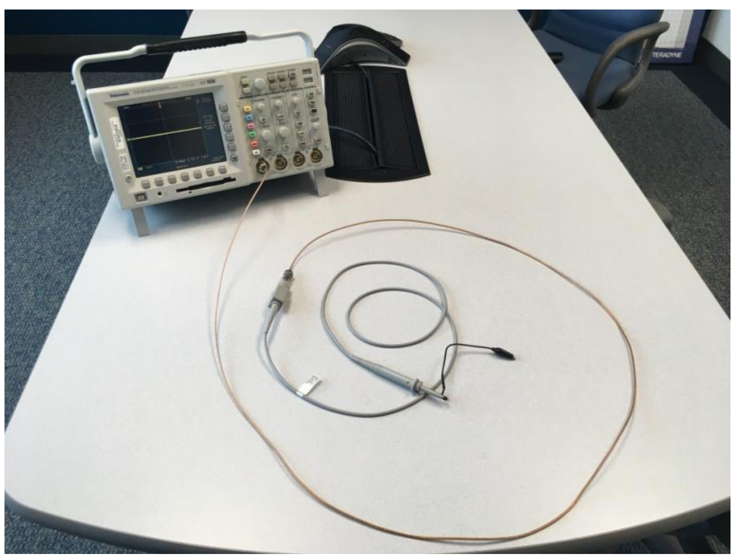

Figure 1 - Example of Probe with Added Cable

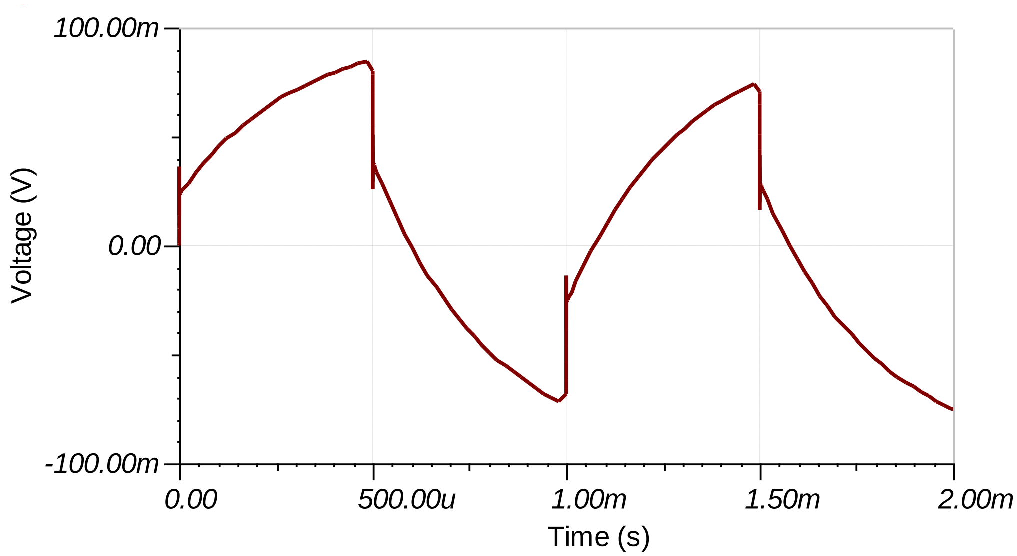

Figure 2 - Distorted 1kHz 200mV Square Wave

A WALK THROUGH PASSIVE PROBE DESIGN

You might think of a passive resistive probe with 10X attenuation as a simple voltage division with a 9:1 resistance ratio, but there are other components at play that need to be addressed in the design of a probe. There is some internal capacitance present in the oscilloscope. The introduction of this capacitance affects how we see the signal measured on the oscilloscope.

A probe also has some length to it, so we need to add some cable to our probe model. In the following example, we have a typical scope capacitance of 17pF, and have added 3 ft of 50 Ohm coax cable to our probe tip. The 3 ft of 50 Ohm coax adds capacitance to the system of 28.8pF/ft.

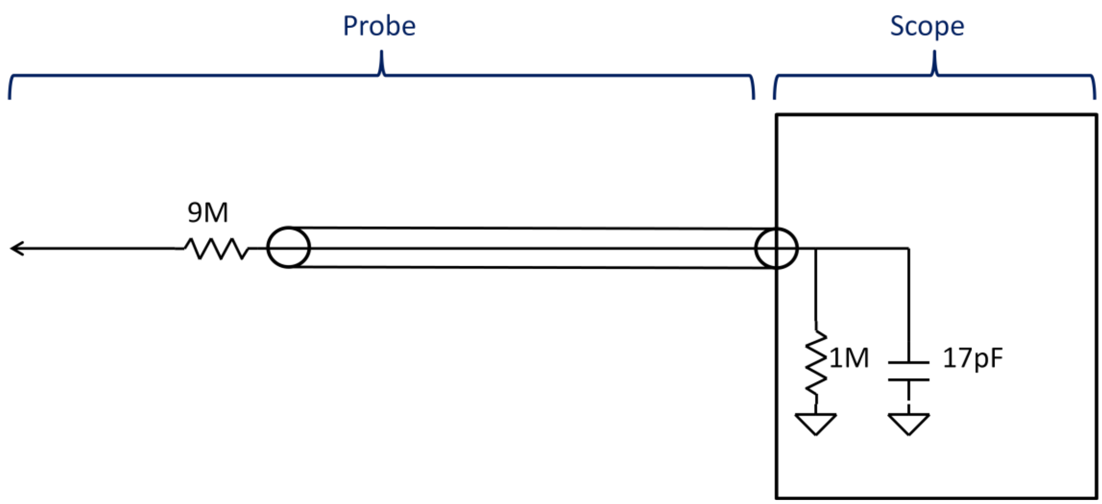

Figure 3 - Simple 10X Probe with 50 Ohm Coax

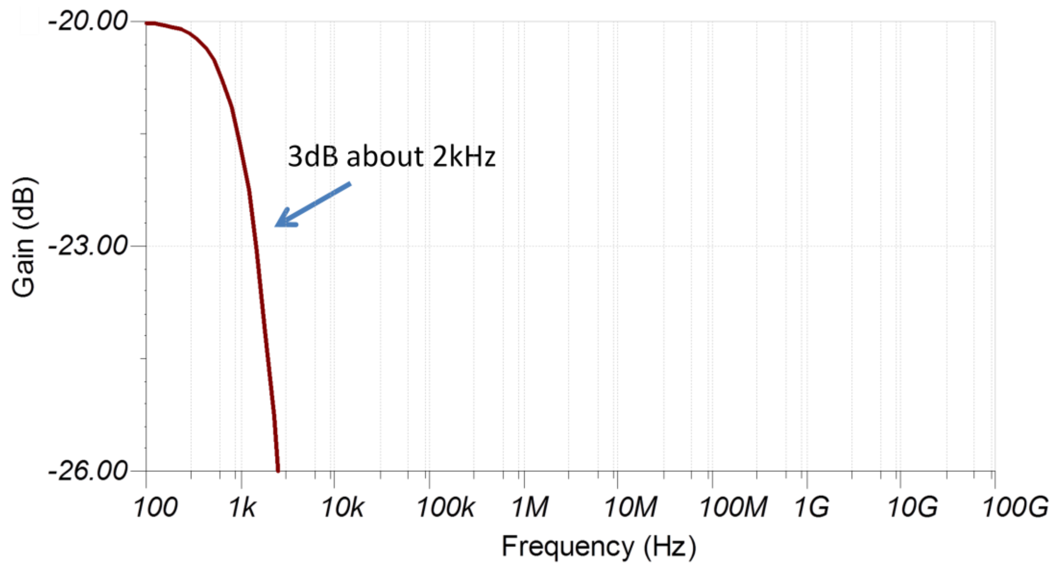

Figure 4 - Frequency Response for Simple 10X Probe with 50 Ohm Coax

Here we see that the roll off occurs at a much lower frequency than the specified bandwidth of the oscilloscope we are using to measure the signal. The 3dB point is occurring at around 2kHz. We need a way to compensate for the capacitance in the oscilloscope and the added cable. To do this, we can add a parallel capacitance at the probe tip of 1/9th the total existing capacitance. This capacitor may need to be large to compensate for the capacitance in the scope and in the cable.

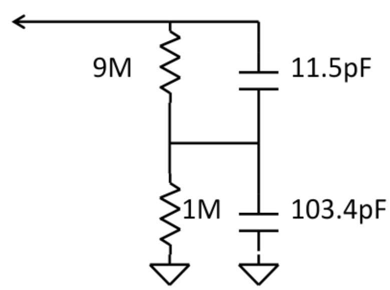

Figure 5 - AC Compensation Model Equivalent Circuit

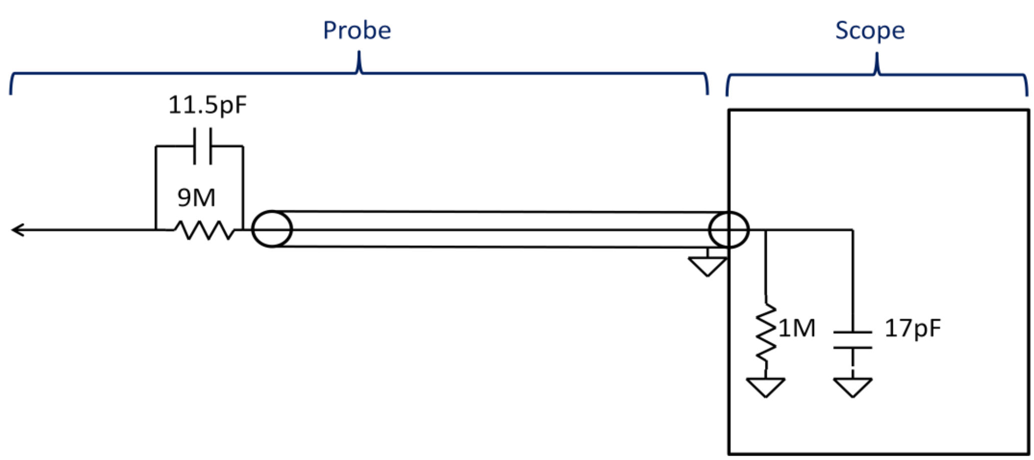

Figure 6 - Compensation Capacitor at Probe Tip

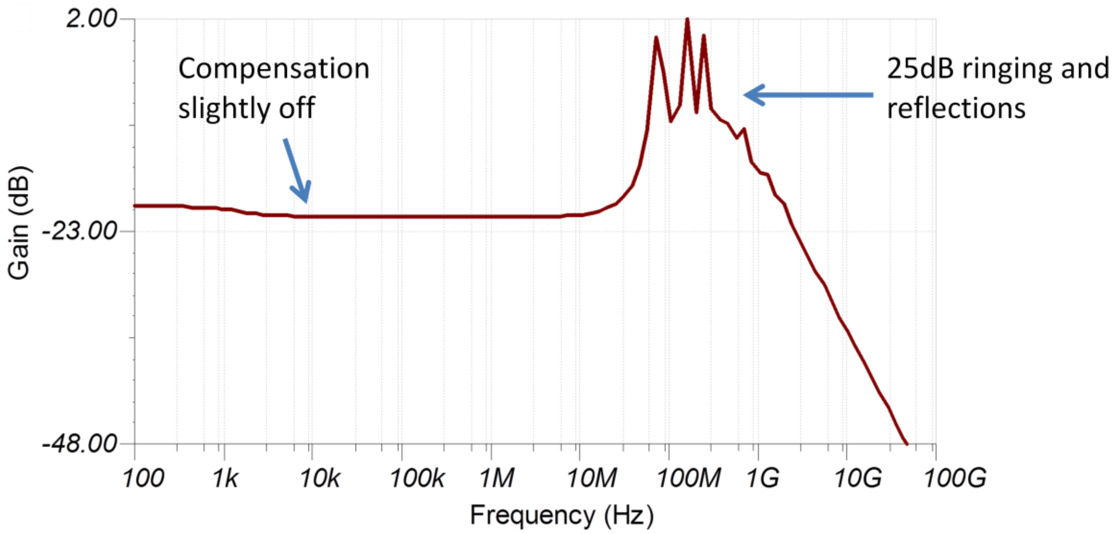

Figure 7 - Frequency Response with Compensation Capacitor

Including the compensation capacitor extended the roll off, but resulted in high frequency reflections, and a compensation that is slightly off. This will result in ringing at transitions of our waveform.

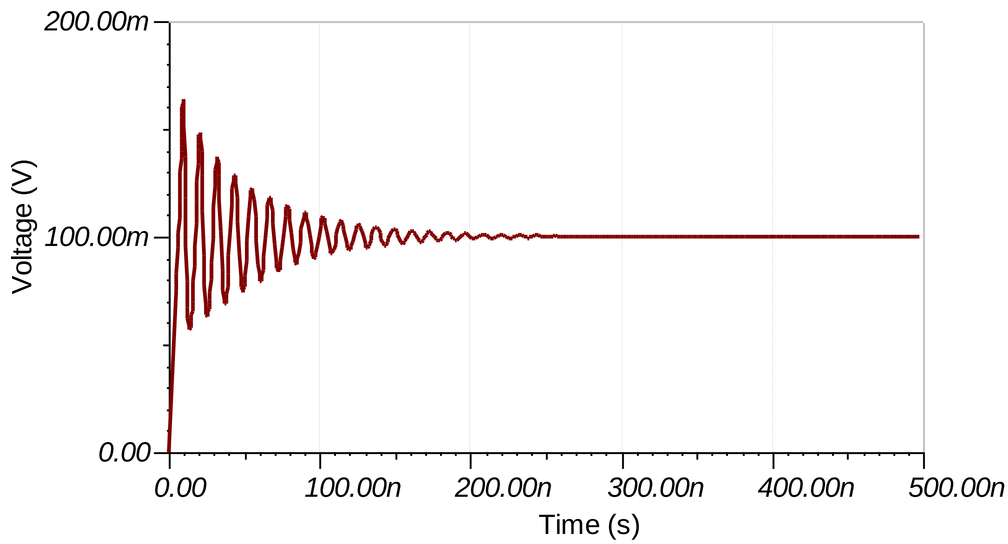

Figure 8 - Step Response for 50 Ohm Coax and Tip Compensation

We need to make a number of adjustments to this design to get rid of the reflections while maintaining bandwidth. First, we can reduce the effect of the added cable by using a special high impedance, low capacitance, lossy cable in our probe design to replace the 50 Ohm coax. For example, we might replace it with 3 ft of 93 Ohm impedance cable with 15.4pF/ft (compared to 28.8pF/ft with the original case). Using a low capacitance cable, we can design a smaller probe tip capacitor of 7.75pF to complete our 1 to 9 ratio.

Second, to avoid having to redesign the probe tip each time the compensation is slightly off, or for each different oscilloscope we may use, we can add a 7pF variable capacitor for scope input compensation. This is the capacitor that we will make slight adjustments with when we compensate our probe.

Third, to finish dampening the high frequency reflection, we can add a 50 Ohm snubber in the probe tip.

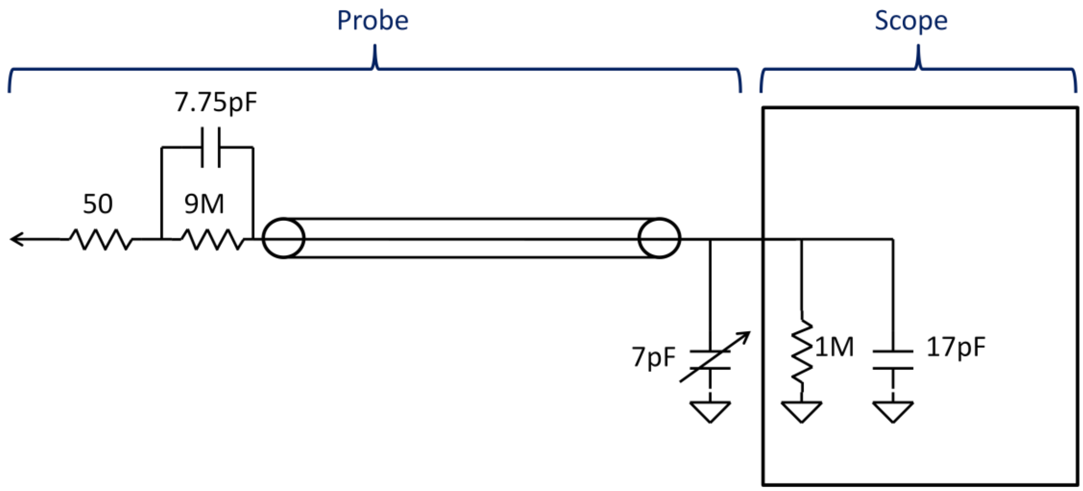

Figure 9 – Variable Capacitor, High Impedance Coax, Snubber Added

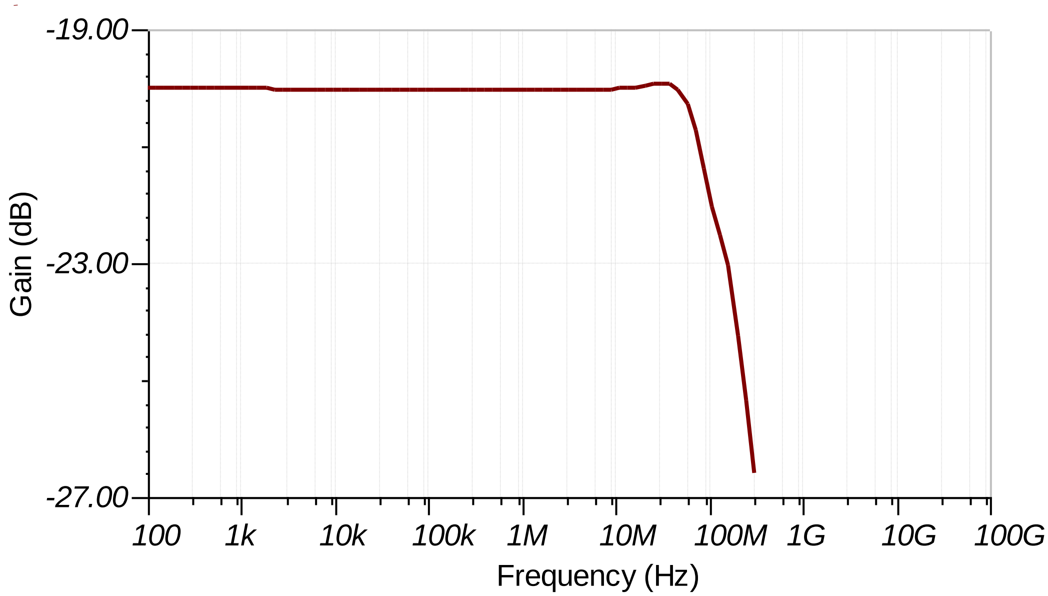

Figure 10 - Frequency Response using Various Improvements

Our ideal probe design tackles the typical bench top three foot probing distance, with less of a hit to bandwidth and eliminated reflections. Success is on the horizon.

However, when you are not using a bench top oscilloscope, the rack mounted instrument may be further away from the unit under test than the design plans for. Our original problem statement mentioned that we had a considerably large distance of system cabling required between the probe and the scope. If we introduce, for example, 9 feet of RG58 cable now, we have intentionally added another 259pF of uncompensated capacitance. Our quick roll off and high frequency reflections will return.

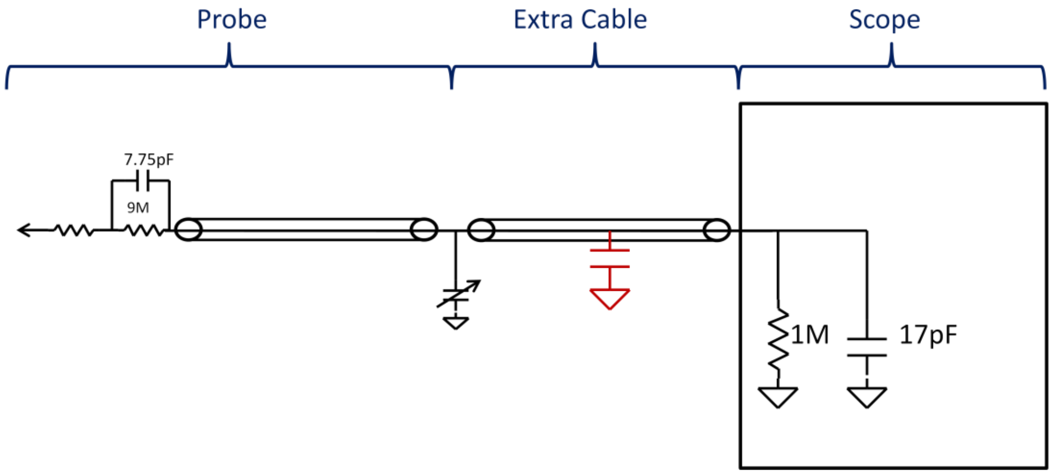

Figure 11 - Introducing Extra Cable to our Carefully Designed Probe

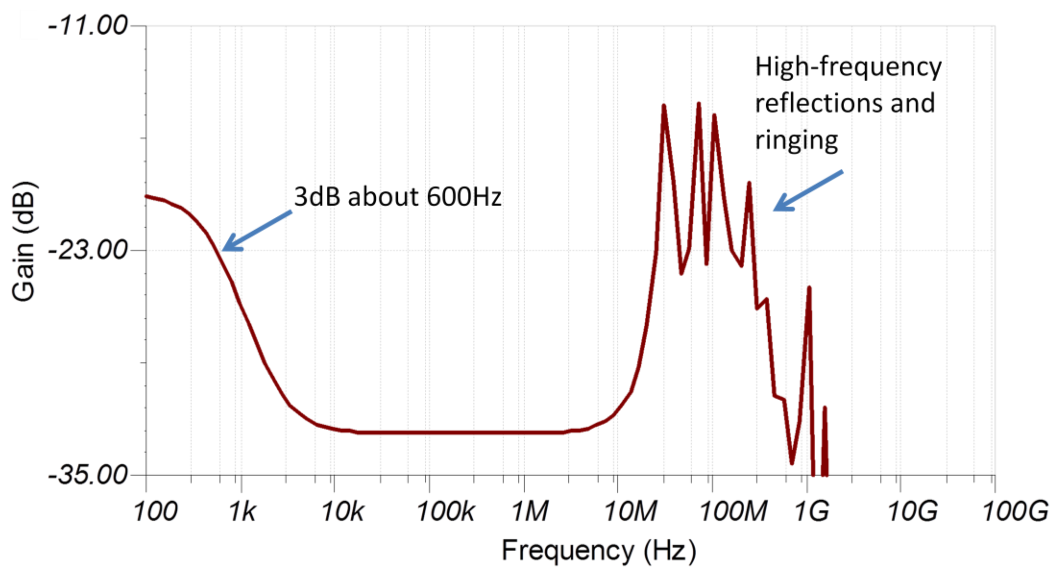

Figure 12 - Frequency Response for Added Cable between Probe and Scope

We have undone the carefully balanced system that we designed, and would have to change the compensation of our circuit, or start our design over. If we try to simply compensate for the added capacitance of the cable by designing a custom probe tip, we may be able to extend our bandwidth, but only to a point.

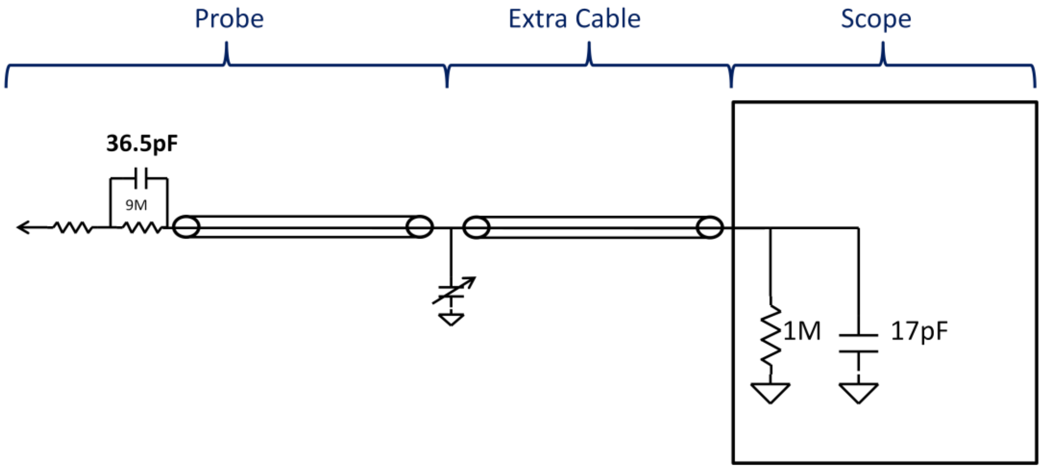

Figure 13 - Increased Probe Tip Capacitance to Compensate for Extra Cable

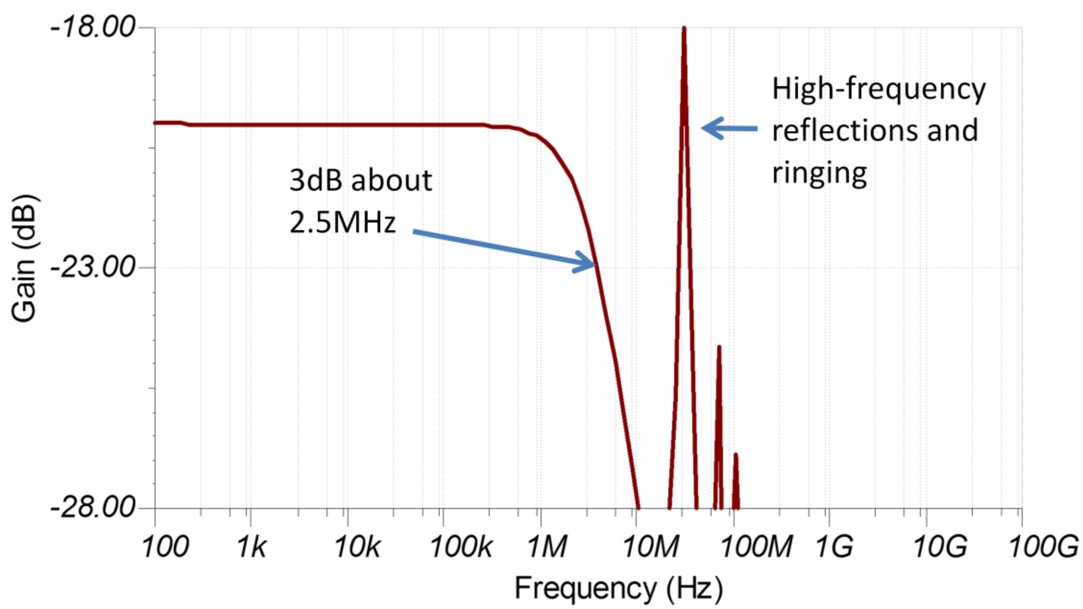

Figure 14 - Frequency Response for Extra Capacitance in Probe Tip

Typically we don't go through this painstaking and expensive process of designing our own probes, perfectly balancing out the distance we may need, or designing a different probe for each possible distance we may need in the future. Instead, we purchase probe off the rack, and figure out a way to make it fit our requirements.

SOLVING AN UNPREDICTABLE LENGTH OF CABLE WITH A PROBE

Some type of intermediate interface is needed so that the probe, as it is designed, sees the 1M impedance and 17pF system capacitance at the three foot mark where it expects to see the oscilloscope, and the oscilloscope needs to be able to see the signal properly after 9 feet of 50 Ohm system cabling. The Teradyne Modular Probe Interface (MPi) solves this problem by providing a buffer in place of the scope in the above diagrams. The MPi acts in place of the "scope" components for the probe end, and drives the 50 Ohm signal all the way back to the actual scope. This allows typical system cabling to be used between the MPi and the oscilloscope to traverse whatever distance is required by the system configuration, and still allows the probe to function properly with its expected impedance and capacitance values.

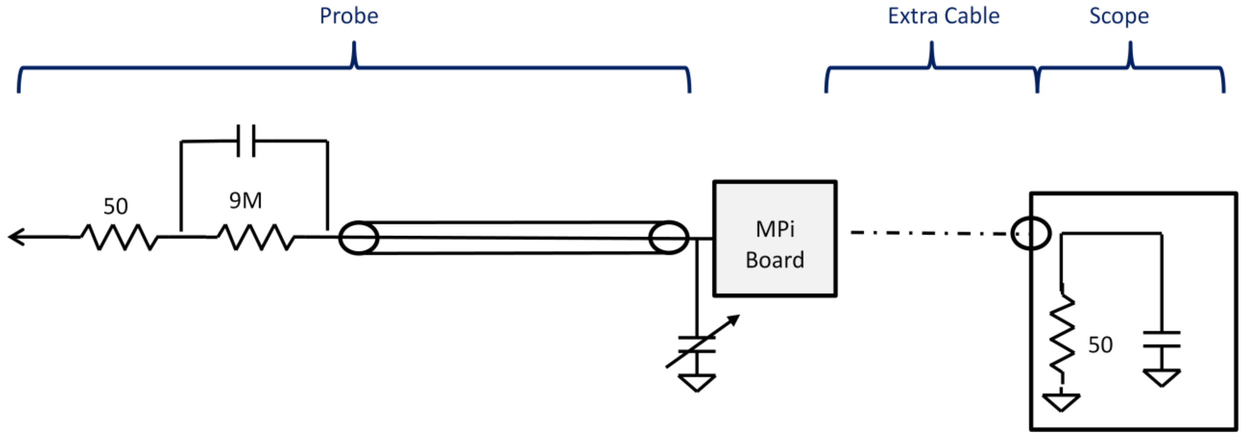

Figure 15 - Probe Circuit with Modular Probe Interface Board

This solution works well for our typical passive probes. The signal comes in through one of two probe connections on the front panel of the MPi. For certain probe models (listed in the MPi documentation), the MPi uses the microprocessor and a probe sensor on the connector to identify whether a probe is passive or active and check the attenuation factor. This information is used by the microprocessor to select the buffer path automatically for a passive probe. The MPi then buffers the signal to drive it to the oscilloscope. The oscilloscope also sends a calibration signal through the MPi and its supplementary calibration circuit to produce a calibrated square wave output for probe compensation.

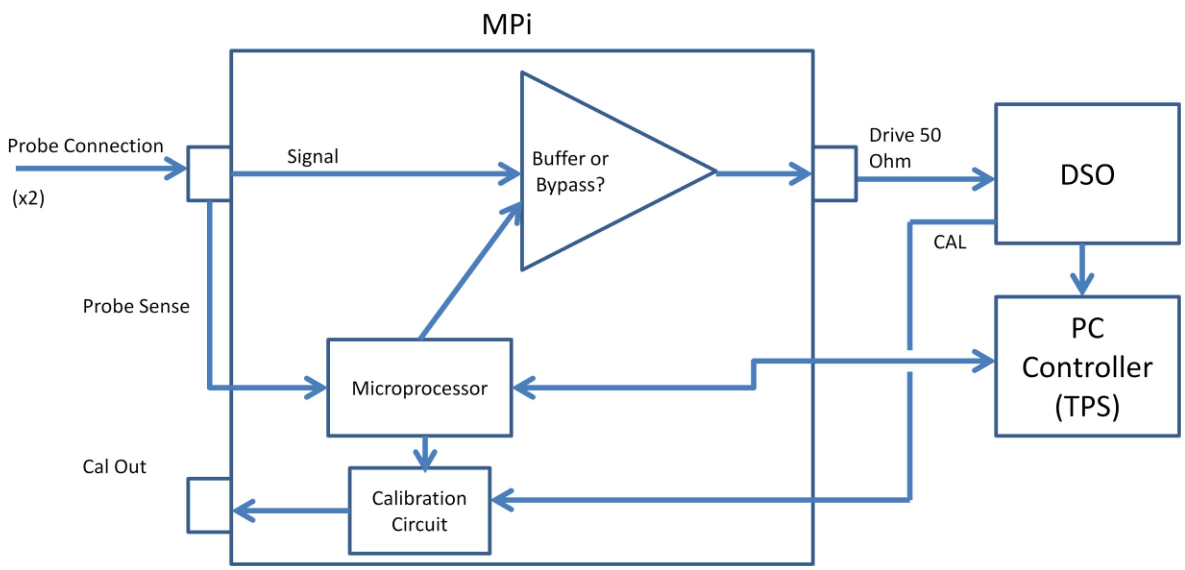

Figure 16 - High Level Block Diagram of Modular Probe Interface

For certain active probes (ones that use the TekProbe BNC interface), the MPi can provide the power required by the probe. It will send the signal through a bypass path to skip the buffer, since the active probe will drive the signal on its own. The bypass path also allows you to make a signal connection from your unit under test to your oscilloscope without a probe, while still passing through the MPi for convenience.

The MPi can be used for debugging using probes, but it can also be optionally integrated into a TPS. A simple programming interface allows a TPS to control the MPi in manual mode, selecting the path and other attributes on the board. This allows for a level of automation and integration beyond what you can get by trying to design a simple buffer into your system.

CONCLUSION

Probes cannot be thought of as simple extensions of 50 Ohm coax cable between your oscilloscope and your unit under test. They have a carefully balanced design that expects components at specific distances, and are compensated to provide the best signal possible under these conditions. If we find that our system is designed so that our unit is not close enough to our oscilloscope front panel to meet these requirements, we need an intermediate solution to provide the probe with what it needs, and to provide the oscilloscope with a properly driven signal. The Teradyne Modular Probe Interface (MPi) board solves this problem by providing the expected components for the probe, buffering the signal, and driving the signal back to the oscilloscope to allow for accurate measurement while probing. The MPi can be mounted on your Spectrum system in such a way that it is no further than your probe's designed cable length from your unit under test. This provides you with the opportunity to easily and accurately debug a problem using a Teradyne oscilloscope and a standard probe.

ACKNOWLEDGEMENTS

Mike Haney, Software Engineering, Teradyne

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