Why Engineers Ignore Cable Loss

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Companies spend large amounts of money on test and measurement equipment. One of the largest purchases for high speed designers is a real time oscilloscope. As is the case with most instruments, oscilloscope vendors charge a premium for cutting edge bandwidths. Companies are willing to pay this premium to be able to know with certainty that the device they are testing is being represented properly by the oscilloscope. An oscilloscope with too little bandwidth will under report rise times and in many cases, over report jitter. This leads to eroding electrical margins and increasing costs and time to market for a project and design. The benefit of higher margins makes the bandwidth premium a worthwhile investment. Despite its cost, an oscilloscope is only part of the entire measurement system and precious measurement system bandwidth can be lost through other links in the channel system. One potential bandwidth bottle neck includes the cabling and adaptors. Despite this, the characteristics of such adaptors tend to be ignored.

Cable Limitations

Compared to the price of an oscilloscope, the cost of a cable is very minor. Yet cables can wreak havoc on any measurement system.

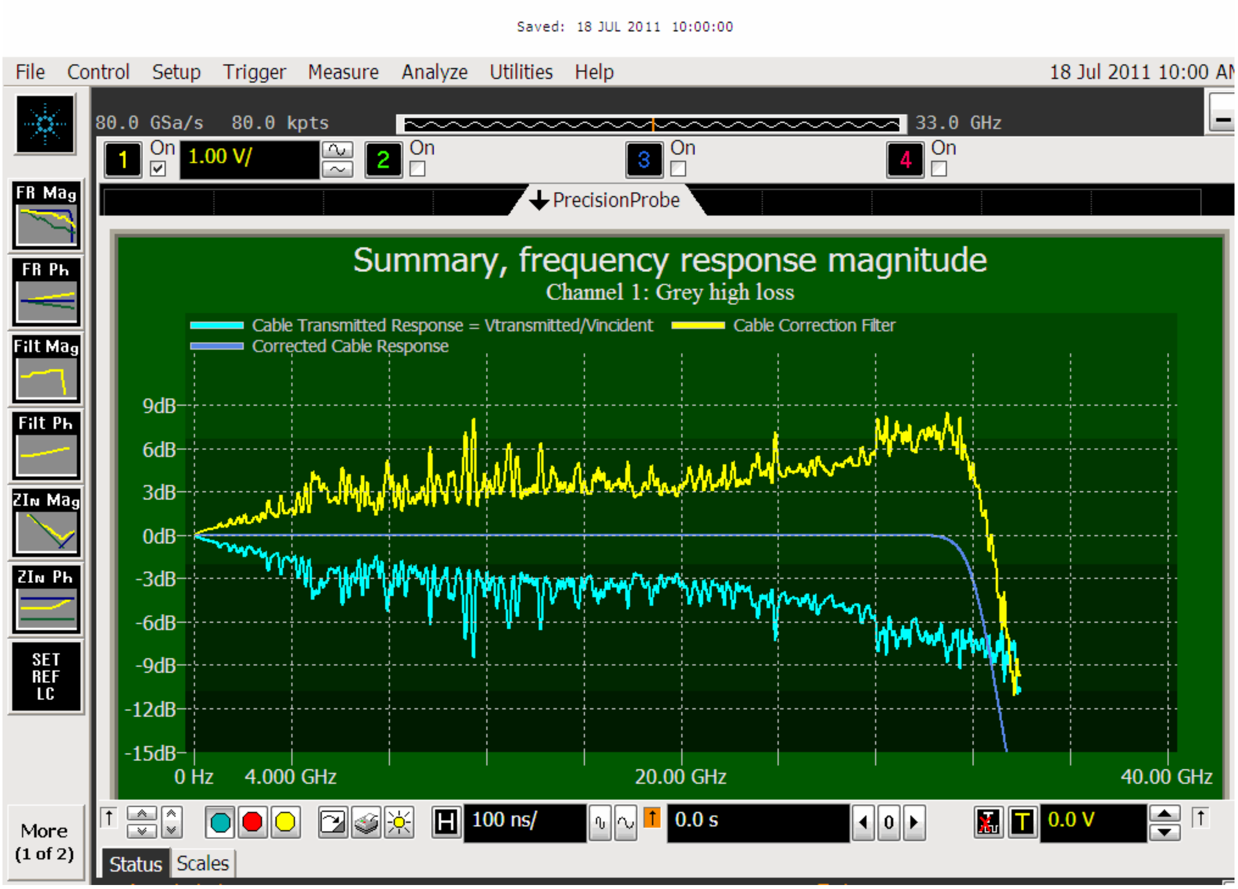

Image 1 depicts a cable that was connected to a 33 GHz oscilloscope (meaning the 3 dB down point was located at 16 GHz). The light blue trace represents the frequency response of the cable. Notice that its 3 dB point is at 4GHz! Imagine a company that purchased a 33 GHz oscilloscope (paying the large premium for the extra bandwidth), only to have the cable limit the bandwidth to 4 GHz. Beyond losing the biggest portion of the investment (the bandwidth) because of cable loss, precious margins are now lost as well. Amplifying the problem, companies now use more links in their measurement channels including switches (to measure multiple channels), adaptors, and fixtures. Similar frequency responses potentially could be found in each one of these components, all causing erosion of crucial margins and potentially wasting hundreds of thousands of dollars. Yet the underlying theme is that the loss is largely ignored.

Overcoming Cable Loss

S21 insertion loss is described as the loss that a cable experiences due to dielectric loss or conductor resistance. In a transmission line, S21 is the transmission coefficient. With S21 in dB, its negative is insertion loss and represents the loss suffered in the transmission. If the cable has a characteristic impedance (Z0) of 50 ohms and the source and load are 50 ohms as well, this measured insertion loss is truly the cable loss for that length of cable. If the source and the load are not perfectly matched, reflections can occur which require deeper modeling. It is important to note that this article will only be concentrating on the matched source and load case.

To address S21 insertion, engineers have two options. The first is to invest in much higher quality cables; however even the highest quality cable begin losing bandwidth essentially from DC due to insertion loss. This first option essentially means the engineer is ignoring cable loss and unfortunately, this is the solution engineers choose far too often. The second method is to characterize the frequency response (both magnitude and phase) and compensate for any error through digital signal process boosting. The advantage of this second method is that engineers can characterize and compensate for every cable in their system. The compensation corrects for the insertion loss of the cables. However, the second method has two drawbacks. First, it takes time and expertise to measure and characterize a cable. Second, the characterization could be wrong. As a result, option one is typically what engineers use.

Characterizing and Compensating for S21 Insertion Loss

For those engineers that choose to characterize and compensate for their cable loss, there are numerous methods to characterize the elements in their links. Until recently, these methods included Vector Network Analyzers (VNA), Time Domain Reflectometry (TDR), and simulation through tools such as ADS. Each of these methods has trade-offs that need to be considered. Ultimately the goal is to get the characterization into a file (known as an s-parameter file) that an oscilloscope can read. The oscilloscope then creates a transfer function. In the case of insertion loss removal, the file would be a simple two port model. All high performance oscilloscope vendors offer de-embedding software which will create the transfer function and remove the cable loss. For example, Agilent offers the N5465A

InfiniiSim software that provides both a basic and advanced software version. For cable loss, the basic version is all that is needed.

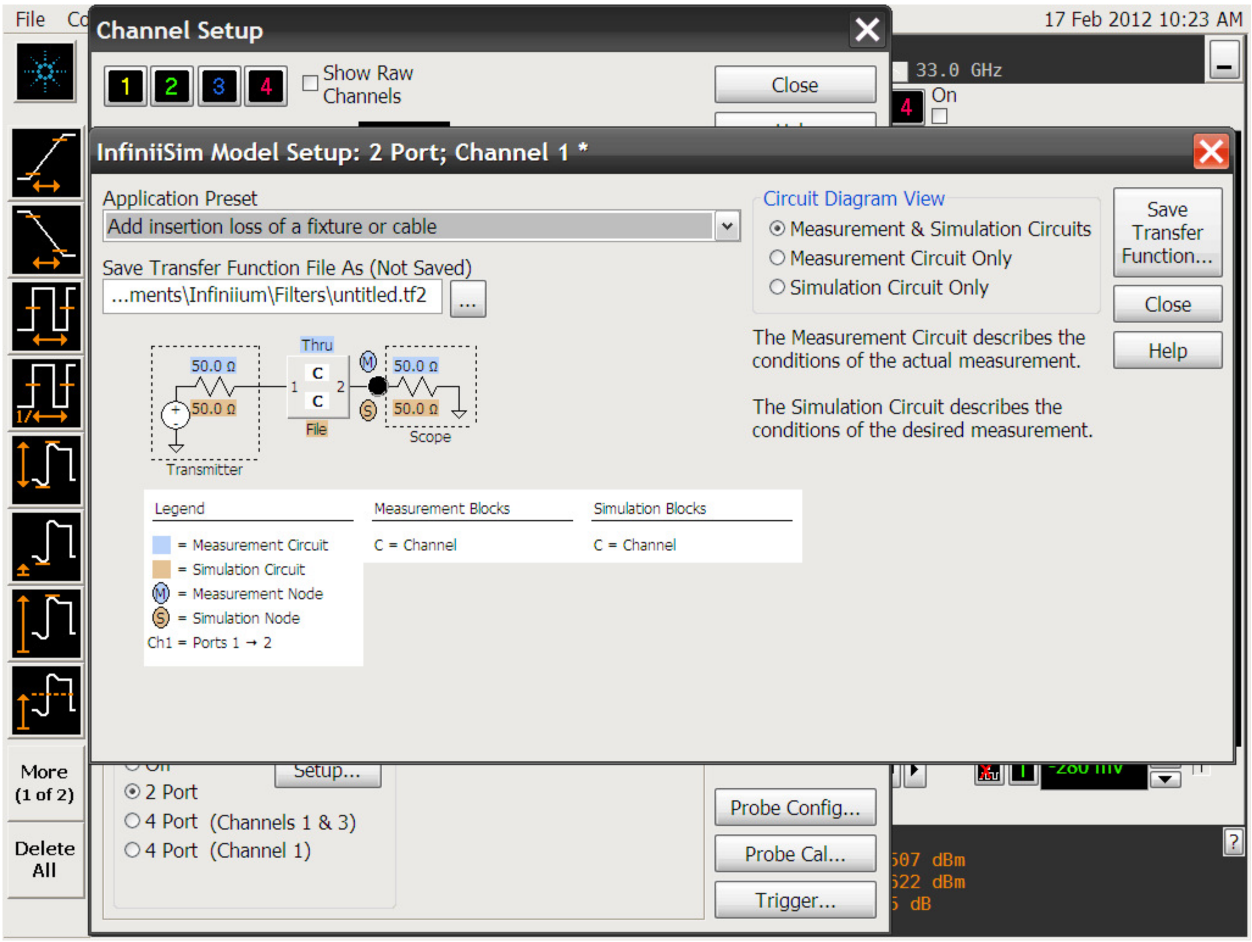

Image 2: Agilent's InfiniiSim software showing how to remove insertion loss through its menu

As explained above, the other methods for characterizing cable loss include a VNA or a TDR. A VNA is an instrument which measures the frequency response of the device under test (DUT). A sine wave input to the DUT and the vector magnitude ratio is calculated between the reference and transmitted (S21) or reflected (S11) signals. The frequency response is obtained by sweeping the signal input across frequency. A band-pass filter is located in the receiver to remove noise and unwanted signals from the measurement to improve accuracy.

The TDR works by emitting a fast rising edge waveform into the DUT and it then measures the reflected waveform and displays the characteristics based on the reflections that occurred. The advantage of the TDR is that the same mainframe that makes the TDR measurement (typically a sampling oscilloscope) can be used to measure the DUT. The sampling oscilloscope mainframe shares its hard drive so there is no exporting of files. It also means less equipment as two modules are needed instead of two entirely different instruments.

Of course, neither the VNA nor TDR-based method is available for real time oscilloscopes. Also, both a VNA and a TDR require expertise to run them. If cable characteristics are measured incorrectly, the s-parameter file will be invalid. Unfortunately, oscilloscope software cannot distinguish between a valid and an invalid file. Transfer functions will be created in either case, which means there is potential for error (typically the waveform transformation will warn users if a bad file is created). As a result of the complicated task of creating s-parameter files through a VNA or TDR, oscilloscopes users tend to ignore cable loss. The belief is that the hours it takes to characterize a cable plus the requirement of extra equipment, will only gain the designer a few picoseconds of margins. This leads many engineers to make the assumption that cables are lossless. Unfortunately, as high speed serial lanes continue to get faster, it is becoming increasingly important to measure and compensate for cable loss as the loss is no longer negligible.

Emerging Measurement Science

To avoid the challenges of TDR and VNA methods, a new method of characterization has emerged. One example is Agilent's Infiniium real time oscilloscope N2809A PrecisionProbe software. PrecisionProbe is cable loss characterization and, more importantly, compensation software that can be performed on a real time oscilloscope. The key advantage of software tools (oscilloscope characterization tools) such as PrecisionProbe is that it can be done using a real time oscilloscope and the characterization only takes a few minutes instead of hours. Another advantage is that after the cable is characterized, the software automatically does the compensation of the cable in real time. There is no need to run it through de-embedding software.

Software tools such as PrecisionProbe work by using the fast edge built into the oscilloscope that is used for calibration (the Agilent 90000 X-Series' edge is less than 15ps). The calibration edge is then deeply averaged and a differential math is applied to the fast edge, creating a pulse. The fast fourier transform is taken of the pulse and the characteristics are then known for the edge. PrecisionProbe takes a baseline measurement as described above. The new cable is then added to the measurement circuit as pictured in Image 1 and a comparison is made between the baseline and the new measurement. The differences are known to be because of the addition of the cable and S21 characteristics are then known.

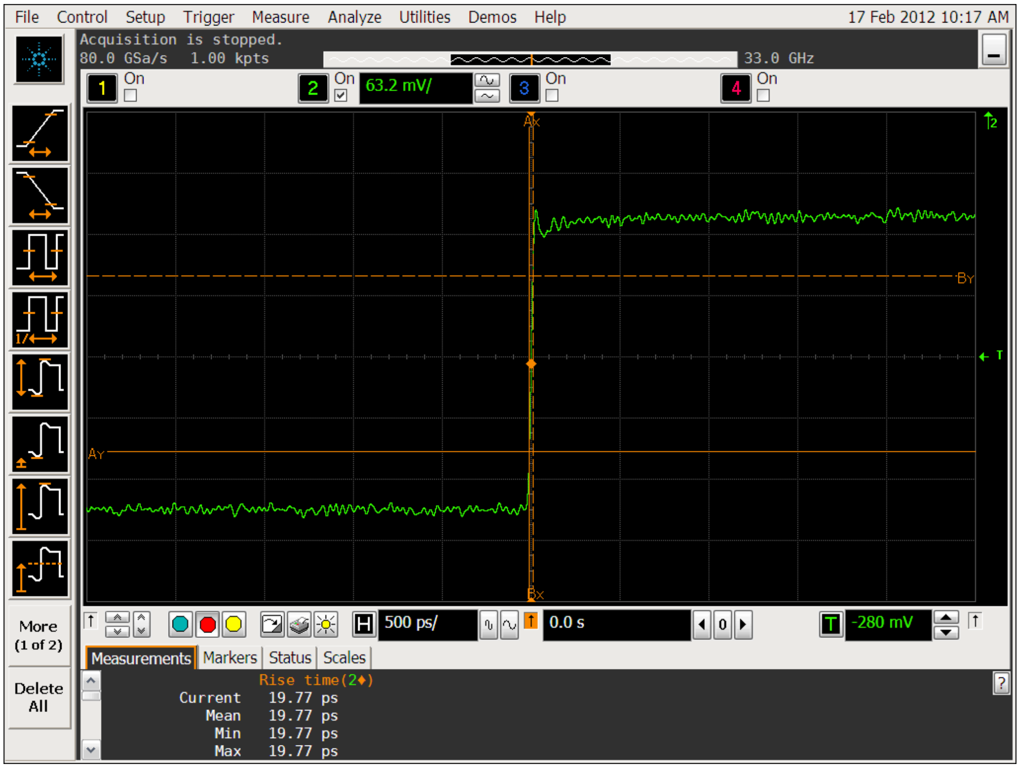

Image 3: Image of the calibration edge of the 90000 Q-Series oscilloscope

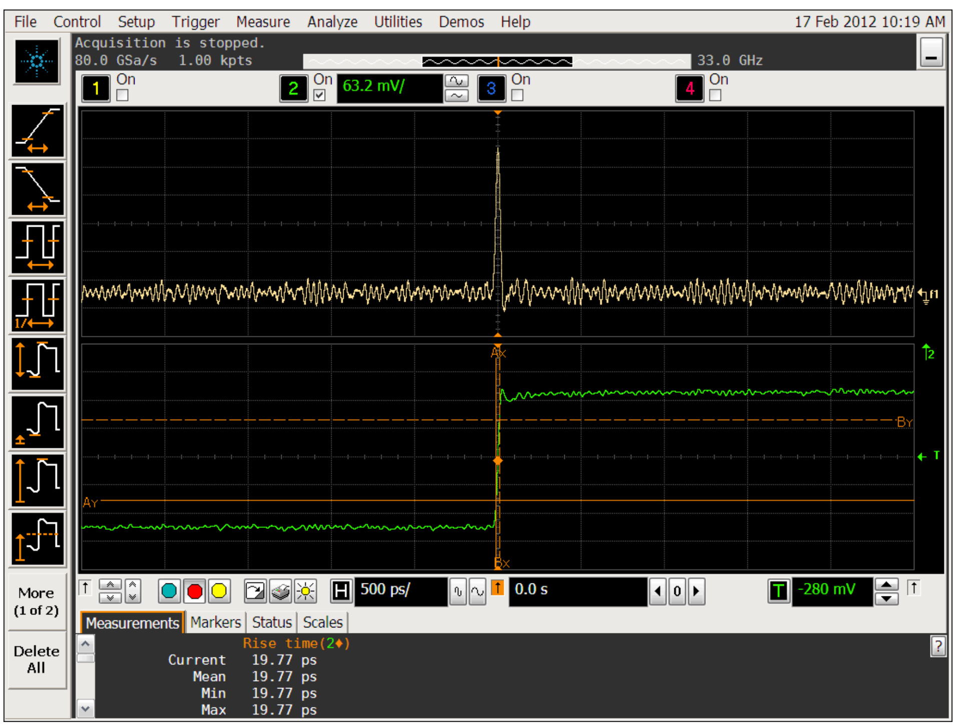

Image 4: Pulse created from differential math of the fast edge

Image 5: FFT of the pulse of the differential math from the calibration edge of the 90000 Q-Series

Typically a wizard is used to guide the user through the steps and the entire process takes less than five minutes. Again, it is important to note that no additional equipment is required other than the real time oscilloscope which the engineer is already using. Because of its simplicity, designers no longer need to ignore cable loss, but instead can characterize them on their oscilloscope and compensate for them.

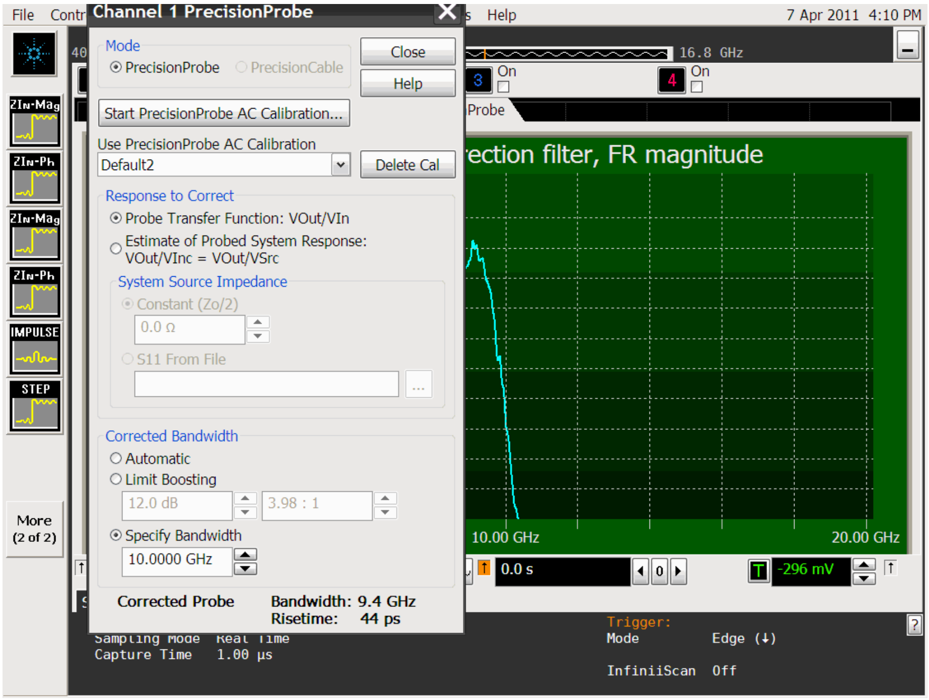

Image 6: Step by step wizard from the PrecisonProbe software

Conclusion

Cable insertion loss erodes margins, yet is largely ignored by designers and oscilloscope users. The reasons that cable loss is largely ignored has to do with requiring additional equipment that requires additional expertise, So, rather than go through this process, the loss is ignored. By ignoring cable loss, companies are potentially losing or wasting large sums of money on oscilloscope bandwidth. To solve this dilemma, oscilloscope vendors have invented new software that takes advantage of hardware built into the oscilloscope such as Agilent's N2809A PrecisionProbe software. This software allows for engineers to quickly characterize and compensate for cable, fixture, or loss in a switch matrix without requiring additional equipment. This new software enables engineers to get precious margins back that previously were lost due to cables - margins that will enable them to get to market faster.