

DesignCon 2009

Characterizing Non-Standard Impedance Channels with 50 Ohm Instruments

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Abstract

Today's telecommunication systems are undergoing tremendous change due to demands on bandwidth requirements. The triple play of voice, video, and data demand high performance systems with optimized backplanes and interconnects. To achieve high speeds, new protocols are emerging that break from the traditional 100 Ohm differential circuit architecture. New 75 Ohm single-ended and 85 Ohm differential topologies have been proposed to enable higher data rates, but care must be taken to avoid channel simulation errors caused by mixed reference impedances of cascaded S-Parameter blocks. This paper critically examines various test and measurement methodologies to provide unique insight into characterizing non-standard impedance designs.

Author Biographies

Julian Ferry – Samtec, Inc. - earned a BSEE with an emphasis in RF and microwave engineering from Penn State University, University Park, PA. He has more than twenty years experience in the high speed interconnect industry focusing on product design and development, test and simulation, and team management. Julian has authored more than twenty articles and papers and has been granted thirteen U.S. and numerous international patents covering products and processes for improved Signal Integrity and EMC performance.

Jim Nadolny – Samtec, Inc. - received a BSEE from the University of Connecticut in 1984 and an MSEE from the University of New Mexico in 1992. He has focused on EMI design and analysis at the system and component levels for fifteen years and has recently been focused on multi-gigabit data transmission. Jim is active within the technical community having served as chairman of TC-10, a technical committee dedicated to signal integrity in the IEEE EMC Society, and as a track chairman for DesignCon 2008. At Samtec, Jim leads a team of SI specialists dedicated to providing models, data, and simulation services.

Craig Rapp – Samtec, Inc. - earned an Associate Degree in Electronic Engineering supplemented with a BS degree in Organizational Management. In a 20 year engineering career, Craig has obtained vast knowledge in High Speed test equipment utilization which he fosters with the latest technological advances in frequency and time domain analysis tools. His testing experiences include disciplines in RF/Microwave military inspection, product qualifications, and development of test procedures for micro-probing. Craig currently is project manager for Samtec High Speed Connector Characteristic formal reports and assumes responsibility for managing test laboratory resources.

Mike Resso – Agilent Technologies, Inc. - is a Signal Integrity Measurement Specialist in the Component Test Division of Agilent Technologies and has over twenty years of experience in the test and measurement industry. His background includes the design and development of electro-optic test instrumentation for aerospace and commercial applications. His most recent activity has focused on the complete multiport characterization of high speed digital interconnects using Time Domain Reflectometry and Vector Network Analysis. He has authored over 25 professional publications including a book on signal integrity. Mike has been awarded one US patent and has twice received the Agilent "Spark of Insight" Award for his contribution to the company. He received a Bachelor of Science degree in Electrical and Computer Engineering from University of California.

O.J. Danzy – Agilent Technologies, Inc. - is a RF and Microwave Application Engineer at Agilent Technologies specializing in areas surrounding physical layer test, network analysis, test system design and automation. Most recently he has focused on fixture removal and in-fixture calibration methods and techniques for multiport network analysis applications. He received Bachelor of Science in Electrical Engineering from Tennessee State University and a Master of Electrical Engineering from Cornell University.

Introduction

The industry has seen a recent emergence of high speed data transmission protocols based on non-traditional system impedances. For example, systems operating in an 85 Ohm differential impedance environment with single-lane bandwidths to 10 GHz and beyond are in development. Also, high definition video transmission standards based on 75 Ohm single-ended systems with 6 GHz bandwidths are already in place.

The move from typical system impedances can lead to measurement and simulation challenges. The majority of high speed, RF, and microwave test instrumentation operate in a 50 Ohm single-ended or 100 Ohm differential environment. Some 75 Ohm single-ended instrumentation is available, but is typically limited to lower bandwidths.

Dedicated systems for characterizing 85 Ohm differential components are currently non-existent. Test methods using standard instruments with custom calibration standards are possible, but not yet straight forward, and will suffer from traceability issues for the foreseeable future. Therefore, characterization of component and channel properties for such emerging systems is not yet a push-button affair.

To compound the problem, there is a recent move toward system simulations based on S-Parameter component models. Such S-Parameter models are often created from measurements, and confusion can arise when using S-Parameter models in environments other than which they were measured or derived.

Fortunately, existing 50 Ohm instrumentation and calibration standards can be employed in conjunction with data post processing routines to adequately characterize components for these emerging systems. Such measurements can also be used to generate S-Parameter models compatible with industry standard simulation packages.

This paper describes several approaches for characterizing non-standard impedance devices using existing test instruments, familiar fixturing and calibration techniques, and commercially available post processing software. The paper provides a brief discussion of the history and motivation behind the choice of various system impedances. Issues and challenges faced when attempting to characterize non-standard impedance devices are also discussed, and several methods for performing such characterizations are presented.

The methods are demonstrated by characterizing real world, high speed components. To illustrate the basics of the techniques, a 75 Ohm 5 GHz coaxial cable assembly from a high definition video system is characterized with the objective of determining its performance in a 75 Ohm environment. The assembly is characterized with several procedures using both 75 Ohm and 50 Ohm VNA systems.

We follow with a multi-port example of an 85 Ohm differential, multi-pair high speed cable assembly. The objective of this measurement is to obtain a S-Parameter model which can be used in circuit simulations.

Readers are assumed to have a working knowledge of VNA operation including standard calibration methods for 50 Ohm single and multi-port instrumentation, a familiarity with typical post processing software, and an understanding of S-Parameter based circuit simulations.

System Impedance Choices

Many considerations go into the choice of system impedance. Cost, size, loss, and power handling are a few major considerations. Over time, several impedance values have evolved into de-facto system impedance standards. Some examples are 600 Ohm differential for telephone, 50 Ohm single-ended for RF and Microwave systems, 100 Ohm and 150 Ohm differential for high speed data, and 75 single-ended and 300 differential for video. Standardized impedances benefit the industry by providing consistent impedance targets for components and test instruments, as well as standardized characterization data.

Most RF and microwave hardware is currently designed and specified for 50 Ohm operation. While the topic is subject to some debate, the standardization on 50 Ohms probably began as early as the 1930's. 50 Ohms is a good compromise between minimum loss/maximum high voltage and power handling for air-dielectric coax cables. Both issues were important with early transmitter designs. No matter the reason, 50 Ohms has become the most widely accepted standard for system impedances, and hence, the vast majority of high frequency and high speed test instrumentation is constructed with 50 Ohm test ports.

The 75 Ohm video standard emerged later. 75 Ohms is a good compromise between lowest theoretical cable losses and cable cost. In video applications where it was first used, low attenuation was more important than handling high power. An impedance in this range also allows simple construction of transformers to match the 75 Ohm single-ended cables to 300 Ohm differential twin lead which was often used to feed antennas.

Most 75 Ohm CATV (community antenna television) systems were limited in bandwidth to approximately 200 MHz to 800 MHz, but the recent move to high definition and digitally switched video has pushed bandwidth requirements higher. Current systems are specified to 3 GHz, with bleeding edge designs pushing 6 GHz. Large investments exist in 75 Ohm legacy infrastructure, so 75 Ohm systems will be with us for the foreseeable future. Some dedicated 75 Ohm test instruments are available, but typically with a limited frequency range and calibration options.

The move to 85 Ohm (differential) systems is very recent. This move has been promoted by leading edge I/O developers as offering better Signal Integrity performance with typical PCB based systems [1]. No 85 Ohm test instruments are known to exist at this time.

Clarifying Measurement Objectives

Before we undertake our measurements, we must consider the desired outcome of the characterization of our DUT (Device Under Test). Some measurements are performed to determine how a component will behave in a certain impedance environment. For example, the return loss of a 52 Ohm cable assembly will look much different in a 50 Ohm system than in a 75 Ohm system.

Many component specifications are written around the component's performance when used in a system's native impedance. This provides standardization among suppliers and users of components, and allows system designers to perform some basic calculations. For example, many assemblies designed for use in 75 Ohm systems will have their specifications written assuming a 75 Ohm test environment.

Generally, it is not difficult to mathematically transform the data from one reference measurement to another. An approach to reference impedance transformation of an S-Parameter matrix is described in [2] which can be applied to ports with differing impedances.

Assume a scattering matrix S with reference impedance of A_{ii} . To compute S' with reference impedance of B_{ii} , the following equation can be used:

$$S' = P^{-1}(S - \gamma)(I - \lambda S)^{-1}P \quad \text{where}$$
$$P_{ii} = \sqrt{\frac{\text{Re}(A_{ii})}{\text{Re}(B_{ii})} \frac{B_{ii}}{A_{ii}} \frac{2A_{ii}}{A_{ii} + B_{ii}}}, \quad \gamma_{ii} = \frac{B_{ii} - A_{ii}}{B_{ii} + A_{ii}}$$

If we make the assumption that all port impedances are real and the same value the transformation simplifies to a renormalization of the Z-Parameters. The S-Parameter matrix is converted to Z-Parameters then renormalized and converted back to an S-Parameter matrix as shown in [3]. Such transforms can be programmed into a spreadsheet or similar calculator for post processing VNA data. Many RF and SI circuit simulators perform this function automatically.

Measurements for Creation of Simulation Models

In addition to “testing to spec”, it is increasingly common to characterize DUTs so that the measured data may be used in circuit simulations. S-Parameters are commonly used today for such applications. Fortunately, it is fairly straight forward to perform S-Parameter characterizations using standard 50 Ohm lab equipment. In fact, most mainstream simulation software defaults to S-Parameters with a 50 Ohm reference impedance. As our experiments will show, it is often more practical and accurate to create models for many non-50 Ohm devices using 50 Ohm test instruments and calibration structures.

Test Approaches

In an ideal world, test instrumentation would be available for characterizing devices in any arbitrary impedance environment we desire, with connection schemes which allow us to connect our DUTs directly to the test instrument's ports. Suitable calibration standards would also be available so we could define our reference plane at the input port of the DUT. Unfortunately, our world is not yet ideal.

The vast majority of high speed, high frequency test instrumentation is constructed with 50 Ohm coaxial test ports. And we must keep in mind that there is a real and an imaginary component to impedance. So we're actually talking about a 50 Ohm real + 0 Ohm imaginary (or 50 Ohm magnitude, 0 degrees phase) test port impedance.

And except for a few fortunate instances, most DUTs don't come with a standard coaxial interface, or a perfect 50 Ohm (or even a known) impedance. Adapters or fixturing must be used to connect the DUT to the instrument. Ideally, the adapters will have no effect on the measurement. But that is not the case in the real world. So we must utilize special methods to determine the effects of adapters and remove them from the measurement.

Matching Port Impedances in the Real World

From a practical perspective, very few devices exist which exhibit consistent impedance across a wide frequency band. So in most measurements, an impedance mismatch will naturally occur between the instrument test port and the DUT at some frequency points. The magnitude and phase of the mismatch will likely vary with frequency. These mismatches cause signal reflections which lead to errors in the perceived response of the DUT. Such discrepancies lead to "mismatch error". Fortunately in many cases, these errors can be quantified and compensation can be added to the measurement so that it is in effect "corrected".

In the time domain, mismatch will appear as a change in the impedance profile with a deviation from the reference impedance at a particular point in time. In the frequency domain, mismatch will commonly appear in the return loss as a periodic ripple. The peak-to-peak magnitude of the ripple helps quantify the size of mismatch, but frequency domain magnitude information does not easily yield the location of the impedance discontinuity.

Compensating for this measurement mismatch can greatly improve the quality of measurements [12]. Failing to correct for mismatch can cause designs, measurements, or simulations based on the uncorrected data to be questionable at best, or misleading and unusable. Because of the use of non-ideal, variable components, mismatch errors often occur in a measurement system prior to even connecting a device. In a typical Vector Network Analyzer (VNA) measurement system, the familiar full 1, 2, or N-port calibration process can correct for most inherent system mismatch errors.

Mismatch Error at the Test Port

Since most VNAs have a 50 Ohm port impedance, most traceable calibration standards are also designed at 50 Ohms. Calibrations performed with these standards work well when the measuring system and device are close in impedance. However, the greater the difference in characteristic impedance between the test port and the DUT, the greater the uncertainty in the measurement will be.

Current calibration techniques are not perfect, but they can provide a quantifiable and useful measurement. Calibration corrections bring the system into a “pseudo known” region bounded by maximum uncertainty levels which are determined mathematically.

An uncertainty analysis between the source and load impedance values can be used to bound the possible impedance range of the measured data [5].

$$Mismatch_Error = \frac{1}{(1 \pm \rho_S \rho_L)^2}$$

where ρ_S and ρ_L are the magnitudes of the source and load reflection coefficients

Correcting Fixed Mismatch Errors Mathematically

Three predominant methods are used to correct mismatch errors mathematically: time domain gating, re-normalization, and model de-embedding.

In time domain gating, the user selects a non-ideal section of the test path to “remove” from the measured data. This part of the test path is mathematically replaced with an ideal transmission line fit between the defined gate start and stop points. A source of uncertainty in this method is the fact that gate placement is subject to human interpretation, and is often not precise. Additionally, the effect of large discontinuities can have propagating effects on the remainder of the measurement [6].

A significant limitation of the gating method is that it can only account for reflection parameters of the gated segments. Phase uncertainties are also difficult to quantify. Therefore, time domain gated data is of limited use in developing models for use in circuit simulations where quantifiable loss or phase accuracies are required.

In the renormalization method, a calibrated measurement made in one impedance environment is mathematically transformed to determine its equivalent response in a different impedance environment. As mentioned earlier, the effect of port impedance changes can be easily calculated [7]. This method works very well if the device has a near instantaneous change from the measurement port reference impedance to the secondary impedance. Otherwise, it may be necessary to combine multiple reference plane extensions prior to applying the final impedance renormalization, and each extension adds to measurement uncertainty.

Another common correction method, model de-embedding, uses a mathematical model of the impedance transition (often based on S-Parameters) to remove the effects of the mismatch from the measured data using circuit simulation techniques. The accuracy of this method depends heavily on the accuracy of the model of the impedance transition section.

Correcting Fixed Mismatch Errors with Hardware Approaches

Several methods are also commonly used to correct mismatch errors using non-standard measurement hardware, sometimes in combination with previously described mathematical methods. Among these are custom calibration standards, impedance matching transformers, and minimum loss pads.

The use of custom calibration kits, that is, calibration standards designed for use at the impedance of interest, has increased in popularity recently. Designing, constructing, and characterizing such kits can be time consuming and costly, with the level of complexity dependent upon accuracy requirements and the frequency range of interest. At higher frequencies, such efforts typically require 2D and 3D electromagnetic simulations of the desired standards, construction and measurement of prototypes, correlation efforts, optimization, and reiteration.

When acceptable characterization data for the calibration standards is obtained, it must be integrated with the VNA firmware or otherwise implemented through post processing software [8]. If properly carried out, this method can be a very accurate. But issues related to manufacturing tolerances, material properties, and computational accuracy can lead to uncertainty and a lack of certifiable traceability [9].

Another method especially common at frequencies below 1 GHz is the use of impedance matching transformers. This method is easy to implement and works especially well with differential measurements, but it can be limited by stability issues caused by the potentially non-linear nature of transformers. Non-linear behavior makes it almost impossible to remove the effects a transformer may have on measured data, even when proper VNA calibration methods are used before and after insertion of the transformer.

Another hardware based approach uses impedance matching pads. The impedance transforming effect of the circuits can practically eliminate mismatches across a certain frequency range. At the same time, attenuation in the pads can lessen the effects of standing waves [10]. This method can be extremely accurate as it is often possible to perform calibration after the impedance conversion and/or use models of the pad network to de-embed the effects of the pads.

One drawback to using this approach is that it leads to a reduction in system sensitivity. The reduction is proportional to the amount of attenuation in the pads, which is typically close to 6 dB. The noise floor and directivity rise by the amount of pad attenuation, which may be unacceptable for some situations. Most modern network analyzers have enough dynamic range head room to handle the loss of dynamic range. But the decrease in directivity limits the values of return loss that can be measured by the system.

Acceptable Impedance Mismatch Levels

With any of the procedures described above, there is a range of impedance values that can be reliably measured with an acceptable level of accuracy confidence. As methods are combined, uncertainty increases, often in ways that are not intuitively predictable. Therefore, it is clearly desirable to keep the number and magnitude of impedance mismatches in the test path as small as possible.

Within reasonable mismatch limits, the uncertainty related to the initial impedance mismatch encountered after the calibration plane is quantifiable to a level acceptable for most any practical use. Many designers use the 10% uncertainty points as reasonable cut off bounds for acceptable measurement uncertainty.

For 50 Ohm network analyzer based measurements, this equates to DUT impedance ranging between 2 Ohms and 1.5 KiloOhms [11]

Real World DUT Examples

Let's now examine our first real word example: a 75 Ohm coaxial cable assembly with a 75 Ohm male and female BNC connector.



Figure 1
5 GHz 75 Ohm BNC Cable Assembly

This assembly is designed for current high definition, high speed video applications. A standard covering such applications is the Society of Motion Picture and Television Engineers (SMPTE) Standard 424M-2006. A recently approved revision spells out requirements for 75 Ohm system bandwidths of 3 GHz and above. Many system engineers currently design for a 6 GHz bandwidth to allow future head room for rapidly emerging applications.

This specification details a 75 Ohm BNC connector as a standard I/O interface. Other connectors may be used in certain instances as long as electrical performance is sufficient. It is interesting to note that prior specifications actually allowed the use of either 75 Ohm or 50 Ohm BNC connectors interchangeably, as long as they were mechanically intermateable. In effect, at speeds up to around 1 GHz, the BNC connector is so electrically short that its impedance is irrelevant in all but the most demanding applications. But as speeds have crept to 2-3 GHz and beyond, previously indistinguishable differences now become performance limiters.

SMPTE 424M-2006 defines a return loss specification for 75 Ohm connectors and cable assemblies. The exact details of the spec are fuzzy, but they clearly require a return loss in a 75 Ohm environment of better than 10 dB to 3 GHz. The Return Loss limit can be extended to a system bandwidth above 3 GHz if so desired. Cable assemblies and other transmission lines must have better than 15 db return loss up to one half the clock frequency, better than 10 dB from one half the clock frequency to the clock frequency, and must display a “typical” $1/\sqrt{f}$ attenuation response.

The ideal, “golden standard” method for characterizing components for such applications is a dedicated 75 Ohm VNA. Such VNAs are available, though they are not nearly as common as 50 Ohm units. They are often limited in bandwidth and tend to lag behind their 50 Ohm counter parts in offering the latest integrated calibration and data post processing capabilities. Calibration standards tend to be limited as well.

In environments where the majority of systems and components are 75 Ohm based, the ease of use, speed, and straight forward operation offered by dedicated 75 Ohm instruments often justifies their use. But as we shall show, dedicated 75 Ohm instrumentation is by no means a prerequisite for proper characterization of 75 Ohm devices.

Demonstration of Measurement Methods

To demonstrate the advantages and disadvantages of the measurement approaches described above, we measured a 75 Ohm BNC assembly using several approaches. We first measured the assembly with a 75 Ohm VNA, and then repeated the measurements using a 50 Ohm VNA.

Testing with a 75 Ohm VNA

The instrument we used is a typical modern, dedicated 75 Ohm measurement system. It functions over a frequency range of 300 KHz to 3 GHz, with 75 Ohm Type N connectors as the standard test port interface.

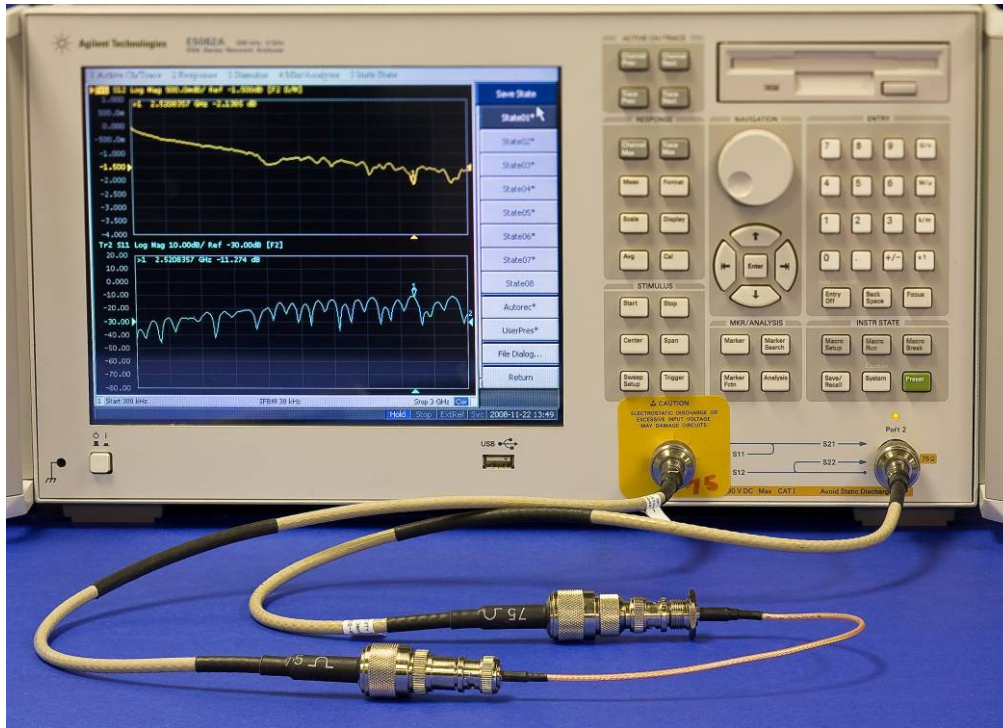


Figure 2
75 Ohm VNA System

Even with such optimal test instrument, we ran into several problems out of the gate. The instrument ports use 75 Ohm Type N connectors, and the standard calibration kit is also Type N, but our DUT interface is 75 Ohm BNC. So we have several options.



Figure 3
75 Ohm Type N Calibration Standards

We could purchase or construct 75 Ohm N to BNC adapters and a BNC calibration kit. This approach would allow us to attached the adapters to the N test ports and calibrate at the far end of the adapters, thus “calibrating them out” of the measurement. And fortunately, our device is directly insertable, so with appropriately sexed adapters on either end of the test ports, we could get a “true’ measurement of our DUT after calibrating out the adapters.

In such a case, the reference plane would be located in the middle of the mated BNC pairs. So in effect, we would measure the performance of only one half the connector pair on each end of the assembly. With proper documentation in a specification, this is a good approach. In fact, it may even be the most desirable method if the connector will be used in a situation where connectors from various manufacturers or of different configurations (such as right angle and straight feed) will be mated with it.

Another common approach with such assemblies is to calibrate at the N ports, and then consider the N to BNC adapters to be in effect, part of the DUT. This works fine when testing to a specification such as the SMPTE spec. It is unlikely that the adapters would cause the cable assembly look better than in actuality. So in many applications it is safe to assume that if the DUT meets the spec with the adapters in place, it will also pass as a stand alone unit. We chose this approach first, with the test set up pictured below. Note that the small arrows indicate the calibration reference plane.

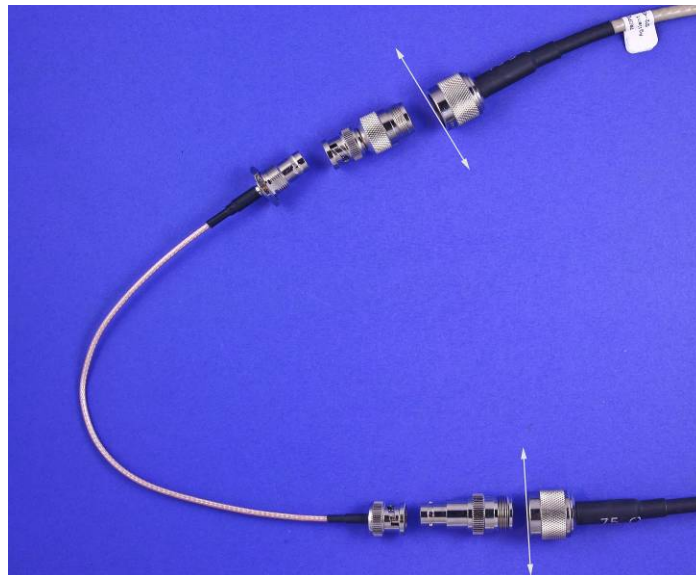
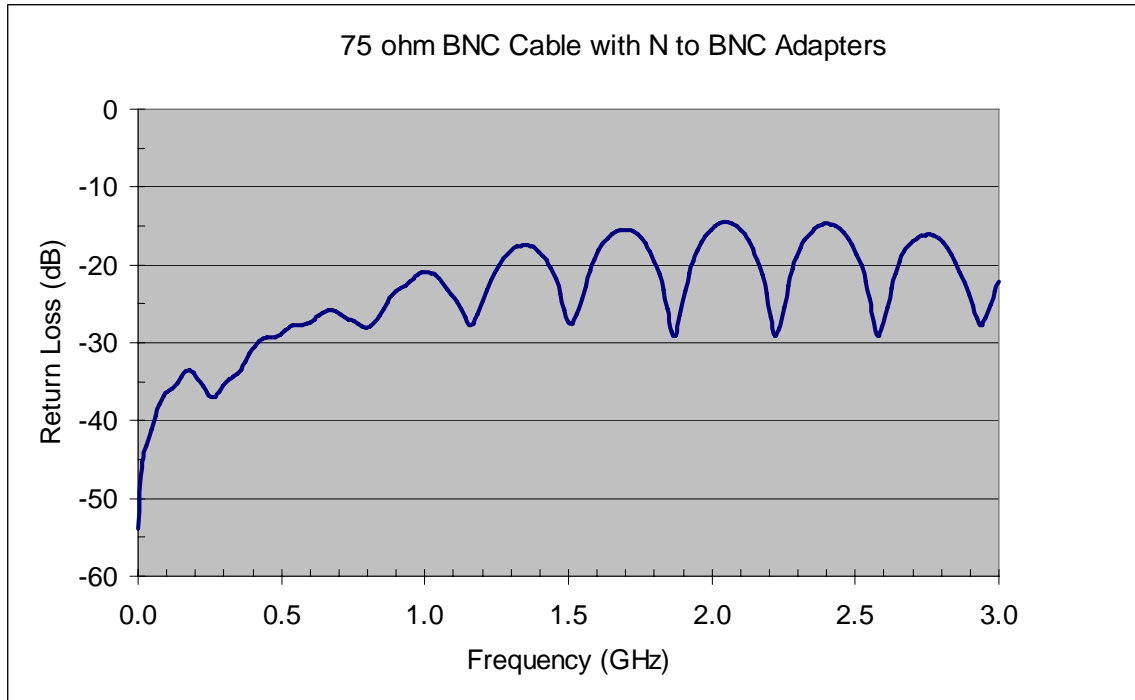


Figure 3
75 Ohm Measurement with Adapter Effects Present
(Note calibration plane at arrows)



Plot 1
DUT with adapters

This data demonstrates that the assembly meets the return loss specifications requirements even with the adapters in place. In most applications, the accuracy of this type of measurement will be limited by the performance of the adapters. However, measurement uncertainty is impossible to define. Models of the DUT can be extracted from the data, but they should be used with caution. Simulations based upon such models will likely provide lower than worst case performance, which can lead to unnecessary system over design.

This DUT lends itself quite well to a time domain gating approach. With this method, the calibration is made at the N ports, and the DUT is measured with the adapters in place. Gates are then placed around the impedance discontinuities presented by the adapters, and their effects removed mathematically.

However, as mentioned earlier, if the adapter does not present a clear and discernable impedance transition, questions about proper placement of the gates can arise. To minimize this issue, we constructed a set of precision cable assemblies which in effect stretch out the length of the adapters. Thus, we have a clearly discernable break between the N to BNC adapters and the cables used in our adapter assemblies, which allows us to easily determine where to place the gates. Another advantage of this approach is that it allows us to characterize the effects of a mated pair of connectors, as opposed to only half a connector pair as with the previous method. The test set up is illustrated below.

Note that the small arrows indicate the calibration reference plane, while the large arrows indicate the location of the time domain gates. This standard will be followed throughout this document.

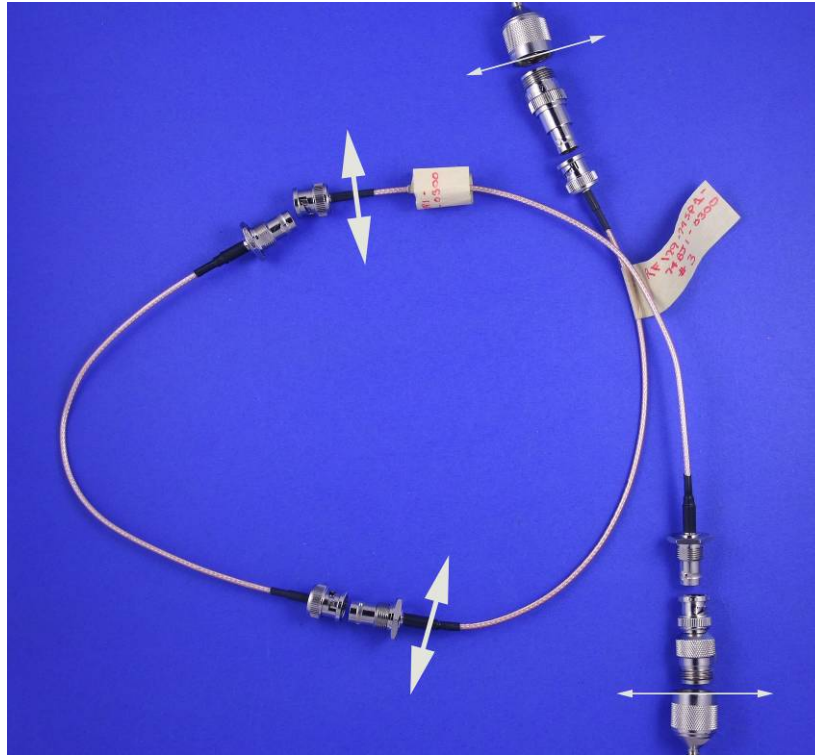
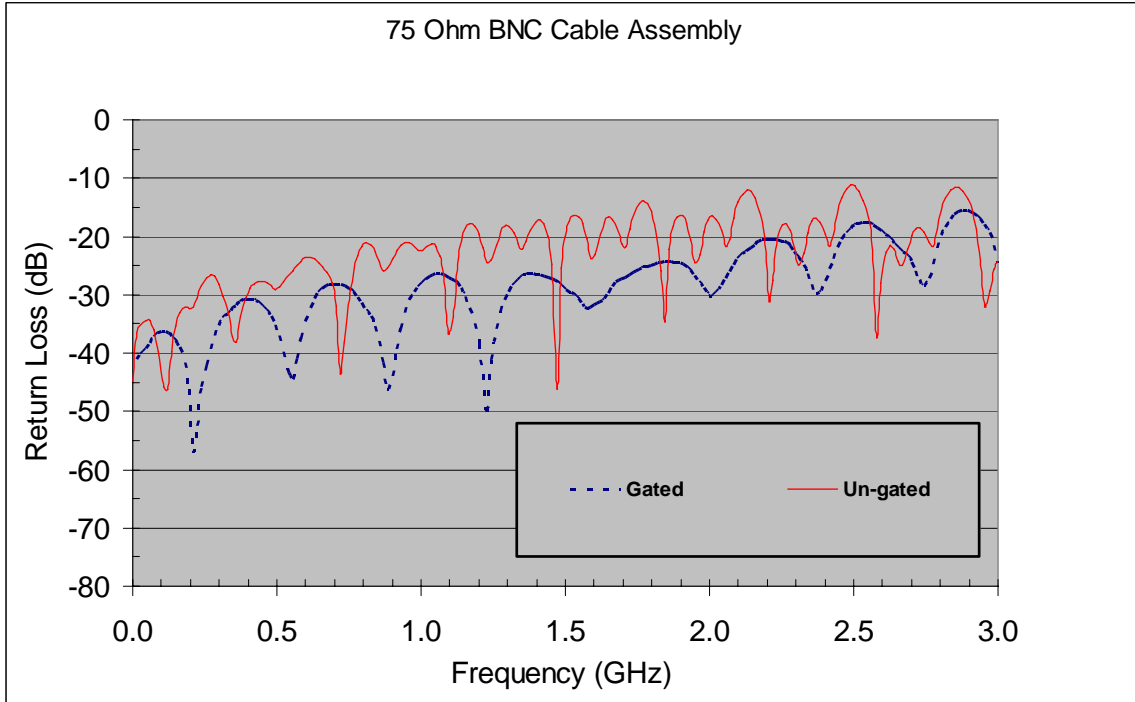


Figure 4
75 Ohm Measurement with Cable Assemblies as Adapters
(Small arrows mark calibration plane, large arrows mark gating plane)

Time domain gating capabilities were not available with the 75 Ohm VNA used in this experiment, so we exported the measurement data in S-Parameter format and performed the gating using commercially available post processing software. Results are below.



Plot 2
75 Ohm DUT data gated and un-gated

This data shows that with the effects of the adapters removed, we have much more margin with respect to the specification.

Testing with a 50 Ohm VNA

For the 50 Ohm measurements, we used a 10 MHz - 50 GHz VNA system. The system was controlled by commercially available control and calibration software, which was also used for data post processing.



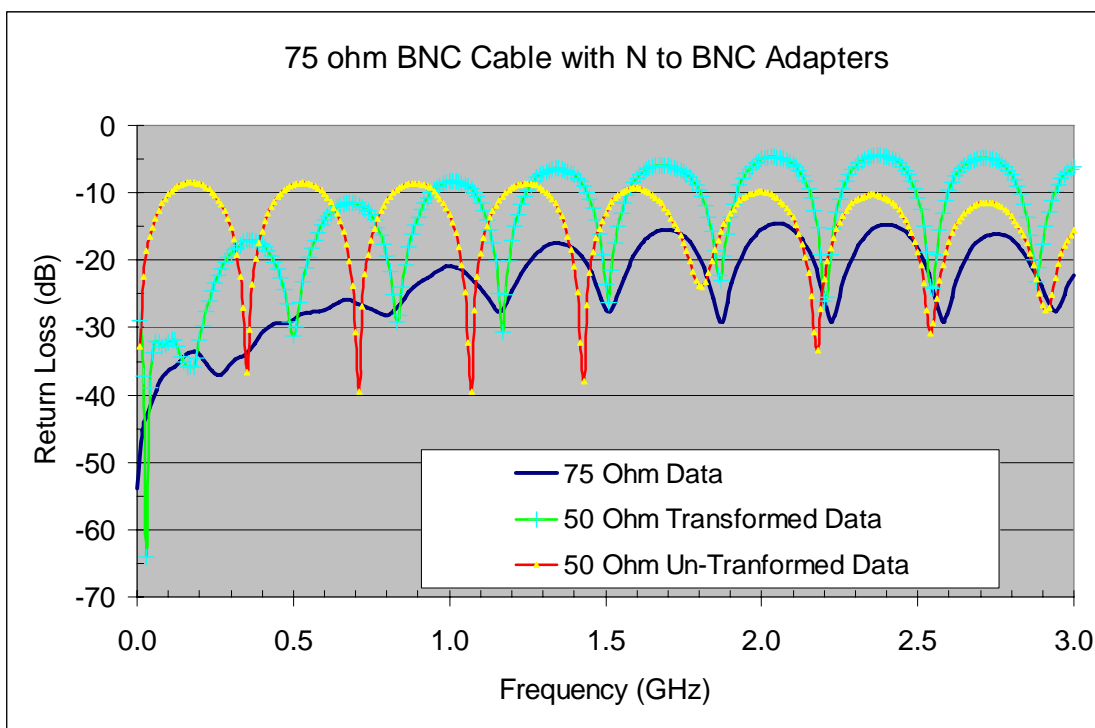
Figure 5
50 Ohm Measurement System

The methods used with the 75 Ohm VNA are easily transferred to a 50 Ohm VNA, with an appropriate change of adapters. In light of the earlier impedance transform discussion, our results should be very similar, and just as valid.

An advantage of the BNC connector is that some 75 Ohm designs are mechanically intermatable with some 50 Ohm designs. This is less than optimal electrically at higher frequencies, but it allows some direct measurement comparisons. So next, we duplicated our previous 75 Ohm measurement with the 50 Ohm VNA. However, it was necessary to use a different set of adapters to mate with the 50 Ohm SMA calibration plane.



Figure 6
50 Ohm Measurement with Adapter Effects Present



Plot 3
DUT with adapters, 50 untransformed data, 50 ohm transformed data, and previous 75 Ohm data (from Plot 1)

Based on these results, it was obvious that the 50 Ohm BNC adapters did not perform as well as the 75 Ohm N to BNC adapters used earlier, and gave poor results above a few hundred MHz.

For our next experiment, we attempted to repeat the gated measurement made earlier with the 75 Ohm VNA, with a test set up pictured below.

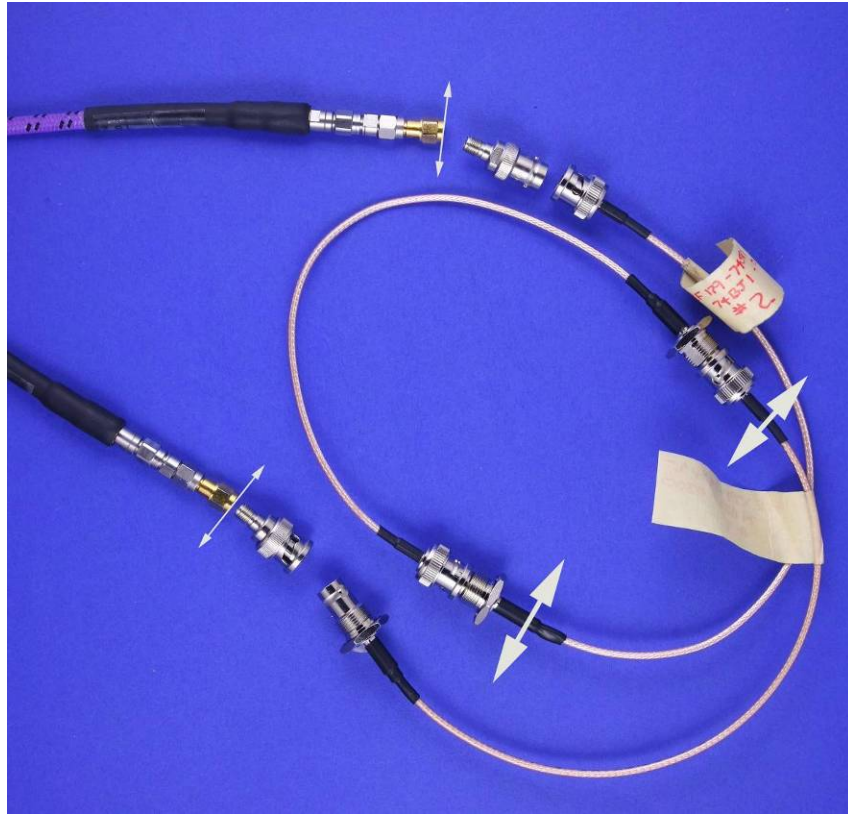
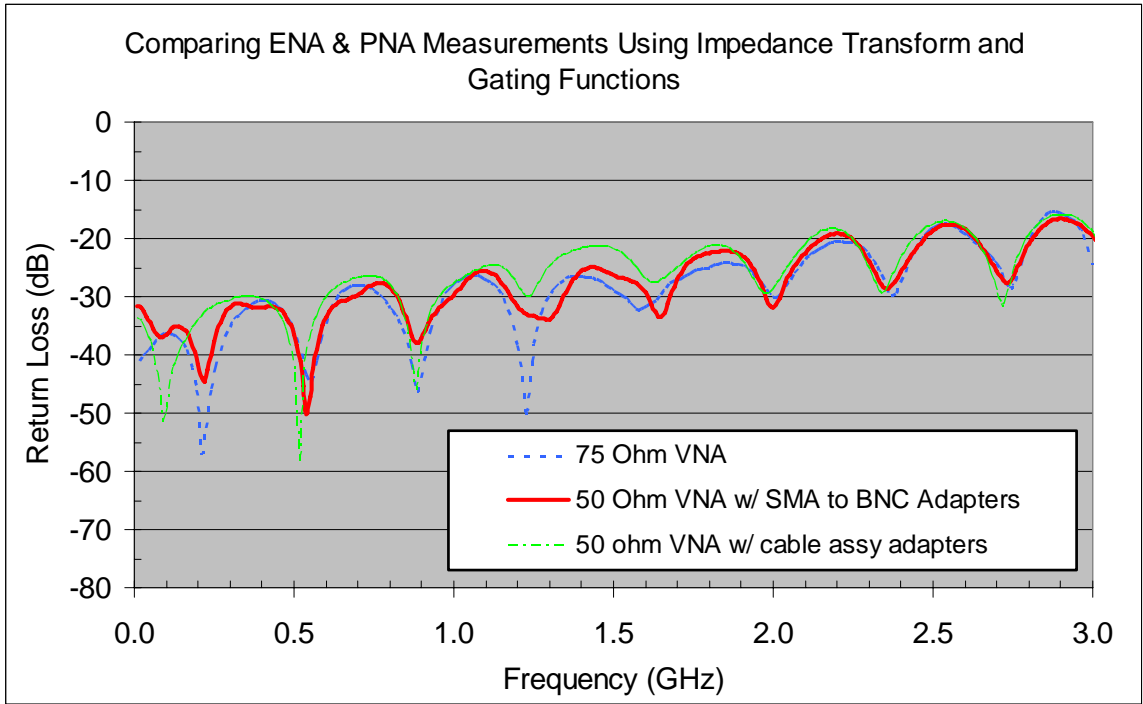


Figure 7
50 Ohm Measurement with Cable Assemblies and BNC Adapters

During this measurement, we suspected that the low quality BNC adapters could impact our accuracy here as well, even though we gated their effects. To investigate this issue, we constructed another set of adapter cable assemblies utilizing 50 Ohm SMA connectors. This provided a cleaner electrical transition. Results are presented below.



Figure 8
50 Ohm Measurement with SMA Cable Assemblies



Plot 4
Data for both 50 Ohm Gated configurations above, plus previous 75 Ohm gated data

We consider this correlation to be perfectly acceptable for our application. Somewhat to our surprise, the gating is actually effective in removing the effects of even the poor performing SMA to BNC adapters.

Time domain gating and enhanced calibration options are more widely available with many 50 Ohm VNAs as compared to their 75 Ohm counterparts. Versions of multi-port 50 Ohm VNAs are also available which open up the door to characterizations of more complex devices including those used in differential applications.

An 85 Ohm Differential Example

To demonstrate differential multi-port methods, we characterized a high speed 85 Ohm differential, 1 meter cable assembly. The assembly is based on a new high speed I/O interconnection system, with the test sample constructed from specially developed 85 Ohm twin axial cable.

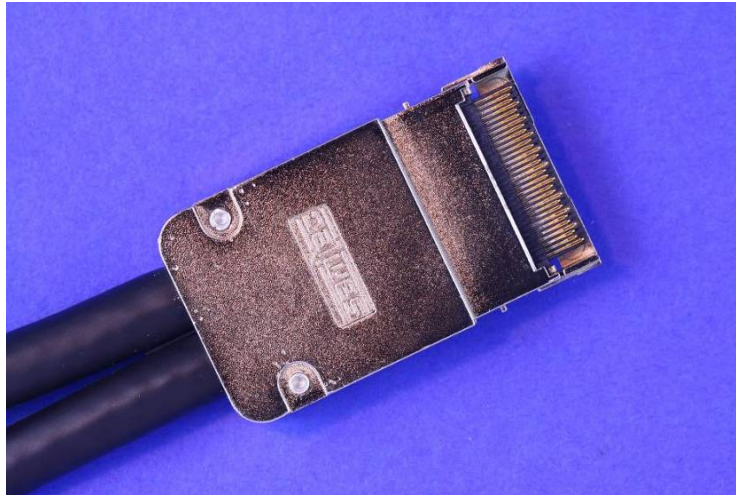


Figure 9
High Speed I/O Cable Assembly

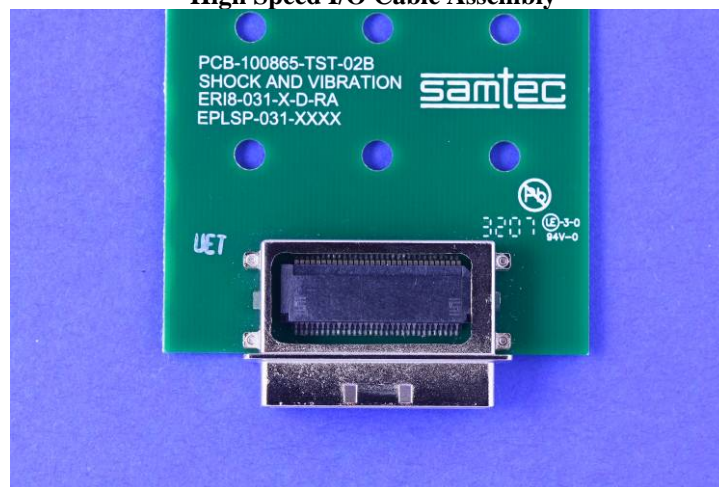


Figure 10
High Speed I/O Board Mount Connector
Note shield is cut away to allow examination of connector

Most 85 Ohm system specifications currently proposed are based on channel performance limits. This is a different approach from many traditional specifications where performance requirements are provided for each individual component. Therefore the desired objective of our measurement was not to test to a pass/fail requirement. Instead, our goal was to obtain a S-Parameter based model that could be used in system level channel compliance simulations.

As mentioned previously, obtaining S-Parameters for simulation purposes is actually straight forward with 50 Ohm instrumentation. In addition, 50 Ohm instruments can open the door to a full suite of cutting edge calibration and post processing techniques.

Overview of S-Parameter Based Simulations

A brief discussion of S-Parameter simulations is now in order. “Generalized S-Parameters” describe the behavior of a device when a perfect impedance match is present at all ports. Note that port impedance could be a complex value (with magnitude and phase) and will likely vary with frequency.

In the Signal Integrity environment, it is common to work with “Normalized S-Parameters”. Normalized S-Parameters are constructed such that each port has a constant, implicitly defined impedance known as the reference impedance. By tradition and convenience, most normalized S-Parameters are referenced to a 50 Ohm real, Zero Ohm imaginary port impedance.

S-Parameters generated from most modern VNAs will be referenced to the VNA’s system impedance, which is in most cases 50 Ohms. If a reference impedance isn’t mentioned, it is usually safe to assume 50 Ohms. However, with a component typically used in a 75 Ohm or 85 Ohm system, it is a good idea to verify the reference impedance.

Most modern simulation software can handle S-Parameters with any reference impedance. The conversion between impedances follows directly from the equations provided earlier. Most widely accepted standards for S-Parameter data formatting (such as Touchstone and .citi formats) spell out the reference impedance of the model in a designated portion of the file header.

For example in this section of a .sp4 Touchstone model, the reference impedance is as noted below:

```
!S4P File: Measurements: <S11,S12,S13,S14>,  
!<S21,S22,S23,S24>,  
!<S31,S32,S33,S34>,  
!<S41,S42,S43,S44>:  
# Hz S dB R 50  
10000000 -2.310623e+001 2.726391e+001 -2.171497e+001 5.360749e+001 -  
4.421907e-001 -2.869534e+001 -3.266447e+001 -1.569800e+002.....
```

Since 50 Ohms is the de-facto standard for normalized S-Parameters, it is convenient to characterize devices in a 50 Ohm environment. To characterize the 85 Ohm cable assembly, we used a TRLM calibration procedure. The interconnect channel consists of a PCB mount connector at each end, connected by a cable assembly. This channel was based on an optimized PCB footprint and reference design package, so we wanted to include the effects of footprint pads and via structures in our characterization. So we defined the reference plane of the TRLM calibration at the transition of the constant impedance trace to the slightly wider connector mounting pad.

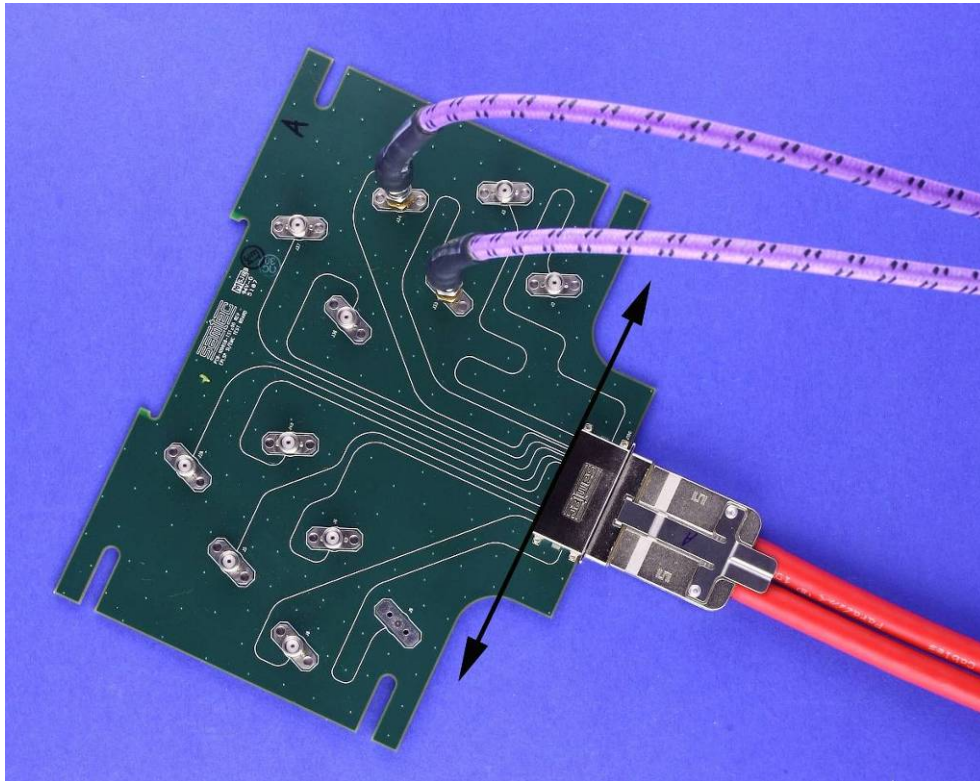


Figure 11
Cable Assembly Test Boards
Note arrow defines calibration plane

We were not interested in evaluating the effects of the PCB transmission line traces, nor did we wish to include their effects in our S-Parameter model. Therefore, we chose to use 50 Ohm traces on the test boards. It is possible to design the test board and TRL calibration lines to other impedances such as 42.5 Ohms for an 85 Ohm differential application or 75 Ohms for video applications. Either approach is viable, with choice of one over the other coming down to individual familiarity and preferences, and available instruments and software.

Below are results of the measurement and eye pattern simulations based on the S-Parameters extracted from the measurements. The data illustrates the effect of translating the reference impedance from 100 Ohms to 85 Ohms. Note that the effect is extremely minimal in this case. This cable assembly was actually within a 10% tolerance level for both system impedances.

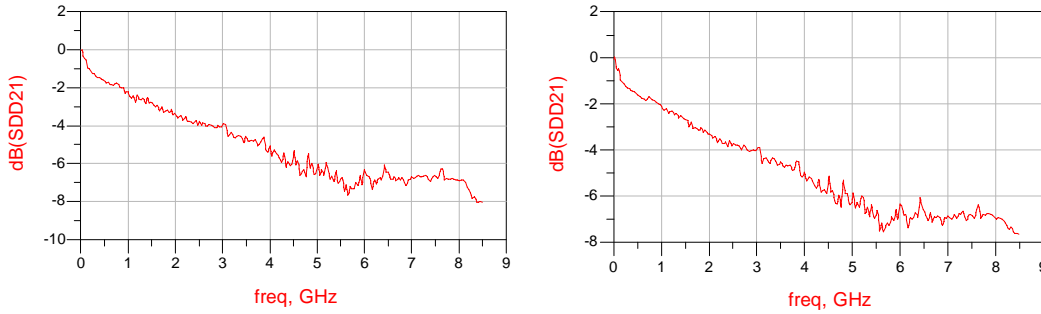


Figure 14
Insertion Loss in 85 (left) and 100 Ohm (right) Systems

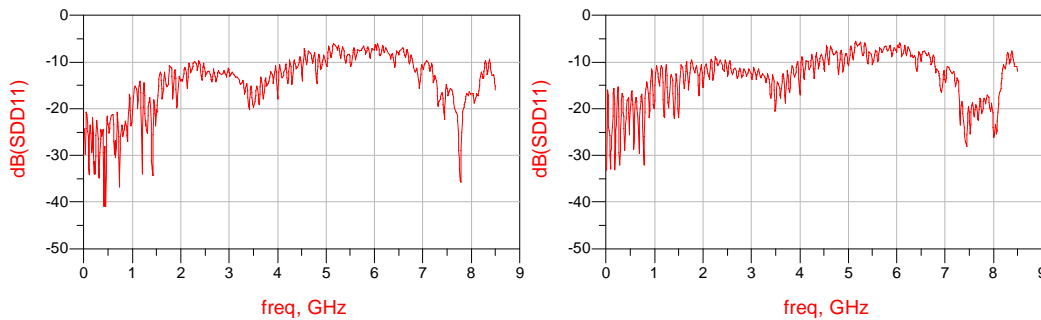


Figure 15
Return Loss in 85 (left) and 100 Ohm (right) Systems

Below are the results of eye-pattern simulations based on the S-Parameter models.

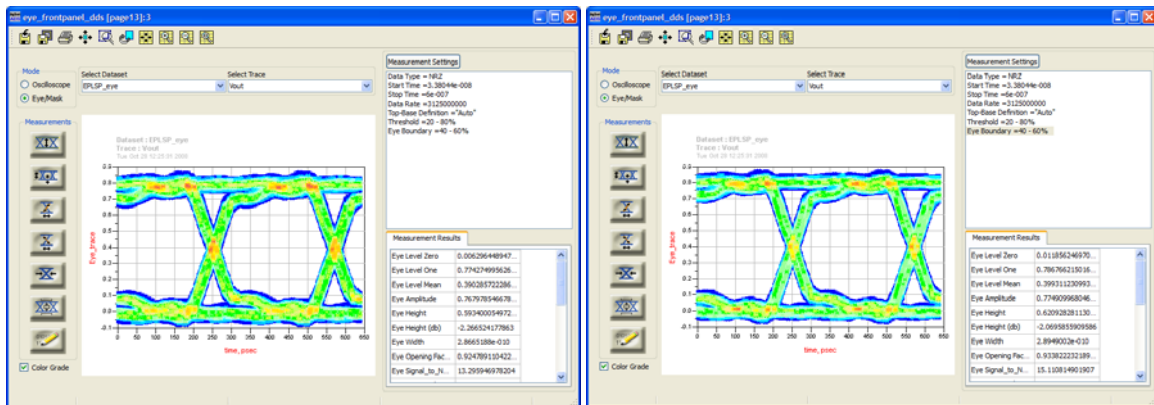


Figure 16
Eye Patterns in 85 (left) and 100 Ohm (right) Systems

Conclusions

- The need for quality high frequency characterization of non 50 Ohm components and channels continues to grow.
- A typical modern 50 Ohm VNA can be used successfully to characterize components of arbitrary impedance. In many cases, it is the preferred instrument.
- Excellent correlation between 50 Ohm and 75 Ohm instruments has been demonstrated.
- In many typical applications, connector adapters are a larger source of measurement error than the impedance mismatch of the DUT and the test port. Custom “adapters” made from short cable assemblies offer advantages with methods based on gating.
- A general rule of thumb is that a 50 Ohm system is suitable for DUTs between 2 Ohms and 1.5 KiloOhms.
- Modern data post processing routines allow removal of adapter and fixture effects for certain applications.
- A 50 Ohm VNA is an ideal instrument for characterizing arbitrary impedance devices to obtain S-Parameters for use in circuit simulations.

References

- [1] Jan De Geest – FCI, Dana Bergey – FCI, John Lynch – Intel, Dennis Miller – Intel, Stefaan Sercu – FCI, “Improving System Performance by Reducing System Impedance to 85 Ohms”, presented at DesignCon, Santa Clara, CA, 2007
- [2] The Anritsu Company, “Arbitrary Impedance” Application Note
- [3] Pozar, David M “Microwave Engineering”, Addison-Wesley, 1990
- [4] A. Lymer, “Improving Measurement Accuracy by Controlling Mismatch Uncertainty,” techonline.com, July 2002. [Online]. Available: <http://www.techonline.com/article/printArticle.jhtml?articleID=192200507>. [Accessed: Nov. 8, 2008].
- [5] Agilent Technologies, Appl. Note 56, “Microwave Mismatch Uncertainty.”
- [6] Agilent Technologies, Appl. Note 1287-12, “Time Domain Analysis Using a Network Analyzer.”
- [7] Maxim Integrated Products, Appl. Note 2866, “Converting S-Parameters from 50W to 75W Impedance.”
- [8] V. Duperron, D. Dunham, and M. Resso, “Practical Design and Implementation of Stripline TRL Calibration Fixtures for 10-Gigabit Interconnect Analysis,” presented at DesignCon, Santa Clara, CA, 2006.
- [9] R. Schaefer, “Challenges and Solutions for Removing Fixture Effects in Multiport Measurements,” presented at DesignCon, Santa Clara, California, 2008.
- [10] Maxim Integrated Products, Appl. Note 3250, “Characterizing the S-Parameters of 75W Circuits using 50W Lab Equipment.”
- [11] Agilent Technologies, Appl. Note, “Impedance Measurement Handbook.”

Resources

Agilent E5062A 75 Ohm VNA

Agilent E8364B 10 MHz - 50 GHz PNA Series Analyzer with an N4421B 10 MHz – 50 GHz S-Parameter Test Set

Agilent Physical Layer Test System software (PLTS) Version 4.50

Agilent ADS 2008 Update 1, Advanced Design System

Samtec 5 GHz True 75 Ohm Male to Female BNC cable assembly

Samtec Edge Rate™ EPLSP Series Cable assembly

Samtec Cable prototype 85 Ohm twinax cable

Samtec Final Inch® PCB reference design