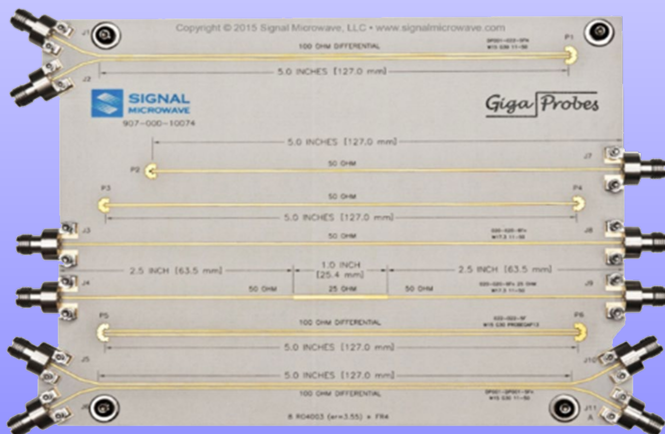
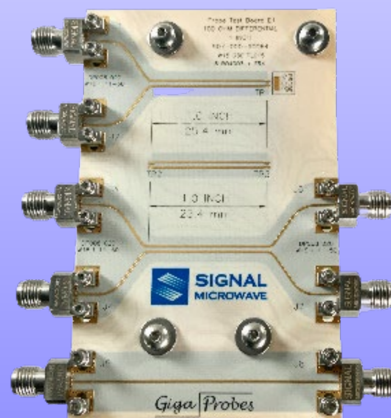
DBNN & ISBNN
Broadband Test Verification Boards™

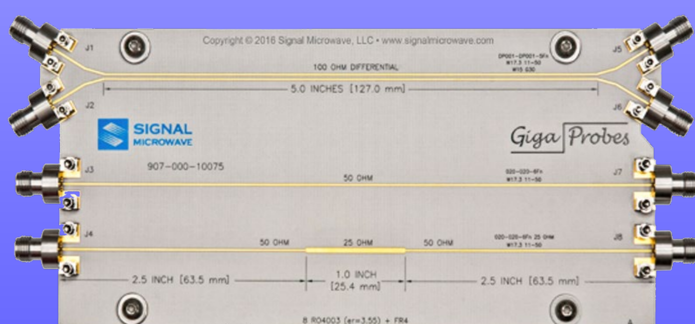
For Secondary Verification of
Vector Network Analyzer Measurement Calibration



DBNN-02



ISBNN-03



DBNN-03

User Guide

Publication/Revision Date: March 2024

Table of Contents

Introduction

This User Guide describes the functions, features and use of the DBNN and ISBNN Broadband Test Verification Boards, available in the following configurations.

Series & Part #s	Bandwidth	The following traces are included on each board in a series
DB40-002 DB50-002 DB70-002	40 GHz 50 GHz 70 GHz	100-ohm, 50-ohm, and Beaty line connector-to-connector traces, connector-to-probe pad traces and probe-pad-to-probe-pad traces
DB40-003 DB50-003 DB70-003	40 GHz 50 GHz 70 GHz	100-ohm, 50-ohm, and Beaty line connector-to-connector traces
ISB40 ISB50 ISB70 ISB110	40 GHz 50 GHz 70 GHz 110 GHz	100-ohm and , 50-ohm connector-to-connector traces, and 100-ohm connector-to-probe pad traces

The Broadband Test Verification Board can be used to:

- Confirm VNA measurement repeatability *after* calibration.
- Rapidly assess whether a VNA system may require calibration.
- Avoid inaccurate and inconsistent measurements due to measurement drift.
- Verify VNA system bandwidth to 110 GHz for differential RF probes.
- Validate 50-ohm or 100-ohm VNA system bandwidth to 110 GHz.
- Create your own Golden Reference board.
- Teach new PCB designers and VNA users how to make VNA frequency domain calibrations that can be used to make time domain and PCB measurements.

S-parameter plots to 110 GHz are provided of known performance response for the connector-to-connector traces and are used as a golden standard trace to corollate with the measured traces in verifying measurement accuracy or detecting calibration drift.

Traces with probe pads and connectors on the other end are used to verify the accuracy of differential probe models that are used by the VNA to de-embed probe loss from measurements. Using these traces, insertion loss measurements are compared with the same measurement (reference) after VNA de-embedding has been applied. When the model is accurate, the difference between the two measurements will represent the known loss in the probe. The method verifies the accuracy of the probe model and can be performed with traces of 50/100 ohms with connectors at each end.

Concerning VNA calibration

Overview

When a VNA does a calibration, it sweeps through multiple frequency points and at every point it locks the frequency to a reference, levels the power, then makes a measurement. During calibration, two major parameters are accounted for by using a calibration kit as a reference: the instrument's system noise is taken out of the measurement and the characteristic impedance of 50 ohms is established. For VNA calibration verification, many operators use only a low loss through adapter. This method only verifies that the system noise was removed by the calibration.

A Golden Reference board such as our Broadband Test Verification Boards, with known response over the frequency range of the calibration, should be used to verify that the calibration was successful in "teaching" the VNA how to make an accurate measurement over the frequency range of the calibration.

Understanding how changes affect measurements

No two measurements and environmental conditions are exactly the same. The best way to understand your conditions is to experiment in order to determine how your test equipment behaves over a period of time. A good way of doing that is to measure a 50 or 100-ohm trace on the Test Verification Board or a known standard, hourly throughout the day. Save or print the measurement results of each measurement (as seen in this guide).

Compare the results to previous measurements when the instrument was considered calibrated in order to gain an understanding of how the ambient environment and drift affect the measurements. Watch for trends that indicate the device is not meeting specifications or not measuring within guard band limits.

When is calibration needed?

Before doing a full calibration, measure the Broadband Test Verification Board 50-ohm or 100-ohm traces. If the measurements correlate with previous reference measurements from the same connector to connector traces, the VNA measurements will be accurate, and no calibration is necessary. If the two sets of S-parameters do not correlate, then calibration is recommended. We also recommend verifying the VNA measurement accuracy when the following conditions are met.

- When connectors are cleaned, repaired, or replaced.
- If there have been any changes to the test cables, such as:
  - A test cable is replaced.
  - Any connections are changed, except the connections to the DUT.
  - If test cables have been excessively flexed, i.e., kinked or unkinked.
- If the frequency range is changed beyond the limits of the previous calibration.
- If the number of measurement points is increased compared to the previous calibration.
- When the ambient temperature changes more than 3 °C.
- Any other ambient environmental changes of significance.
- If none of the previous conditions apply, verify calibration using the Test Verification Board according to the intervals shown below due to possible drift:
  - Check the calibration at least daily (twice a day is recommended).
  - Verify calibration at least weekly (daily is recommended).

Board traces

DBNN-002 Broadband Test Verification Board

Connector Assignment

J1/J2 100-Ohm Connector-to-Probe pad P1

P2/J7 50-Ohm to Probe-Test Pad-to- Connector

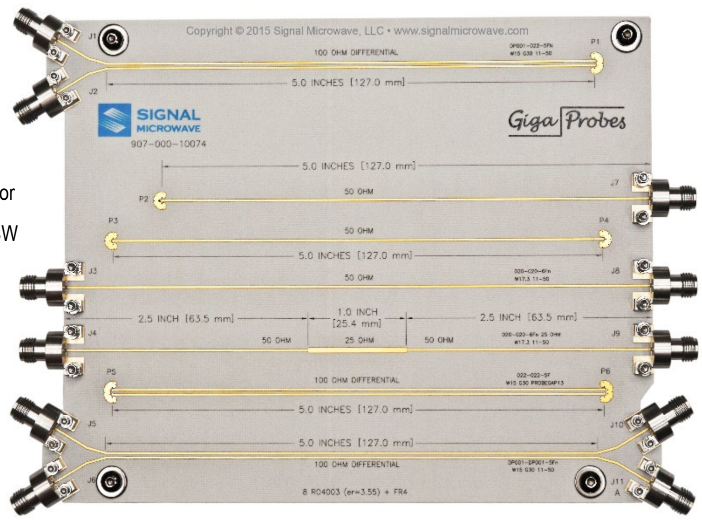
P3/P4 50-ohm Probe-to-Probe trace 70 GHz BW

J3/J8 50-Ohm Connector-to-Connector trace

J4/J9 Connector-to-Connector Beatty line

P5/6 100-Ohm Probe-to-Probe Test Pad

J5/J6 Connector-to-J10/J11 Connector Differential trace



Connector Function

Measure 100-ohm Differential 1mm pitch

Measure 50-ohm .8-1mm *Probe System* Bandwidth to 70 GHz

Measure dual 50-ohm .8-1mm pitch Probe System Bandwidth to 70 GHz

Measure 50-ohm Probe System *Reference* Bandwidth to 70 GHz

Measure 50-25-50-ohm Beatty line in time domain. Calibrate cursors to locate impedance changes and meas. line length.

Measure 100-ohm reference waveform for determining differential probe system bandwidth to 70 GHz.

DBNN-002

A brief description of suggested applications for these traces is provided in the following table, with additional details in the sections that follow.

Trace categories	Measurement verification applications
100-ohm connector-to-connector differential trace	Verify that a 4-port VNA measures accurately to 110 GHz after calibration or that the VNA has not “drifted” out of calibration (avoiding unnecessary calibrations). Use the enclosed waveforms to compare waveform correlation with actual measurements.
50-ohm connector-to-connector single-ended trace	Verify that a 2-port VNA measures accurately to 110 GHz after calibration or that the VNA has not “drifted” out of calibration (avoiding unnecessary calibrations). Use the enclosed waveforms to compare waveform correlation with actual measurements.
100-ohm differential-connector-to probe pads	Verify VNA differential .8-1mm probe models. Measure the differential connector-to-connector trace insertion loss as a “reference” trace with a differential probe. This trace will include the probe and trace loss. Store this trace to the VNA screen. Place the live measurement on the VNA screen and apply the probe model to it to de-embed the trace from the measurement. Overlay both insertion loss measurements. The loss difference between the two measurements is the loss of the probe. The loss difference between the two measurements will be the value of the probe loss leaving only the trace loss.
50-ohm SE connector-to-probe pads	Verify Single-Ended (SE) VNA .8-1mm probe models but repeating the above probe model verification process.
50-25-50-ohm Beatty line	Verify that the VNA is calibrated using a harmonic sweep so that time domain measurements can be made. Use the board’s dielectric constant (er=3.55) to calibrate cursors to determine the 50/25-ohm transition and impedance values. Measure the electrical length of the trace common to TDR measurement functions.

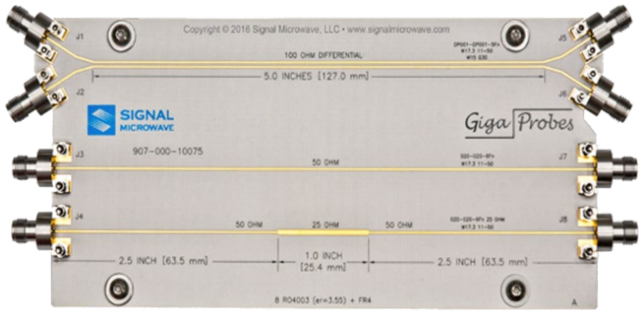
DBNN-003 Broadband Test Verification Board

Connector Assignment

J1/J2 Connector-to-J5/J6 Connector Differential trace

J3 to J7 50-Ohm Connector-to-Connector trace

J4/J8 Connector-to-Connector Beatty line



Connector Function

Measure reference for 100-ohm differential trace to 70 GHz.

Measure reference for 50-ohm single-ended trace to 70 GHz.

Measure reference for 50-25-50-ohm Beatty line. In time domain, calibrate cursors to locate impedance changes and line length.

DBNN-003

A brief description of suggested applications for these traces is provided in the following table, with additional details in the sections that follow.

Trace categories	Measurement verification applications
100-ohm connector-to-connector differential trace	Verify that a 4-port VNA measures accurately to 110 GHz after calibration or verify that the VNA has not “drifted” out of calibration (avoiding unnecessary calibrations). Use the enclosed waveforms to compare waveform correlation with actual measurements.
50-ohm connector-to-connector single-ended trace	Verify that a 2-port VNA measures accurately to 110 GHz after calibration or verify that the VNA has not “drifted” out of calibration (avoiding unnecessary calibrations). Use the enclosed waveforms to compare waveform correlation with actual measurements.
50-25-50-ohm Beatty line	Verify that the VNA is calibrated using a harmonic sweep so that time domain measurements can be made. Use the board’s dielectric constant (er=3.55) to calibrate cursors to determine the 50/25-ohm transition and impedance values. Measure the electrical length of the trace common to TDR measurement functions.

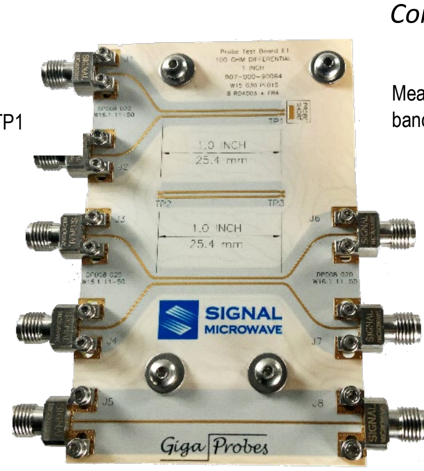
ISBNN Broadband Test Verification Board

Connector Assignment

J1/J2 100-Ohm Differential Connector-to-Probe pad TP1

J3/J4 Connector-to-J6/J7 Connector Differential trace

J5 Connector-to-J8 Connector Single-Ended trace



Connector Function

Measure 0-ohms across the probe tips or in-situ bandwidth up to 70 GHz

Measure reference for 100-ohm differential trace to 70 GHz.

Measure reference for 50-ohm single-ended trace to 70 GHz.

ISBNN

A brief description of suggested applications for these traces is provided in the following table, with additional details in the sections that follow.

Trace categories	**Measurement verification applications**
100-ohm connector-to-probe differential trace, 0-ohm coupon	Measure 0-ohm coupon across the probe tips, or in-situ bandwidth up to 110 GHz. These can be used to create a differential probe model with the Ataitec ISD De-embedding software.
100-ohm connector-to-connector differential trace	Verify that a 4-port VNA measures accurately to 110 GHz after calibration or verify that the VNA has not “drifted” out of calibration (avoiding unnecessary calibrations). Use the enclosed waveforms to compare waveform correlation with actual measurements.
50-ohm single-ended connector-to-connector trace	Verify that a 2-port VNA measures accurately to 110 GHz after calibration or verify that the VNA has not “drifted” out of calibration (avoiding unnecessary calibrations). Use the enclosed waveforms to compare waveform correlation with actual measurements.

Procedures

Verifying VNA calibration to assure measurement repeatability

Once the VNA is calibrated, measure the 100-ohm differential trace (4-port VNA) or the 50-ohm single-ended trace (2-port VNA) and compare the measurements against the waveforms shown in this guide.

If they do not correlate, some of the possible causes are:

- VNA functions affecting the measurement may have been left on.
- There is a bad cable or adapter.
- A de-embedding S-parameter file may have been left activated in one or more of the ports.
- An offset function was changed which may affect the measurement.

The source of the difference should be determined before accurate measurement can be performed.

Detecting calibration drift or determine if VNA needs calibration

When using a VNA, common measurement errors can be caused by a number of factors, including:

- Changes in room temperature
- Excessive internal temperatures for an extended period of time
- Moving the cables
- VNA drifting out of calibration.

To avoid inaccurate measurements due to calibration drift, measure the 50-ohm or 100-ohm trace and store the results in a reference memory with a calibrated VNA, verified by using the DBNN or ISBNN Broadband Test Verification Board.

Prior to making measurements the next day, recall the previous stored measurements and make a new measurement from the same 50/100-ohm traces. The two insertion loss measurements should correlate.

- If they don't correlate, recalibrate the VNA or successive measurements may not correlate with previous day measurements.
- If they do corollate, then no calibration is required, saving valuable test time.

Repeat this process prior to each day of VNA usage to guarantee measurement consistency and repeatability.

Using the Beatty line to measure time domain (impedance)

Calibrate the VNA to measure time domain using one of the DBNN boards. Attach two ports to the Beatty line connectors J4 & J9. The dielectric constant (er) value of 3.55 (stamped on the bottom of the board) can be used to calibrate the cursors to accurately measure electrical distance and the impedance of this trace. If you have calibrated the VNA correctly, your cursors can physically locate the impedance change of this trace when it goes from 25-ohm to 50-ohm and measure the electrical distance of the trace.

This setup procedure mimics that of a TDR and is a good exercise on learning how to accurately set up the VNA for time domain measurements.

Verifying VNA measurement system accuracy

To verify that all VNA cables are good and front panel settings are correct, measure S-parameter bandwidth on a differential or single-ended trace located on a DBNN/ISBNN Test Verification Board. After the measurement, the VNA will display a linear frequency power roll-off graph as shown in *Figure1*.

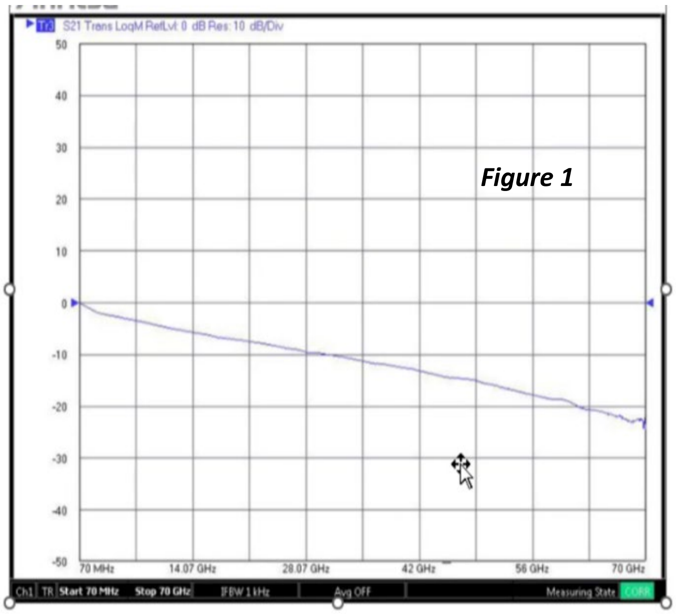


Figure 1

If unsure whether the measurement is correct, compare it with a "Golden Trace" measurement taken from similar traces by a factory calibrated VNA with new cables. See page 13 for these measurement plots. The tests verify that all cables are in good condition and that the front panel settings are correct for passive linear interconnect testing and that it is ready for critical testing.

If the measurement indicates that the front panel is set correctly, but the measurements still contain noise or frequency dropouts, remove all cables and attach one cable at a time. Then run the same comparative verification test on each cable until the defective cable is located. If the measurement is still noisy, the VNA will likely need to be sent to a calibration and repair lab for diagnostics.

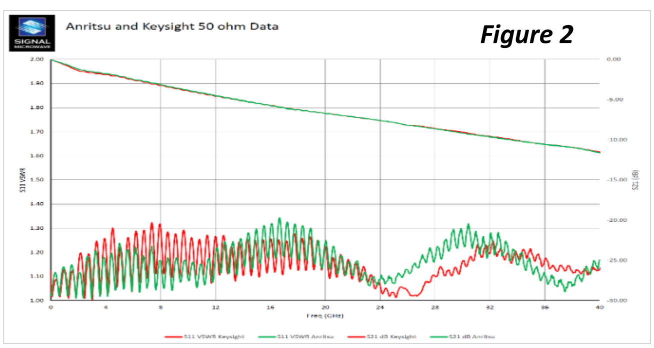


Figure 2

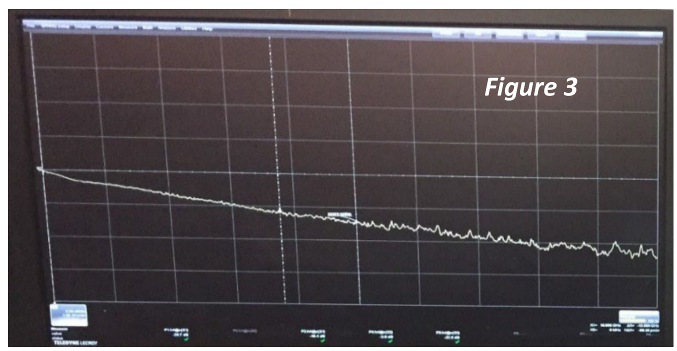


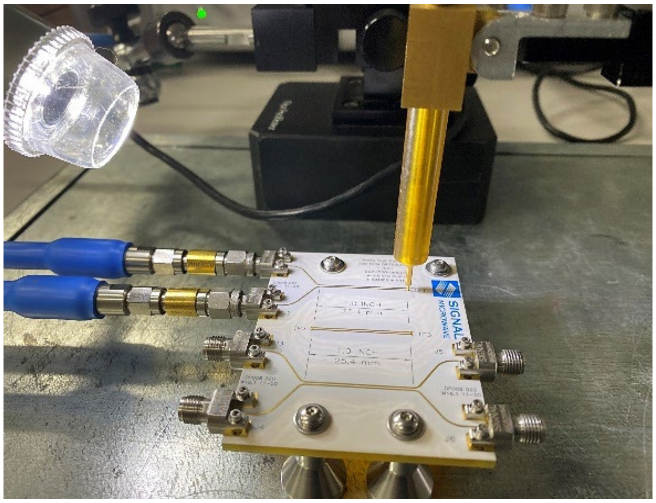
Figure 3

Ideally, you should compare the measurements with your own "Golden Standard" measurements taken with the VNA that you will use to make the test measurements. The S-parameter bandwidth measurements are obtained from the traces on the Test Verification Board once the VNA has been calibrated and the cables are known to be good. Store these measurements as your "Golden Standard" along with the front panel settings on a separate USB drive to prevent overwriting in the VNA.

To verify that the VNA is measuring accurately, recall the VNA settings, then acquire the stored "Golden Standard" measurement from the USB drive. Store the measurement on the screen as a reference waveform. Then, using the Test Verification Board, measure the same trace live and overlap the two waveforms. If the two measurements correlate (*Figure 2*), the VNA will make accurate measurements.

If the two traces do not match (*Figure 3*), there may be a problem with the front panel setup of the VNA, or you may have discovered a defective cable before making critical measurements, and further investigation is required. You may use the same "Gold Standard" measurement and perform the same process to locate the defective cable, switching out a known good cable one at a time until you locate the defective cable.

Ataitec ISD differential probe model development



The ISBNN Broadband Test Verification Board referenced on page 7 is available in incremental bandwidths of 40, 50,70 and 110 GHz. It was created to develop a differential probe model for all our differential probes using AtaiTec "In Situ De-Embedding" (ISD) Software. To create the ISD probe model, three S-parameter probe measurements (Probe_open.S2p, Short.S2p & in_situ.S4P) are required, using a 4 port VNA and an ISBNN Broadband Test Verification Board. Insitu.S4P through measurements are taken from the differential "probe to connector" trace and the short is obtained by probing the short pad behind this trace.

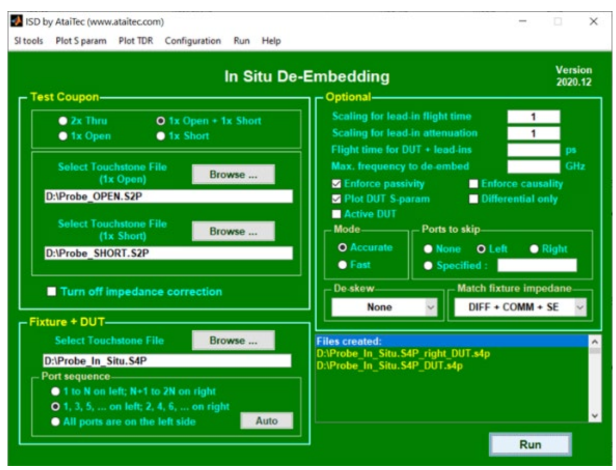
The three measurements are inputted into the AtaiTec ISD software. ISD generates an S4p probe model through network extraction that the VNA uses to de-embed the probe from its measurements. It is recommended to perform a low-pass harmonic VNA calibration to view time domain plots to verify the probe tips are making contact with the shorting block located behind the probe pads of the "probe to connector" trace on the ISBNN Broadband Test Verification board. The ISD S4p touchtone probe model file is loaded into the VNA after system SOLT calibration is performed. Free Technical support and software upgrades is provided.

ataitec

For examples of using ISD, see **https://ataitec.com/products/isd/**

ISD Technical Support is available from Ching-Chao Huang) **Email: huang@ataitec.com)**

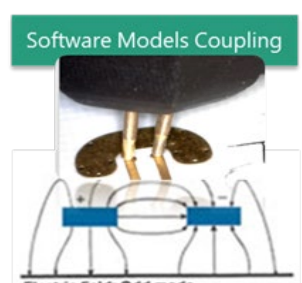
The following three S-parameter measurements are acquired with a 4-port VNA and loaded into the AtaiTec ISD software to create a Differential Probe Model in S4P (Touchstone) format:



1. **Probe_OPEN.S2P** Measurement: Probe tips are not attached to anything.
2. **Probe_SHORT.S2P** Measurement: Probe tips are shorted to copper plate in Probe Kit or any clean copper plate.
3. **Probe_In-situ.S4P** measurement: The ISBXX (xx=bandwidth) board is used to make this measurement that models the probe-to-test pad resonance.

ISD Probe de-embedding benefits for differential

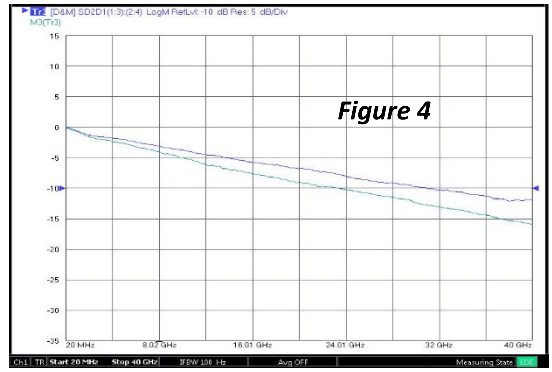
- Probe bandwidth is improved in some probes.
- Probe loss is removed from PCB measurement.
- Reference plane relocated to probe tips to make accurate Time Domain measurements.
- Model contains coupling between the differential conductors, creating its own virtual ground. No physical ground signal pin is required - makes probing easier.



- Probe wide pitch test pads (i.e. .8mm-1.27mm) without degrading bandwidth.
- “probe tip to test pad” launch resonance frequencies removed from S-parameter measurements.

Verify ISD probe model de-embedding accuracy

The green trace (Figure 4) shows a differential in-situ insertion-loss measurement utilizing a differential probe from the probe-to-connector trace on an ISBNN or DBNN-002 board, which includes both probe and trace frequency loss. In conjunction with a short/open S2p measurement, the Ataitec ISD software can be used to create a differential probe model which the VNA uses to de-embed the probe loss from the measurement, resulting in the blue trace. The dB loss measurement between the two insertion-loss measurements represents the probe loss value which verifies the probe model's de-embedding accuracy.



Use boards as a teaching tool

Haven’t used the VNA in months or ever? Practice setting up the VNA to measure the 50-ohm, 100-ohm and Beatty lines and compare the measurements with those that come with the board prior to making measurement on your prototypes.

Use as a Golden Reference

A good method of checking calibration is to use a board as a *Golden Reference* i.e., a measurement that meets all specifications, and where the waveforms are saved for comparison to future measurements.

The DBNN and ISBN Broadband Test Verification Boards can be used to create a Golden Reference to assure repeatability for a specific VNA and serial number.

The following provided S-parameter plots of the 100-ohm and 50-ohm traces are used after calibration as a reference point to verify calibration and determine whether the VNA has drifted out of calibration, or if there are other issues preventing accurate measurement.

Sample Reference waveforms are shown below for 1.85mm/2.4mm Connector to Connector traces. These measurements were taken using a factory calibrated Vector Network Analyzer (VNA). These VNA plots were measured from the DB70-002, DB50-002 and DB40-002 Broadband Test Verification Boards using a pristine VNA system and high-quality cables. To establish your own Golden Reference that is characteristic of your specific VNA, follow the procedures below.

1. Calibrate the system after it has been powered on for the recommended warm-up period.
2. Perform a complete set of measurements on the 50-ohm or 100-ohm traces on the Broadband Test Verification Board.
3. Save the setup and S-parameters to the VNA memory and a memory stick as a backup.
4. Print all the test results from these initial measurements and store them in a binder.
5. (Optional) Serialize the calibration kit, cables, adapters to the VNA that these measurements were acquired from in order to reproduce as close as possible correlation to the acquired waveform measurements.

To assure that the VNA is measuring accurately after calibration, measure the Golden Reference trace and compare it with the saved waveforms. When you suspect your system may need to be calibrated, compare the results of these measurements against the results that you saved and printed from the initial measurements. If the two measurements correlate, the VNA Measurement should be accurate and no calibration is required.

Sample Reference Waveforms

Sample Reference waveforms are shown below for 1.85mm/2.4mm Connector to Connector traces. These measurements were taken using a factory calibrated Vector Network Analyzer.

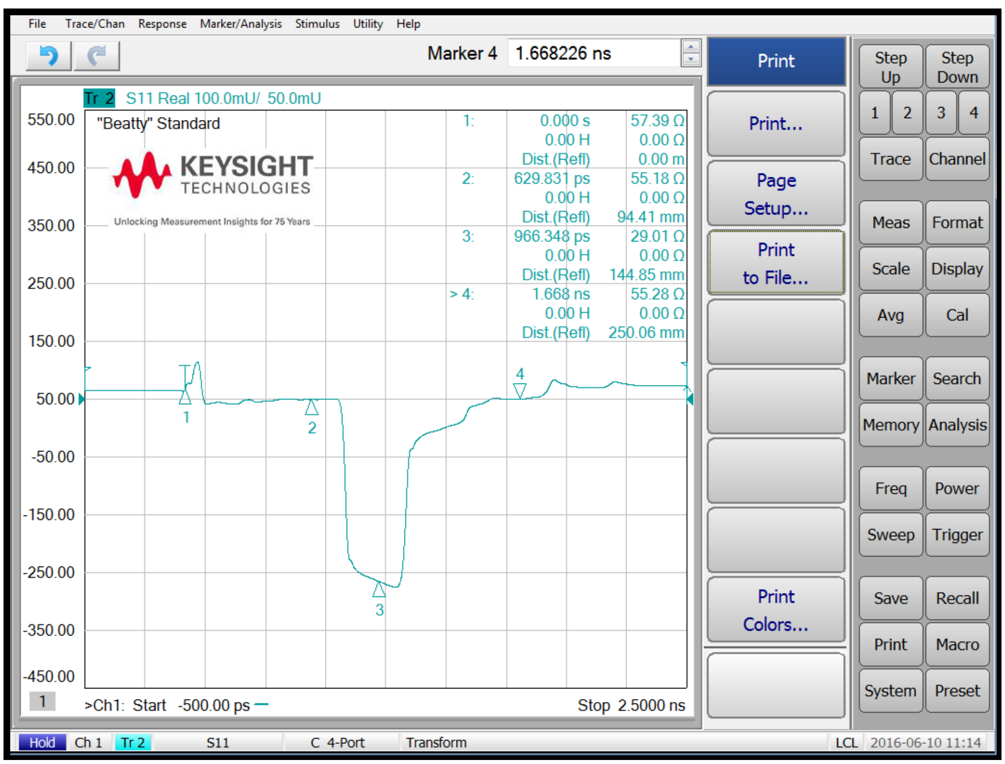
To create a Golden Reference board for your own VNA or PNA Microwave Network Analyzer follow the above instructions to create a Golden Reference board using the Broadband Test Verification Board.

- VNA Instruments with 1.85 mm connectors (part numbers DB70-003 or -002) can be used to create a 70 GHz bandwidth Golden Reference board.
- Instruments with 2.4mm connectors (part Numbers DB50-003 or -002) can be used to create a 50 GHz bandwidth Golden Reference board.
- Instruments with SMA, 3.5mm and 2.92mm connectors can be used to create up to 40GHz bandwidth Golden Reference board.

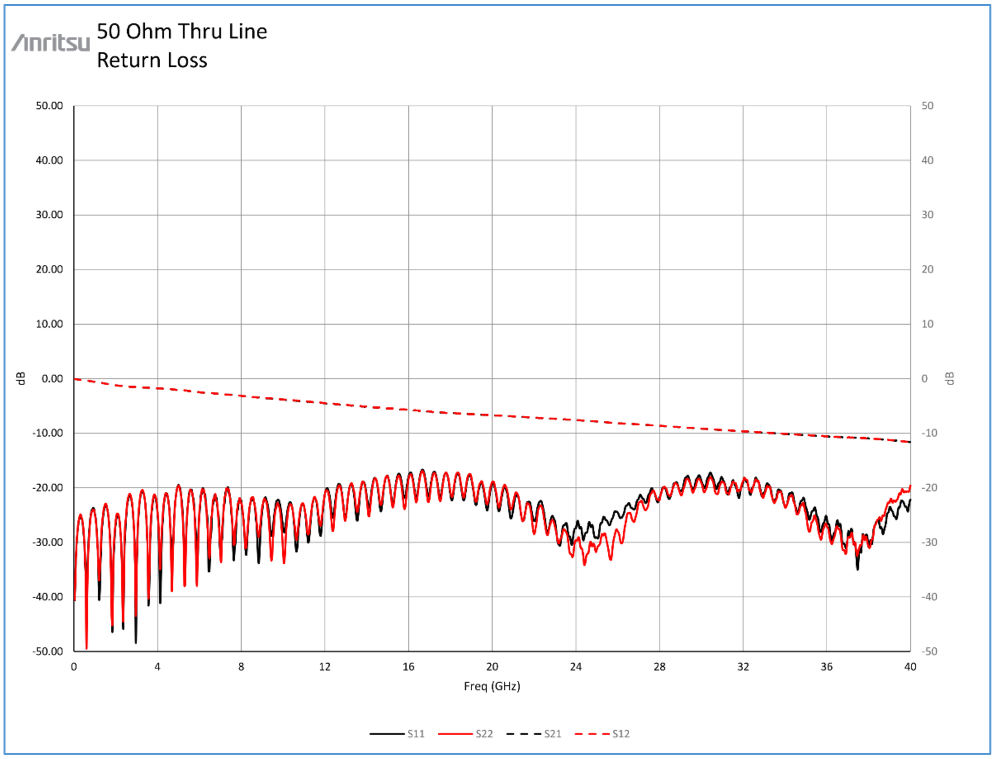
Note that plots can vary slightly from system to system due to the quality of the cables used, ambient temperature of the VNA, length of time between factory calibrations, etc.

50 Ohm Single-Ended Insertion and Return Loss to 50 GHz (DB50-002/003)

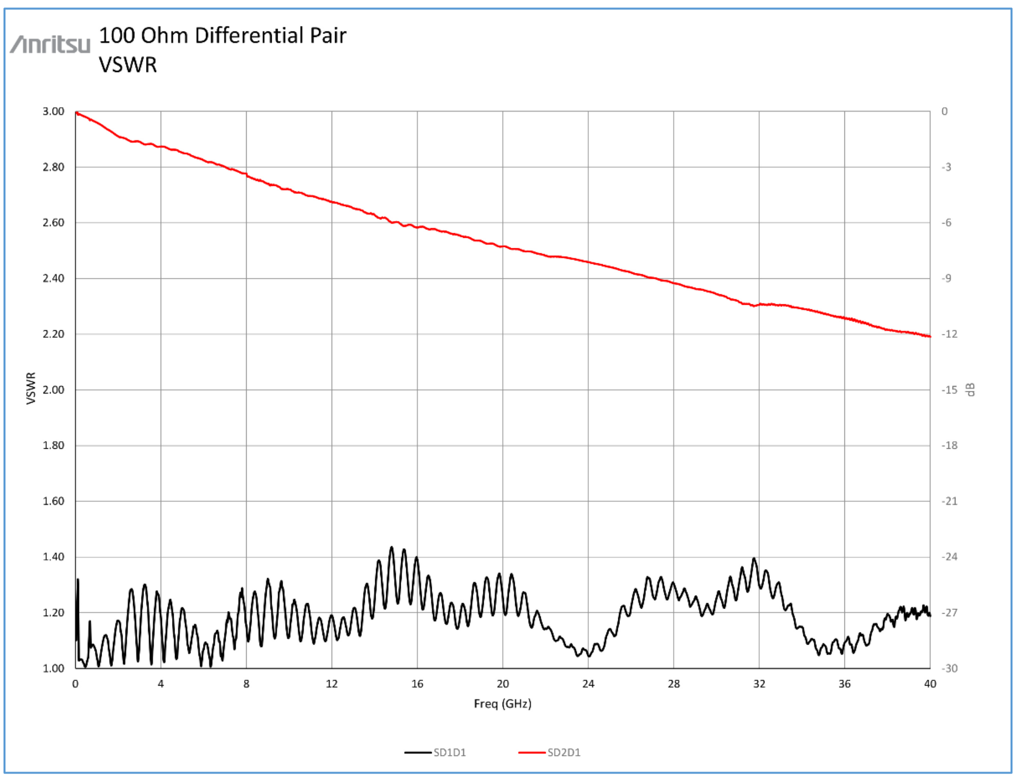
100 Ohm Differential Insertion and Return loss to 50 GHz (DB50-002/003)



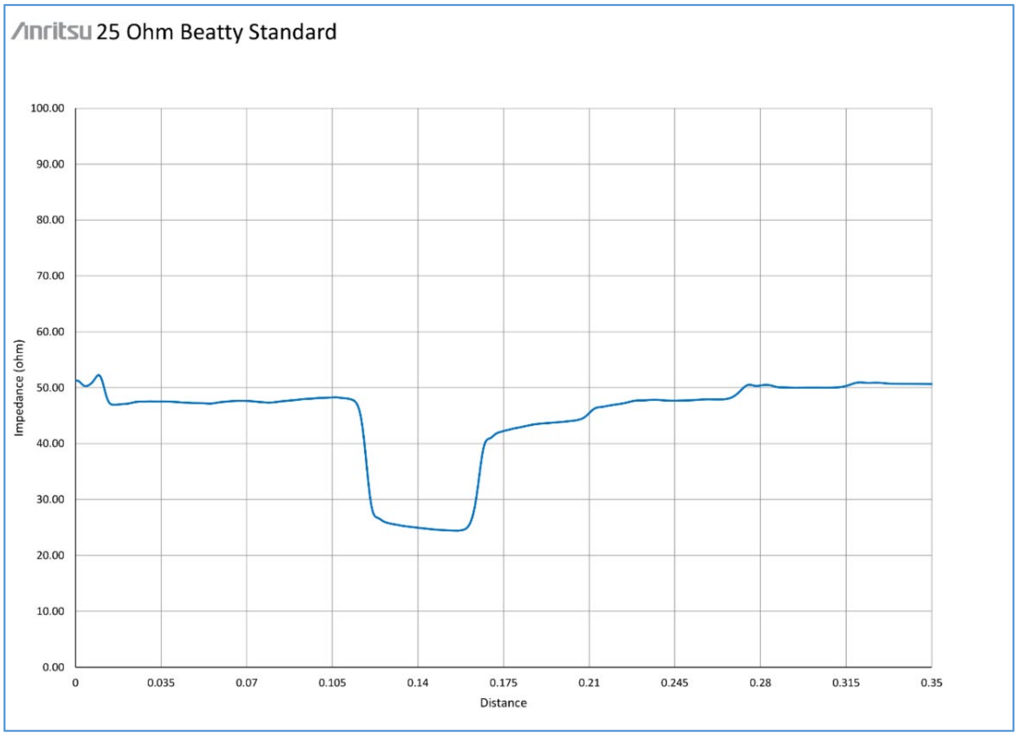
50/25/50 Ohm Beatty line Time Domain Plot to 50 GHz (DB50-002/003)



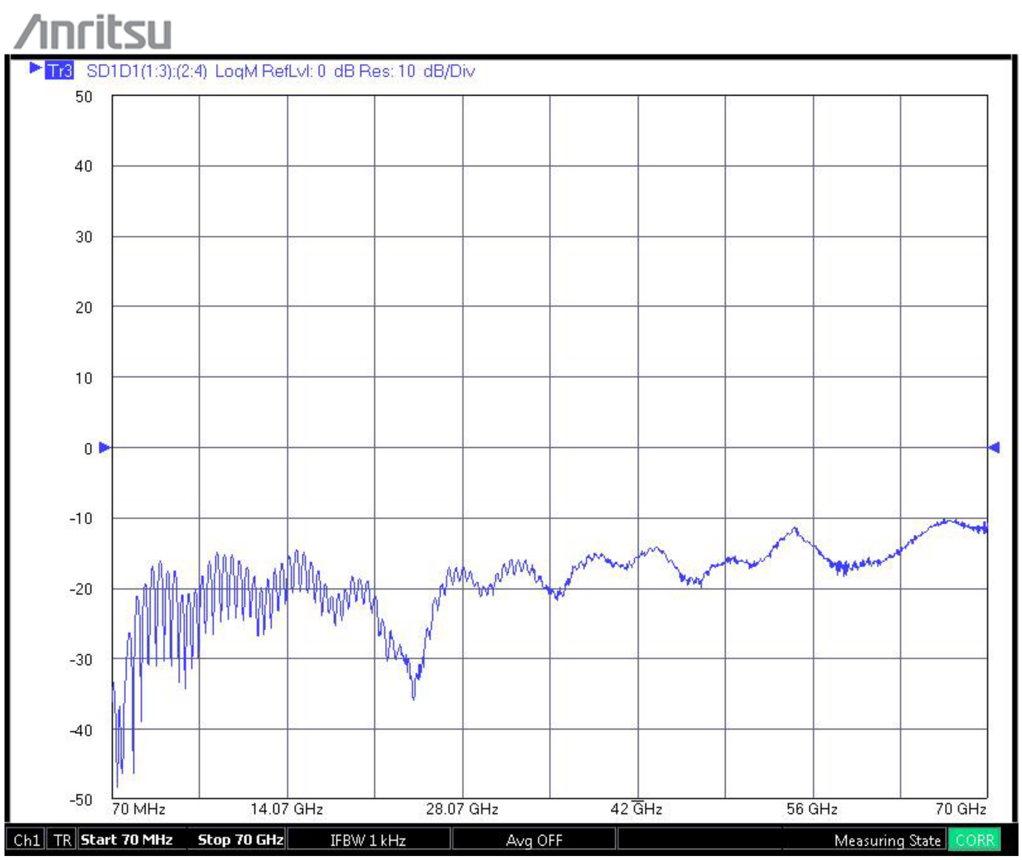
50 Ohm Thru Line and Return Loss to 40 GHz (DB40-002/003)



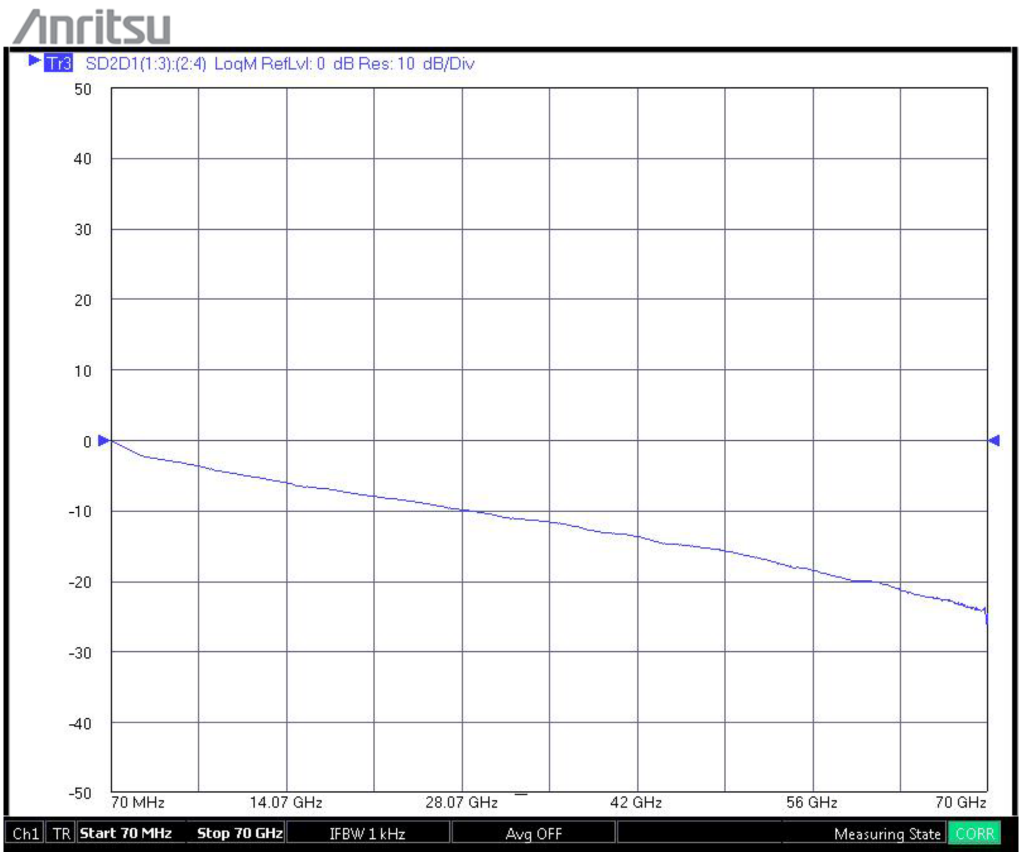
100 Ohm Differential Pair to 40GHz (DB40-002/003)



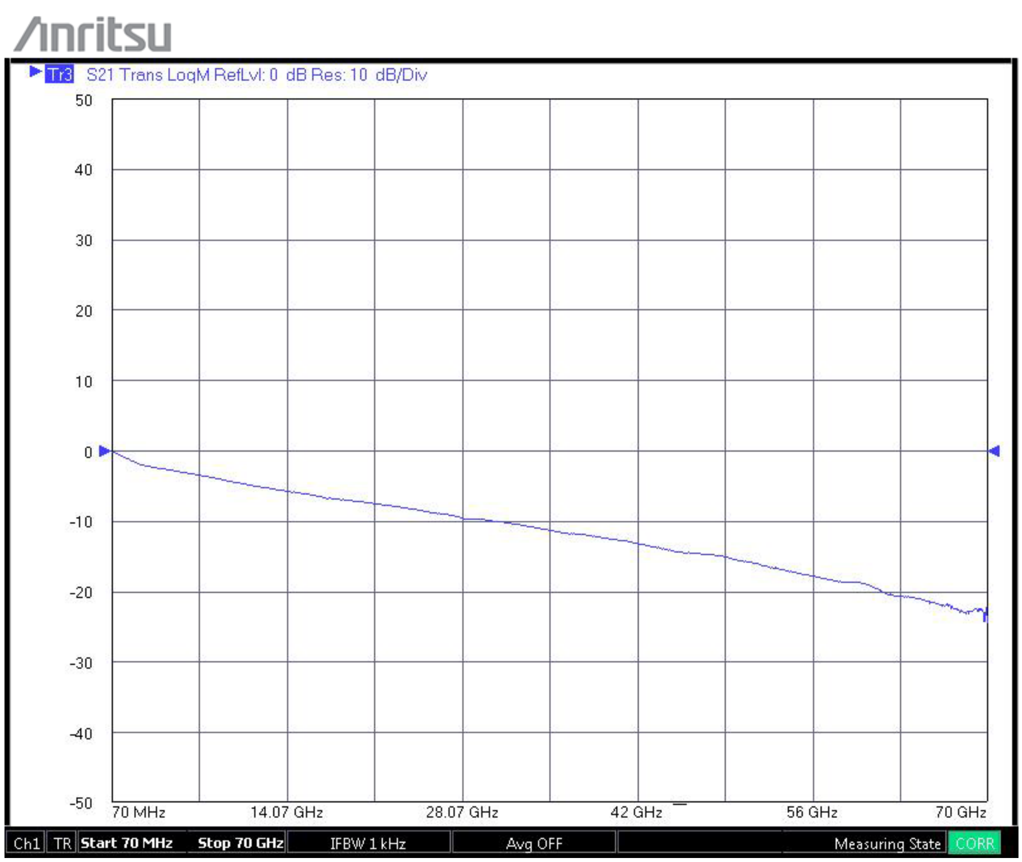
25 Ohm Beatty Standard to 40 GHz (DB40-002/003)



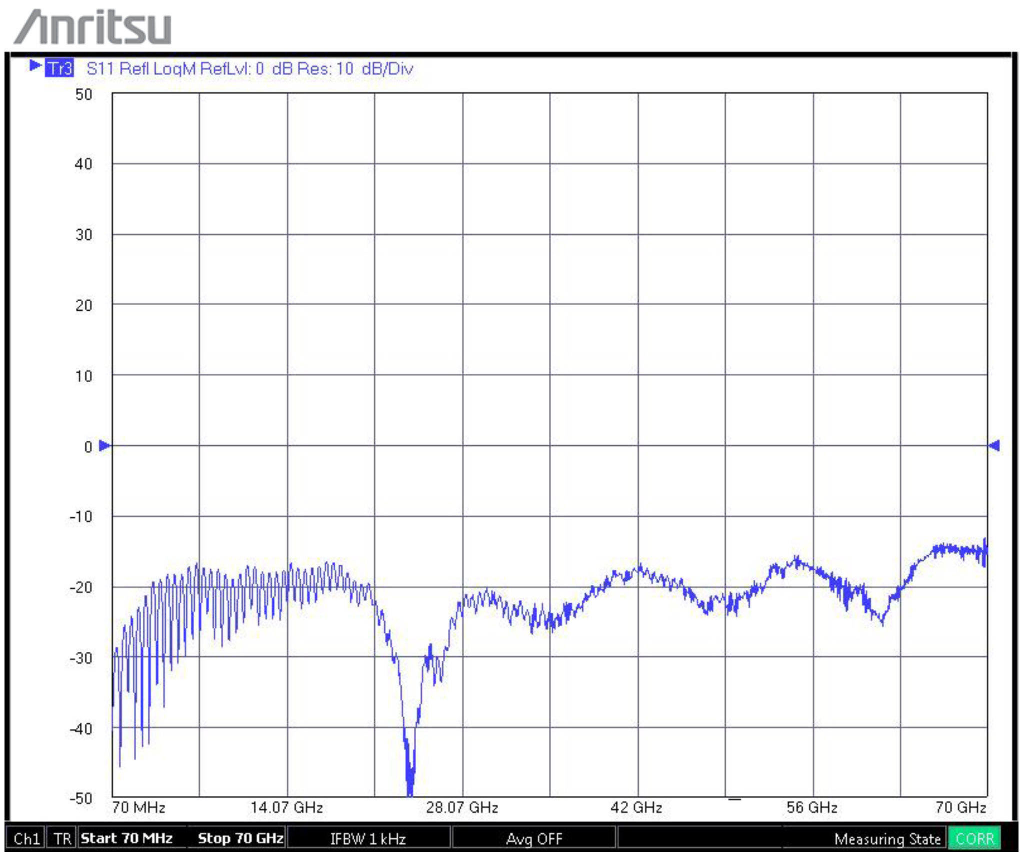
100 Ohm Single-Ended Return Loss to 70 GHz (DB70-002/003)



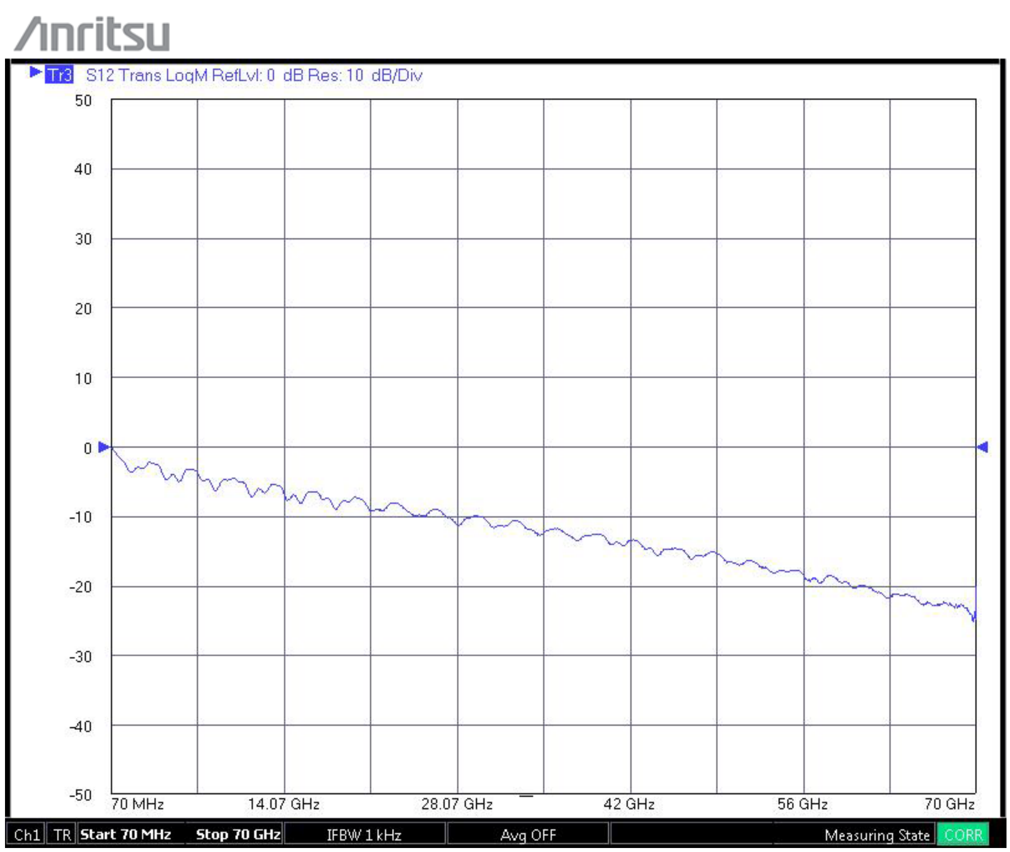
100 Ohm Differential Insertion Loss to 70 GHz (DB70-002/003)



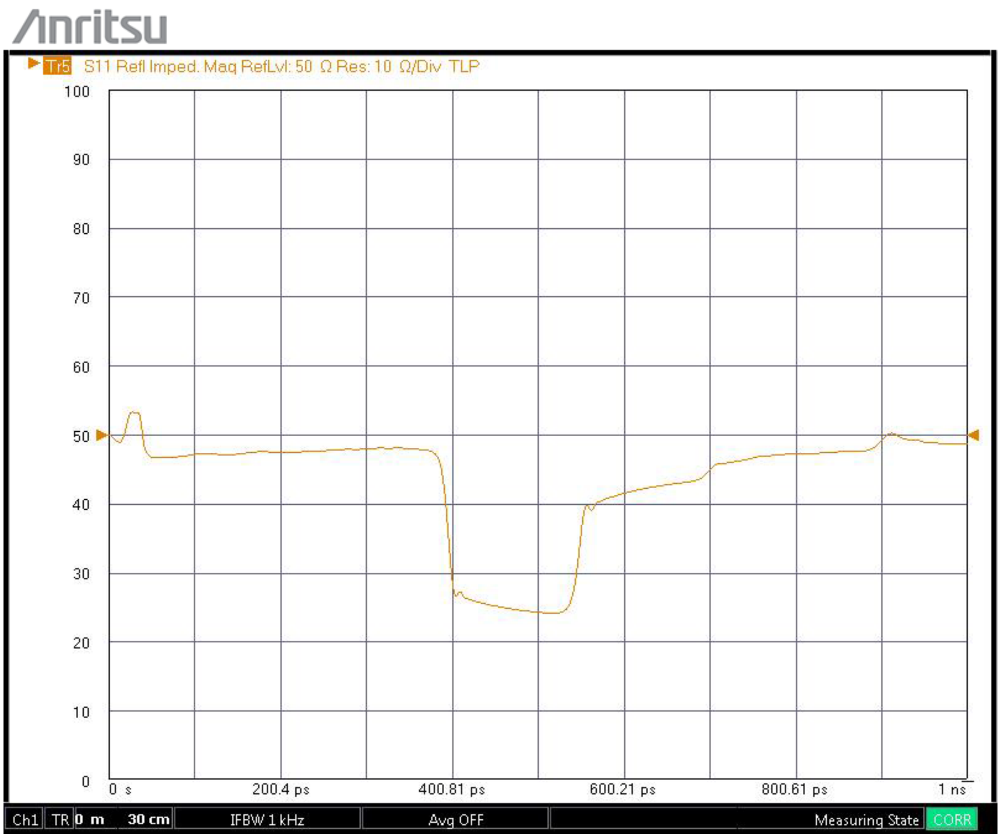
50 Ohm Single-Ended Insertion Loss to 70 GHz (DB70-002/003)



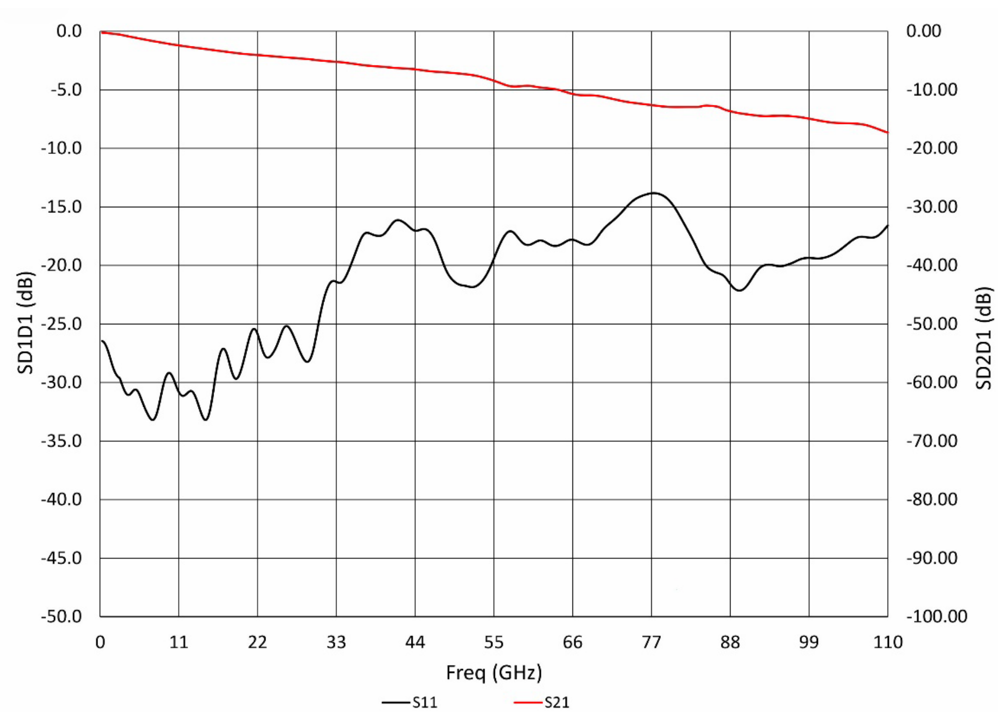
50 Ohm Return Loss to 70 GHz (DB70-002/003)



50 Ohm Beatty Line Insertion Loss to 70 GHz (DB70-002/003)



50 Ohm Beatty Line Impedance Plot (DB70-002/003)



100 Ohm Differential Insertion Loss to 110 GHz (ISB110)

More about the boards

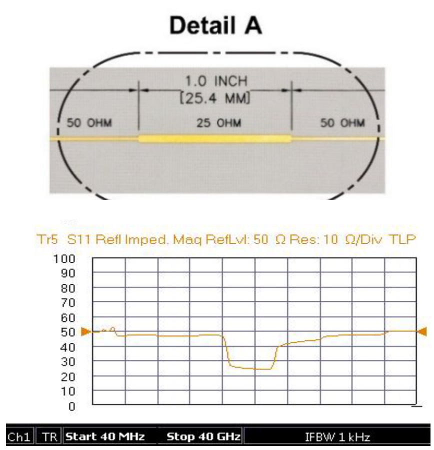
Board Versatility

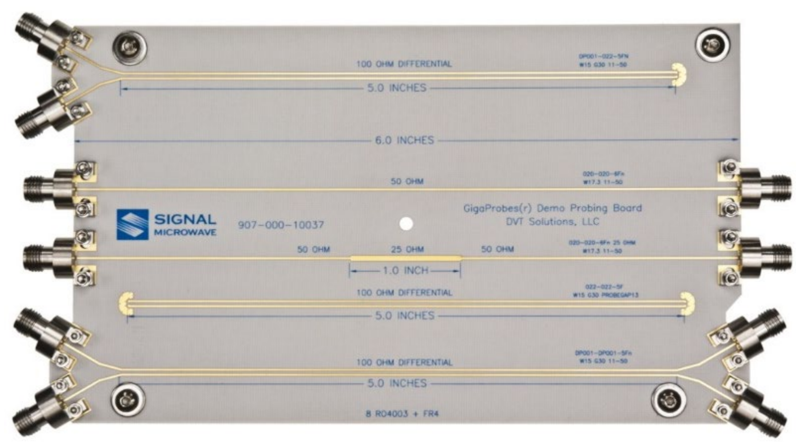
The nature of the Broadband Test Verification Board's design lends itself to the easy creation of different versions.

One version of the board is an expanded version of the basic board which includes test lines for the GigaProbes® 40 GHz DVT40 differential probe. The board allows a user to verify 4 port VNA calibration using a 100-ohm connector-to-connector test line. Then the user can move to a similar 100-ohm differential line that is connector-to-probe so each probe can be evaluated.

This version of the board also includes a 25 ohm "Beatty" line for verification of a TDR measurement using a VNA.

The Beatty line is useful in verifying that the VNA calibration is done correctly to perform accurate TDR transformation for an impedance measurement along a transmission line.





Reasons for the board's high performance

Edge launch connectors

It starts with the high-performance connectors manufactured by Signal Microwave and available for sale by DVT Solutions, LLC (email: sales@gigaprobes.com). These edge launch connectors are designed using 3D modeling and RF transmission line analysis instead of just a mechanical solution. The next component leading to the high performance is the board launch design. The board launch is the transition from the board to the connector. The launch structure on the board starts with a Grounded Coplanar Waveguide (GCPWG) section which incorporates a top ground launch that transitions the ground to an inner layer as it transitions to a microstrip line. The launch design is also done by Signal Microwave using 3D modeling to match the board to high performance connectors and this service is available for customers that are using the connectors in their own products.

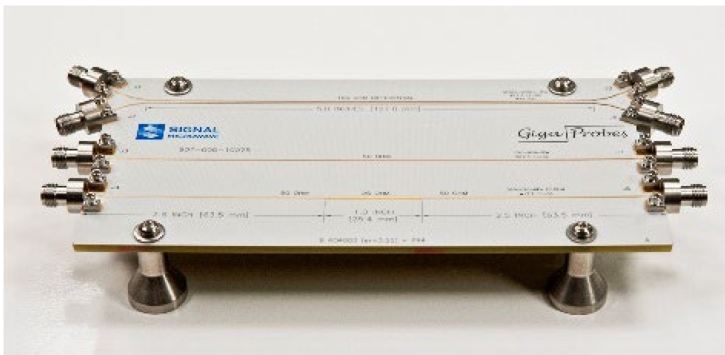
Board material & manufacturing process

Another factor in the high performance of the board is the material and the way it is manufactured. The material is Rogers RO4003 with a thickness of 15 mils and ½ ounce copper. The finish on the trace is 100 micro inches of electroless nickel plating (ENP) with a top layer of 15 micro inches of immersion gold (ENIG). The Rogers material performs superbly through 110 GHz and the plating provides a corrosion-free surface.

The next step in the manufacturing process is where the 8 mil RO4003 is processed completely by itself, including drilling to vias required and the plating. Then the panel is laminated to an FR4 backer for mechanical stiffness without having to backdrill any vias (backdrilling can cause problems at frequencies as high as the 110 GHz bandwidth of the board).

Custom magnetic feet

The board incorporates a custom design stand-off with magnets installed at each corner. When placed on a magnetic plate, they hold the board securely to the plate. The plates are available from DVT Solutions and are very useful in securing the board for measurements with probes.



For sales and pricing, contact

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https://www.gigaprobes.com/

For technical support on board design and connector integration, contact

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