DesignCon 2007

A Novel Procedure for Characterization of Multi-port High Speed Balanced Devices

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Presenters:

- Jim Nadolny – Samtec, Inc.
- Vahe' Adamian - Ultimetrix

Presentation Overview

- Jim Nadolny
  - Motivation for the work
  - Industry relevance
  - Typical results and implicit assumptions
- Vahe' Adamian
  - Ultical – A new calibration method
  - Assumptions
  - Derivation of test fixture S-parameters
  - Results
- Questions and Answers

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Motivation

- Frequency domain simulation tools are increasingly used for SI analysis
- At Samtec, S-parameter models of passive interconnects are routinely requested
  - Assumption is that these models are from full wave simulation tools or from measurements
  - Expectation is that S-parameter models are very accurate
  - Expectation is that the reference plane is at the connector to board interface
- Need for correlation of full wave simulation results with measured data on high density passive interconnect
- Samtec and Ultimetrix partnered to develop a new method to measure high density passive interconnects

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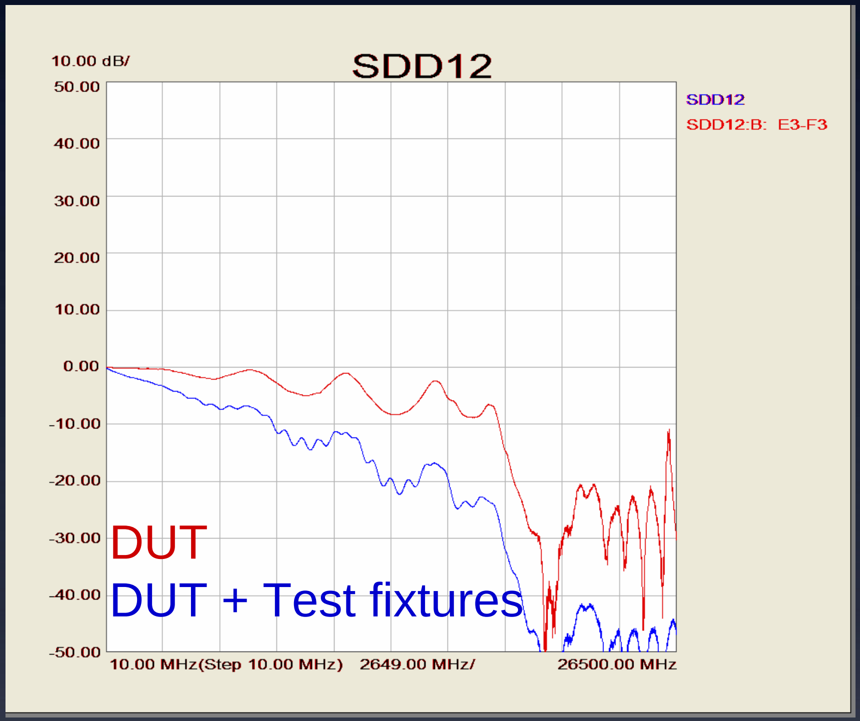
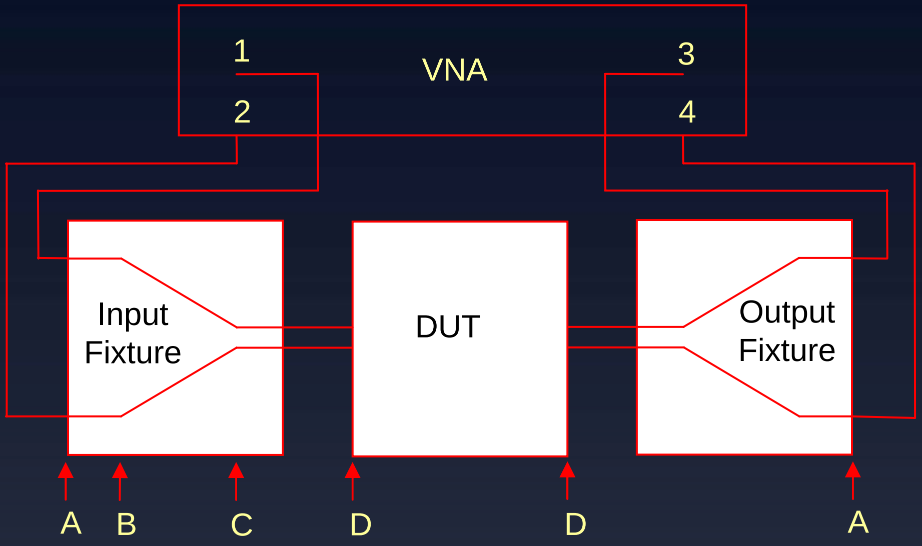
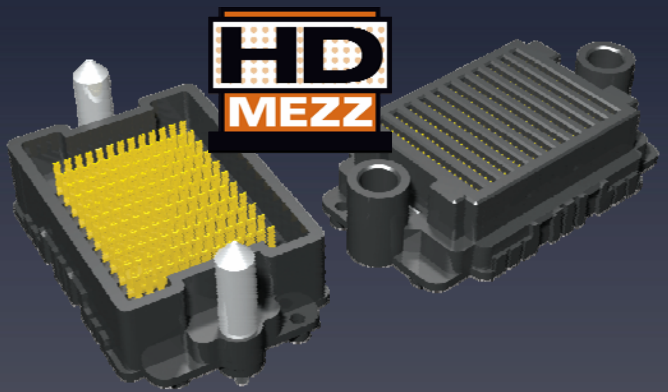
De-embedding/Fixture Removal







- De-embedding removes the effects of test fixtures
- Test fixtures can have a significant impact on performance
- Results are for a high density, mezzanine connector – Samtec's HD Mezz™

™ Trademark of Molex

Industry Relevance

- Active Industry Standards
  - SFF-8414, Passive Cable Assembly S-Parameter Measurement (Greg McSorley-Chair)
  - PICCC, PICMG Interconnect Channel Characterization Committee (Michael Munroe–Chair)
- If fixture removal of high density devices were easy, you would not have active standards groups addressing best practices

Available Methods

- TRL/LRM/LRRM, etc. – based on transmission line standards
- SOLT – requires precision standards mounted on test fixtures
- Full wave modeling of test fixture
- Direct measurement of test fixture

** Each technique has limitations. We will use TRL as a baseline to compare to the new technique.

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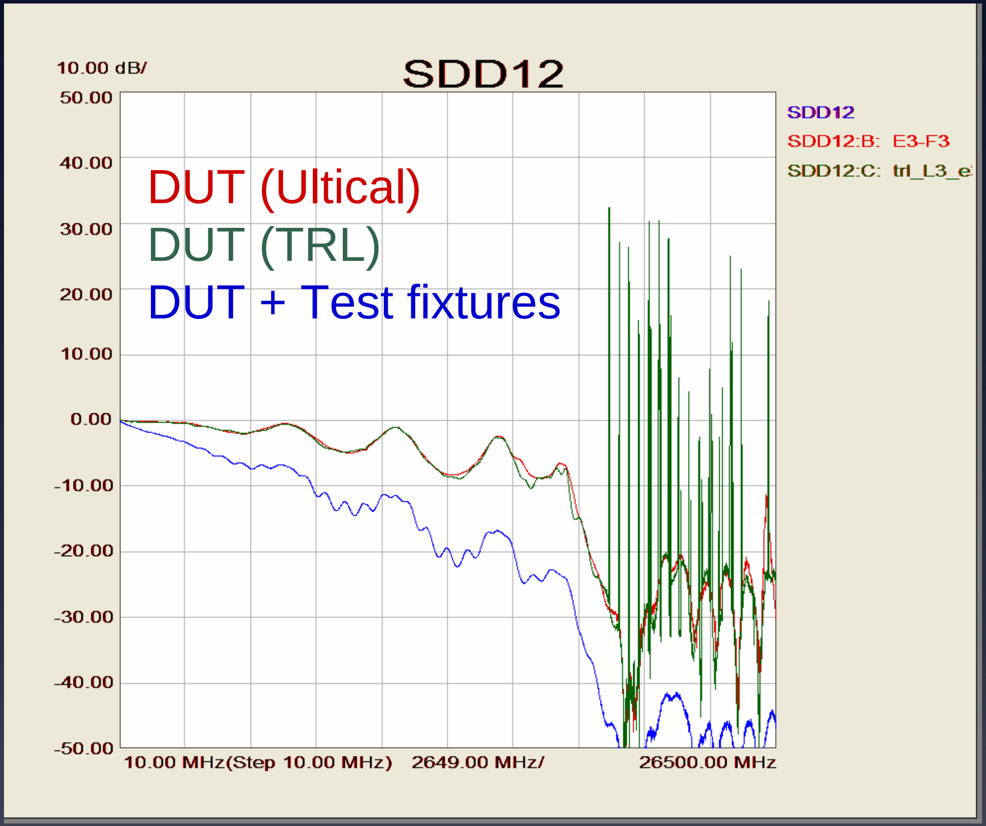
Some Assumptions in TRL

- Reference impedance of S-parameters is the impedance of the line standards
- No coupling between feedlines of fixture
- Fixture halves are mirror images
- PCB standards have same characteristics as fixture feed lines
- Fixture must be low loss
- Standards must behave like transmission lines ($e^{-\gamma l}$)

** Quality of the resultant S-parameters depend on how badly the assumptions are violated.

What Happens When We Violate the Assumptions?



The spikes in the TRL data are due to violating the TRL assumptions

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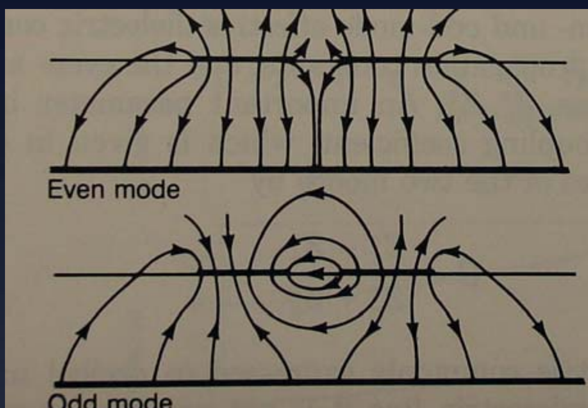
Outline

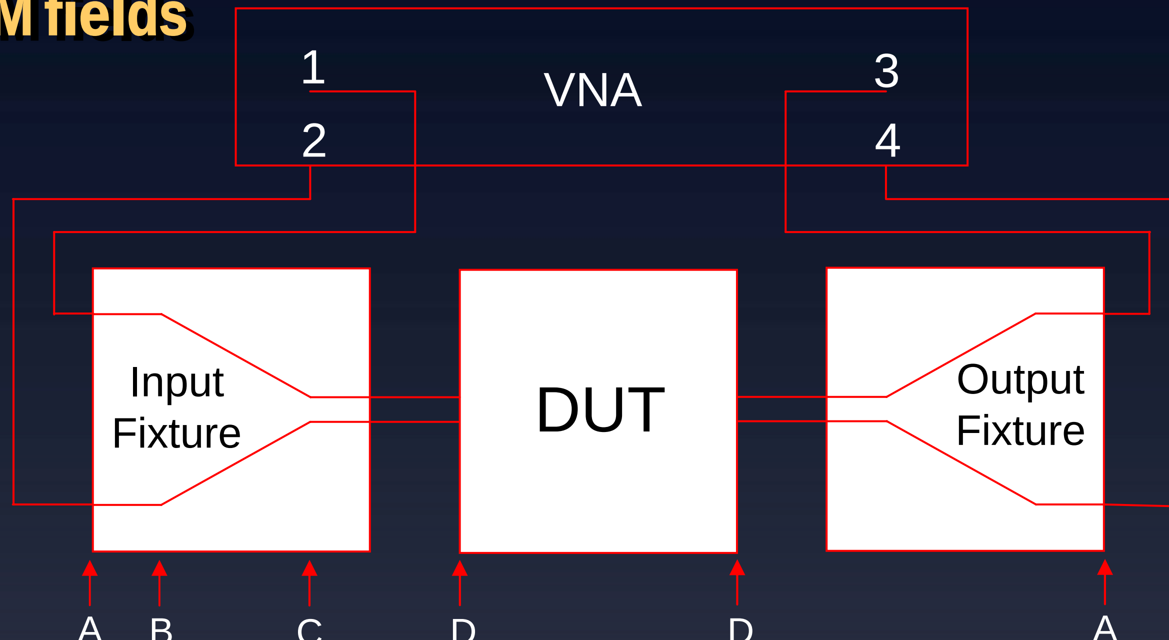
- Introduction/define the problem
- Review of the conventional calibration/measurement procedure and its shortcomings
- Detailed description of novel calibration and measurement procedure
- Conclusion

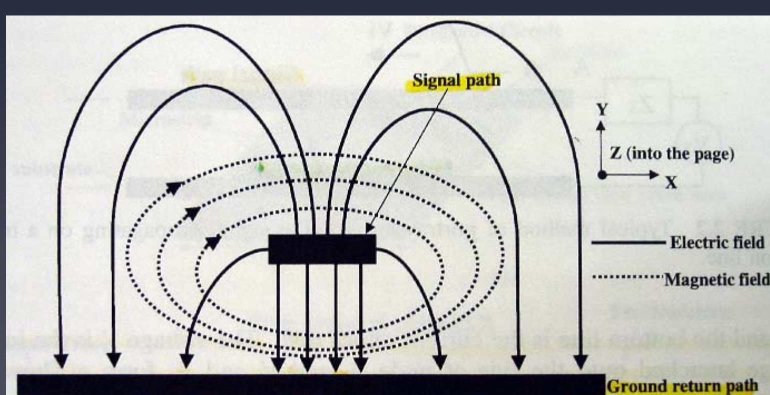
Introduction

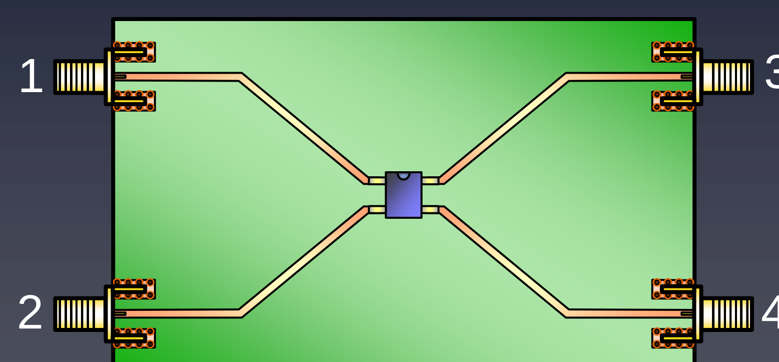
- Differential circuits are used extensively in high speed data transmission
- Almost all differential devices have non-coaxial connectors
- As port (pin) count increases, the available real estate decreases, so there is more coupling between pins
- Differential circuits are measured in a test fixture
- Conventional calibrations do not remove the errors introduced due to electrical coupling and multimode propagation
- The purpose of this presentation is to introduce a novel calibration method in order to get a better measurement accuracy

Connectivity Between VNA and DUT via a Test Fixture.
Close Traces Interact by EM fields

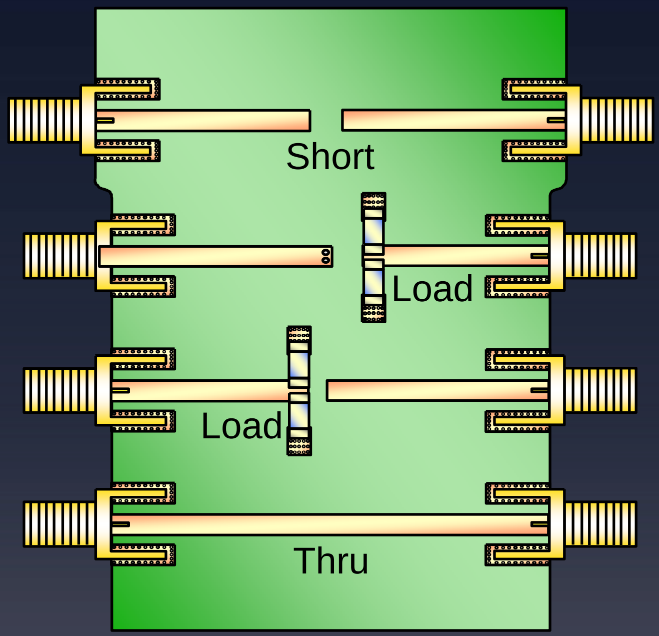


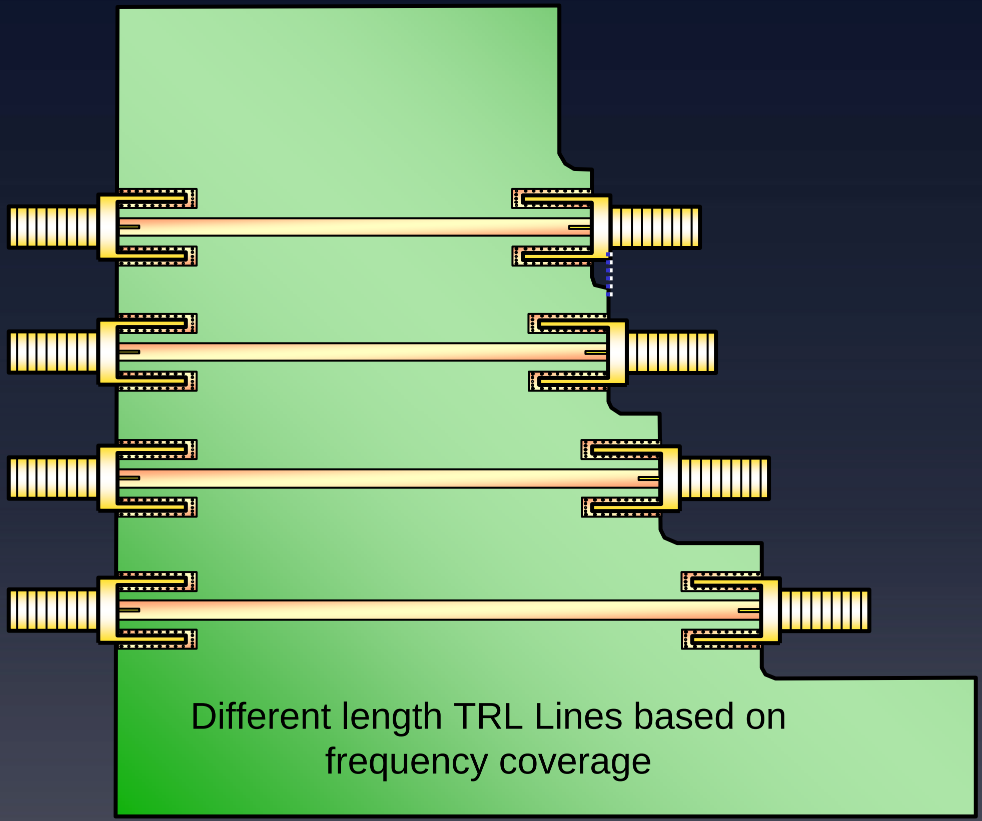




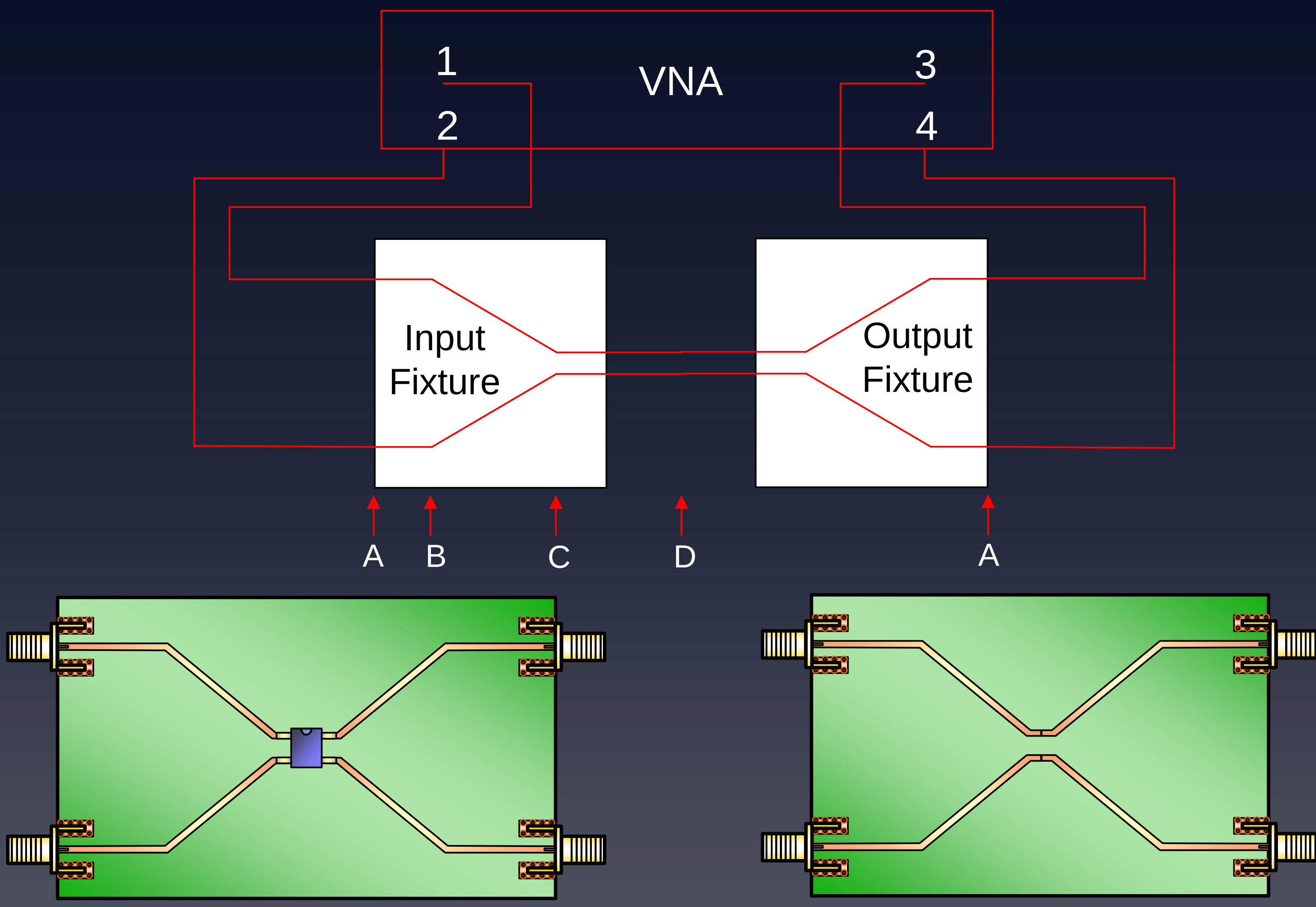


Conventional TRL Calibration Artifacts that Must be Used Per Each Two-Port Path N(N-1)/2

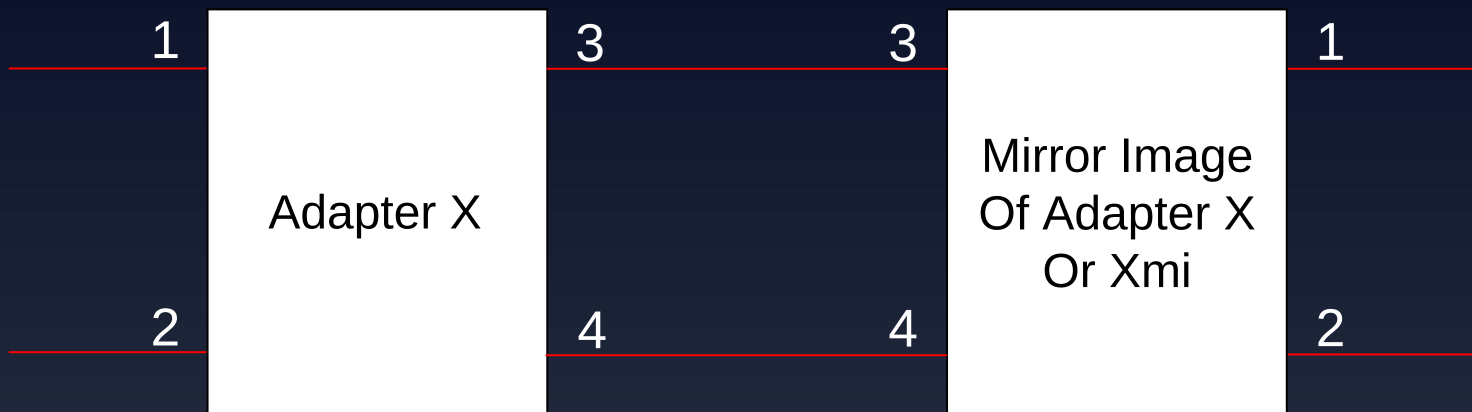




Test Fixture for the Novel Calibration Procedure



Adapter X is Cascaded with its Mirror Image to Construct the Thru Standard. Adapter X is half of the Fixture. Xmi is the Other Half.



$$X = \begin{bmatrix} x_{11} & x_{12} & x_{13} & x_{14} \\ x_{21} & x_{22} & x_{23} & x_{24} \\ x_{31} & x_{32} & x_{33} & x_{34} \\ x_{41} & x_{42} & x_{43} & x_{44} \end{bmatrix}$$

$$Xmi = \begin{bmatrix} x_{33} & x_{34} & x_{31} & x_{32} \\ x_{43} & x_{44} & x_{41} & x_{42} \\ x_{13} & x_{14} & x_{11} & x_{12} \\ x_{23} & x_{24} & x_{21} & x_{22} \end{bmatrix}$$

- The VNA ports are connected to terminals 1 & 2 of adapter X and terminals 1 & 2 of Xmi

Adapter X and Xmi (Each Half) are Non-Symmetrical and Reciprocal. Number of Unknowns Elements are 6.

Relationship between the elements of adapter X and adapter Xmi S-parameters:

$$x_{22} = x_{11}$$
$$x_{12} = x_{21}$$
$$x_{13} = x_{24} = x_{42} = x_{31}$$
$$x_{14} = x_{32} = x_{23} = x_{41}$$
$$x_{34} = x_{43}$$
$$x_{44} = x_{33}$$

Since each half is non-symmetrical (no reflection symmetry), then:

$$x_{11} = x_{22} \neq x_{33} = x_{44}$$

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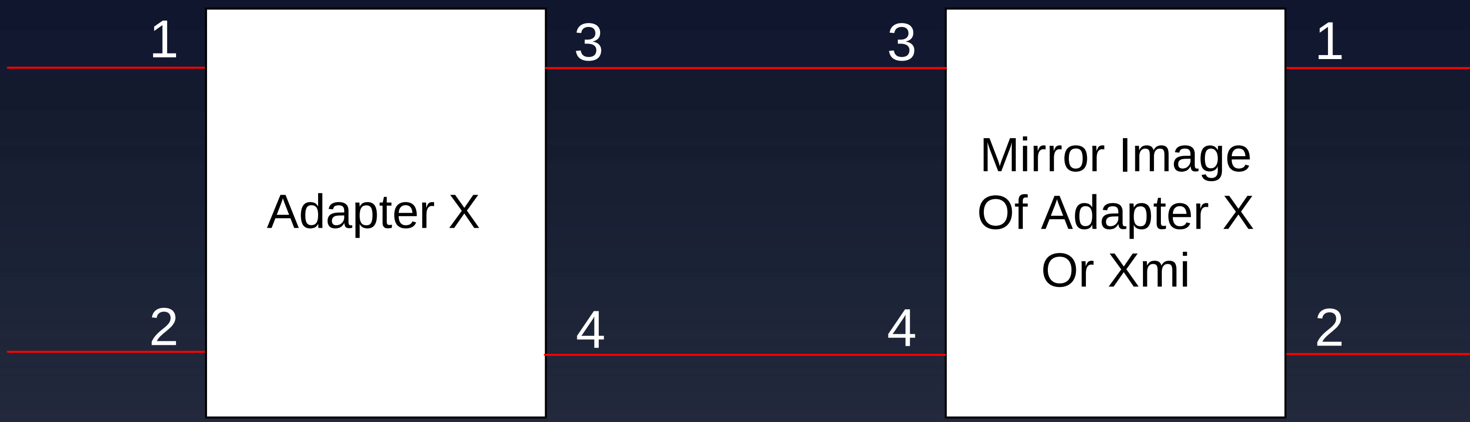
S-Parameter Matrix C represents the Thru Standard (Cascade of Adapter X and Xmi). C Matrix is Symmetrical and Reciprocal.



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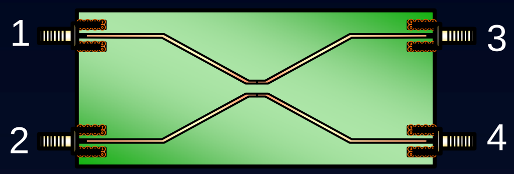
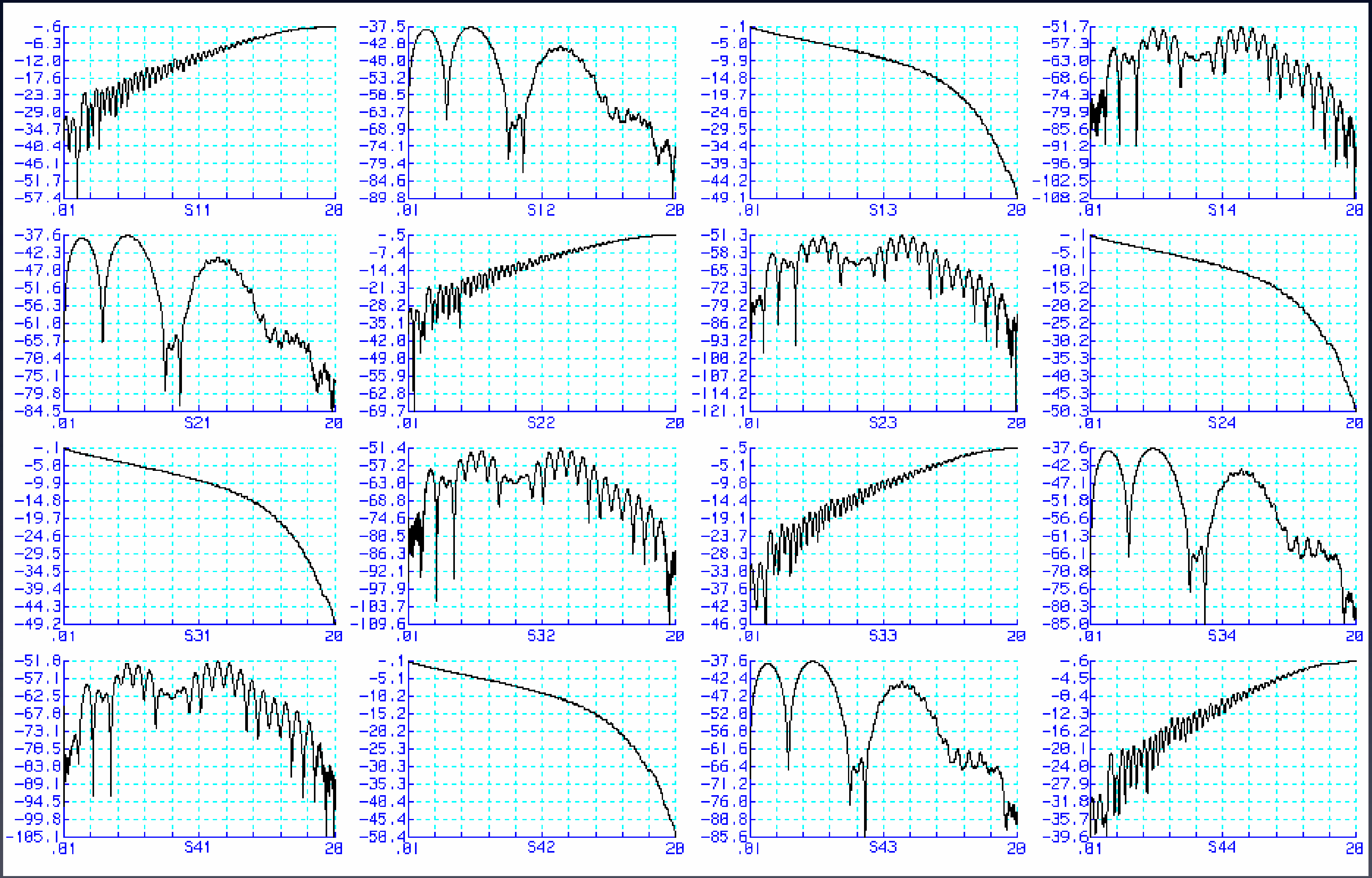
Thru Test Fixture Calibration Standard





Properties of Matrix C (Thru Standard)

1. Thru standard is symmetrical as well as reciprocal; it has transmission and reflection symmetry
2. It is a balanced structure with very little mode conversion from differential to common and common to deferential
3. It has to have the same footprint, material content, and assembly procedure as the DUT embedded in the two fixture halves

S-parameters relationship between the elements of Matrix C:

$c_{11} = c_{22} = c_{33} = c_{44}$	Reflection Parameters
$c_{31} = c_{13} = c_{24} = c_{42}$	Transmission Parameters
$c_{21} = c_{12} = c_{34} = c_{43}$	Coupling Transmission Parameters
$c_{41} = c_{14} = c_{32} = c_{23}$	Isolation Transmission Parameters

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Symmetry Criteria Specifications of Thru Standard (Matrix C]

- Make a broad bandwidth measurement of the Thru Standard
- Optimization program selects a stop frequency such that the vectorial difference of six combination of four parameters taken two at a time is satisfying the following specifications:
  - Reflection parameters is better than 29 dB
  - Transmission parameters is better than 40 dB
  - Coupling transmission parameters is better than 60 dB
  - Isolation transmission parameters is better than 70 dB

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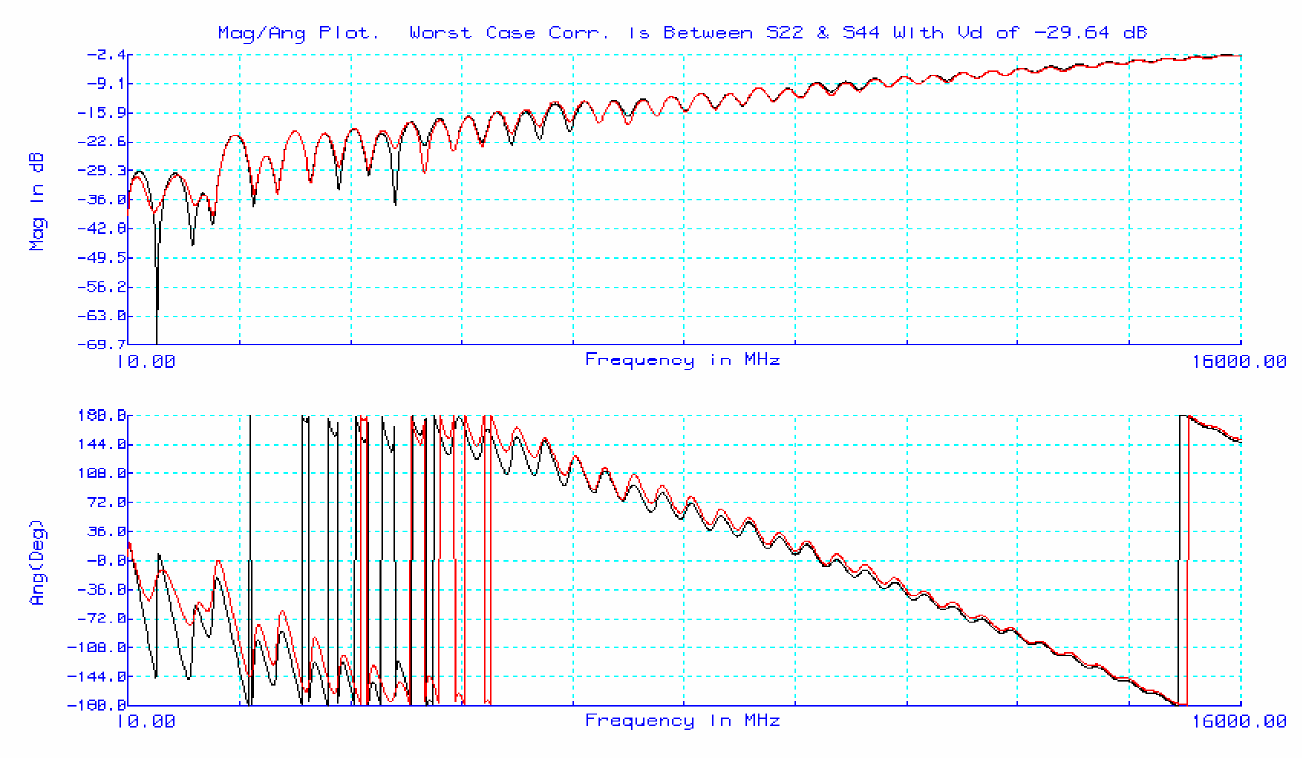
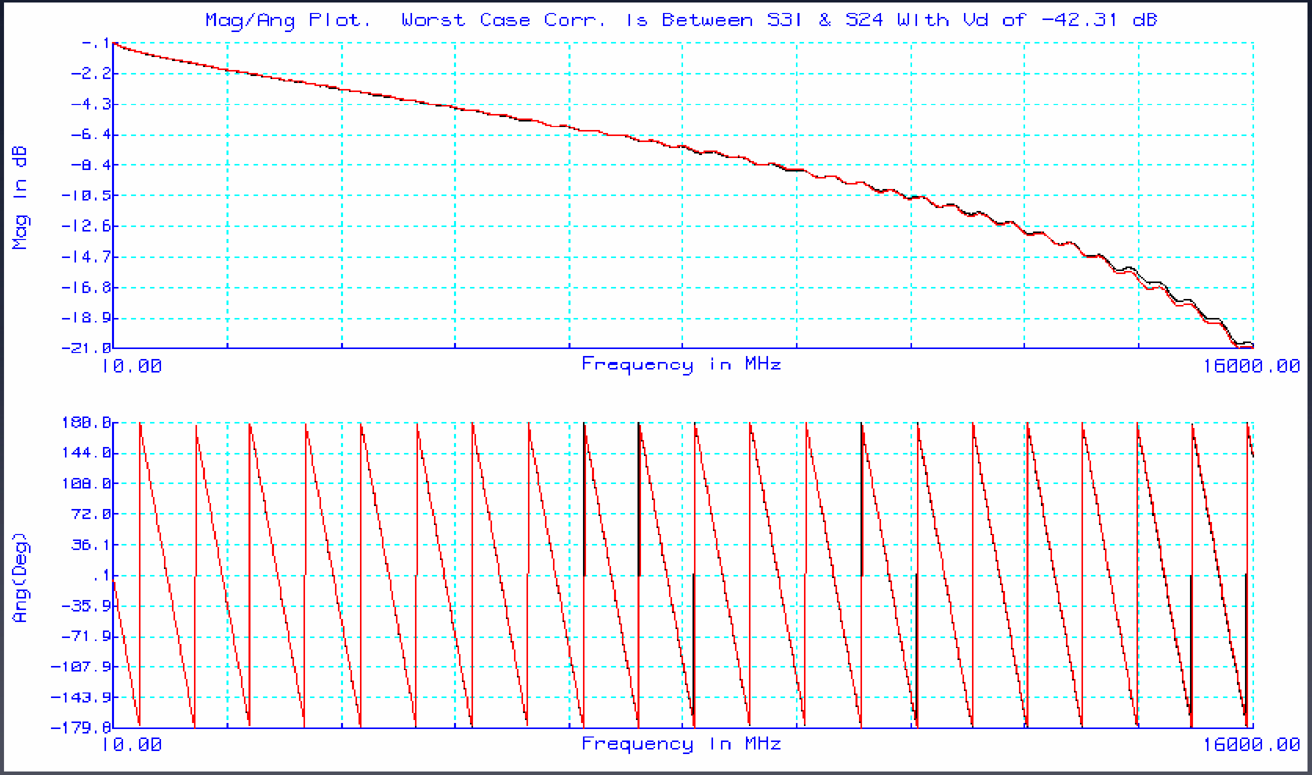
Worst Case Reflection Parameter Correlation

1	MIN=	-76.87	at Freq=	2070.00,	MAX=	-28.42	at Freq=	10070.00,	RMS=	-34.51	S11 vs S22
2	MIN=	-74.41	at Freq=	20.00,	MAX=	-24.73	at Freq=	8740.00,	RMS=	-32.16	S11 vs S33
3	MIN=	-65.31	at Freq=	11400.00,	MAX=	-26.06	at Freq=	1550.00,	RMS=	-31.23	S11 vs S44
4	MIN=	-60.59	at Freq=	2170.00,	MAX=	-25.15	at Freq=	12130.00,	RMS=	-29.85	S22 vs S33
5	MIN=	-74.62	at Freq=	20.00,	MAX=	-23.10	at Freq=	5350.00,	RMS=	-29.64	S22 vs S44
6	MIN=	-77.83	at Freq=	13510.00,	MAX=	-27.77	at Freq=	15750.00,	RMS=	-35.26	S33 vs S44



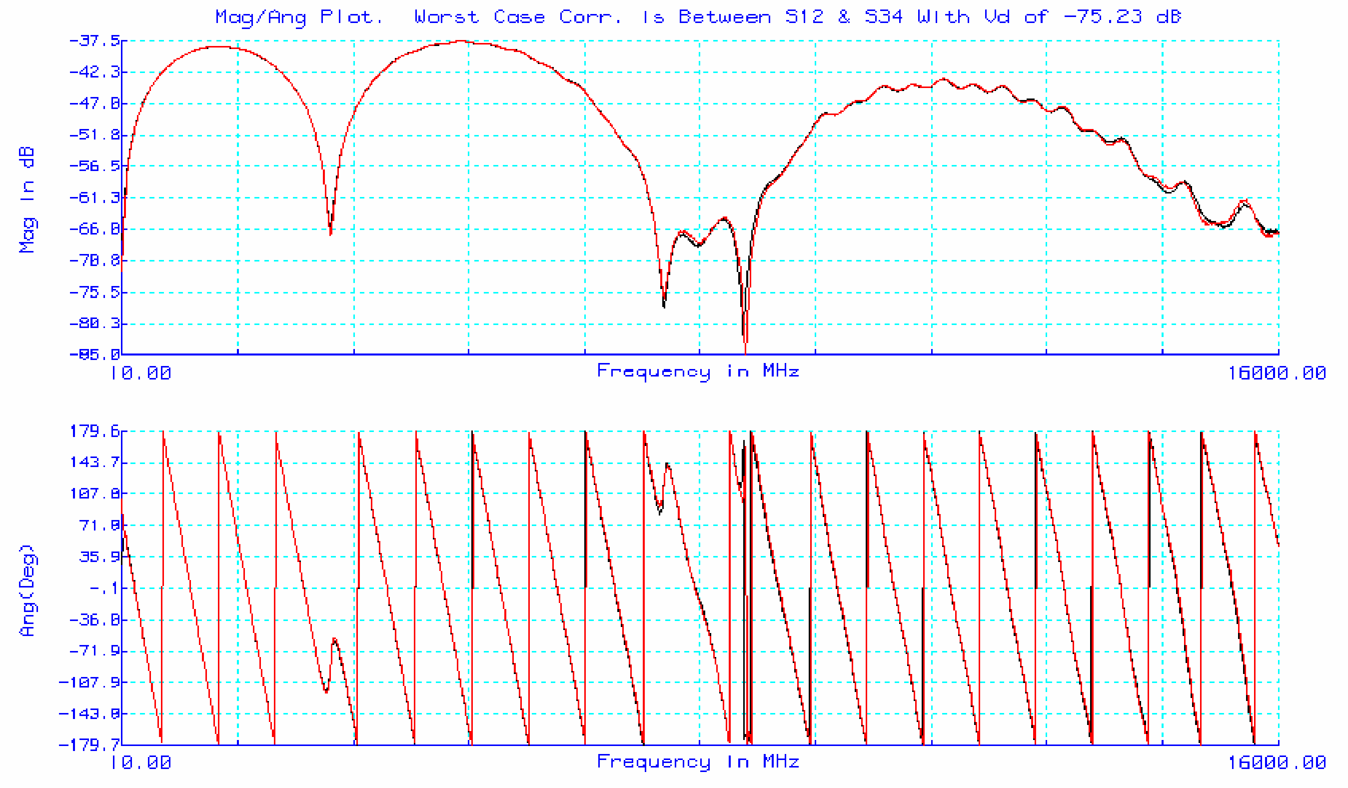
Worst Case Transmission Parameter Correlation

1	MIN= -62.31	at	Freq=15700.00,	MAX= -47.67	at	Freq= 7310.00,	RMS= -50.82	S13 vs S31
2	MIN= -77.45	at	Freq= 310.00,	MAX= -39.44	at	Freq=14650.00,	RMS= -44.88	S13 vs S24
3	MIN= -59.89	at	Freq= 5850.00,	MAX= -40.02	at	Freq=14580.00,	RMS= -47.46	S13 vs S42
4	MIN= -58.85	at	Freq= 20.00,	MAX= -37.47	at	Freq= 8060.00,	RMS= -42.31	S31 vs S24
5	MIN= -81.62	at	Freq= 140.00,	MAX= -39.73	at	Freq=14590.00,	RMS= -46.13	S31 vs S42
6	MIN= -58.47	at	Freq= 40.00,	MAX= -46.20	at	Freq= 6870.00,	RMS= -49.02	S24 vs S42



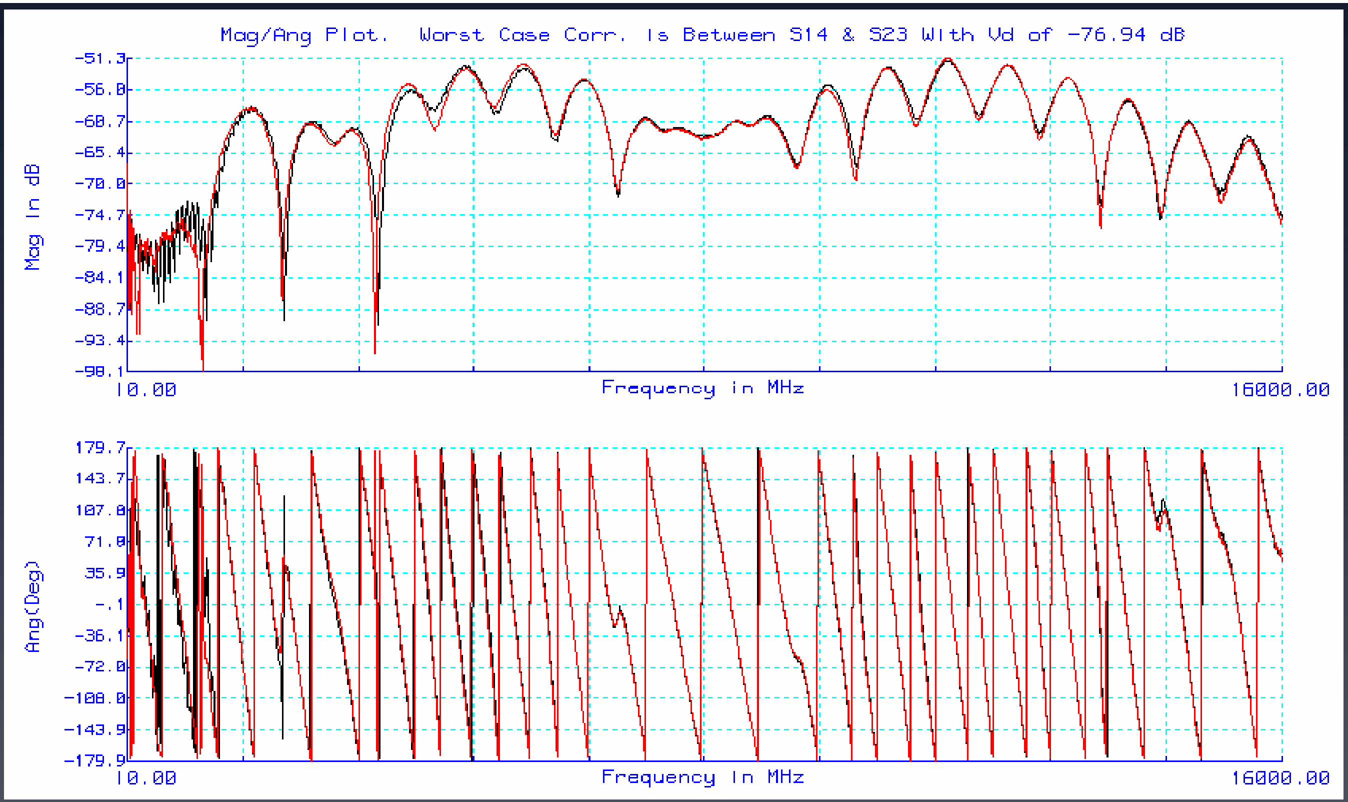
Worst Case Coupling Transmission Parameter Correlation

1	MIN=-124.17	at	Freq= 6930.00,	MAX= -69.77	at	Freq= 10.00,	RMS= -86.52	S12	vs	S21
2	MIN=-122.20	at	Freq= 8270.00,	MAX= -66.90	at	Freq= 10.00,	RMS= -75.23	S12	vs	S34
3	MIN=-130.13	at	Freq= 8220.00,	MAX= -67.97	at	Freq= 4730.00,	RMS= -75.48	S12	vs	S43
4	MIN=-115.81	at	Freq= 8180.00,	MAX= -64.54	at	Freq= 10.00,	RMS= -76.32	S21	vs	S34
5	MIN=-115.69	at	Freq= 7750.00,	MAX= -67.21	at	Freq= 4740.00,	RMS= -76.43	S21	vs	S43
6	MIN=-131.82	at	Freq=14550.00,	MAX= -70.32	at	Freq= 10.00,	RMS= -89.20	S34	vs	S43



Worst Case Isolation Transmission Parameter Correlation

1	MIN=-125.74 at Freq= 7120.00,	MAX= -65.27 at Freq= 10.00,	RMS= -88.88	S14 vs S41
2	MIN=-110.21 at Freq= 7820.00,	MAX= -66.41 at Freq= 4520.00,	RMS= -76.94	S14 vs S23
3	MIN=-118.54 at Freq= 8510.00,	MAX= -66.97 at Freq= 4700.00,	RMS= -77.01	S14 vs S32
4	MIN=-122.44 at Freq= 260.00,	MAX= -63.62 at Freq= 10.00,	RMS= -77.11	S41 vs S23
5	MIN=-114.94 at Freq= 8550.00,	MAX= -66.55 at Freq= 4630.00,	RMS= -77.02	S41 vs S32
6	MIN=-143.28 at Freq= 7770.00,	MAX= -69.94 at Freq= 10.00,	RMS= -89.34	S23 vs S32



Calculation of Matrix X and Xmi Input/Output Test Fixture

- Convert matrix C into mixed-mode S-parameters
- Convert Cdd21(differential quadrant) into time domain impulse response and determine the electrical delay
- Convert Cdd11 into time domain impulse response and gate the response by electrical delay determined by Cdd21
- Convert the gated Cdd11 back to frequency domain; this is the Xdd11 of input fixture
- Calculate Xdd22, Xdd12, and Xdd21

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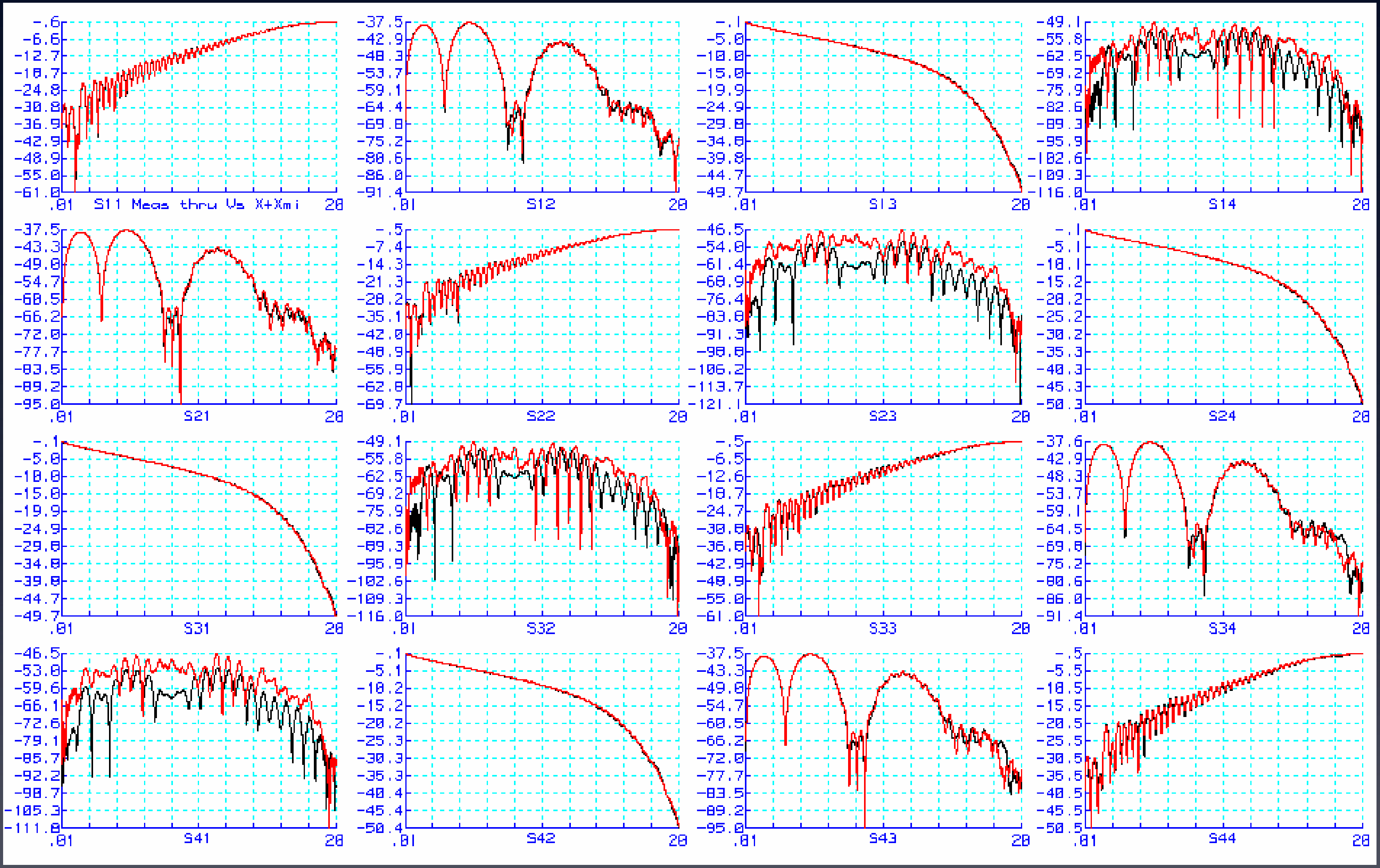
Calculation of Matrix X & Xmi Continuation

- Repeat the same procedure for the Cdc, Ccd, and Ccc quadrants and calculate corresponding Xdc, Xcd, and Xcc balanced parameters
- The Xdd, Xdc, Xcd, and Xcc constitute the mixed-mode S-parameters of the input fixture defined as Xmm
- Calculate matrix X of the input fixture from the mixed-mode S-parameter matrix Xmm
- DUT is de-embedded from the overall measurement and the Thru test fixture

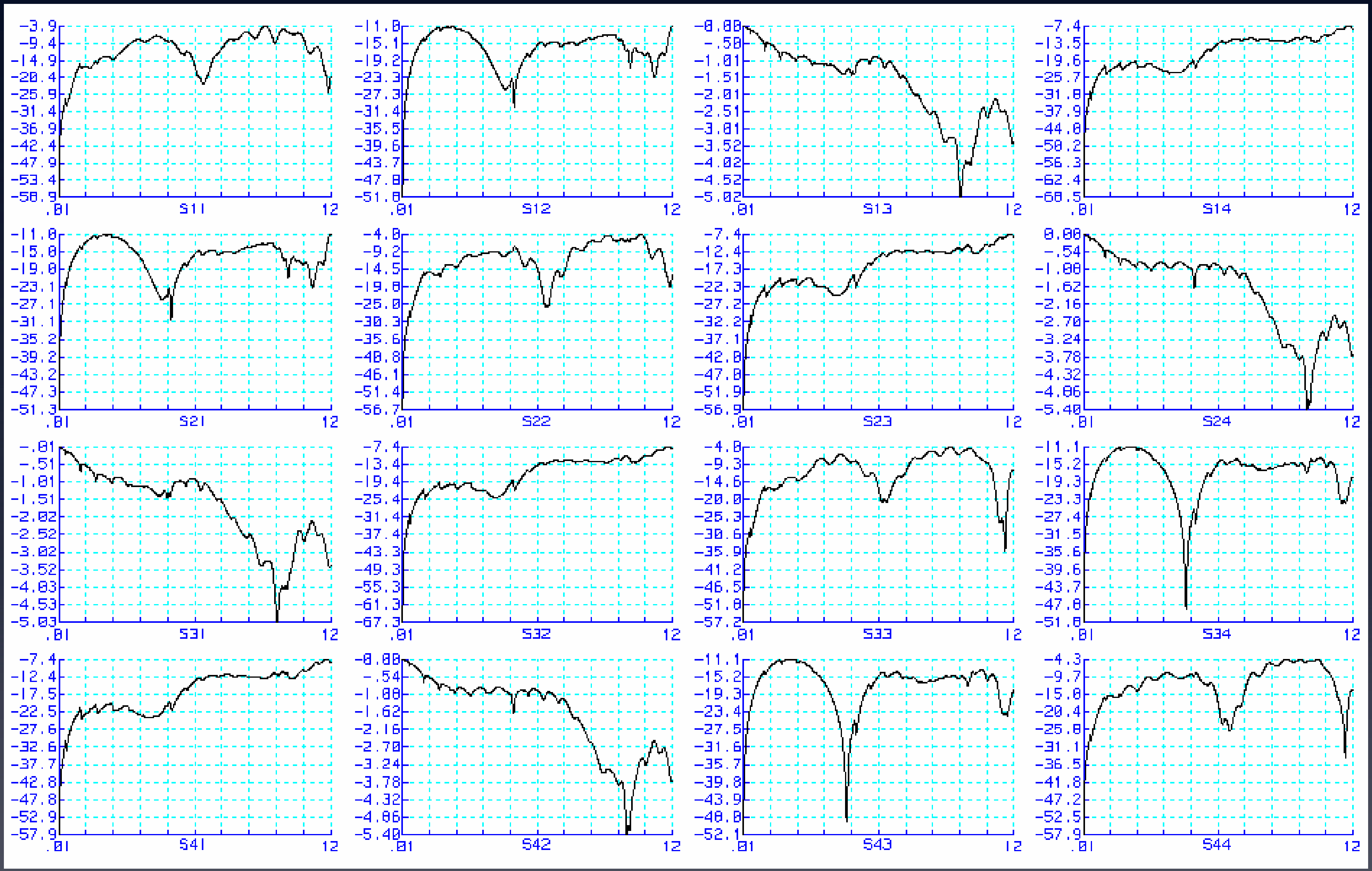
Validation Procedure. Overlay of Cascade of Adapter X & Xmi with Measured Thru



Calibration and Measurement Steps for Novel method

- 4-port coaxial calibration at reference plane A; use a 4-port Ecal or Coaxial calibration standard
- Measure 4-port-Thru; only one multi-port calibration standard
- Measure test fixture and DUT

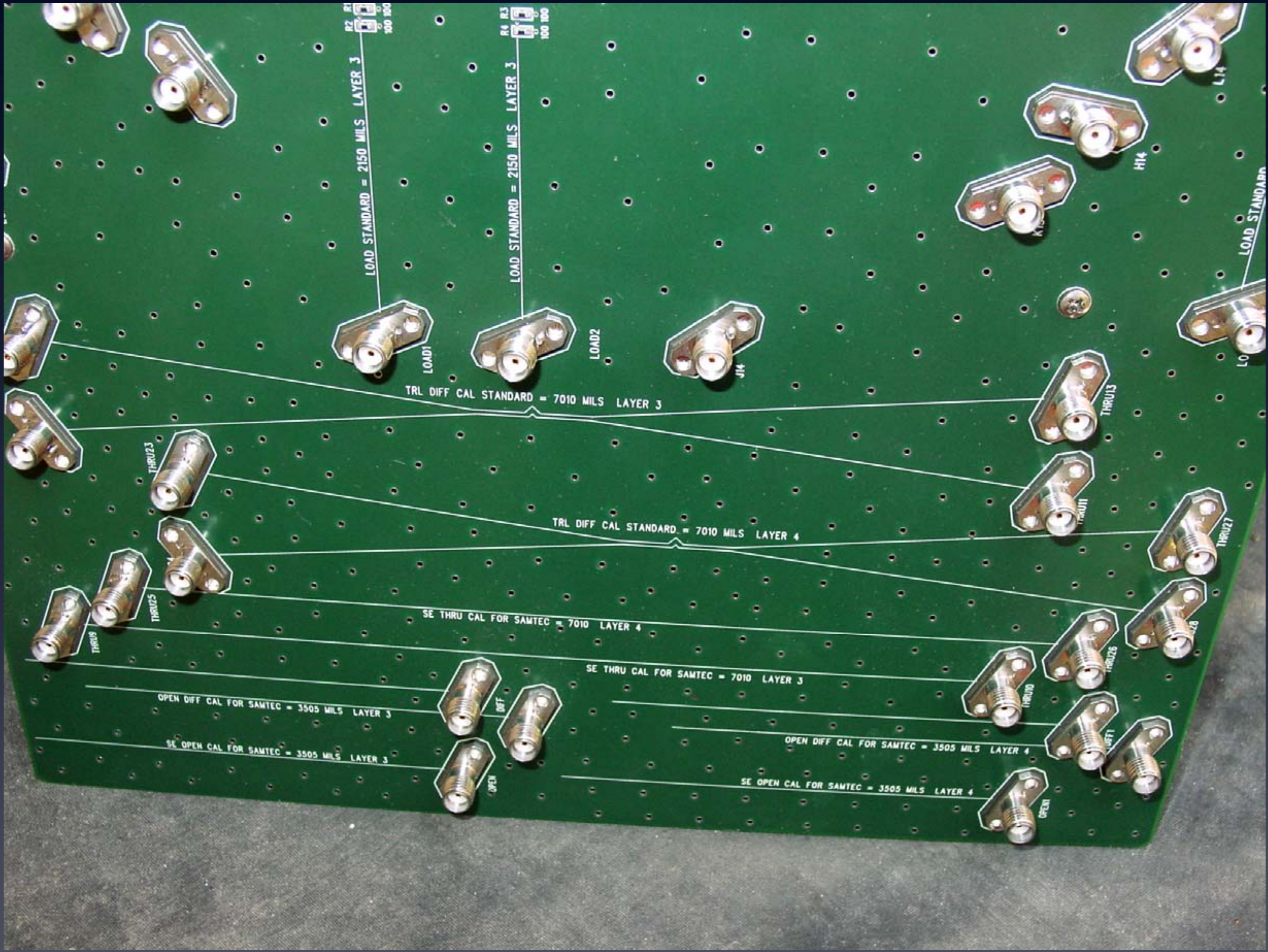
DUT is De-embedded from Overall Measurement and Thru Test Fixture



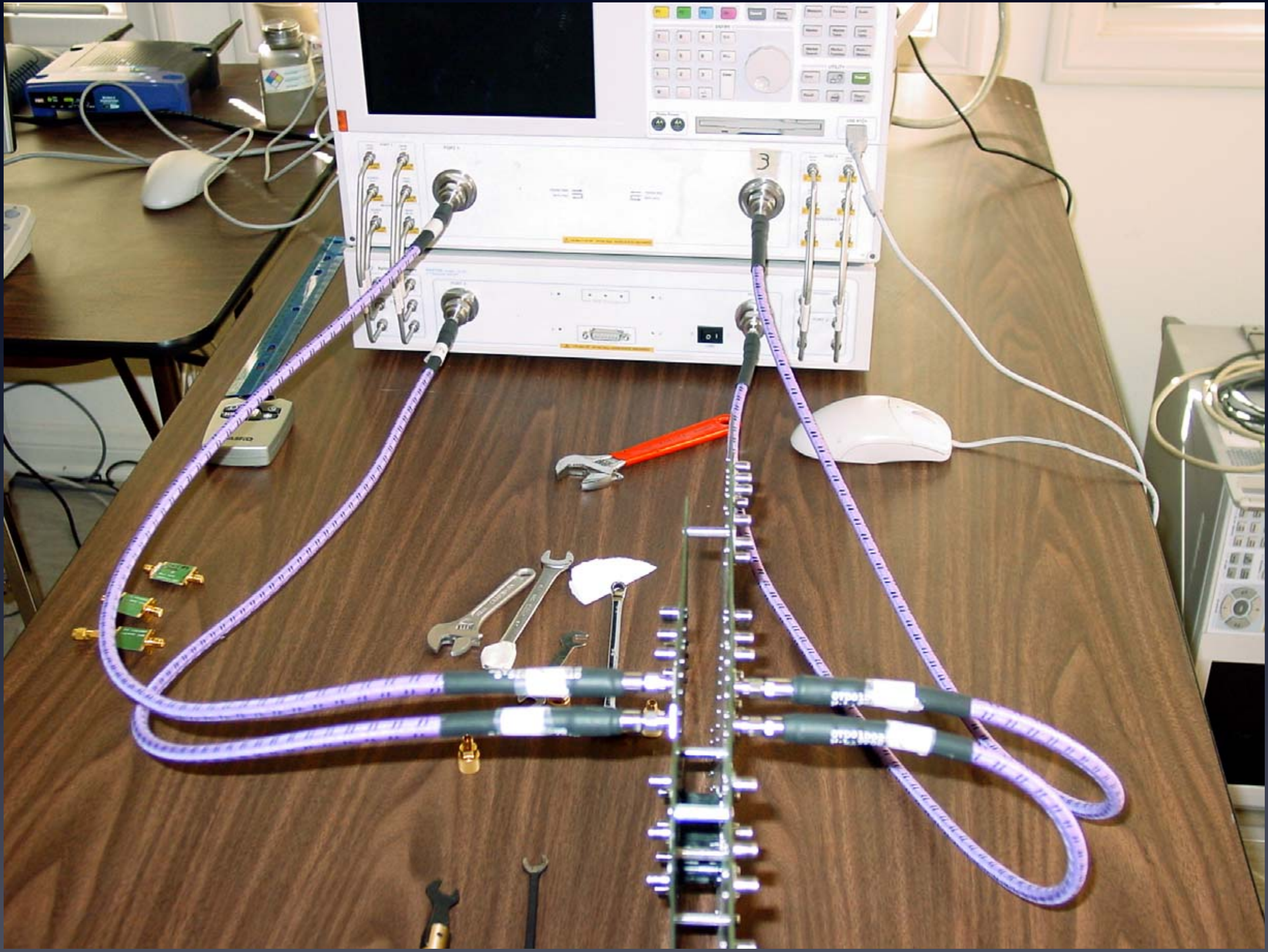
Conclusion TRL vs. Novel Method

- Superior accuracy; no errors due to electrical coupling and no on-board fixture calibration standards
- Faster calibration due to fewer calibration steps
- Simpler calibration and measurement procedure; only one multi-port calibration standard (Thru) is required
- Minimizes operator error
- Simple to manufacture with less cost
- Novel method can be extended to more than a single differential pair

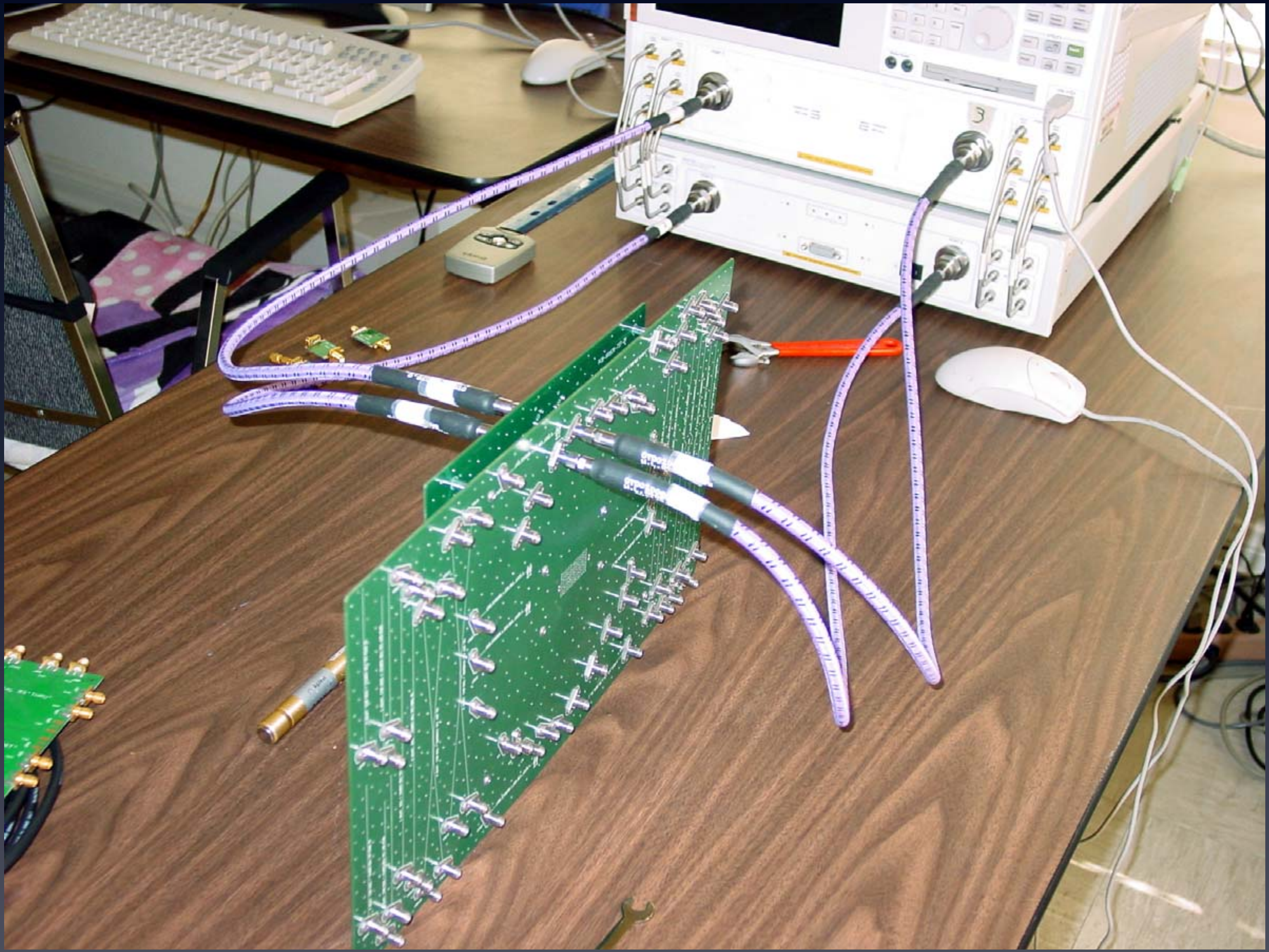
Thru Test Fixture Calibration Standard Board provided by Samtec



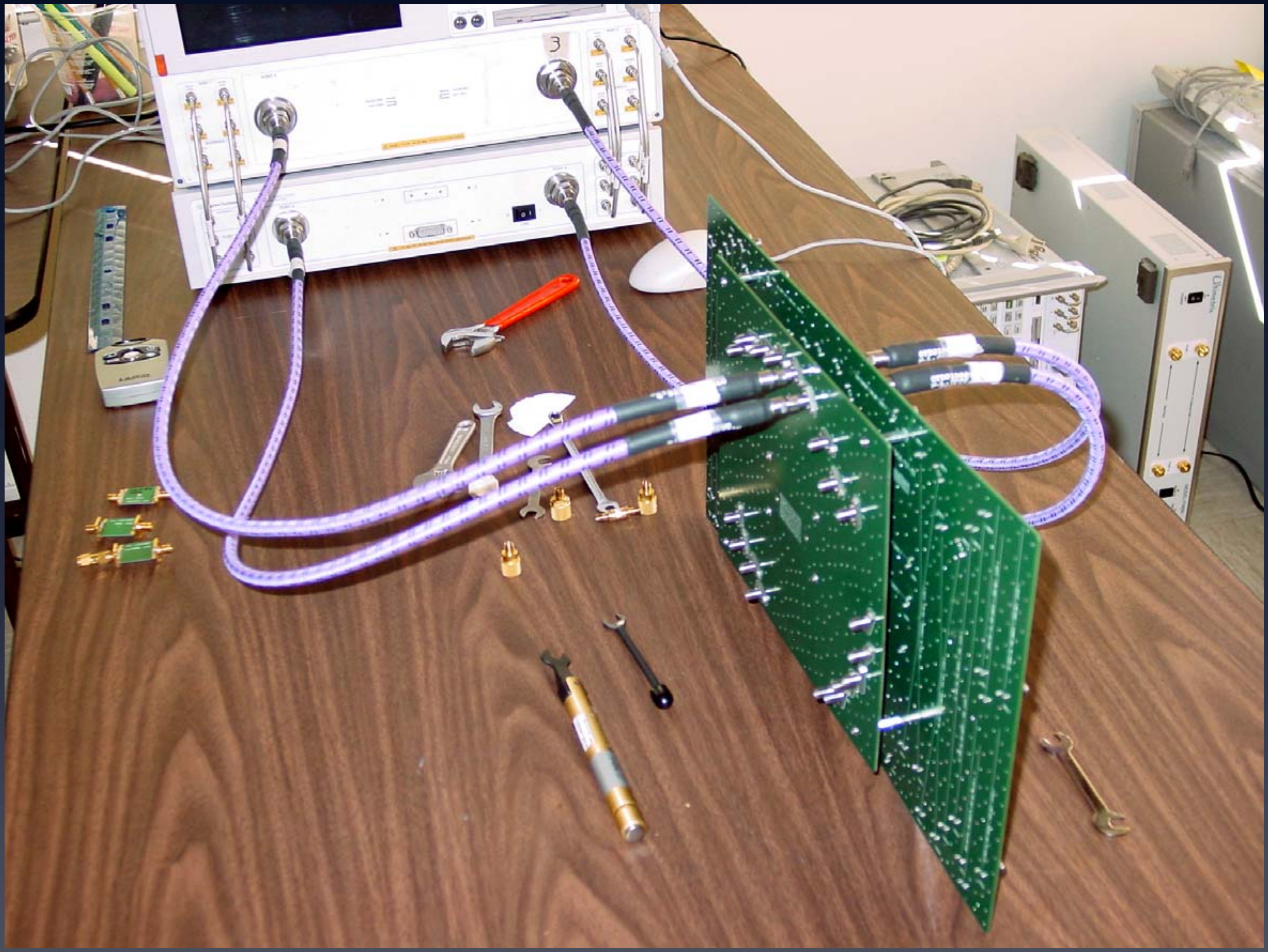
Test Fixture and DUT (Top view)
Board provided by Samtec



Test Fixture and DUT (Left view)
Board provided by Samtec



Test Fixture and DUT (Right view)
Board provided by Samtec



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