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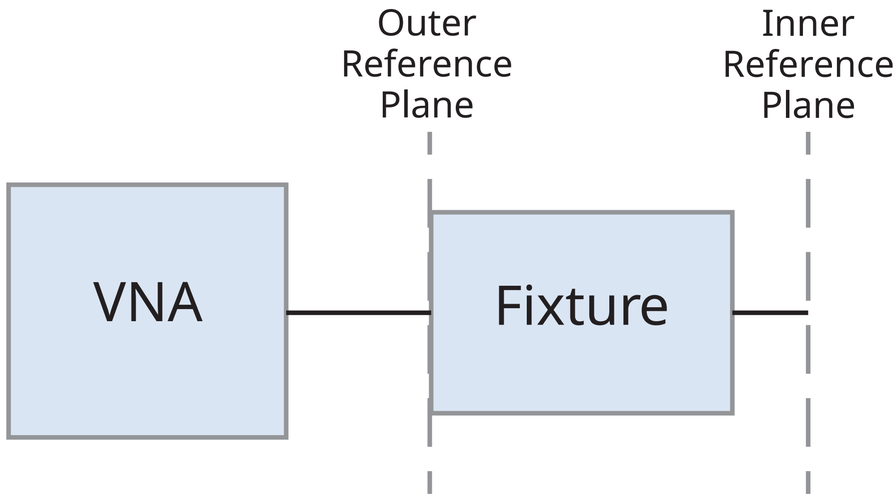
The Application for Type-B Two Tier Calibration with Flex Standard Network Extraction

Introduction

In order to understand the application of Type-B network extraction, several steps will be discussed. The following steps will be shown: 1) a block diagram for the Type-B network, 2) a detailed signal flow model based on the block diagram, and 3) scattering parameters equations that can be derived based on the signal flow model. With the equations from the Type-B two tier calibration with Flex Standard network extraction, its application will be discussed and the measurements with ShockLine™ Compact USB VNA MS46122B will be verified. We will conclude with a comparison between in situ de-embedding ISD software from Ataitec and Type-B is examined.

Concept of Type-B Two Tier Calibration with Flex Standard Network Extraction

The main purpose is to extract the .s2p file of the fixture with different or incomplete calibration standards. Algorithmically, this is similar to the Bauer-Penfield technique (full calibration standard: short, open, and load) but rather an incomplete calibration is performed at the fixture output plane. A general setup for Type-B with a fixture attached to a VNA is depicted in figure 1. The fixture can be modeled by a 2-port scattering parameters as depicted in figure 2.



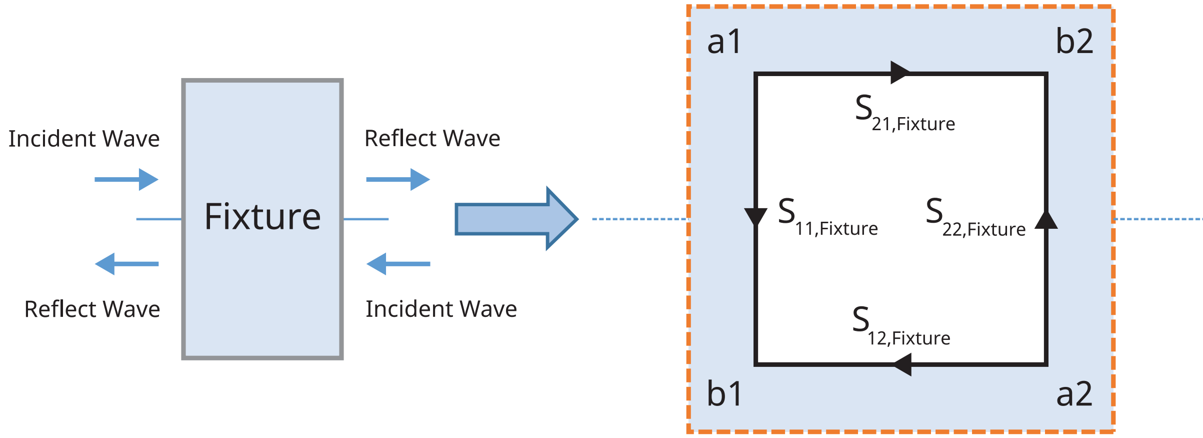


Figure 2. Fixture Modelled as a 2-Port Scattering Parameters

The fixture can be represented by 2 x 2 scattering parameters array denoted as $S_{11,fixture}$ (fixture outer plane reflection on port 1) $S_{21,fixture}$ (transmission loss on the fixture from port 1 to port 2), $S_{12,fixture}$ (transmission loss on the fixture from port 2 to port 1). $S_{22,fixture}$ (fixture inner plane reflection after connecting to reflection standards).

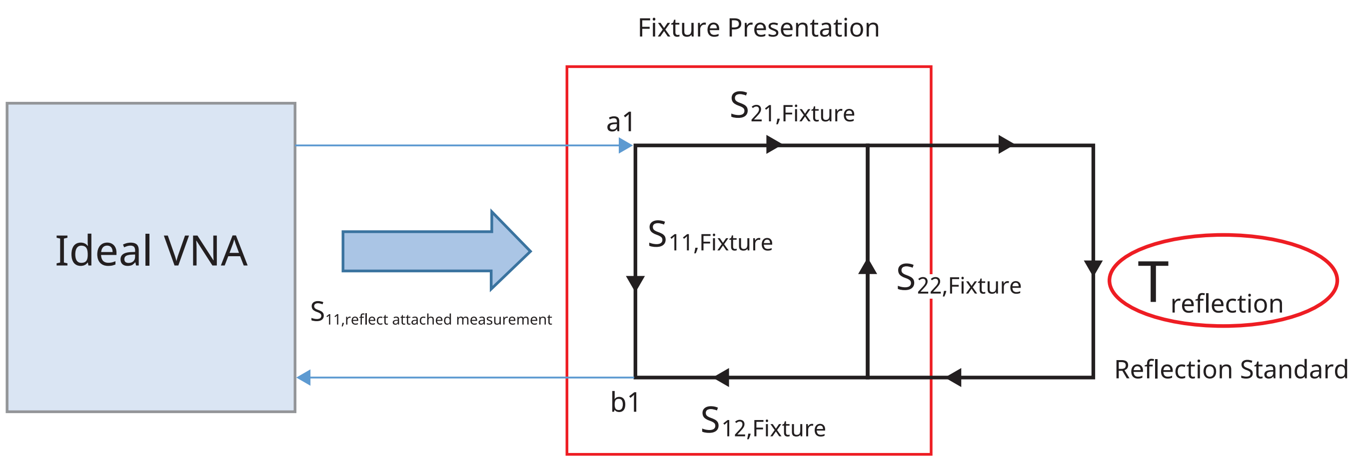


Figure 3. Fixture Network Signal Flow Model

a1 is the incident wave from test port 1 to fixture port 1, b1 is the reflection wave from the fixture to test port 1.

The Non-Touching Loop Rule

The non-touching loop rule is a technique which can be applied on any signal flow model. Figure 3 is a network signal flow where the fixture is placed between the VNA and a reflection standard. The system has only one independent variable (a1). The flow diagram contains “paths” and “loops”. A “path” (P) is defined and a series of lines follow in sequence and in the same direction that no node is touched more than once. The value of the path is the product of all coefficients encountered in the path. There are also loops in the flow diagram.

- A first order “loop” [L(1)] is defined as a series of directed lines coming to a closure when followed in sequence and in the same direction with no node passed more than once.
- A second order “loop” [L(2)] is the product of any two first-order “loops” which do not touch at any point.
- A third order “loop” [L(3)] is the product of any three first-order “loops” which do not touch at any points and so on for the forth-order and subsequent orders.

The solution of a flow graph is accomplished by the application of the non-touching loop rule which can be represented simply by an equation as shown below:

$$bx/ax = \frac{P1(1-\sum L(1)+\sum L(2)-\sum L(3)+\cdots)+P2(1-\sum L(1)+\sum L(2)-\sum L(3)+\cdots)+P3(1-\cdots)+\cdots}{1-\sum L(1)+\sum L(2)-\sum L(3)+\cdots} \quad (1)$$

For the flow diagram shown in figure 4, there are two paths (from incident a1 to reflection b1): path P1 = $S_{11,fixture}$; path P2 = $S_{21,fixture}$ $T_{reflection}$ $S_{12,fixture}$

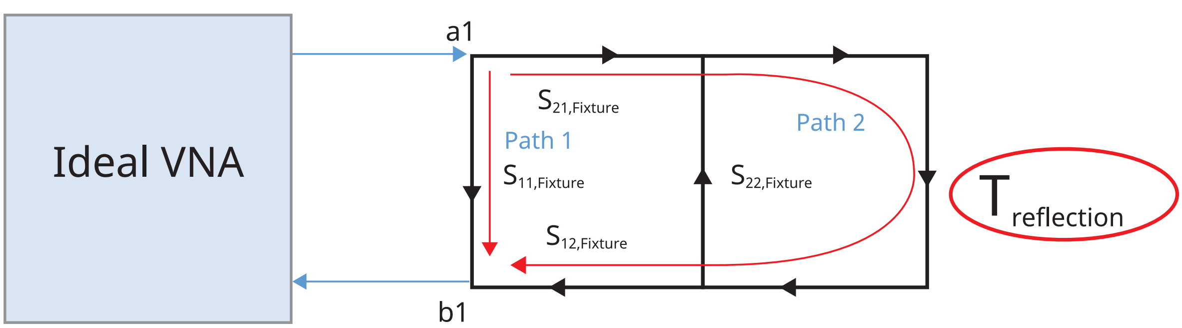


Figure 4. Two Paths Diagram

There is one first-order loop for path 1 $S_{22,fixture}$ $T_{reflection}$

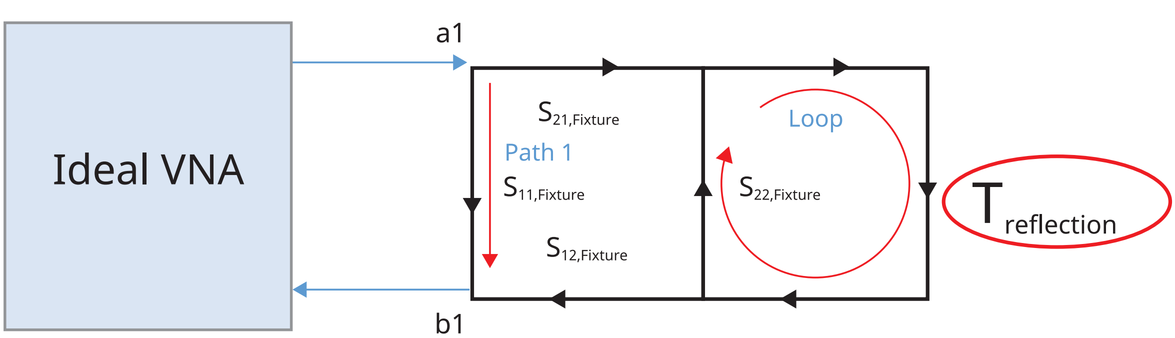


Figure 5. One Path and a Loop Not Touch Any Nodes on the Path

There is no loop for path 2.

From equation 1, it can be reduced to:

$$S_{11,\text{reflect attached measurement}} = \frac{(S_{11,fixture}(1- S_{22,fixture}\,T_{reflection}) + S_{21,fixture}\,T_{reflection}\,S_{12,fixture})}{1- S_{22,fixture}\,T_{reflection}}$$

When connecting an open standard at the end of the fixture, the equation above can be simplified as below:

$$M_o = S_{11,fixture} + \frac{(S_{12,fixture}^2 \times \tau_{open})}{(1 - S_{22,fxiture} \times \tau_{open})} \qquad (2)$$

Same applies for a short standard:

$$M_s = S_{11,fixture} + \frac{(S_{12,fixture}^2 \times \tau_{short})}{(1 - S_{22,fxiture} \times \tau_{short})} \qquad (3)$$

When Equation 2 is substracted from equation 3, the insertion loss for the fixture can be derived as below:

$$S_{12,fixture}^2 = \frac{(M_o - M_s)\,(1 - S_{22,fixture}\,\tau_{open})(1 - S_{22,fixture}\tau_{short})}{\tau_{open} - \tau_{short}} \qquad (4)$$

In Type-B two tier calibration method, the inner plane is assumed perfect match, that is $S_{22,fixture} = 0$.

Then Equation 4 can be simplified as below:

$$S_{12,fixture} = \sqrt{(M_o - M_s)/(\tau_{open} - \tau_{short})} \qquad (5)$$

Where M_o is $S_{11,attached\ with\ open\ reflection}$ and M_s is $S_{11,attached\ with\ short\ reflection}$

Equation 5 is the result of the insertion loss of the fixture.

If open and short are ideal open and short, then $\tau_{short} = -1$ and $\tau_{open} = 1$

$$S_{12,fixture} = \sqrt{\frac{(M_o - M_s)}{2}} \tag{6}$$

To verify if equation 6 is correct, let $M_o = 1\ and\ M_s = -1$, then $S_{12,fixture}$ is a lossless transmission line.

If they are not ideal, then $\tau_{short} = -e^{-j4\pi l/\lambda}$ and $\tau_{open} = e^{-j4\pi l/\lambda}$

Where $\lambda = \frac{C_0}{f}$

Where C_0 is speed of light and f is the frequency of interest.

Measurement with Type-B Two Tier Calibration with Open and Short Using ShockLine MS46122B

The first step is to setup the ShockLine MS46122B.

Start freq: 100 MHz

Stop freq: 10 GHz

Number of points = 100

Perform full 2-port SOLT calibration using TOSLKF50A calibration standard.

Fixture is 3670K50-1 RF cable

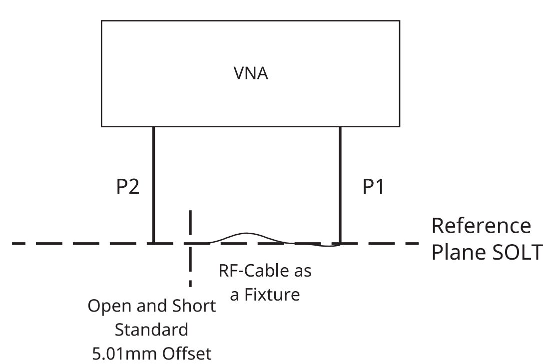


Figure 6. VNA Setup with a Fixture Where the Inner Plane is Being Calibrated with an Open and a Short Standard

Below is the Menu to setup Type-B two tier calibration with only open and short standards.

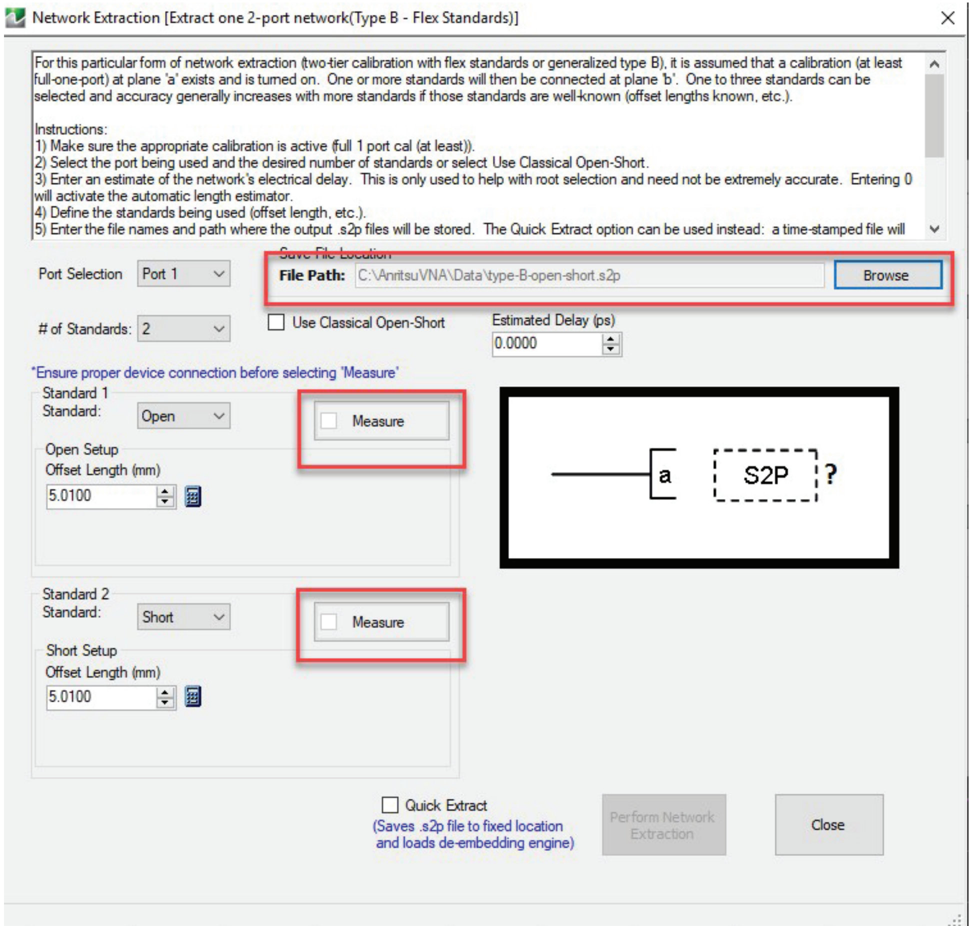


Figure 7. GUI Menu for Type-B Two Tier Calibration with Flex Standards

In this example, the short and open are the TOSLKF50A calibration standards and its offset is 5.01 mm. The estimated delay for the fixture can be set 0ps and the software will automatically measure the fixture delay.

After clicking both measure box, and then click on perform network extraction button, a .s2p file will be generated.

Note: the check box for the classical open-short standard is only for the when an electrically short, lumped model for the fixture is used in keeping with the original on-wafer implementation of open-short de-embedding.

Below is the fixture .s2p file.

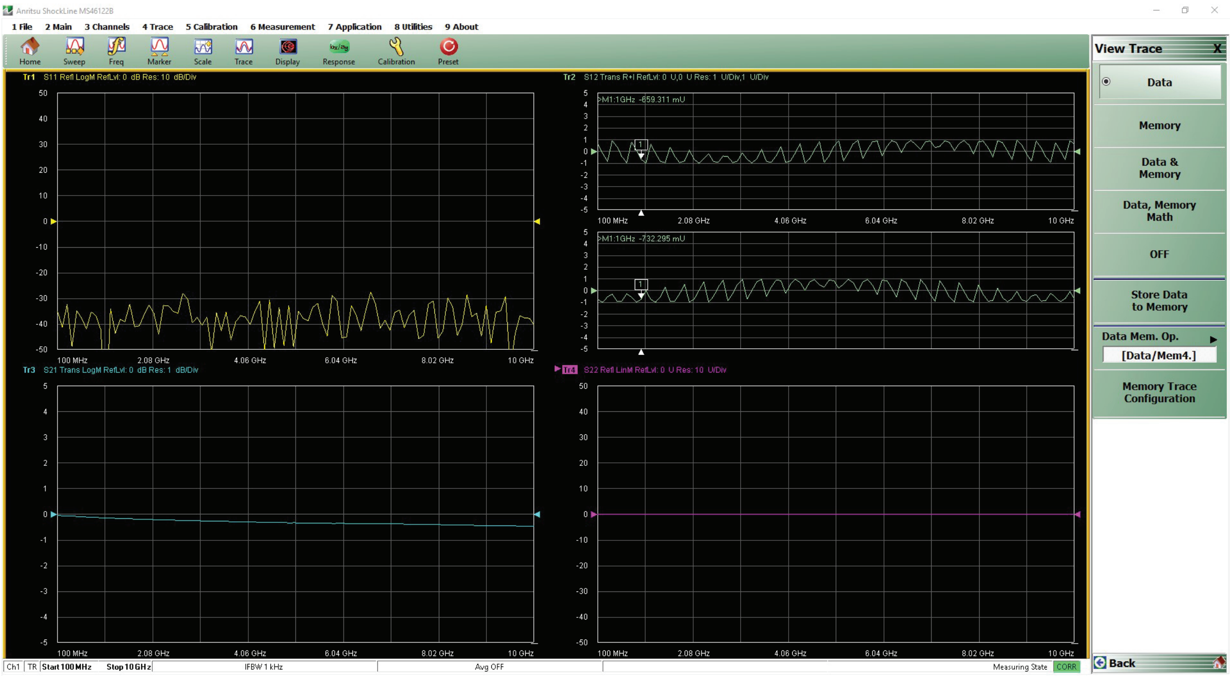


Figure 8. The Fixture .s2p File Plots

When using open and short standards, the inner plan which is S_{22} is assumed perfect match and also $S_{12} = S_{21}$ (assume symmetry).

Below is an excerpt of .s2p file data in real and imaginary format.

```
! 2/9/2021 9:38:04 AM
# GHZ S RI R 50.0
0.100000000000  1.34705454E-002 -1.17682815E-002  6.48309946E-001 -7.54283965E-001  6.48309946E-001 -7.54283965E-001  0.00000000E+000  0.00000000E+000
0.200000000000 -7.39699602E-003  4.68885899E-003 -1.46899655E-001 -9.83206451E-001 -1.46899655E-001 -9.83206451E-001  0.00000000E+000  0.00000000E+000
0.300000000000  1.95588171E-002 -1.40342116E-002 -8.40226531E-001 -5.30273795E-001 -8.40226531E-001 -5.30273795E-001  0.00000000E+000  0.00000000E+000
0.400000000000 -4.33921814E-005 -3.69113684E-003  9.49187458E-001 -2.89821208E-001  9.49187458E-001 -2.89821208E-001  0.00000000E+000  0.00000000E+000
0.500000000000 -1.09655857E-002 -1.46843791E-002  4.00389463E-001 -9.06602383E-001  4.00389463E-001 -9.06602383E-001  0.00000000E+000  0.00000000E+000
0.600000000000  8.42165947E-003  1.01584792E-002 -4.24121380E-001 -8.94080997E-001 -4.24121380E-001 -8.94080997E-001  0.00000000E+000  0.00000000E+000
0.700000000000 -2.67338753E-003 -7.70074129E-003 -9.52729464E-001 -2.63277352E-001 -9.52729464E-001 -2.63277352E-001  0.00000000E+000  0.00000000E+000
0.800000000000  1.13997906E-002 -1.31981969E-002  8.21608663E-001 -5.47767162E-001  8.21608663E-001 -5.47767162E-001  0.00000000E+000  0.00000000E+000
0.900000000000 -1.39399171E-002 -4.17182595E-003  1.22610323E-001 -9.78755355E-001  1.22610323E-001 -9.78755355E-001  0.00000000E+000  0.00000000E+000
1.000000000000  3.72865051E-003 -6.83104992E-003 -6.59310818E-001 -7.32295036E-001 -6.59310818E-001 -7.32295036E-001  0.00000000E+000  0.00000000E+000
1.100000000000  1.11639500E-004 -1.53183937E-005 -9.84204471E-001  1.94871873E-002 -9.84204471E-001  1.94871873E-002  0.00000000E+000  0.00000000E+000
1.200000000000 -3.05840373E-003 -1.96321607E-002  6.28670394E-001 -7.56731153E-001  6.28670394E-001 -7.56731153E-001  0.00000000E+000  0.00000000E+000
1.300000000000 -4.38779593E-003  5.00899553E-003 -1.61629021E-001 -9.69421983E-001 -1.61629021E-001 -9.69421983E-001  0.00000000E+000  0.00000000E+000
1.400000000000 -8.21632147E-003 -9.33188200E-003 -8.38308990E-001 -5.11779487E-001 -8.38308990E-001 -5.11779487E-001  0.00000000E+000  0.00000000E+000
```

The red rectangular data for S_{21} matches the marker 1 in the display. This is to make sure the plot is reading the correct .s2p file.

After de-embedding the fixture, S_{12} and S_{21} traces become around 0 dB as depicted below:

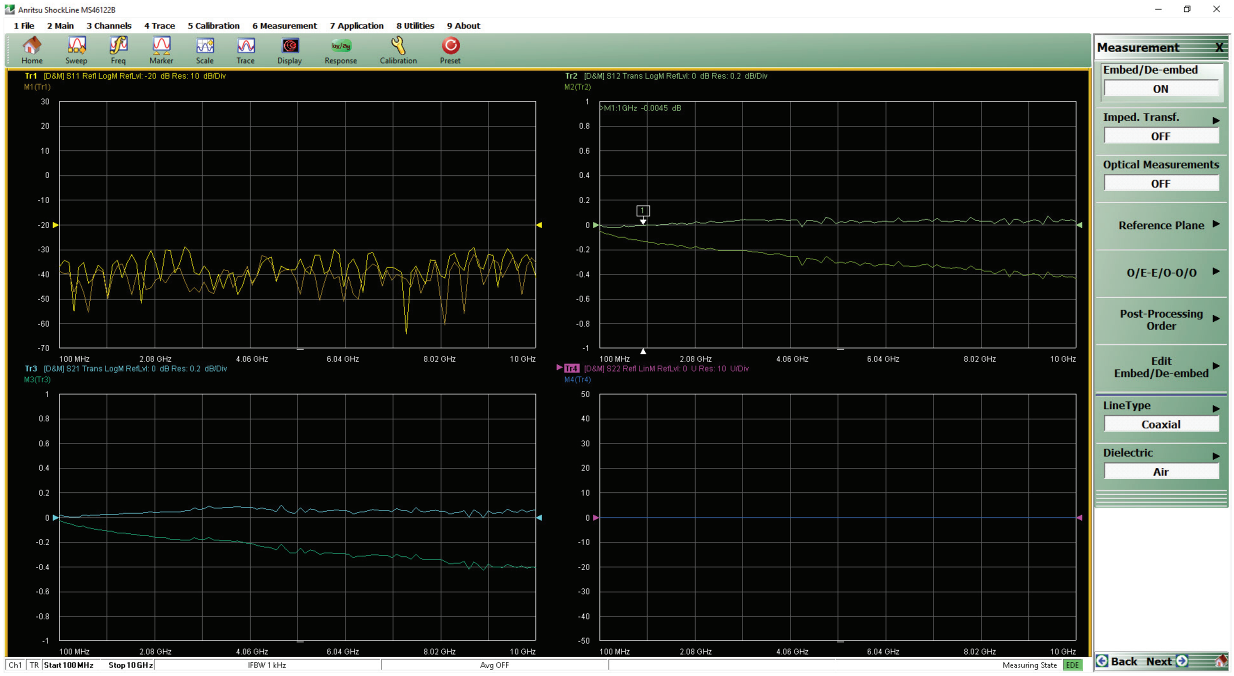


Figure 9. The Plots After De-Embedding the Fixture

S_{11} is a bit worse before de-embedding because $S_{11,fixture}$ is not a perfect match.

Network extraction of the fixture using Type-B open and short vs ISD using open and short is shown below.

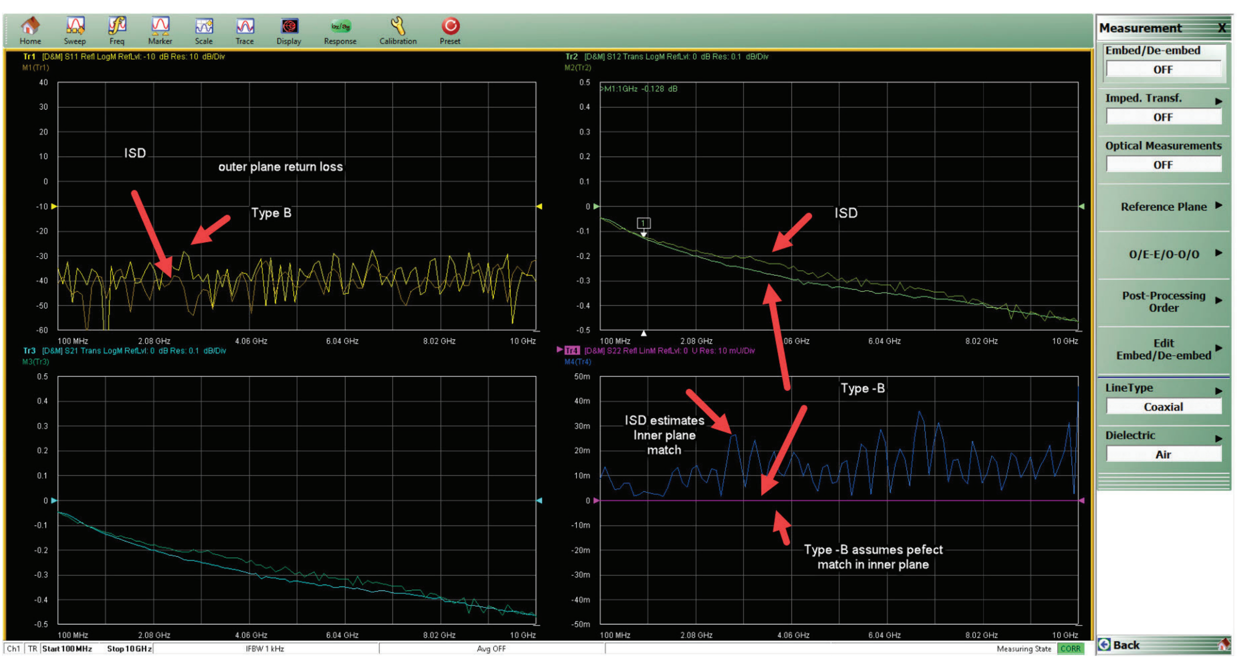


Figure 10. Comparison Between Type-B Two Tier Calibration with Flex Standard vs ISD with Open and Short Standards

The insertion loss using Type-B is smoother than ISD and the fixture return loss is more or less the same. In Type-B the inner plane match assumes perfect whereas return loss for the fixture is not perfectly matched.

Comparison between ISD with open and short and Type-B with open and short standard after de-embedding is shown in figure 11.

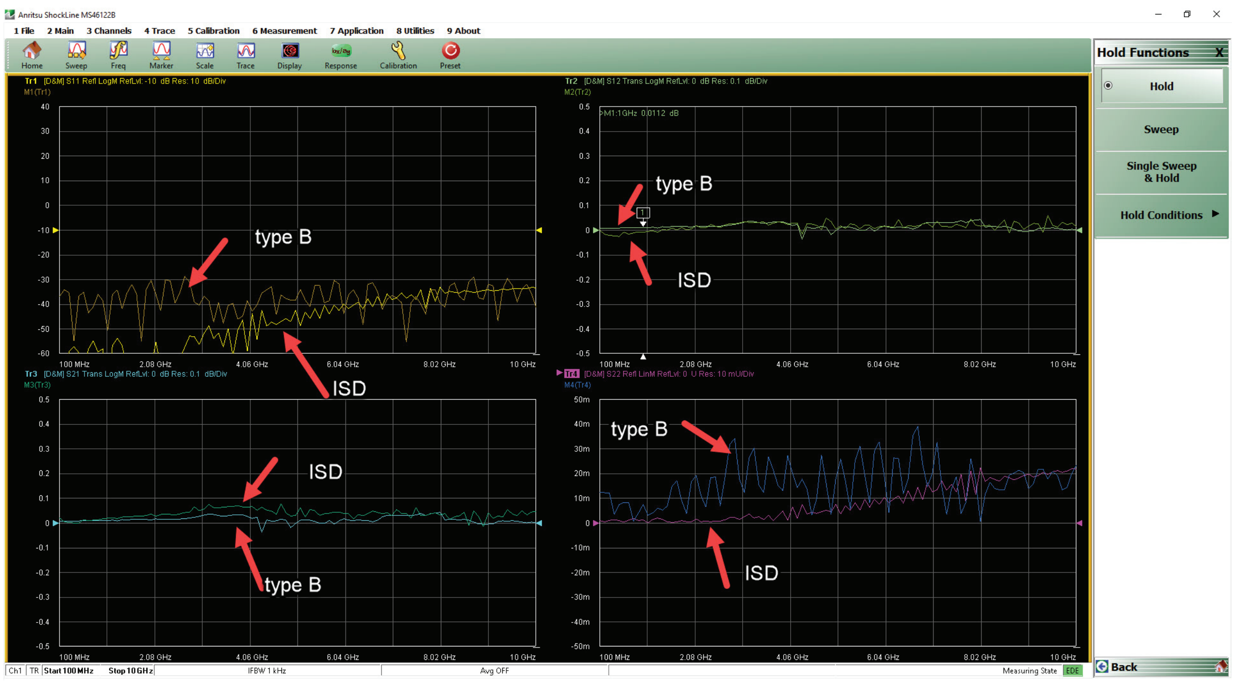


Figure 11. Comparison Between Type-B Two Tier Calibration with Open and Short vs ISD with Open and Short Standards

The insertion loss matches quite well but not the reflection measurement. This is because in Type-B, it assumes inner plane is a perfect match and in ISD it does make that assumption.

Type-B should only be used when insertion loss is the measurement of interest.

Conclusion

The non-touch loop of equation 1 is a general equation not limited to network extraction with only reflection standards. It can be applied to other types of network extractions such as line + reflection standards.

Using the non-touch loop method with the signal flow diagram, the scattering parameters of the fixture can be mathematically modeled. Using ISD with open and short standards, the inner plane of the fixture can be estimated, whereas using Type-B, two tier calibration with open and short standard, the inner plane is assumed to be perfect.

The application for the Type-B two tier calibration with Flex standard is a useful tool when the fixture has incomplete calibration standard and the user is only interested in de-embedding the loss of the fixture and measure the DUT for the insertion loss.

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