Automatic Fixture Removal (AFR)

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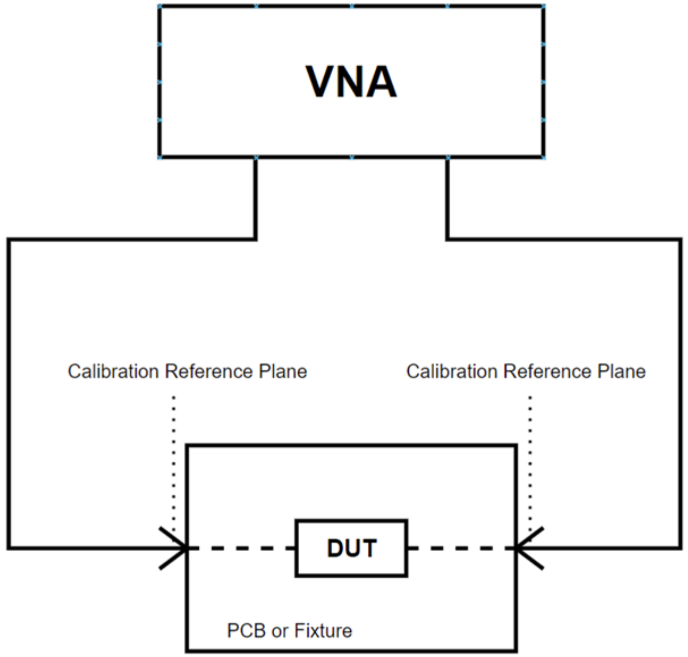
What is AFR for?

- It is often necessary to measure a device or component while it is mounted in a fixture or installed on a PCB
- De-Embedding the fixture can be challenging
- Port Extension is usually not good enough
  - Extension only fixes phase and does not remove fixture reflections

What is AFR for?

- With the VNA calibrated at the cable ends, the measurement includes the connectors and traces on a PCB
- An accurate measurement of the DUT alone is impossible
- AFR can characterize this part of the circuit and remove it mathematically



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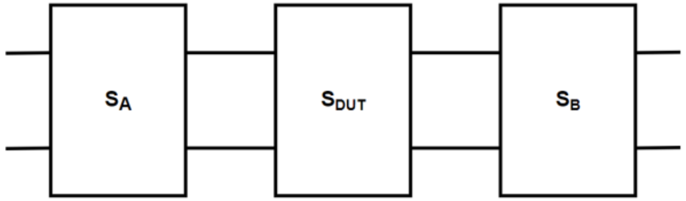
Why do we need it?

- Engineers often want the S-Parameter measurement of a device which is either buried in a circuit or only accessible by connectors and traces
- They only want the measurement of the selected device and don't want that measurement changed by connections which add loss, delay and phase-shift
- AFR allows the user to ***De-Embed*** the component to be measured

De-embedding

- If a Device Under Test, DUT is placed within fixture, it can be said that there are two halves, “A” and “B” which must be removed or “De-embedded” from the measurement
- If the S-Parameters of each half can be obtained, then this can be done mathematically
- Fixture S-Parameters can be converted to Transfer Parameters which are then inverted, multiplied and removed



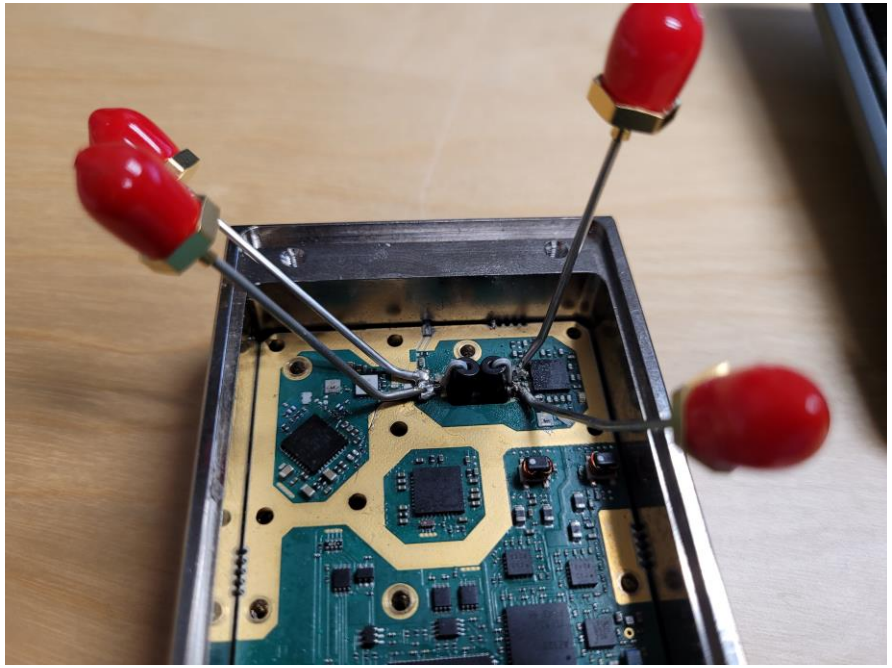
$T_m = T_A * T_{DUT} * T_B$ $T_{DUT} = T_A^{-1} * T_m * T_B^{-1}$

Conversion between T and S Parameters

$S = \frac{1}{T_{22}} \begin{vmatrix} T_{12} & \Delta T \\ 1 & -T_{21} \end{vmatrix}$ $T = \frac{1}{S_{21}} \begin{vmatrix} -\Delta_S & S_{11} \\ -S_{22} & 1 \end{vmatrix}$

$\Delta T = T_{11}T_{22} - T_{21}T_{12}$ $\Delta_S = S_{11}S_{22} - S_{21}S_{12}$

Who uses AFR?



- Engineers that want to add “pigtails” to a circuit to evaluate part of a circuit and want to remove the effect of those pigtails
- Engineers evaluating a component mounted on a PCB that want to eliminate the effects of the connectors and the traces
- Engineers that want to reliably move the reference plane right up to the matching circuit for an antenna so proper matching components can be determined
- Let’s call them RF circuit design engineers

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What you need to know about AFR

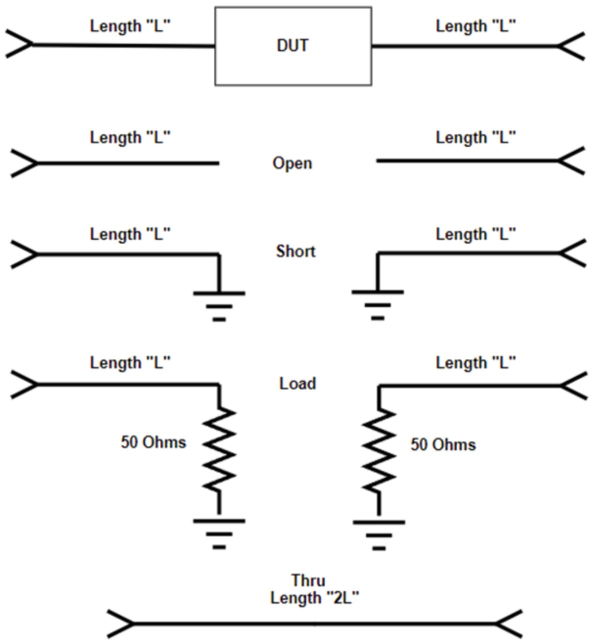
- AFR should be performed over the widest possible bandwidth from the VNAs lowest frequency to as high as the fixture is flat and resonance free
    - A fixture with a series coupling capacitor cannot be measured to low frequencies
- The resulting de-embedding file can be used at a lower frequency as needed
- The file can be shared and used with any VNA which has a de-embedding capability

Are there alternatives to AFR?

- There are, but they are not as accurate
- One can create on-board calibration standards, Open, Short, Load and Thru (SOLT)
- One can add traces to perform on-board TRL calibration
- One can simply perform Port Extension

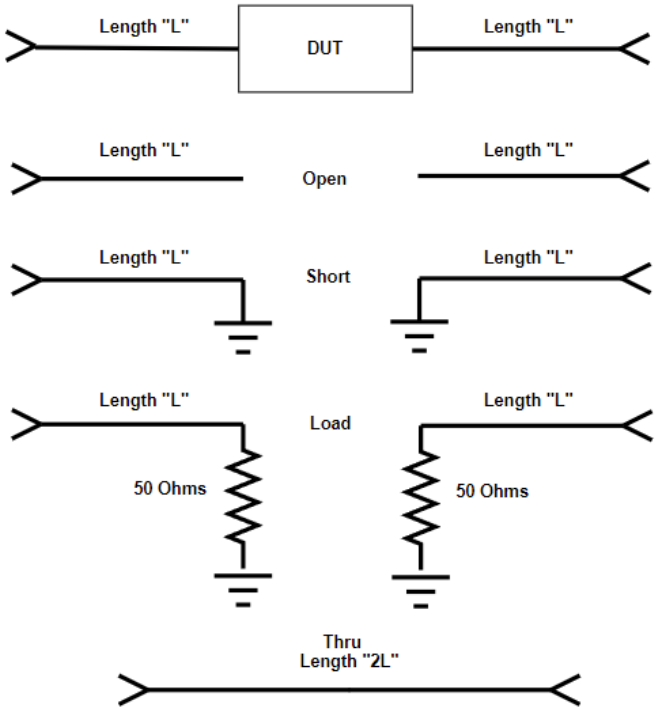
How might a fixture be de-embedded?

- One could create a fixture with the same two connections to the Device Under Test, (DUT) with Open, Short, Load and Thru standards installed



SOLT

- There are several problems with this approach:
  - The imperfect “Open” will have fringing E fields which will introduce error
  - The imperfect “Short” will have parasitic inductance which will introduce error
  - Return loss of the connectors, trace and “Load” will likely not be much better than 15 dB resulting in unacceptable calibration errors



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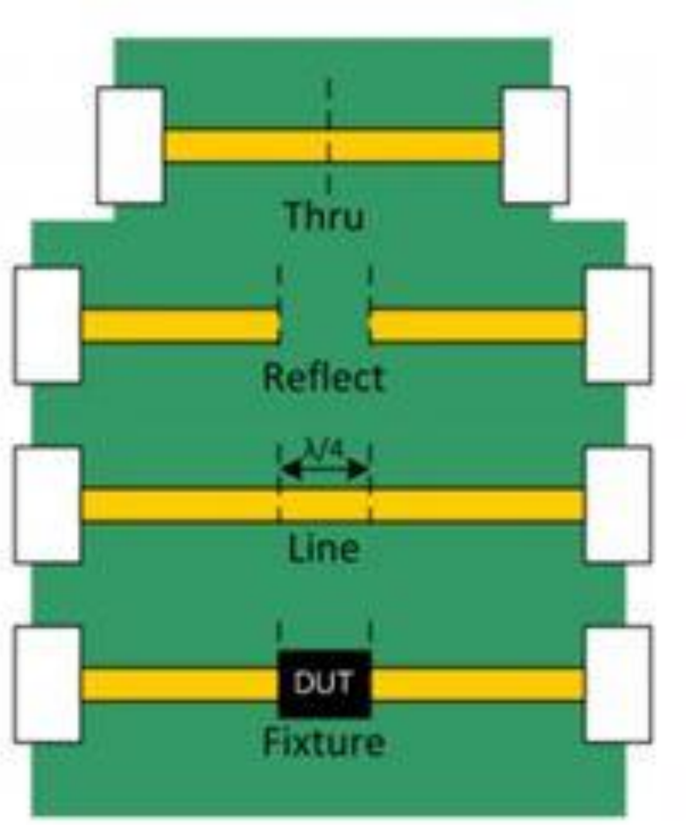
TRL

- One could create a TRL fixture with a “Thru” line, a 90 degree longer “Match” line and a pair of Shorts for the “Reflect” calibration
- The length 2L Thru will put the reference plane in the center which is the desired result



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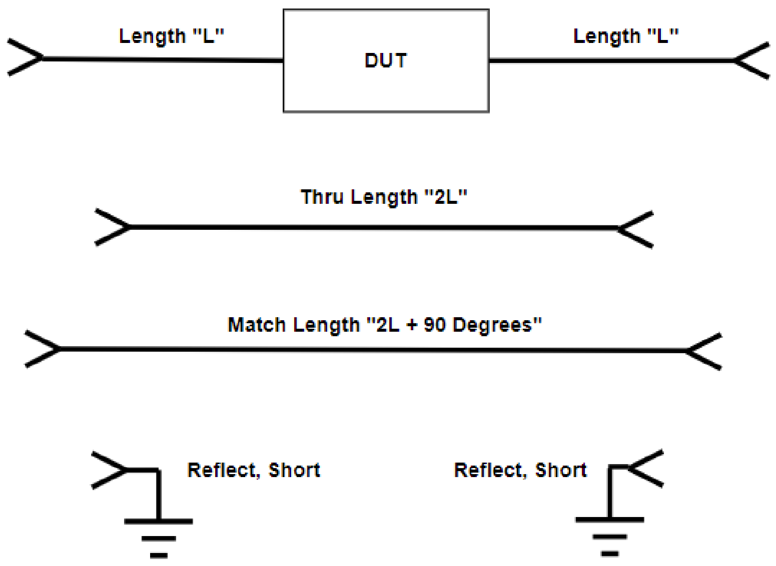
TRL

- This is a viable approach with some caveats:
  - TRL is band-limited
  - The “Match” line **including connectors**, should have return loss better than 25 to 30 dB which is **extremely** difficult to achieve
  - The VNA reflection calibration will usually be poor
  - **Can’t be used at low frequencies**



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Port Extension

- The VNA allows the user to apply “Port Extension” which can compensate for fixture loss and “dials out” the delay from the cable ends to the DUT
- This corrects the phase error introduced by the fixture but does not eliminate connector reflections
- Reflection measurements of the DUT may not be accurate

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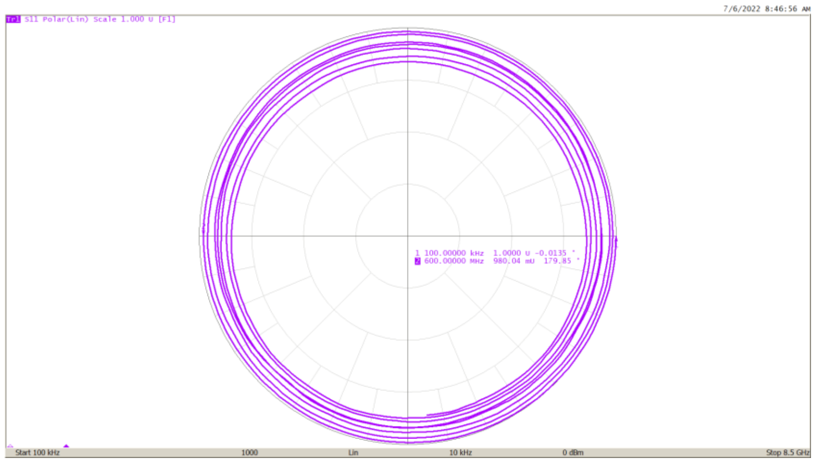
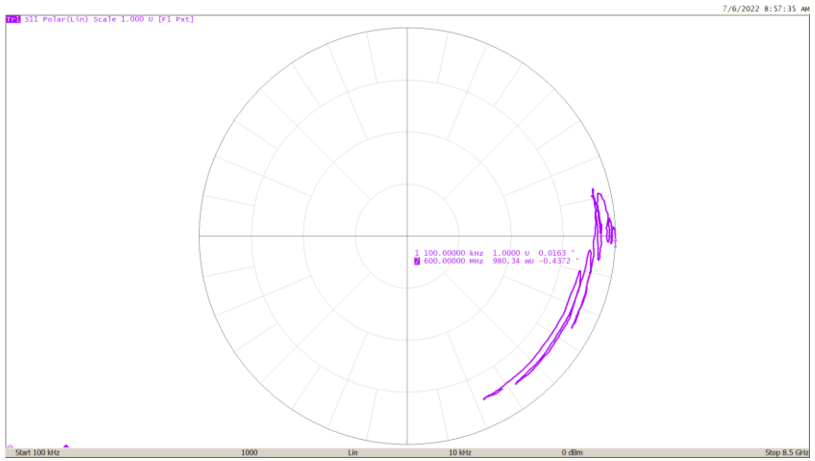
Port Extension

- Additionally, port extension removes a set delay, but the delay of the fixture won’t be constant over a wide bandwidth and this method will fail
- Port extension should create a “dot” on the right side of the Smith Chart
- Below, it is clear that port extension won’t work

Before extension



After extension



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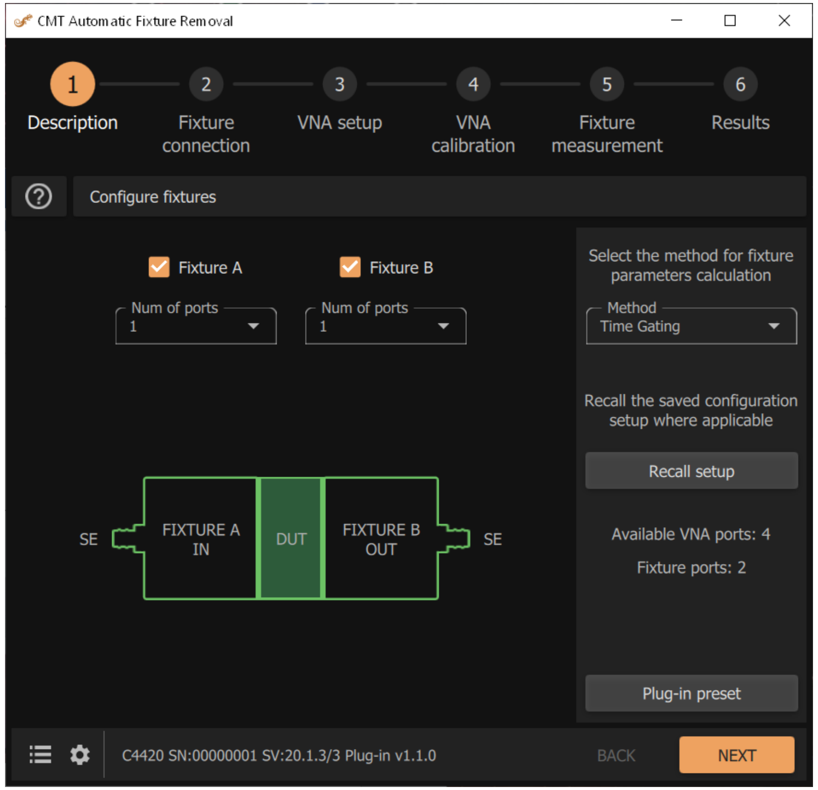
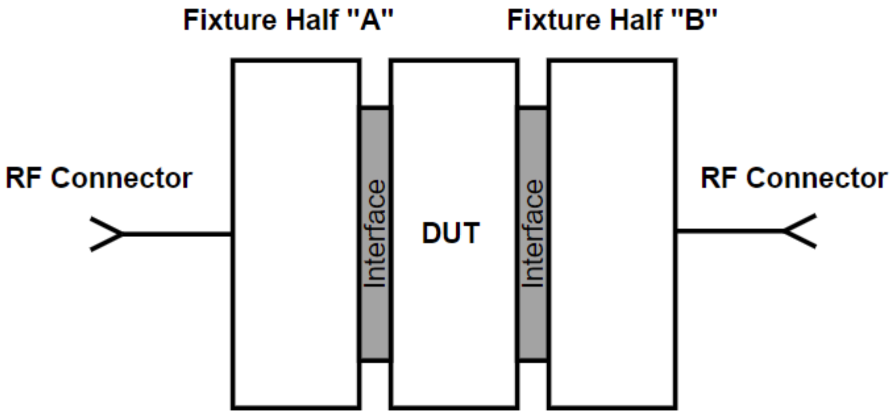
What are the benefits of AFR?

- AFR is an easy-to-use software program which measures the fixture and then creates and applies the de-embedding to the VNA
- This is the most accurate method for removing fixture effects. Nothing else comes close



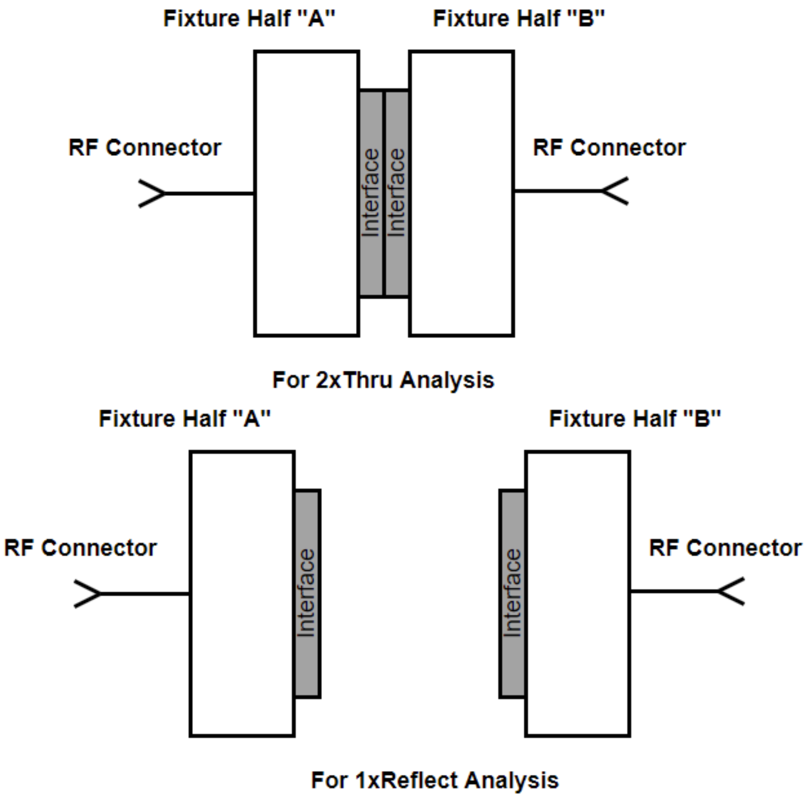
AFR Overview

- Automatic Fixture Removal, AFR is intended to characterize and remove the effect of fixturing on the measurement of a DUT
- A fixture might have two halves each with one RF connector and some sort of physical connection to a DUT
- Here, it is not possible to make a simple 2-port measurement of “A” and “B” because only one side is connectorized



1xReflect and 2xThru characterization

- If the two halves of the fixture can be pushed together, a 2xThru Characterization may be performed
- If not, the two halves may be characterized separately with the DUT removed using 1xReflect Characterization
- 2xThru is more accurate



AFR – Time gating

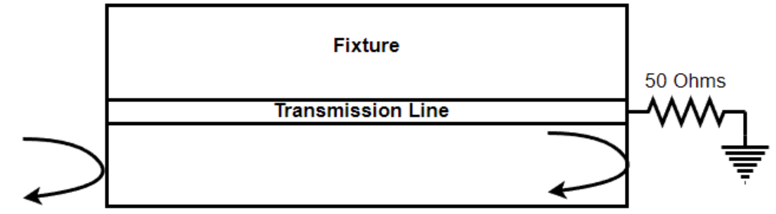
- AFR offers three methods of fixture de-embedding
- Time Gating
  - Appropriate for fixtures with DUT connections of 2 wavelengths or greater and some connection impedance variation
  - 1x Reflect and 2x Thru may be used
  - 2x Thru is more accurate
- Filtering
  - Appropriate for fixtures with short or long DUT connections but with good connection impedances. Somewhat better at 2 wavelengths than Time Gating
  - 1x Reflect and 2x Thru are allowed

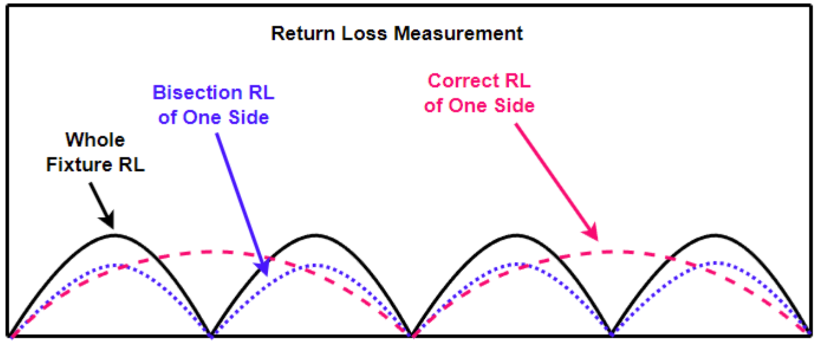
1xReflect and 2xThru characterization

- These two methods use Time Domain Gating, and the fixture must be physically long enough for the gating to be successful
  - Minimum of 2 Rise Times for each fixture half or 4 Rise Times from end to end
- For a 20 GHz bandwidth the AFR rise time is 44.5 pS so the total fixture length of 178 pS minimum
  - This is 0.98" for an FR4 PCB
- The Filter Method which also uses gating will work somewhat better at this minimum length
- **The Fixture must have reasonable return loss and the thru insertion loss must be smooth and free of resonances**

AFR - Bisection

- Bisection
  - For fixtures with shorter DUT connections, less than 2 wavelengths is feasible
  - Return Loss is not quite right
- Each half of a fixture should have Return loss with half the periodicity of the full fixture
- Bisection does not produce this result
- Return loss is a 6 dB lower version of the full fixture



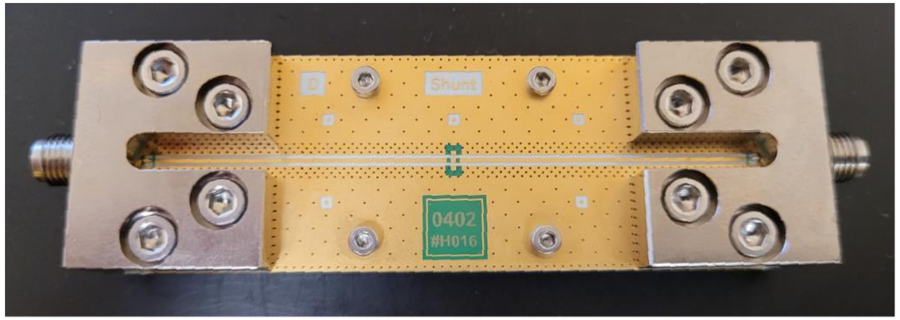


Fixturing

- AFR is a “Secondary Calibration”
- The connectors and traces leading to the DUT must have good properties
- Connectors with worse than 15 dB of Return Loss will give poor results
- Fixturing must be sufficiently long (2 wavelengths each side) to allow for successful gating for Time gating methods
- Return loss for Bisection must be quite good
- **Resonances, significant dips in Return loss or Insertion loss cannot be characterized properly**

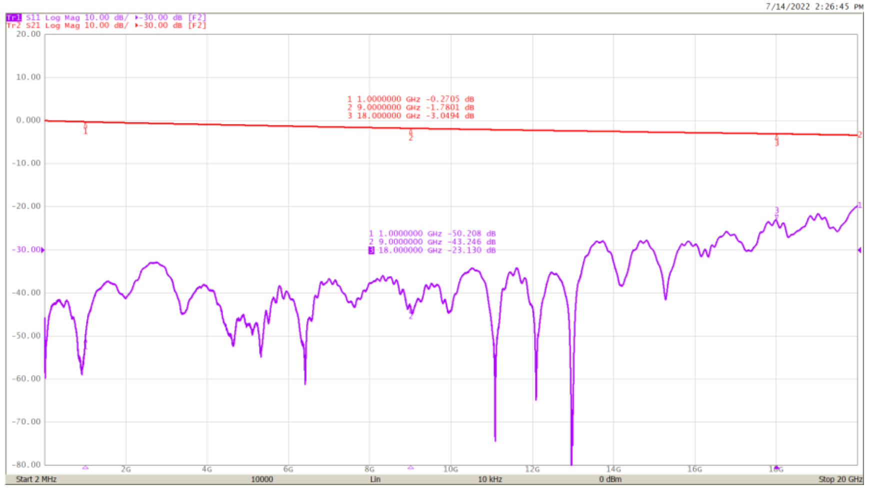
Fixture comparison

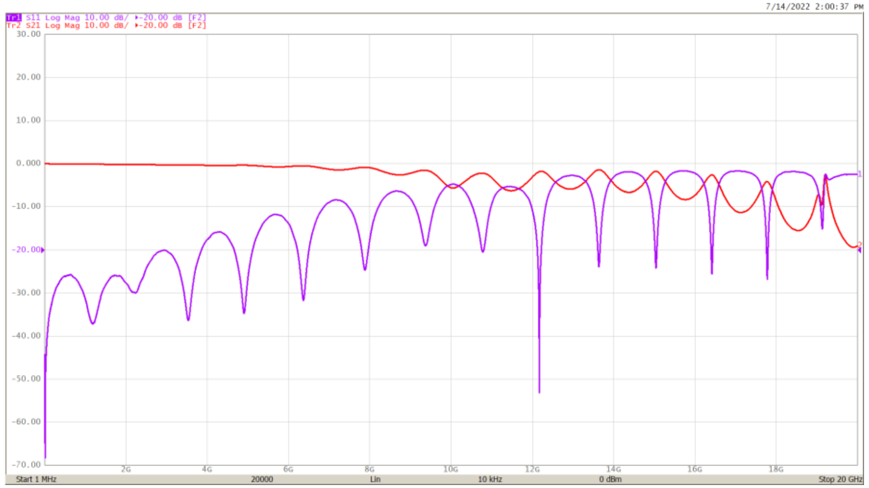
- The top fixture was fabricated with very high-quality connectors
- The bottom fixture was created with economy grade end-launch connectors



Fixture comparison

- The insertion loss and Return loss of the top fixture is good to 20 GHz
- The bottom fixture shows significant ripple above 6 GHz
- AFR analysis should be limited to 6 GHz for the economy grade fixture
- Characterization should always be done to high frequencies even if actual measurements will be at lower ones





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Notes on fixturing

- It isn't necessary to spend a fortune creating a fixture like the really good one shown
- Connectors are the biggest culprit for Return Loss problems
- It is best to run the characterization in the widest possible bandwidth in order to get the highest resolution data
- Careful, a low-cost end-launch SMA connector might only be specified to 3 or 6 GHz
- The connectors must be rated for the frequency range and must have good return loss or VSWR at least 15 dB or 1.5:1 VSWR. 20 dB or 1.2:1 VSWR is preferred

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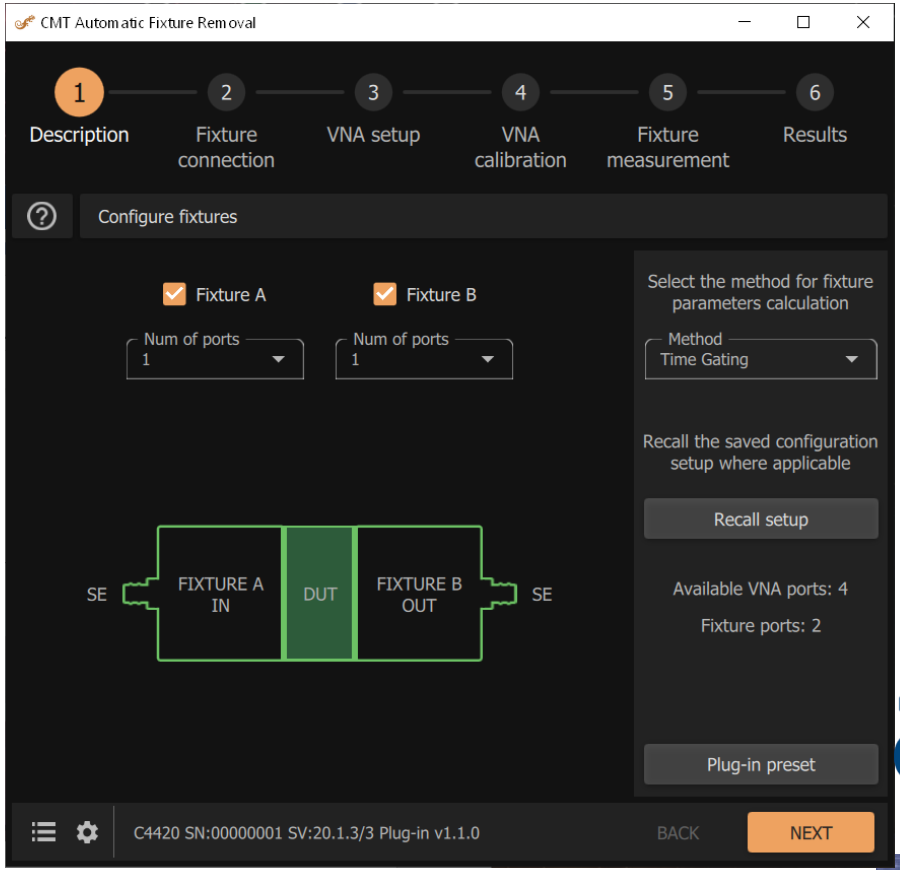
Notes on fixturing

- The launch from the connector to the trace must be done as specified by the connector manufacturer
- The trace must have good characteristic impedance and should remain on the top layer. Via transitions to inner layers create reflections
- De-embedding files generated to high frequencies will interpolate to lower frequencies

Visit our booth, nr. 5, for the AFR demonstration

In this demonstration, the Automatic Fixture Removal (AFR) software from Copper Mountain Technologies will be demonstrated.



Thank you!

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