ADVANCED CALIBRATION TECHNIQUES WITH A VNA

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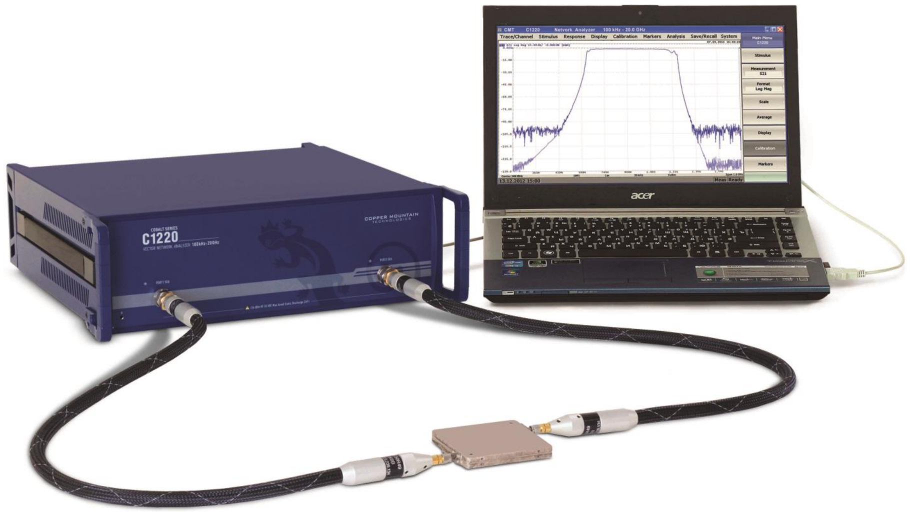
OVERVIEW

- Types of errors
- Systematic Errors
- SOLT/SOLR
- Port extension
- TRL
- Automatic Fixture Removal
- Power and Receiver Calibration

CALIBRATION - TYPES OF ERRORS

There are three kinds of errors: Random, Drift and Systematic.

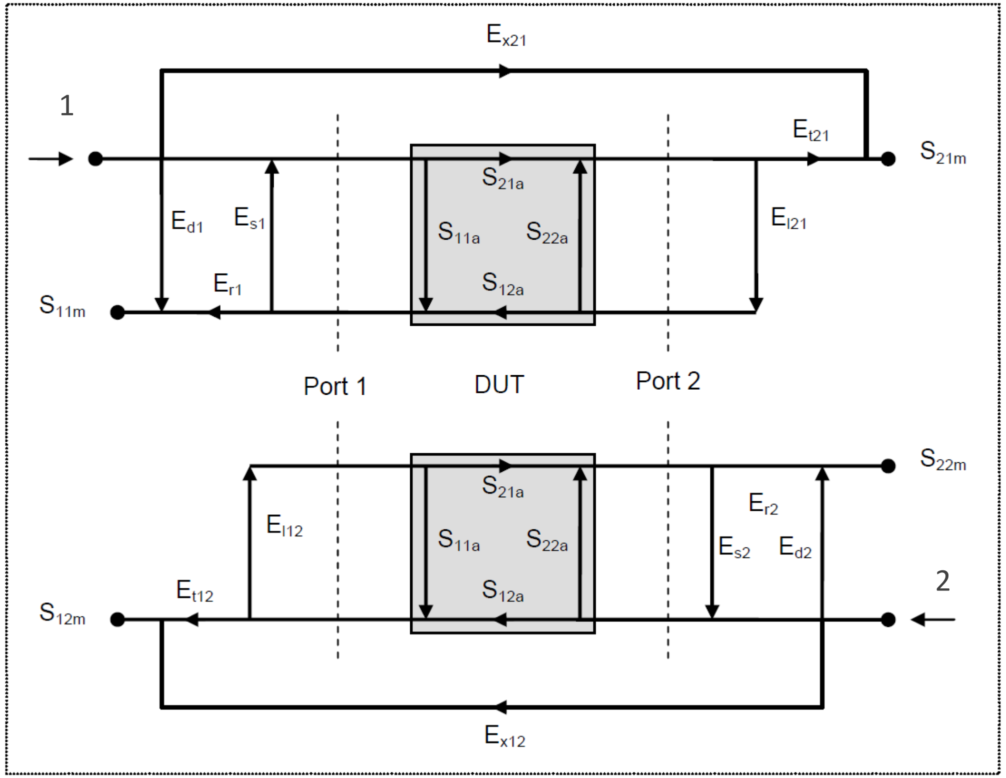
- *Random errors* are caused by noise in the measurement system. It is impossible to remove these by calibration. Good receiver design will minimize these.
- *Drift error* caused by temperature variation is minimized with thermal compensation in the circuitry. Ambient temperature variation will cause measurement variation of approximately 0.02 dB / Degree C in an S21 measurement.
- *Systematic errors* are time invariant and can be removed with error correction techniques such as Short Open Load Thru (SOLT)/ Thru Reflect Line (TRL)



CALIBRATION - SYSTEMATIC ERRORS

- Calibration standards helps determine the error terms
- Six errors in the forward direction and six in the reverse.
- Directivity, Source Match, Ref Tracking, Load Match, Trans Tracking and Isolation
- For 1-Port calibration only the first three are used

Description	Stimulus Source	
	Port 1	Port 2
Directivity	E_{d1}	E_{d2}
Source match	E_{s1}	E_{s2},
Reflection tracking	E_{r1}	E_{r2}
Transmission tracking	E_{t1}	E_{t2}
Load match	E_{l1}	E_{l2}
Isolation	E_{x1}	E_{x2}



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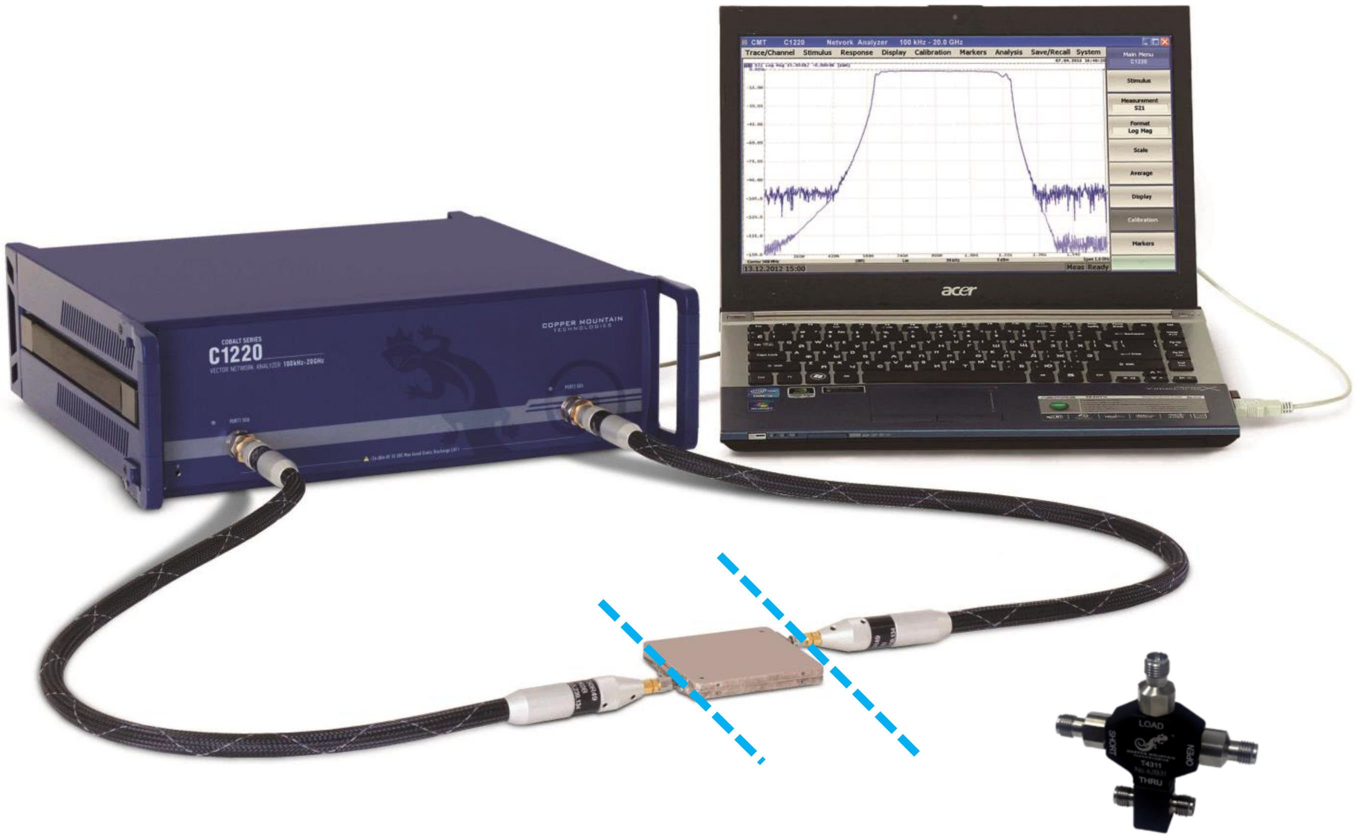
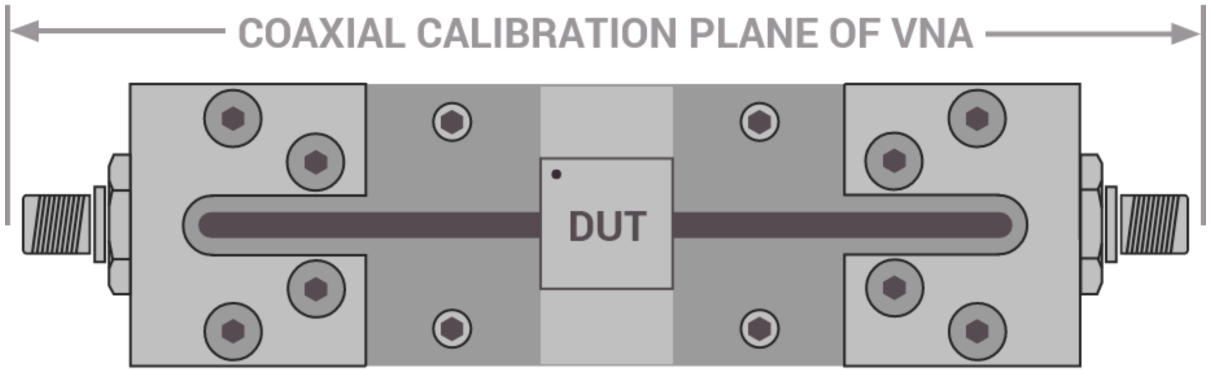
SYSTEMATIC ERROR CORRECTION - SOLT/SOLR

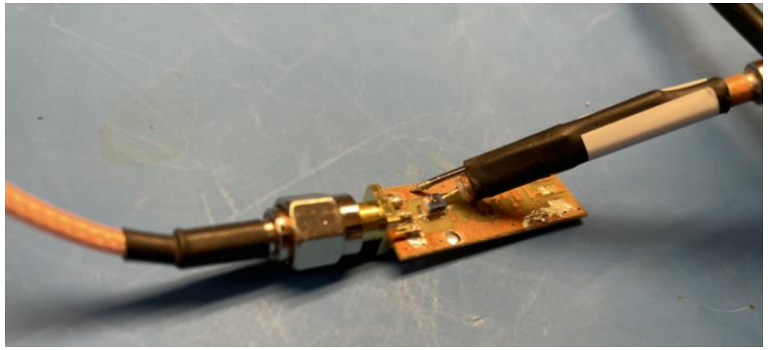
- SOLT uses Short-Open-Load-Thru standards.
  - Thru has defined Delay.
- SOLR is Short-Open-Load-Reciprocal.
  - Can utilize almost any “reciprocal” Thru, (S21 = S12).
- Calibration process is identical.
- Suitable for DUTs with coaxial connectors



CHALLENGES MEASURING NONCOAXIAL DUTS

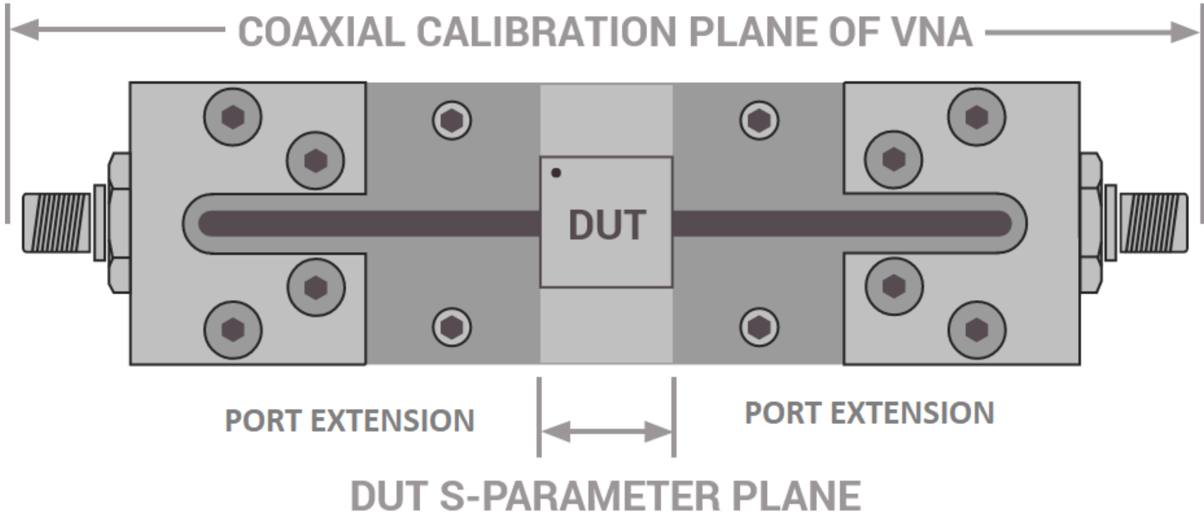
- SMD DUT is usually mounted on a fixture
- Measurements include the DUT parameters plus the effects of the coaxial connectors, coaxial to coplanar waveguide transitions and the transmission line
- At high frequencies, the fixture parameters impact DUT measurements and obscure actual DUT characteristics
- In some applications, probes or pigtails are also used to measure components





PORT EXTENSION

- If the reference plane isn't moved, the delay through the pigtail will give incorrect phase measurement of the DUT..
- Port extension or electrical delay is available in the VNA application to dial in the delay of the additional setup.
- If the delay of the added length is unknown, auto port extension feature is available to automatically calculate the delay. If "Include Loss" is enabled, the VNA will include this in the extension calculation.



Disadvantages:

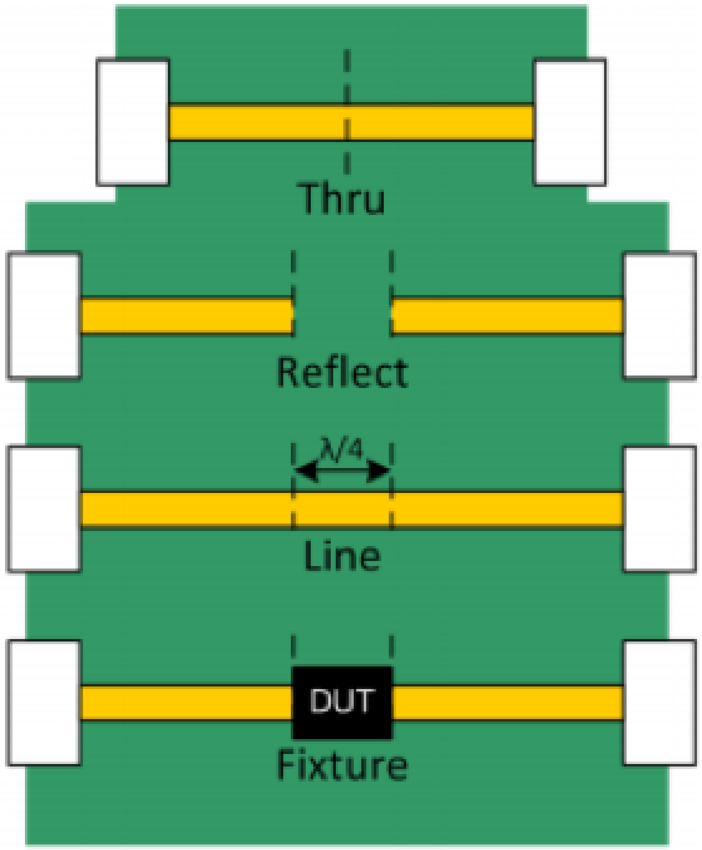
- This works well at low frequencies.
- This does not remove the mismatches – only fixture delay and losses.

TRL CALIBRATION

- For higher accuracies, perform on board TRL calibration.
- TRL calibration is made up of a Thru Line, a Reflect standard and another Line.
- The thru sets the zero length. The “line” can be used over a frequency range where it is 20 degrees to 160 degrees longer than the thru. The reflect can be an open or a short.

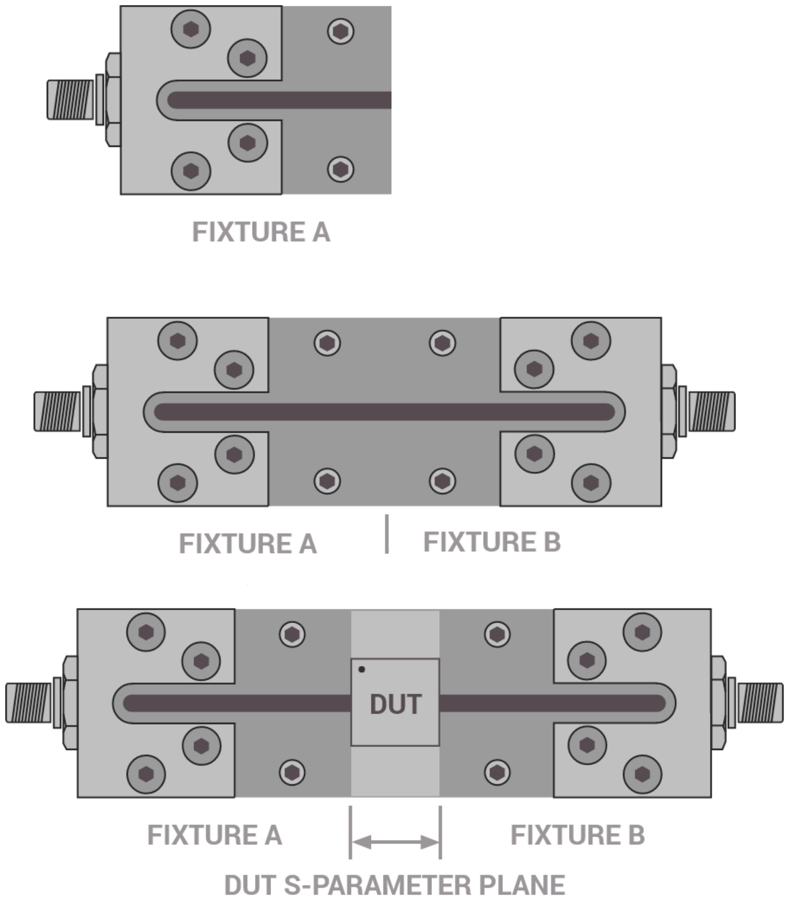
Disadvantages:

- Time consuming
- Difficult fabricating lines to cover wider frequencies
- Assumes all the standards to be identical



AUTOMATIC FIXTURE REMOVAL

- 3 methods available to de-embed the fixture: Bisect, Time Gating and Filtering approach
- Simple and accurate measurement process
- Perform 2-tier calibration
- Requires an identical 2xThru line or a fixture with open or short termination



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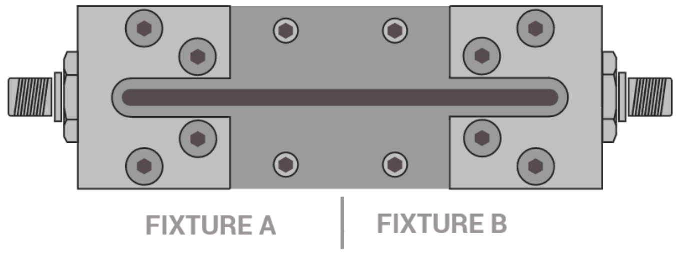
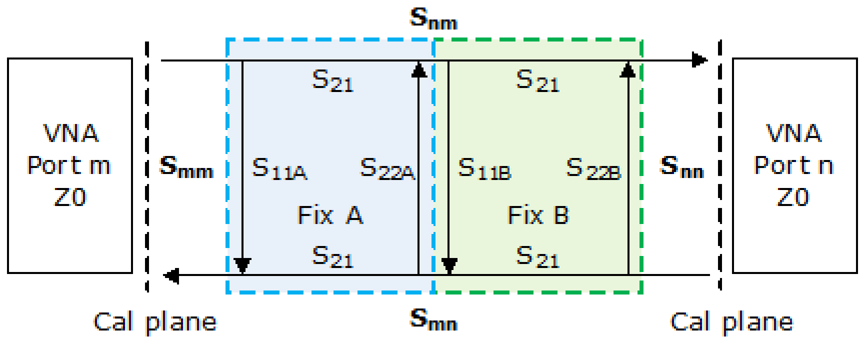
AUTOMATIC FIXTURE REMOVAL- BISECT METHOD

- Splits measured S-parameters of the reciprocal fixture into two halves
- Uses only frequency domain data
- Fixtures need to have low reflections
- Assumes Z0 at each port
- Suitable for 2xThru line standards only
- Works well with fixtures of small electrical length





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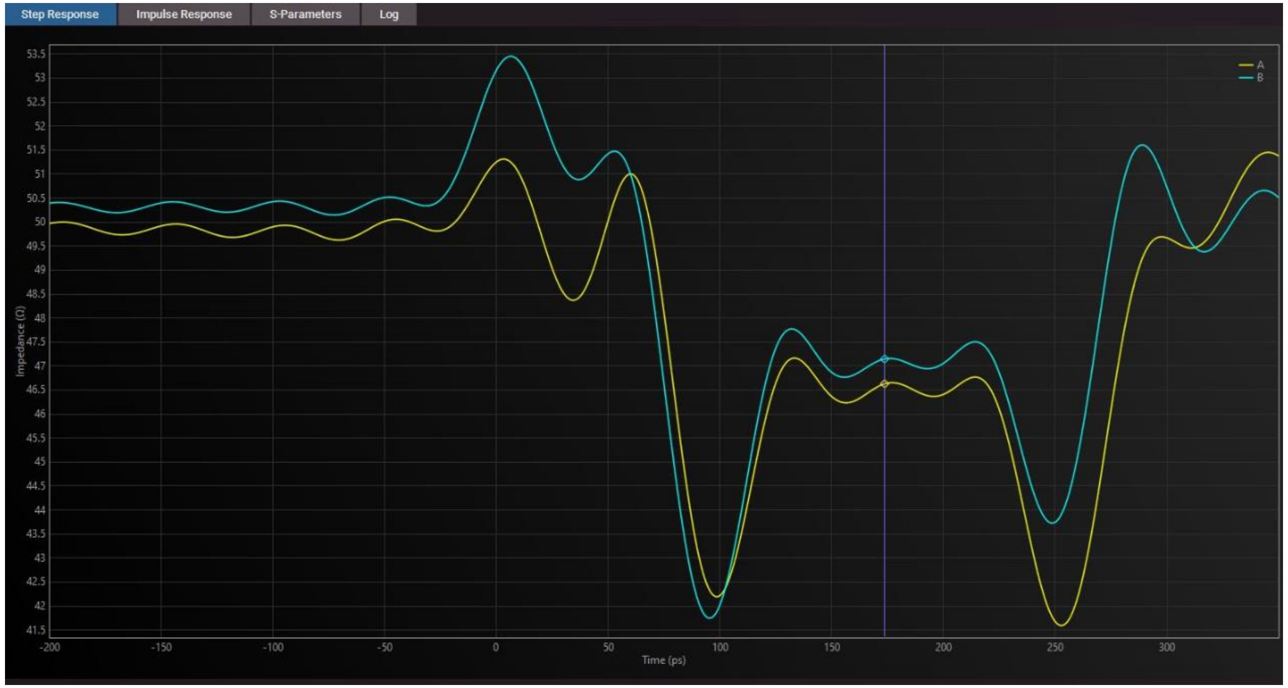
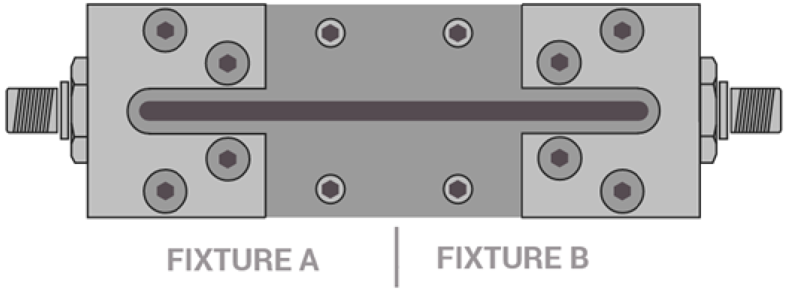
AUTOMATIC FIXTURE REMOVAL – TIME GATING METHOD

- Traditional time domain gating algorithm which extracts fixture parameters separated by time or distance
- Requires appropriate resolution in time domain (resolution is limited by the frequency range of the VNA)
- Fixture's electrical length must at least 4xrise-time of the VNA





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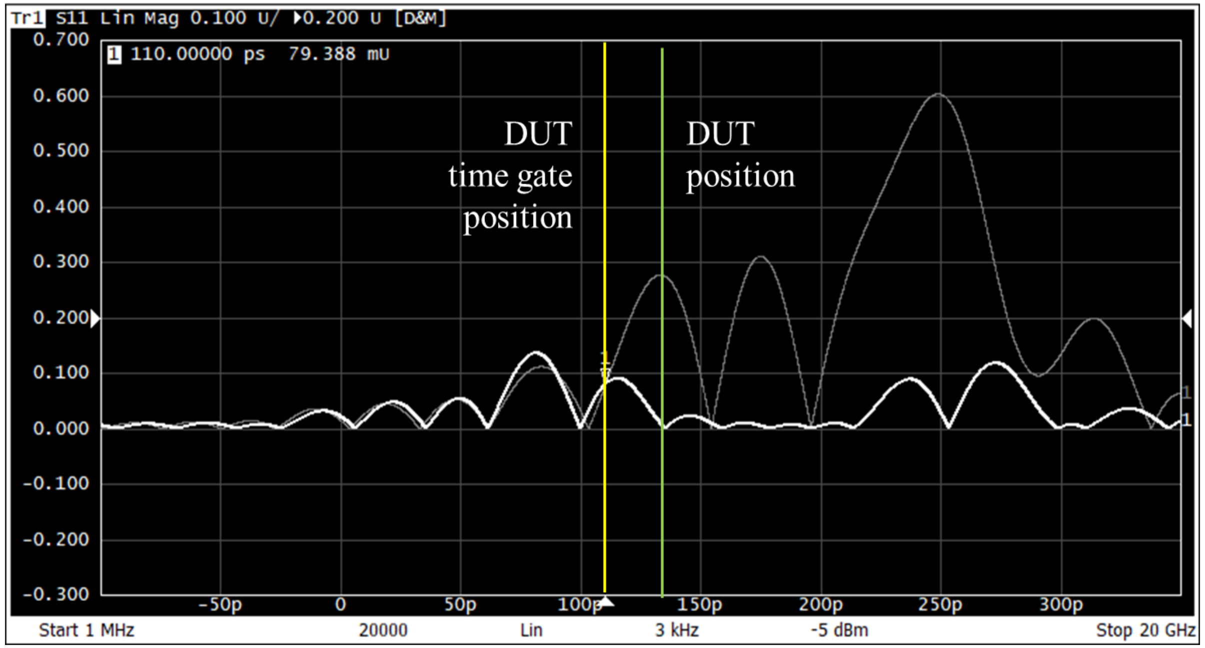
AUTOMATIC FIXTURE REMOVAL – TIME GATING METHOD

- Impulse responses are analyzed to determine time gate positions
- Gating with appropriate shift and phase adjustments are performed to achieve best resolution
- Windowing functions are used to smoothen the sharpness of the original response
- Supports 2xThru and 1xReflect models



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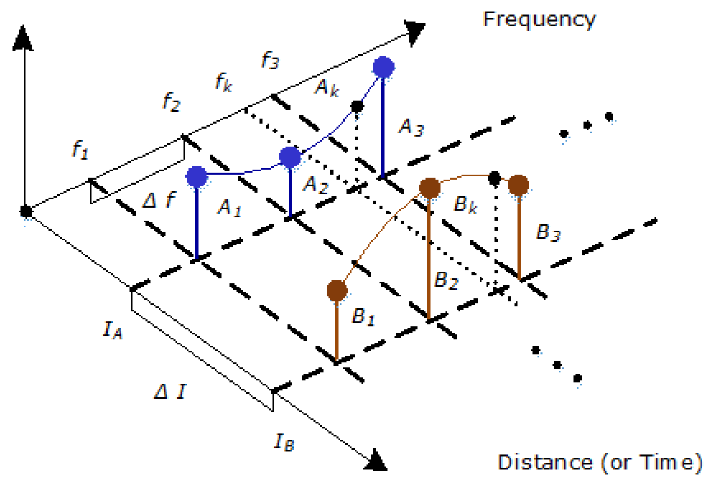
AUTOMATIC FIXTURE REMOVAL– FILTERING METHOD

- A modified time domain gating algorithm
- Filters signals as per signal flow graph representation of the fixture
- Uses LMS joint estimation algorithm to determine fixture parameters according to a time-frequency model
- Yields better resolution than time gating method due to its ability to effectively separate signals which are closer in time domain



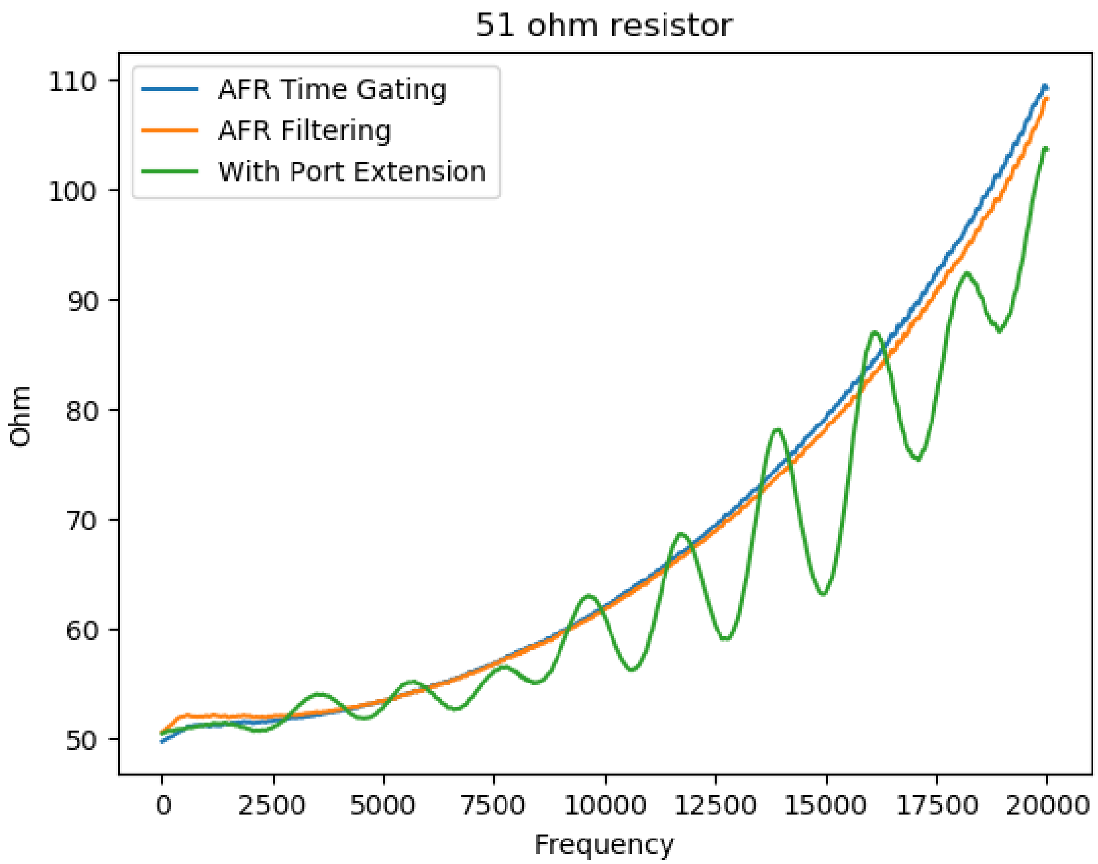
Time - Frequency model. Reflection measurement of the thru connection: A and B – input and output reflections of a fixture, connected between calibrated VNA ports, separated by a distance (or time)

Measurement result M:

$$M_k = A_k \cdot \exp(-j \cdot 2\pi \cdot f_k \cdot \tau_A) + B_k \cdot \exp(-j \cdot 2\pi \cdot f_k \cdot \tau_B)$$

COMPARE MEASUREMENTS- 51 OHM RESISTOR

- The plot shows measurements of a 51 Ohm resistor with various possible 1-port fixture removal methods
- Green plot shows measurements with port extension performed
- Blue plot shows measurements with time gating performed
- Orange plot shows measurements with filtering performed
- Measurements with port extension shows ripples which get prominent at higher frequencies
- Time gating and filtering methods show no ripples and the measurements almost overlap



POWER AND RECEIVER CALIBRATION

- The output power of the stimulus signal is set for the measurement and is typically 0 dBm. This will vary over frequency by as much as +/- 1 dBm.
- Because the S-Parameter measurements are expressed as ratios of incident and reflected power, the absolute accuracy of the stimulus is usually not a concern.
- For certain measurements such as gain and power compression on active devices, the output power of the stimulus signal can be calibrated to obtain a much more accurate power level.
- A power meter or sensors are required to perform this calibration. We support various power sensors.
- Power sensors receive careful transfer calibrations from a standard. LadyBug's calibration standards are thermal mount sensors that have been directly calibrated by NIST (National Institute of Standards and Technology)
- After stimulus power calibration is performed the receivers can be calibrated by attaching a thru cable between the ports and choosing "Calibrate Test Receiver" or "Calibrate Reference Receiver" or "Both"

Demo

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CONCLUSION

- Various methods are available to measure non coaxial DUTs
- Automatic Fixture Removal is an easy and accurate method to remove fixture effects
- Power and Receiver calibration can be performed applications requiring accurate absolute power measurements