LIZARD LESSONS – CALIBRATION TYPES

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AGENDA

- SOLT, SOLR Calibration
  - How are standards Defined?
  - What should an Open or Short look like after Calibration
  - What is an “Unknown Thru”?
  - What errors are Removed by Calibration?
- TRL Calibration
  - What is needed to perform TRL?
  - What are the Advantages?
  - What are the Pitfalls?

AGENDA

- Waveguide Calibration
    - SSLT Calibration
    - What Calibration Pieces are Used?
        - SOLT
            - Why 1 ohm Characteristic Impedance?
            - Waveguide Horns
        - TRL
            - Waveguide Horns

SOLT/SOLR CALIBRATION

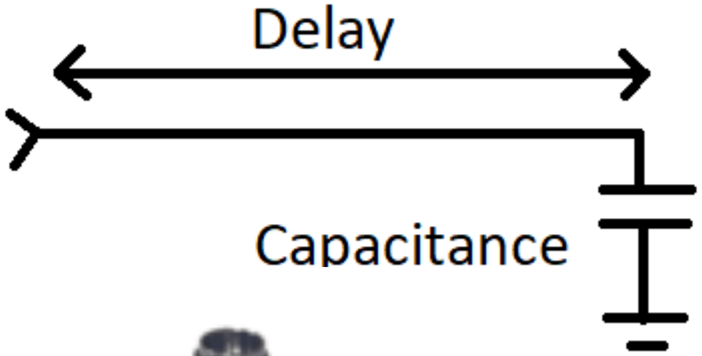
- SOLT uses Short-Open-Load-Thru standards.
  - Thru has defined Delay.
- SOLR is Short-Open-Load-Reciprocal.
  - Can utilize almost any “reciprocal” Thru, (S21 = S12).
- Calibration process is identical.

OPEN STANDARD

- An ideal Open standard would look like the cross-section of an ideal transmission line with radial electric fields which stop abruptly at the slice .
- In the real world, the electric fields “fringe” and curve out into the air before returning to ground and there is a small delay between the connector and the “Open”.
  - This looks like a delay followed by a small capacitor.

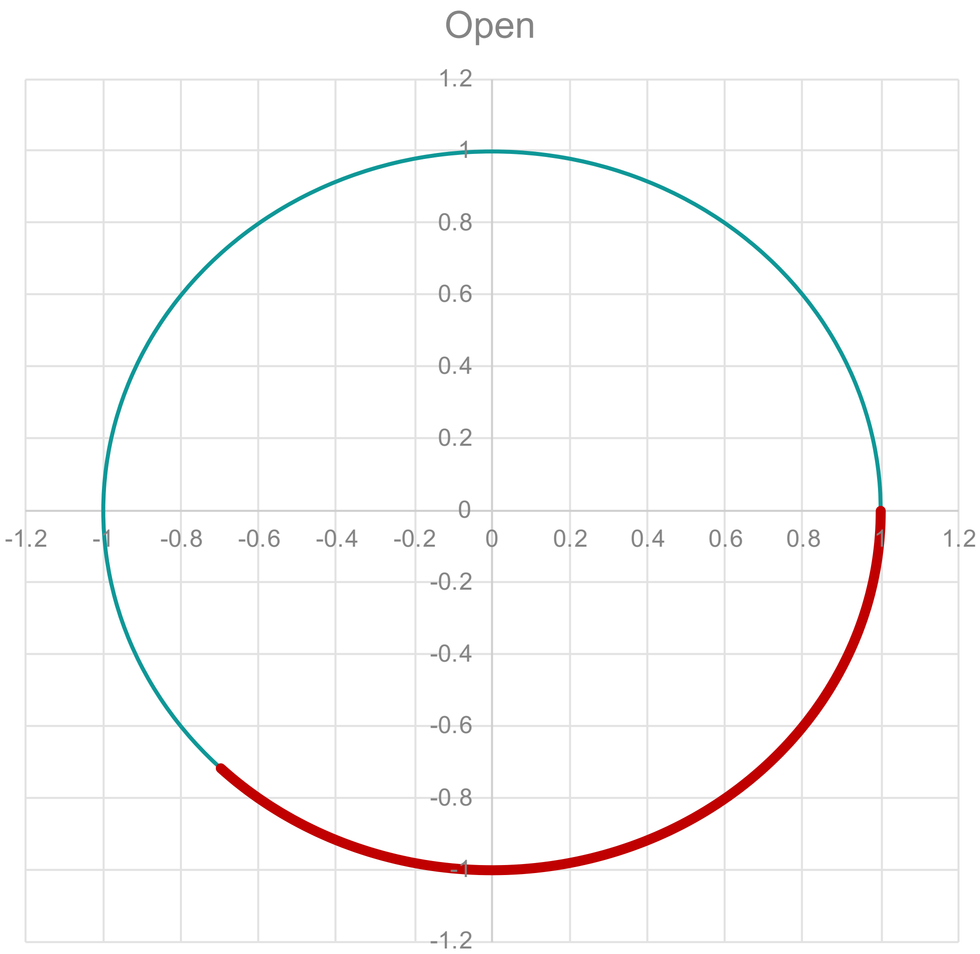
OPEN STANDARD

- The Open may defined by a short transmission line followed by a capacitance to ground which is characterized by a third order polynomial over frequency.
- $C = C_0 + C_1 * f + C_2 * f^2 + C_3 * f^3$
- A loss term which increases linearly with frequency may also be included.



OPEN STANDARD (WHERE'S MY DOT?)

- For the T4311 mechanical standard, the delay is 28.353 pS and the capacitance is defined by:
- $C = -4.3e\text{-}15 - 431e\text{-}25 * f - 11.5e\text{-}35 * f^2 + 0.12e\text{-}46 * f^3$
- From 9 kHz to 6.5 GHz this will look like a curve from 0 degrees on the right to -132 degrees
- **A Real Open does NOT look like a "Dot" at 0 degrees.**



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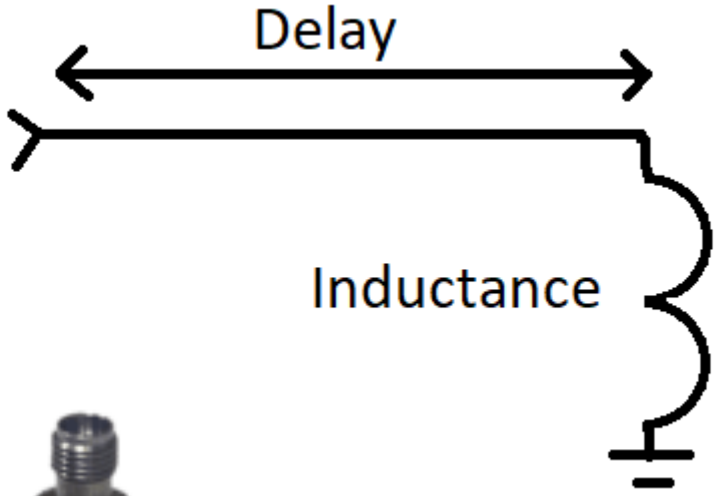
SHORT STANDARD

- An ideal Short standard would look like a perfect Short with no inductance.
- In the real world, there is a small delay between the connector and the Short and the Short has a finite inductance.

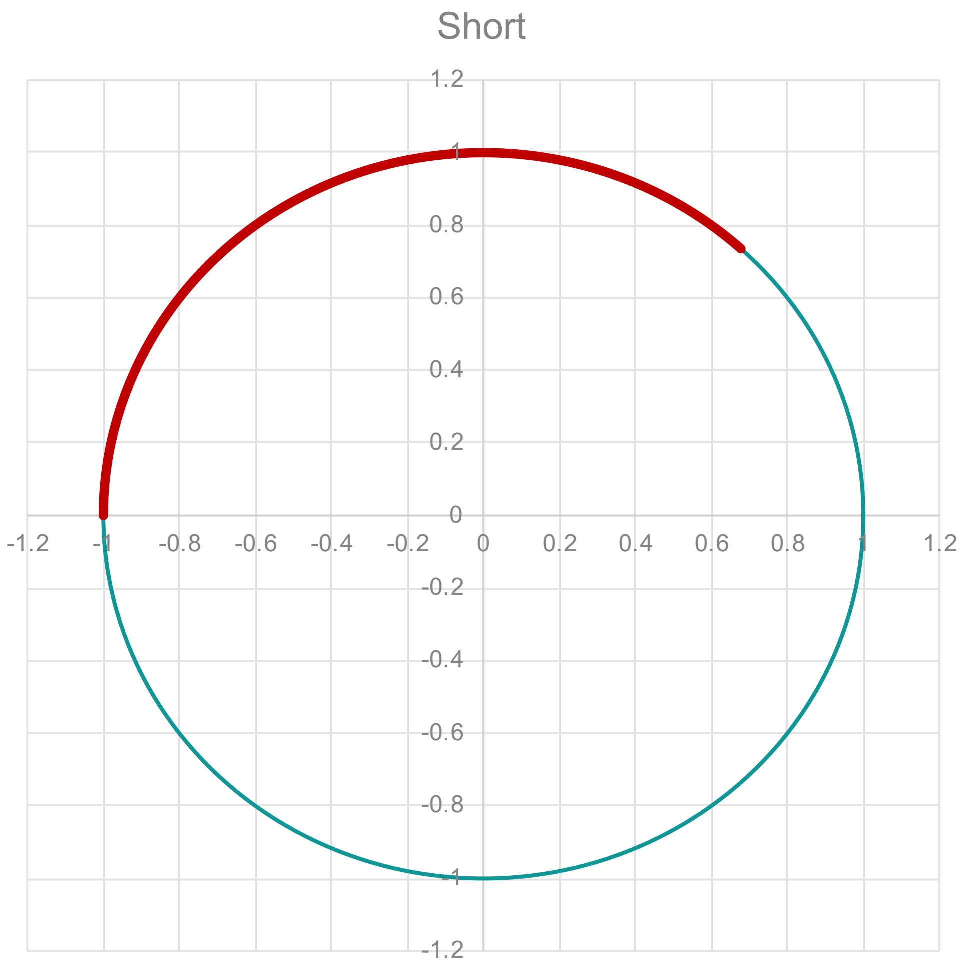
SHORT STANDARD

- The Short may defined by a Short transmission line followed by an inductance to ground which is characterized by a third order polynomial over frequency.
- $L = L_0 + L_1 * f + L_2 * f^2 + L_3 * f^3$
- A loss term which increases linearly with frequency may also be included.



SHORT STANDARD

- For the T4311 mechanical standard, the delay is 28.353 pS and the inductance is defined by:
  - $L = 0 + 0 * f + 0 * f^2 + 0 * f^3$
  - In this case the inductance is negligible
- From 9 kHz to 6.5 GHz this will look like a curve from 180 degrees on the left to 48 degrees.
- **A real Short does NOT look like a “Dot” at 180 degrees.**



THRU VS "UNKNOWN" THRU (SOLR)

- It is recommended to use "Unknown" Thru and perform SOLR calibration whenever possible.
- In SOLT the characterized Thru must be very high quality and properly characterized
- Errors in Thru definition result in ripples in an S21 or S12 measurement, ripples in the passband of a filter for example.
- "Unknown" Thru, SOLR calibration is free of this deficiency.
- See "Conducting Calibration with the SOLR (Unknown Thru) Method" April 19, 2018. (https://coppermountaintech.com/conducting-calibration-with-the-solr-unknown-thru-method/)

DATABASED CALIBRATION STANDARDS

- In the earlier examples, the calibration standards were defined by third order polynomials.
- These polynomials are the same for every calibration piece of the same type from a manufacturer.
- Small differences in machining and fabrication will give rise to errors in the characterization.
- Loads are usually assumed to be perfect.

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DATABASED CALIBRATION STANDARDS

- Databased standards are measured with a “Golden” VNA such that each piece has a unique S-Parameter characterization, including the load.
- This is more accurate than polynomial characterization but not quite as accurate as an electronic calibration using an Automatic Calibration Module (ACM).
- See: https://coppermountaintech.com/calibration-kits/

QUESTIONS?

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TRL CALIBRATION

- TRL refers to Thru-Reflect-Line calibration.
- It is intended for full 2-Port Calibration.
- Technically, the Thru must be zero length.
- TRL with non-zero length Thru is called LRL, Line-Reflect-Line But that's just being fussy. I'll call it all TRL.

TRL CALIBRATION

- Calibration consists of:
  - Measurement of the Thru.
  - Measurement of the Reflect.
  - Anything at all, Short, Open or anything on the perimeter of the Smith Chart.
  - Measurement of a Line which is nominally 90 degrees longer than the Thru.

THE REFLECT

- The very same reflect must be measured by each port.
- Leaving the cable connector completely open on each side may be good enough in some cases.
- A good Short will be better.
- NO characterization of the reflect is needed!

THE LINE

- TRL calibration will be accurate between frequencies where the line is between 60 and 120 degrees longer than the Thru.
- That is 90 degrees at the center frequency.
- The line MUST have EXCELLENT characteristic impedance.
- Errors in characteristic impedance will severely limit the return loss accuracy.

THE LINE

- A length of regular coaxial cable is normally not good enough to be used as a line.
- A precision air line is required for good calibration.
- Calibration frequency range may be extended by using more lines.
- 20 to 160 degree length of each line should overlap somewhat for best accuracy.

TRL APPLICATION

- If the actual non-zero Thru delay has been defined in the calibration kit then the reference plane will be at the cable connections.
- If the non-zero Thru delay has been set to zero then the reference plane will be in the center of the Thru.
- This can be very useful.

TRL ON A PCB FOR AUTO-DE-EMBEDDING

- A connectorized PCB is designed with equal length traces to and from a Device Under Test (DUT).
- Create a Thru trace between two connectors equal to the length of the input and output traces together.
- Create a line trace between two connectors which is 90 degrees longer than the Thru at the center frequency of interest.
    - Must be a REALLY good 50 Ohm line
- Add a connector with a Short for the reflect.
- After TRL Calibration, the reference plane will be at the DUT pins.

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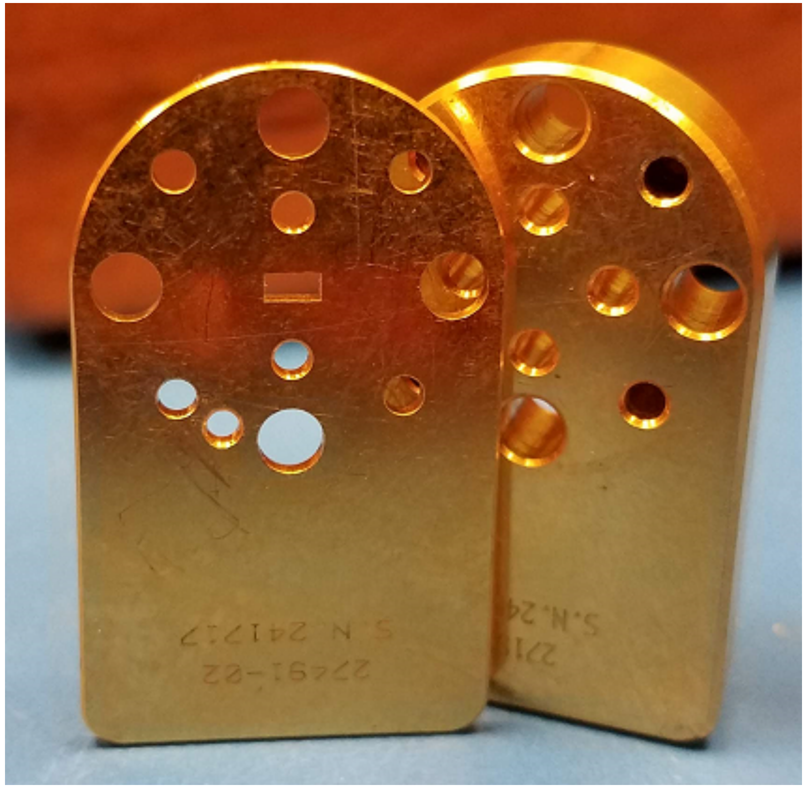
WAVEGUIDE SSL CALIBRATION

- It's possible to perform SOLT and TRL calibration using waveguide calibration standards.
- A waveguide "Short" is simply a metal plate bolted to the output of the waveguide.
- There is no such thing as a waveguide "Open". Instead a Shim which is 90 degrees long at the center frequency of calibration is added in front of the Short to rotate the phase by 180 degrees. This is used as the Open.
- Although similar to SOLT this is called SSL, Short-Short-Load



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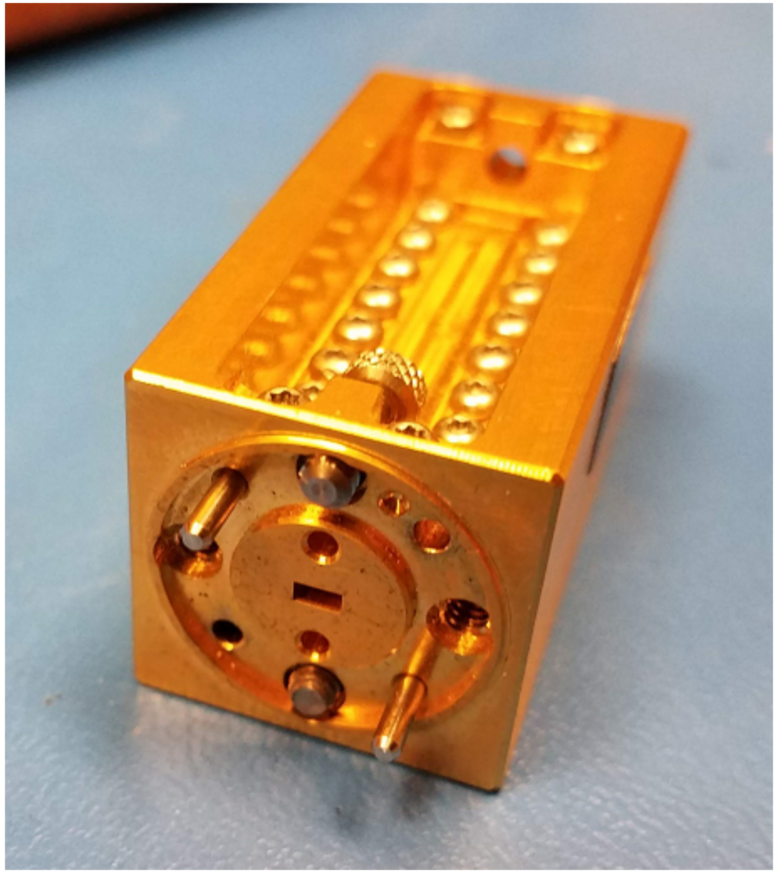
WAVEGUIDE SSL CALIBRATION

- A waveguide 50 Ohm Load is used for the Load.
  - Difficult to make.
  - It is expensive.
  - TRL Calibration requires no Load.



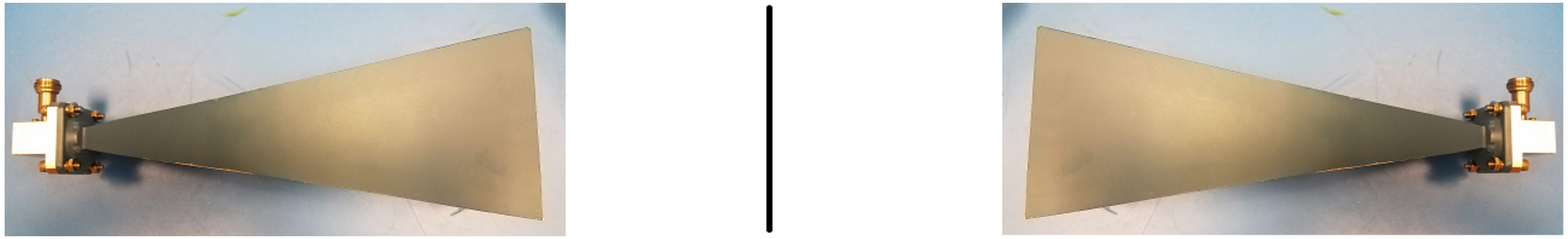
WAVEGUIDE TRL CALIBRATION

- As described previously for a coaxial calibration.
- Bolt input and output waveguides together and measure zero length Thru.
- Short input and output waveguides with shorting plates and measure reflect.
- Install length of waveguide which is 90 degrees long at center frequency of calibration and measure line.
- Calibration is now complete from frequencies where line is 20 degrees long to 160 degrees long.
- Keep in mind that phase length is not linear with waveguides so determining these frequencies is a little complicated.

$$v_{ph} = \frac{c}{\sqrt{\varepsilon_r}\sqrt{1-\left(\frac{f_c}{f}\right)^2}} = \frac{c}{\sqrt{\varepsilon_r-\left(\frac{f_{c0}}{f}\right)^2}}$$ phase velocity for waveguide

HORN TRL CALIBRATION

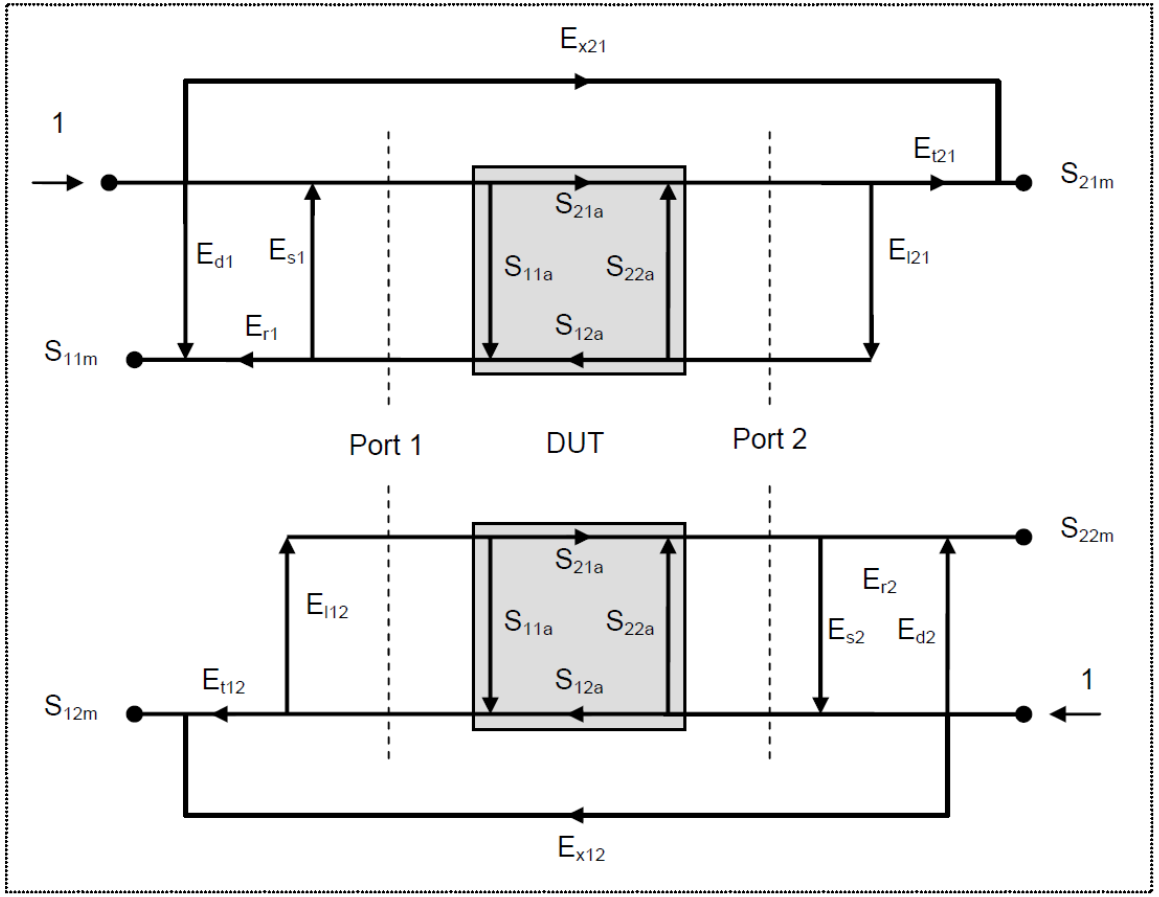
- TRL may also be used to calibrate a pair of antenna horns.
- Measure Thru between the horns.
- Place a shorting plate in the precise middle between the horns and measure reflect.
- With the reflect still in place, move one horn enough to achieve a 90 degree phase shift as measured on the screen.
- Remove the reflect and measure line.
- Calibration is now complete with reference plane at the midpoint.
- This technique may be used for material measurement if the waves at the midpoint are sufficiently planar.



WHAT ERRORS ARE REMOVED WITH CALIBRATION?

Table 14 Systematic error terms

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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