# VNA 101 BOOTCAMP – IMPORTANCE OF CALIBRATION

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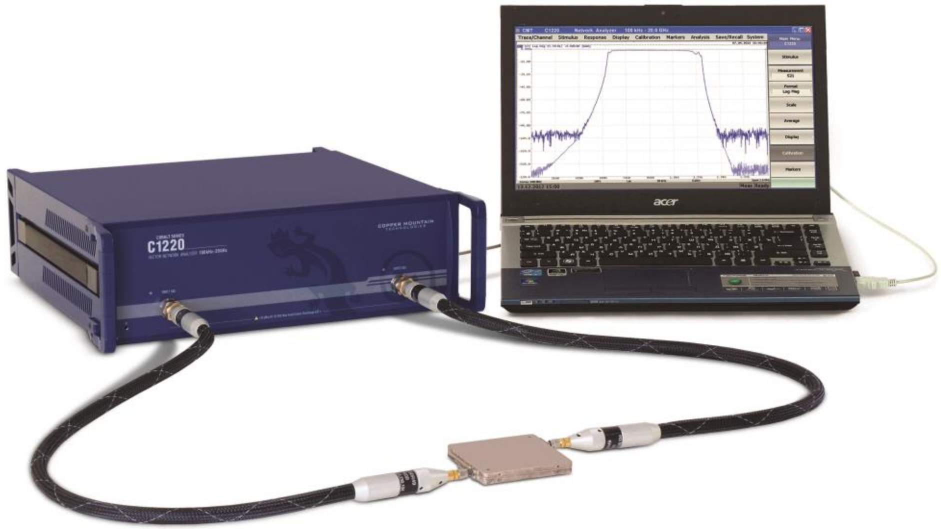
# AGENDA

- Why Calibrate?
- Types of Errors
- Systematic Error Correction – SOLT/SOLR
- SOLT/SOLR Calibration
    - How are standards defined?
    - What should an Open or Short look like after Calibration
    - Thru and Unknown Thru (SOLT vs SOLR)
    - Data-Based standards
    - Automatic Calibration Module
- Conclusion

# WHY CALIBRATE?

- Imperfections exist in every test equipment
- Measurements performed on a Device Under Test (DUT) must eliminate the effects of cables, adapters, fixtures and other accessories
- The term calibration can be confusing:
    - *Factory calibration or factory adjustments* refer to sending out the instrument to the manufacturer to adjust the drift associated with the internal hardware over time
    - *Annual calibration* refer to sending out the instrument to an accredited calibration lab to verify the instruments performance; typically performed once a year
    - *User Calibration or systematic calibration* refer to performing field calibration by the user prior to performing measurements on a DUT

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# 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)

# 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


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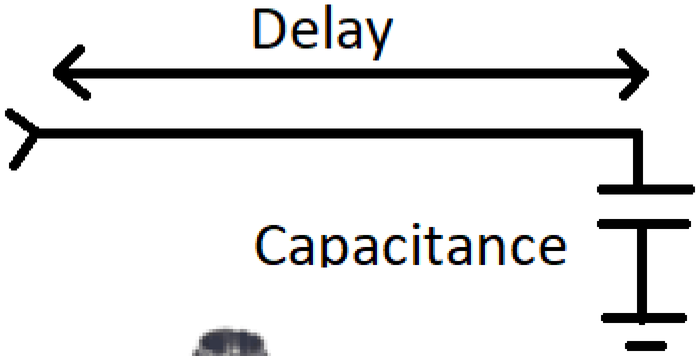
# OPEN STANDARD

- 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.

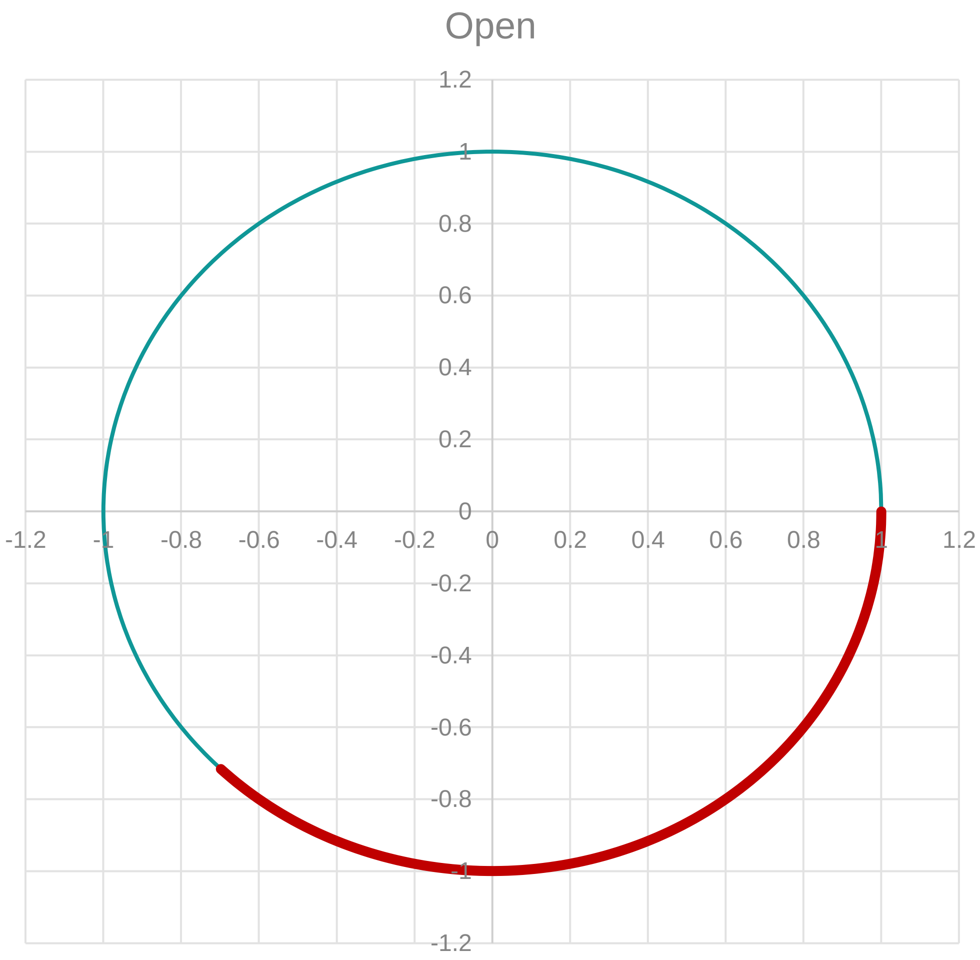
# OPEN STANDARD

- 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.**
- Phase shift is from the delay plus the fringing capacitance

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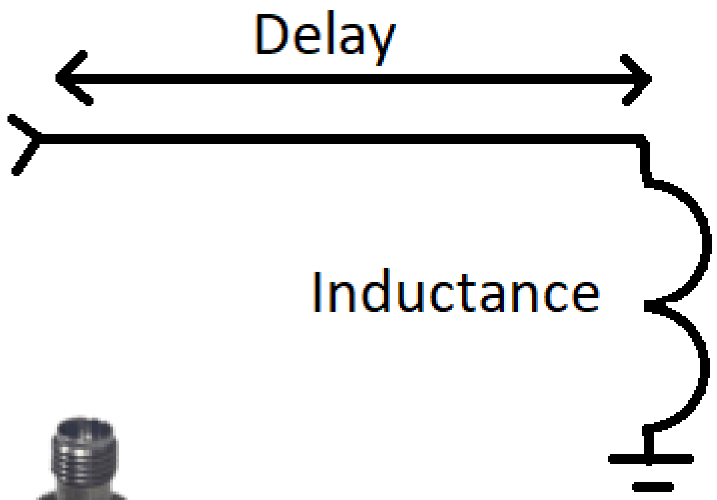
# SHORT STANDARD

- 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.





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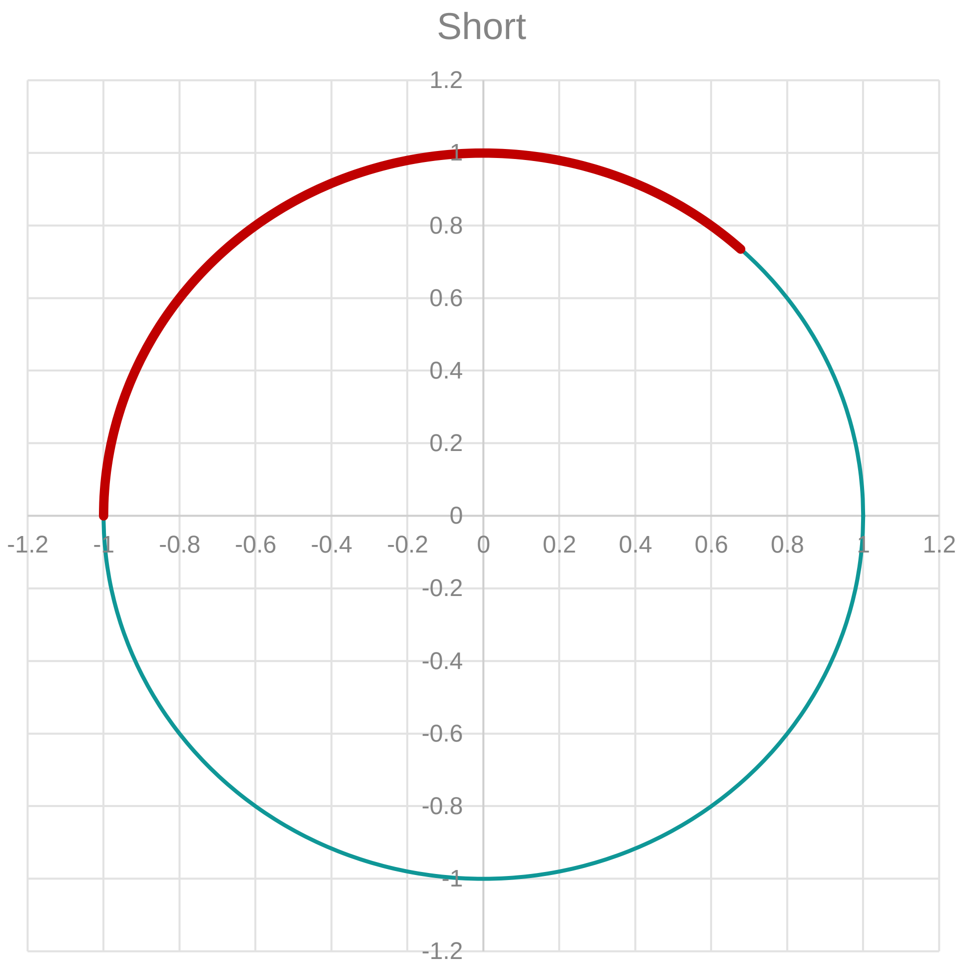
# SHORT STANDARD

- 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.**

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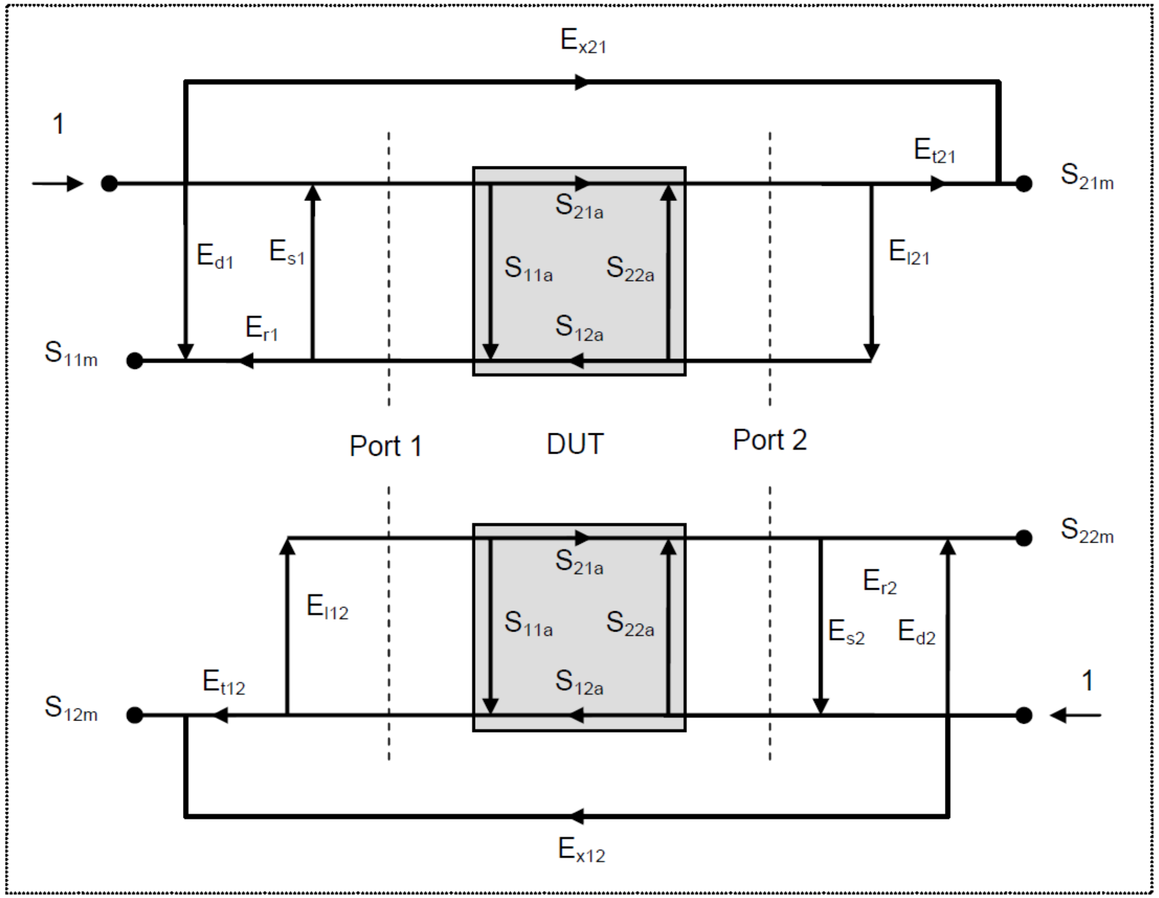
# THRU VS "UNKNOWN" THRU (SOLR)

- 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/)

# ERROR TERMS

- 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

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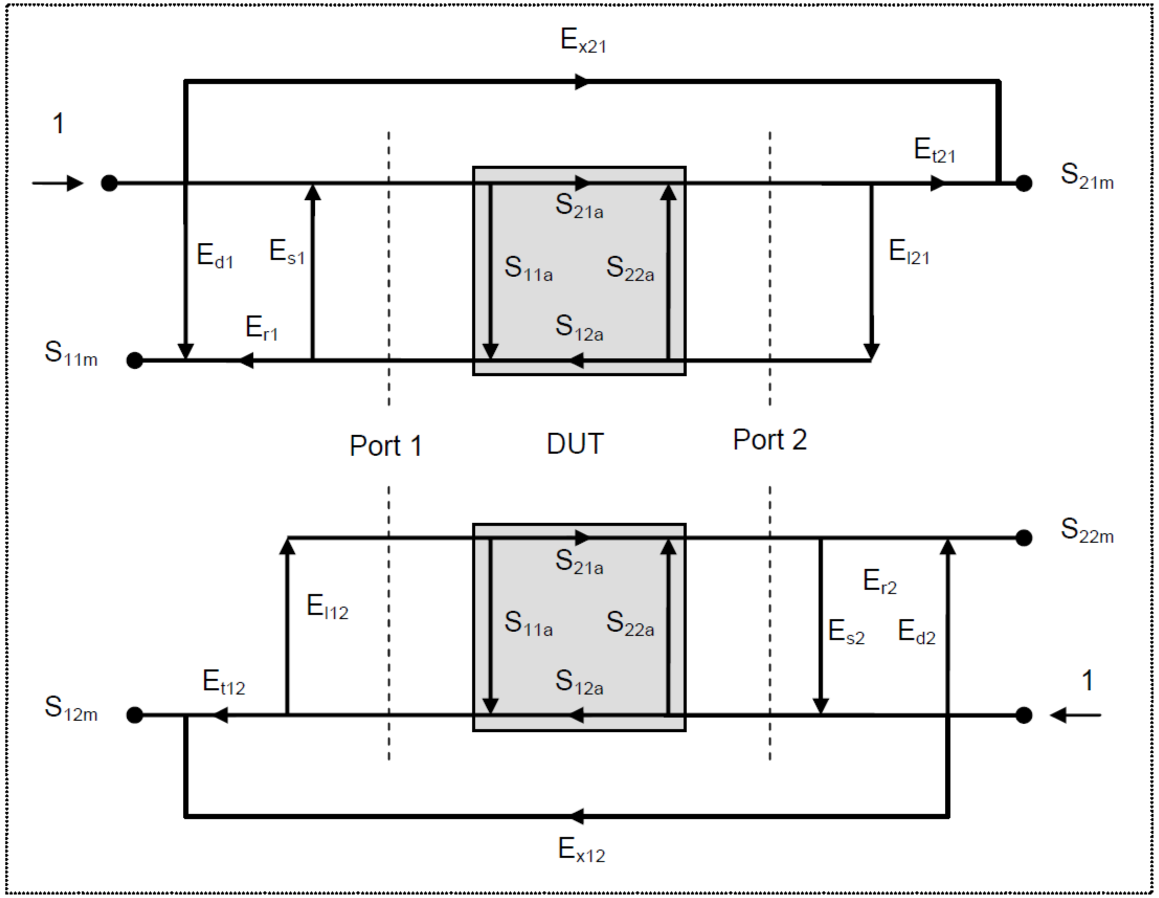
# ERROR TERMS

Table 14 Systematic error terms

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

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# POLYNOMIAL DEFINITIONS

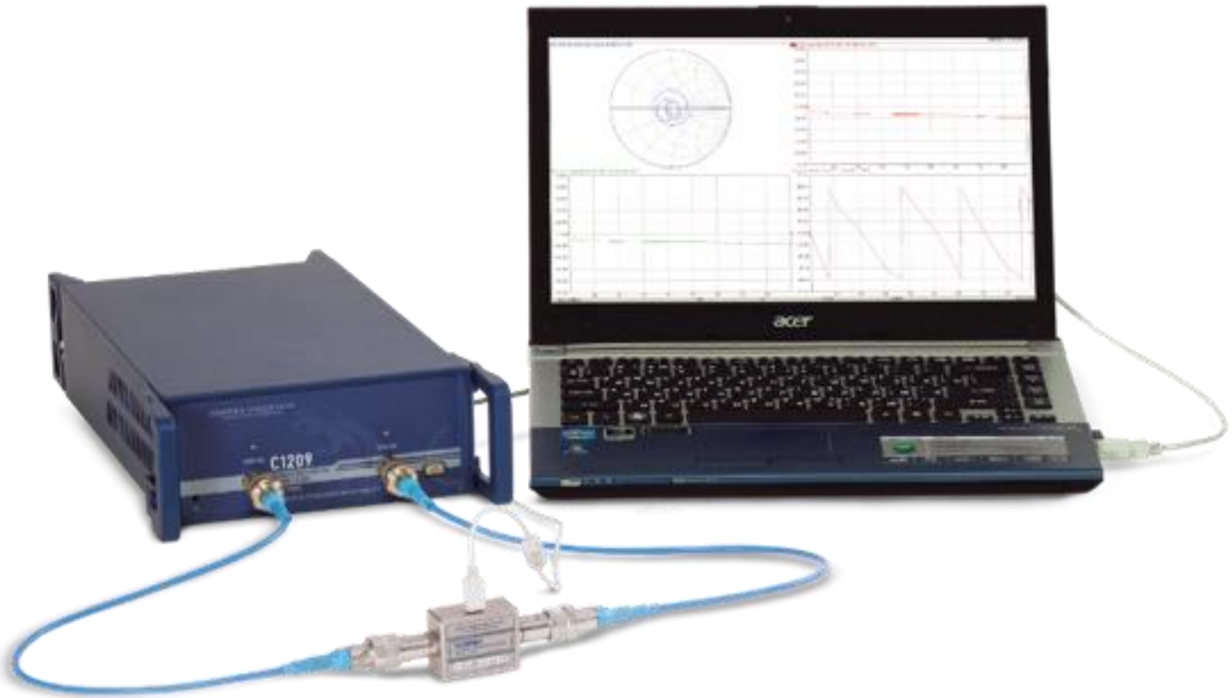
- In the earlier examples, the calibration standards were defined by third order polynomials.
- These polynomials are the same for every calibration piece of the same type from a manufacturer.
- Small differences in machining and fabrication will give rise to errors in the characterization.
- Loads are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

# DATABASED CALIBRATION STANDARDS

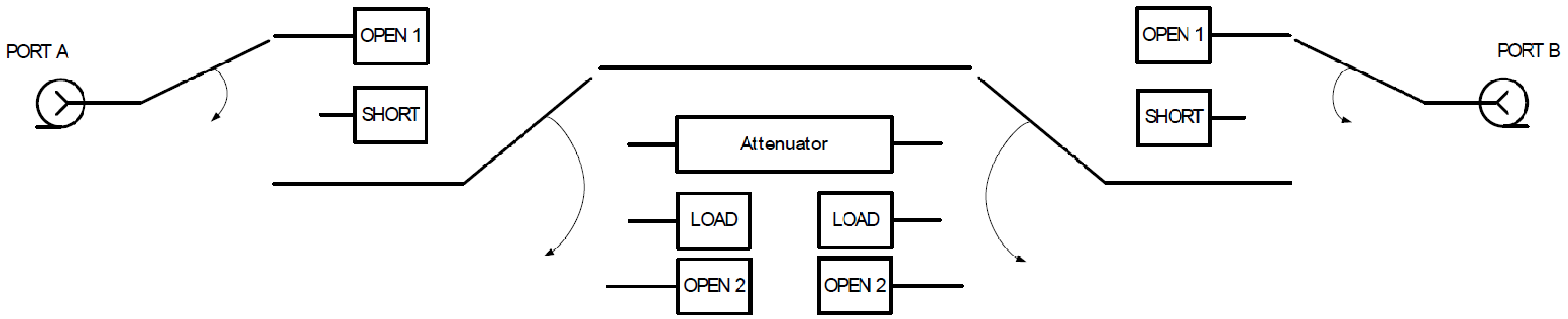
- Databased standards are measured with a “Golden” VNA calibrated with a primary standard such that each piece has a unique S-Parameter characterization, including the load.
- This is more accurate than polynomial characterization.
- Highly accurate for low reflection measurements.

# AUTOMATIC CALIBRATION MODULE

- Automatic Calibration Module (ACMs) have databased definitions for each internal impedance state: open, short, load and thru
- ACM switches to the various impedance states one by one during calibration process with a click of one button
- Faster and reduces risk of user error
- Easy to verify the quality of calibration using 'Confidence Check' feature



# AUTOMATIC CALIBRATION MODULE

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# CONCLUSION

- SOLT/SOLR calibration uses open, short and load standards to perform 12-term error correction

- Databased definitions for each standard yields higher accuracy at higher frequencies and low return loss levels

- Automatic Calibration Module is easy to use and performs error correction quickly and accurately

# QUESTIONS?

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