THz Vector Network Analyzer Development & Measurements

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Abstract: Virginia Diodes has been developing a series of Vector Network Analyzer extenders to cover waveguide bands from WR-10 (75-110 GHz) up to WR-1.2 (600-900 GHz). This poster presents some of the challenges of performing THz VNA measurements, including calibration, flange issues, and the lack of wideband isolators. Several measurement examples are discussed, including the measurement of waveguide loss, flange repeatability, calibration stability, and calibration methodology. A VDI WR-1.5 frequency extender will be presented, which has been used to perform the first calibrated VNA measurements over the WR-1.5 band. Measurements of a variety of WR-1.5 waveguide components are presented.

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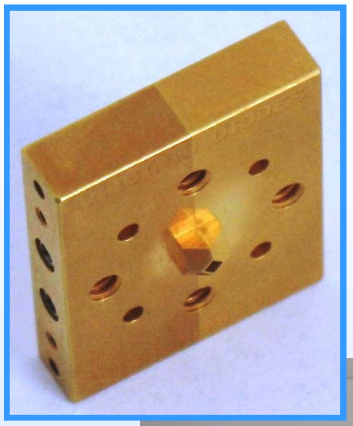
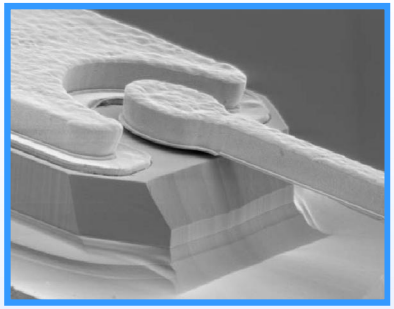
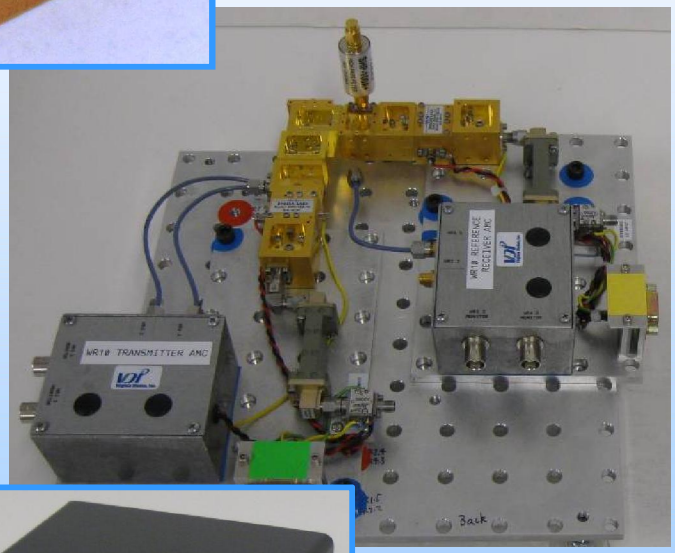
VDI VNA Extenders to THz

- VDI has developed a wide range of THz sources and receivers
  - State-of-the-art performance
  - Broadband
  - Electronically sweepable
- These components are now being used as the basis for high performance VNA extenders to THz
- Working on both Reconfigurable and Packaged systems
  - Reconfigurable system are for customers wanting wideband peak performance, and who are willing to use more complex systems
  - e.g. Universities and Research Labs
- Generally Custom products
  - Packaged Systems are for more general users
  - Dedicated bands, a standard product







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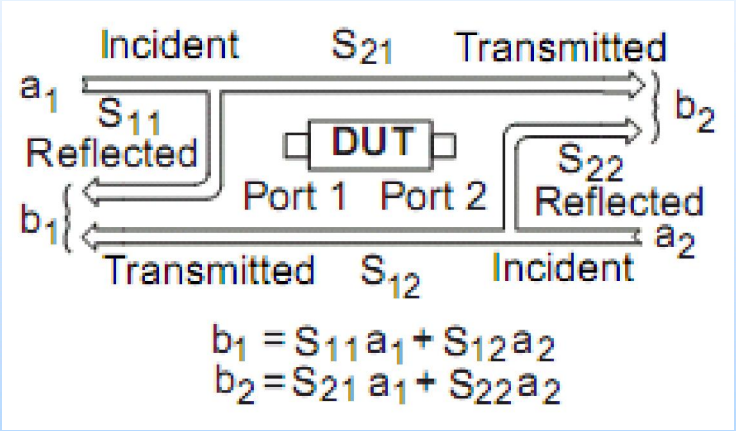
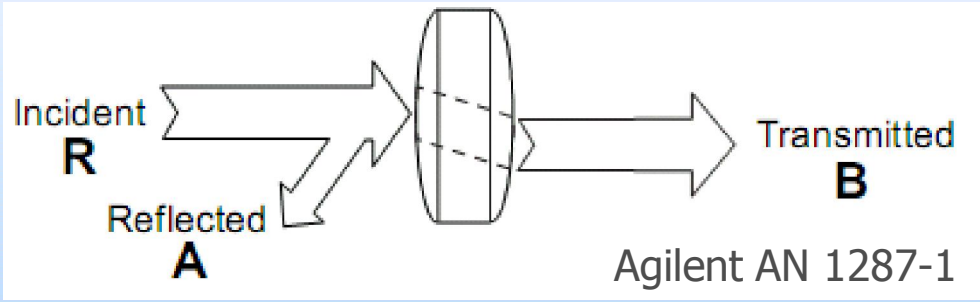
VNA Extenders

- What is a Vector Network Analyzer?
  - In its fundamental form, network analysis involves the measurement of incident, reflected, and transmitted waves that travel along transmission lines (or free space)
  - VNA analysis is a frequency domain technique
    - Frequency sweep, with each point independent
  - VNAs measure the scattering-parameters of a component



Optical Analogy



- Importance of Vector Measurements
  - Complex (i.e. magnitude and phase) measurements are required to fully characterize a component
    - Verify designs, and to build up models of real life devices
  - Even if you only need magnitude information (e.g. standing wave ratio) a complex measurement allows the use of sophisticated calibration methods
    - Greatly reduced systematic errors
  - Complex measurement needed to calculate time domain response
    - Allows location of position where reflection occurs

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VNA Calibration

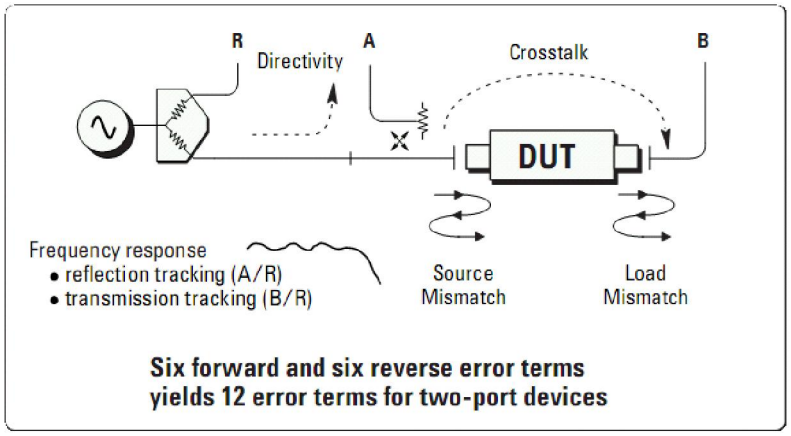


Figure 2. Systematic Measurement Errors

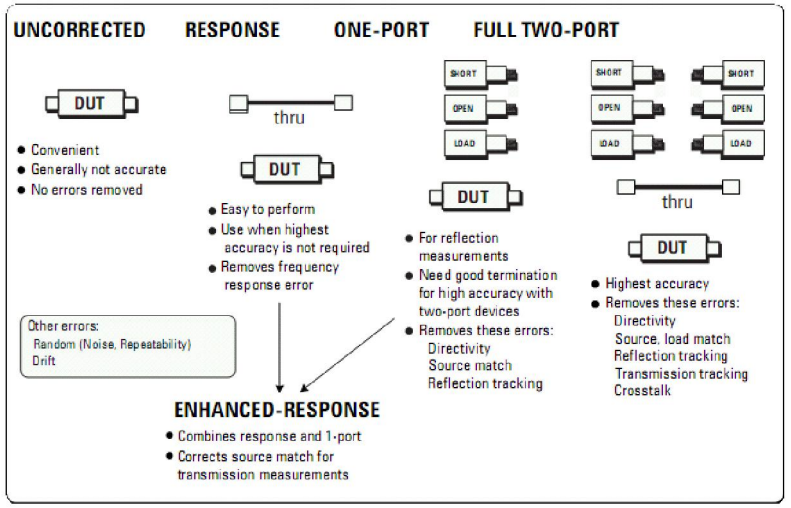
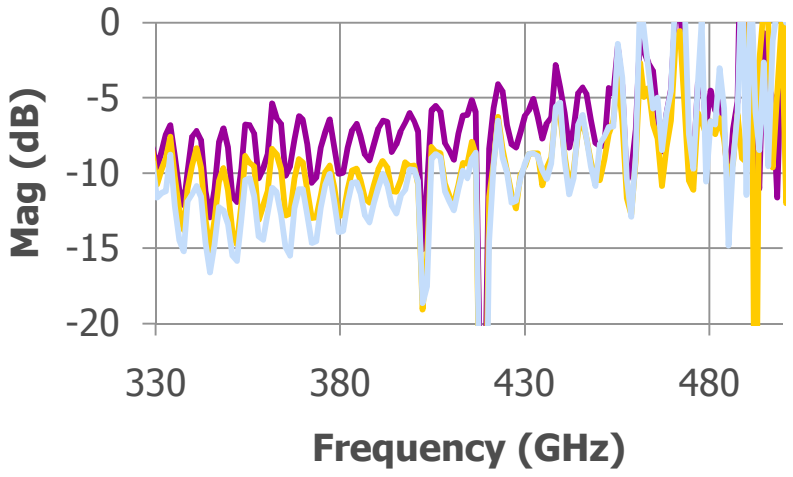


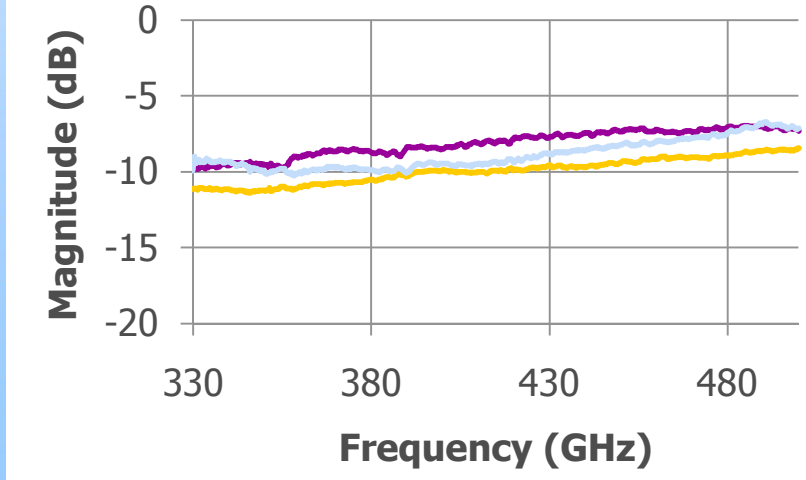
Figure 6. Errors and Calibration Standards

Measurement of WR-2.2 Coupler

Response Calibration (i.e. normalization)



Full 2-Port Calibration



Waveguide Calibration Kits

- 1-Port Calibrations
  - Delayed Short
    - Short, 1/8 Delayed Short, ¼ Wave Delayed Short
  - Delayed Load
    - Zero, 1/8 & ¼ wave delays
- 2-Port Calibrations
  - TRL Calibration
    - Flush Thru, Short & ¼ Wave Delay
  - SOLT
    - Use delayed shorts or load for Load

WR1.5 VNA Extender Calibration Kit:

WR-1.5-VNA-C-L: Waveguide Terminations (qty 2)
Description: Waveguide Load, return loss 20dB typ
VNA-C-SC: Waveguide Short Circuit (qty 2)
Description: Flush short circuit
WR-1.5-VNA-C-QW: Waveguide Quarter Wave Delay (qty 4)
Description: 1/4-wave Waveguide Shim
WR-1.5-VNA-C-EW: Waveguide Eighth Wave Delay (qty 4)
Description: 1/8-wave Waveguide Shim
WR-1.5-VNA-SWG: Waveguide Length (qty 1)
Description: Section of waveguide for use as a test sample

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Calibration Type	Standards	Parameters	Error Terms	General Accuracy	Application
Reflection Normalization	Open or Short	S_{11} (or S_{22}, ...)	Reflection tracking	Low to medium	Reflection measurements on any port.
Transmission Normalization	Through	S_{12}, S_{21} (or S_{13},...)	Transmission tracking	Medium	Transmission measurements in any direction and between any combination of ports.
Full One-Port	Open, Short, Match[1)]	S_{11} (or S_{22}, ...)	Reflection tracking, Source match Directivity,	High	Reflection measurements on any port.
One-Path Two-Port	Open, Short, Match[1)] (at source port), Through[2)]	S_{11}, S_{21} (or S_{22},...)	Reflection tracking, Source match, Directivity, Transmission tracking	Medium to high	Unidirectional transmission measurements in any direction and between any combination of ports.
TOSM (2-port, 3-port or 4-port) or UOSM	Open, Short, Match[1)] (at each port), Through[2)] (between all combinations of 2 ports)	All	Reflection tracking, Source match, Directivity, Load match, Transmission tracking,	High	Reflection and transmission measurements on DUTs with 2, 3, or 4 ports; classical 12-
TRL (2-port, 3-port or 4-port)	Reflect (at both ports), Through, Line1, Line2 (optional), combination with TRM (optional)	All	Reflection tracking, Source match, Directivity, Load match, Transmission tracking	High, high directivity	Reflection and transmission measurements on DUTs with 2, 3, or 4 ports, especially for planar circuits. Limited bandwidth.

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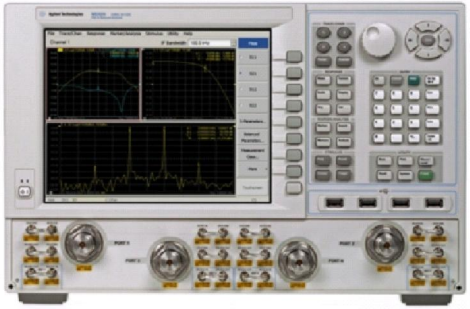
Full TxRx Extender Layout

Operation to ~50GHz



RF LO Ref. Meas.

Operation to THz

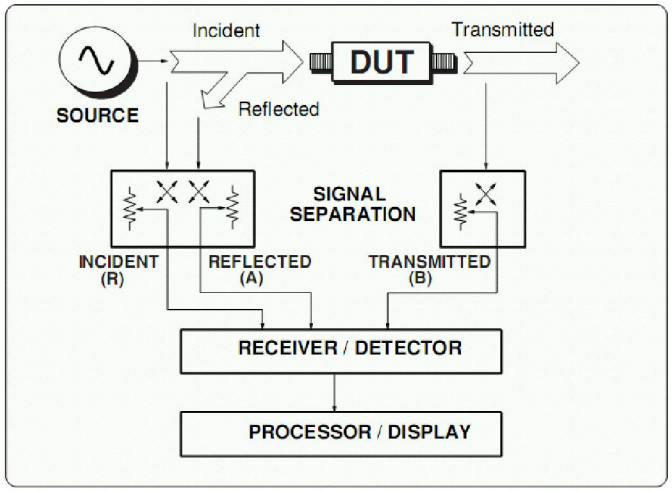
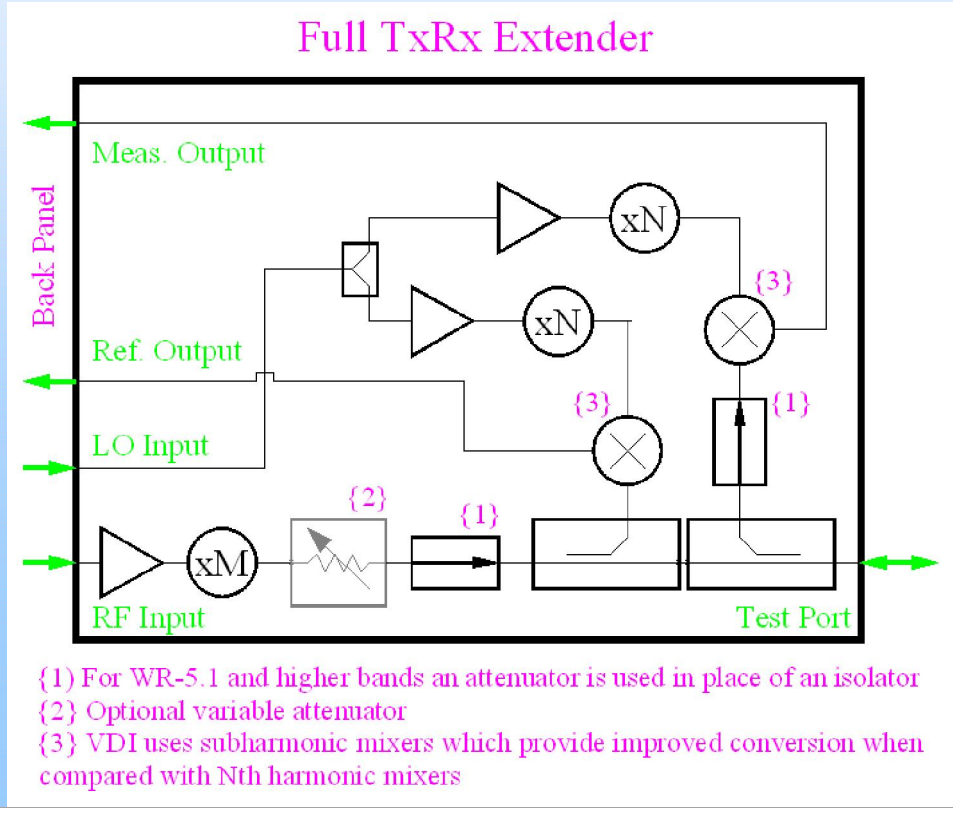


Figure 2. Generalized Network Analyzer Block Diagram

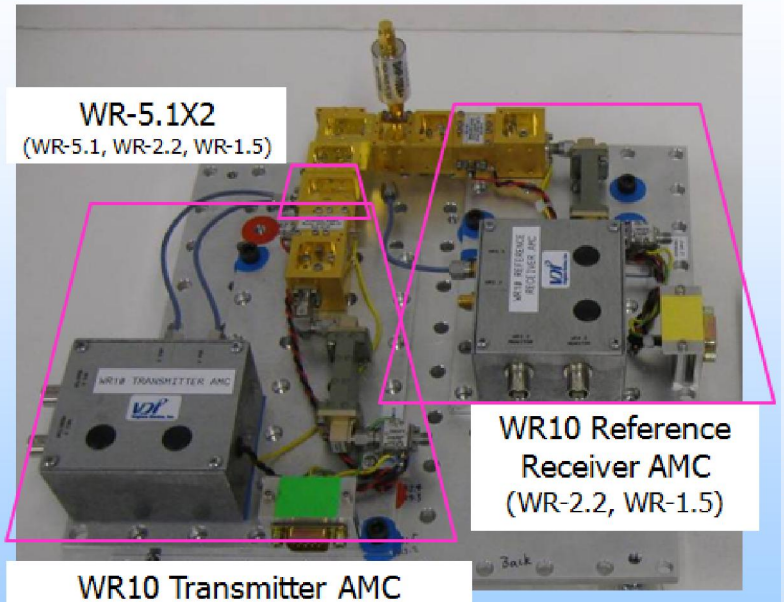


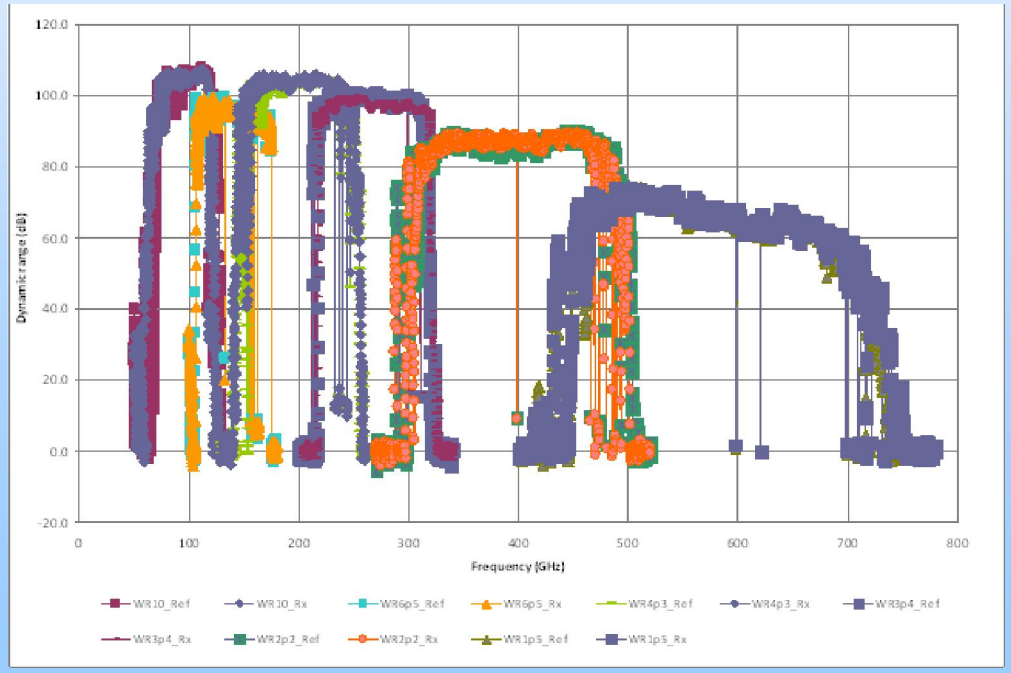
{1} For WR-5.1 and higher bands an attenuator is used in place of an isolator
{2} Optional variable attenuator
{3} VDI uses subharmonic mixers which provide improved conversion when compared with Nth harmonic mixers

Reconfigurable Extender Systems

- A set of reconfigurable components to allow amplitude & phase measurements from 75 GHz up to 660 GHz
  - Coverage achieved in 6 bands
  - Reuse the base components
  - User must connect and disconnect components, and so rather complex to operate

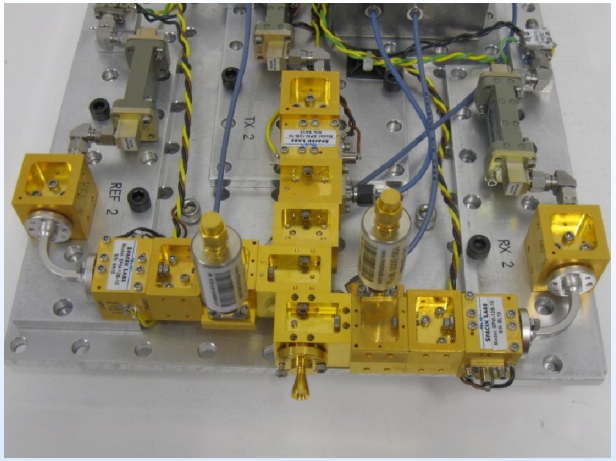
WR1.5 (465-696 GHz) Extender



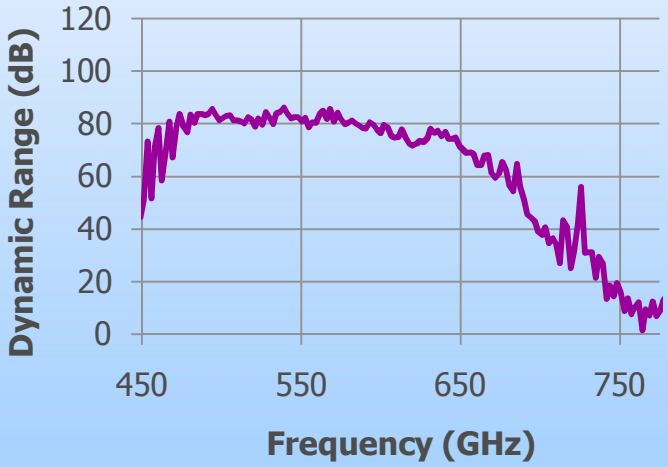


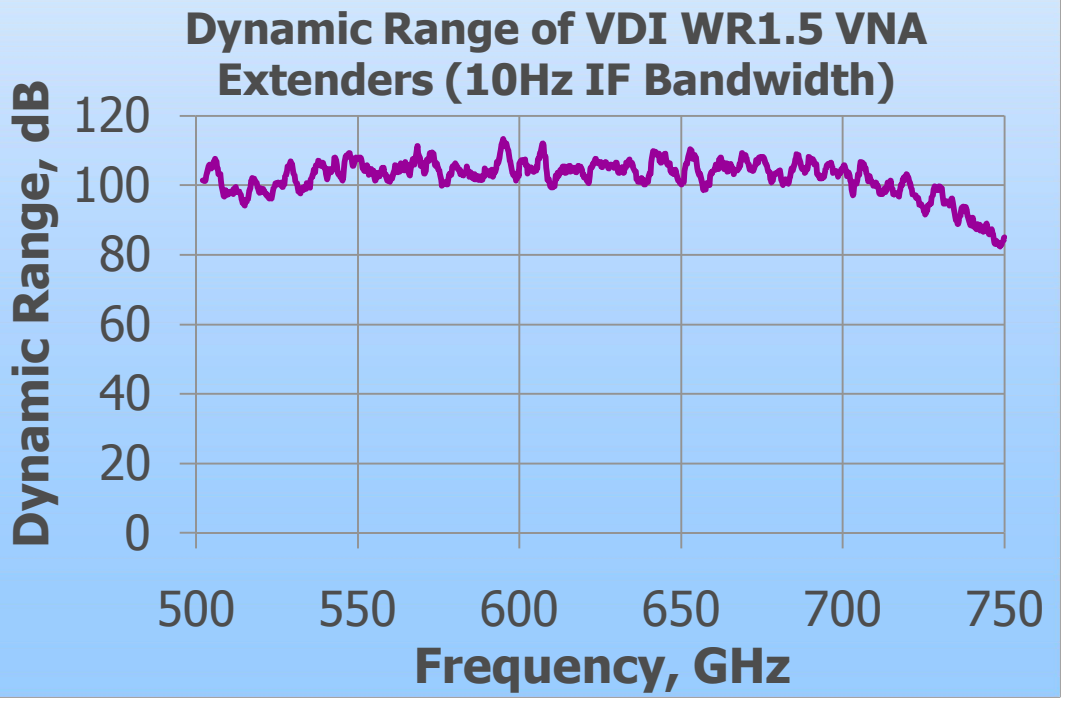
WR-1.5 VNA Extender

WR-1.5 Prototype



Packaged WR-1.5 Extenders





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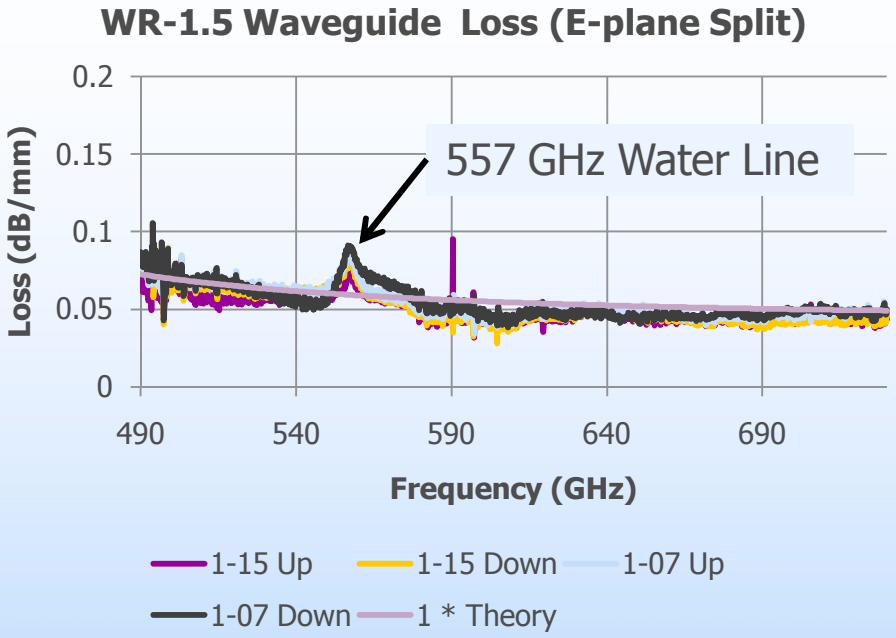
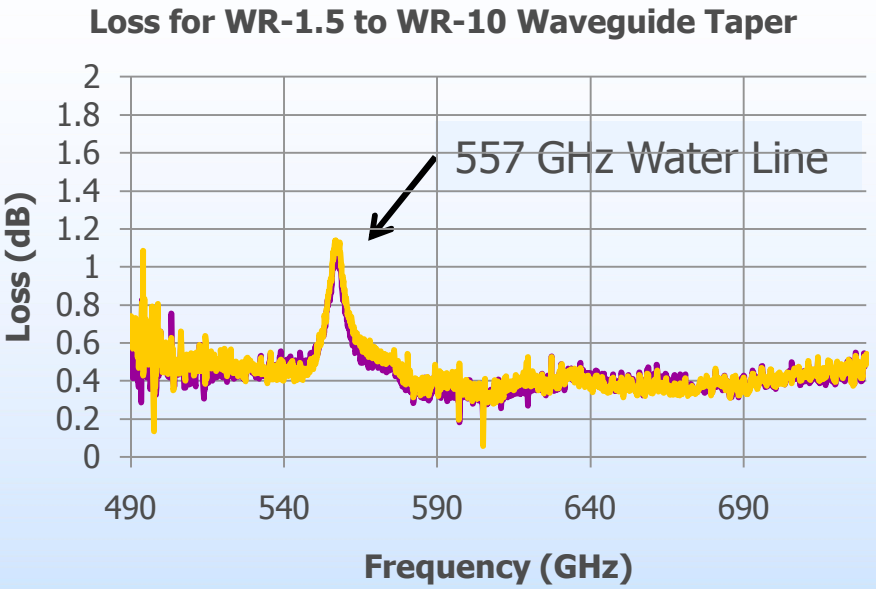
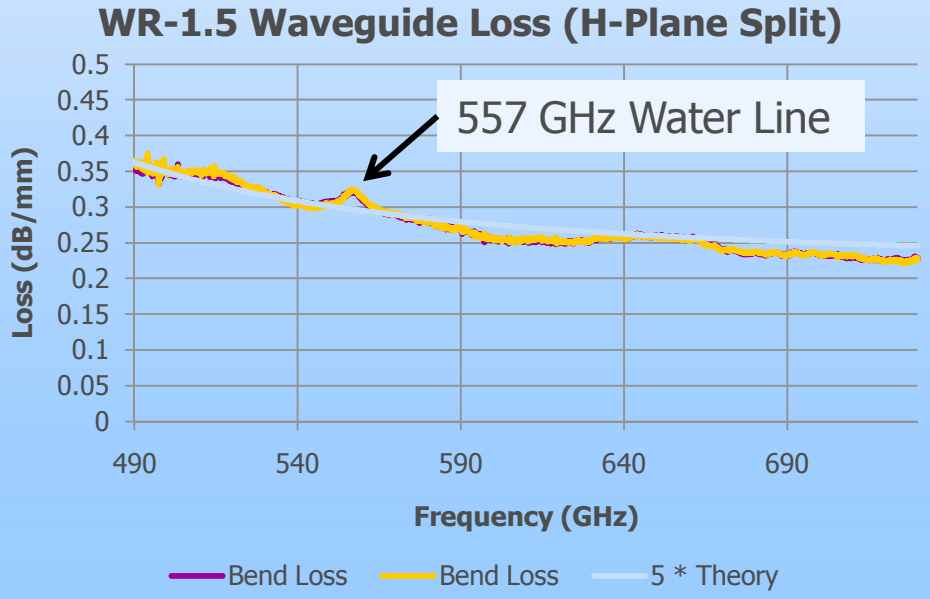
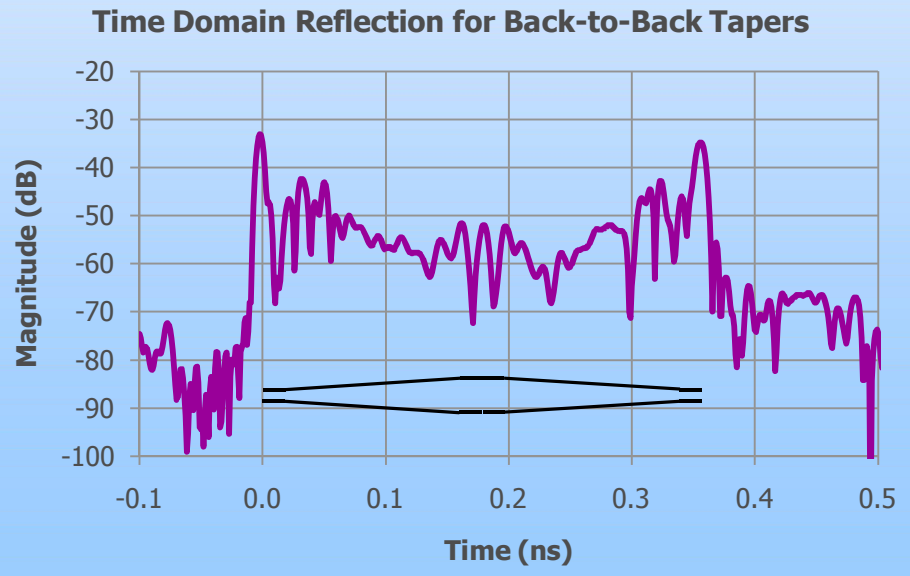
WR-1.5 Measurements

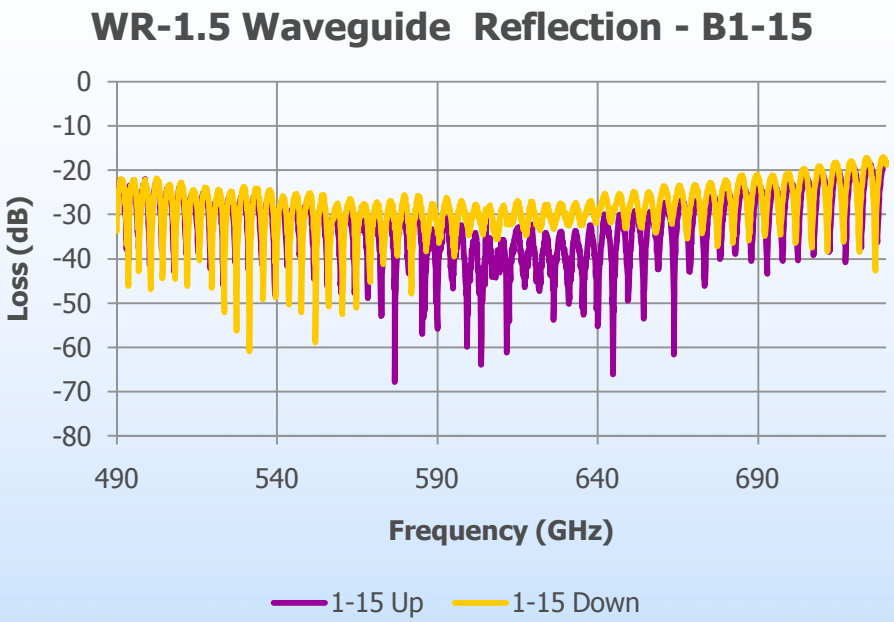


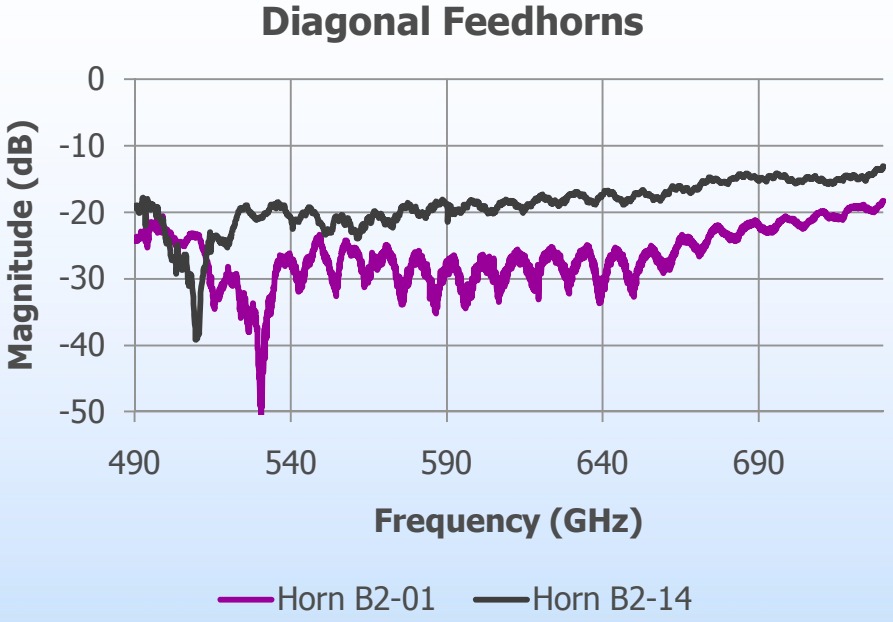


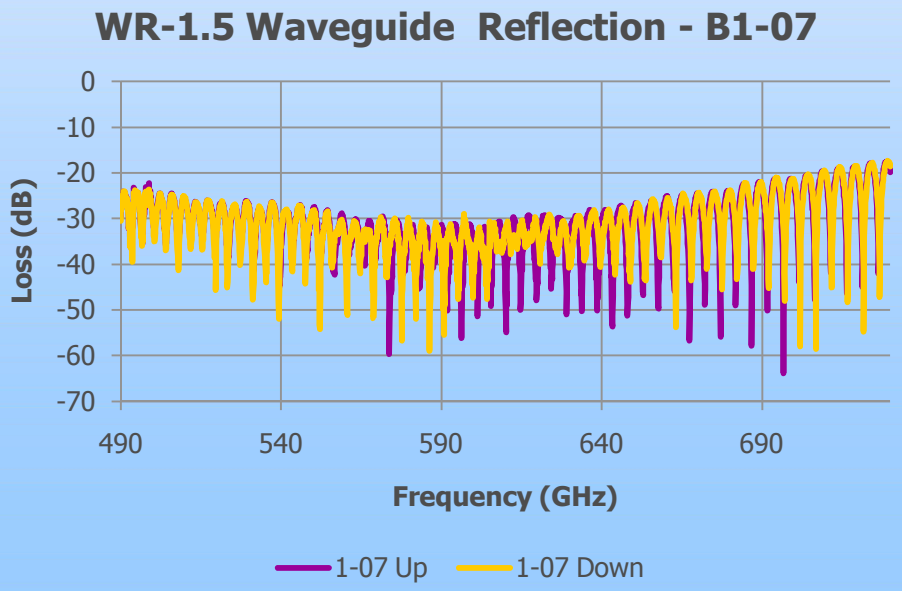


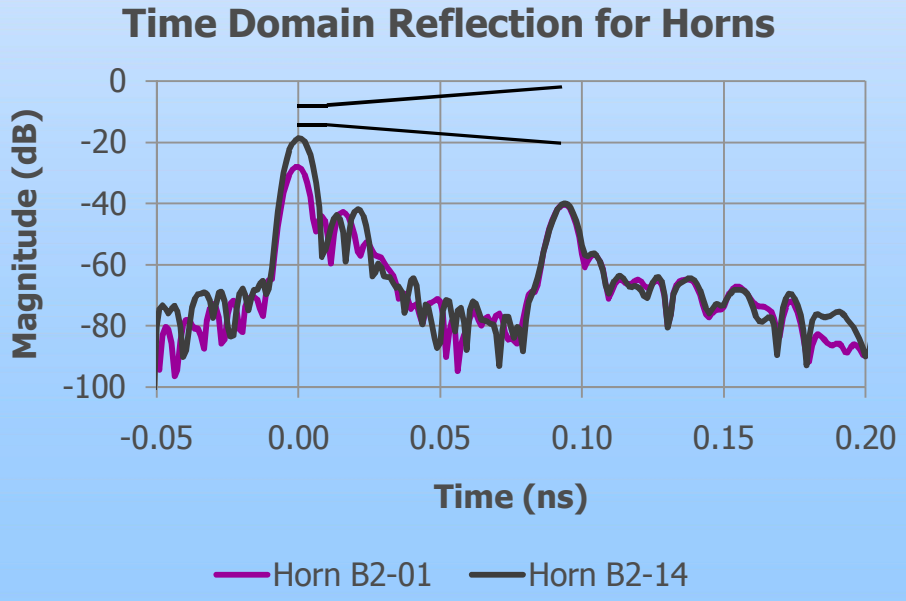


WR-1.5 Measurements



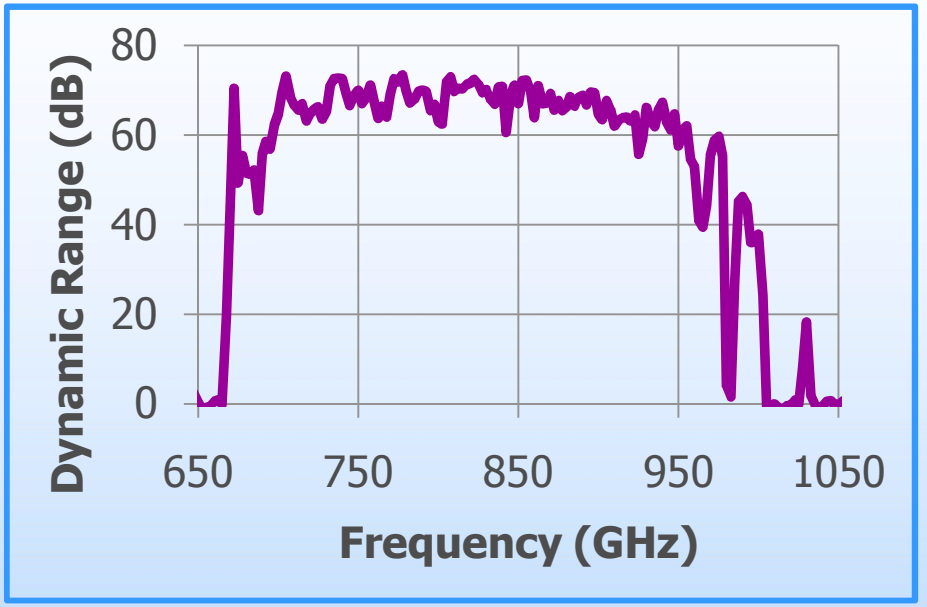


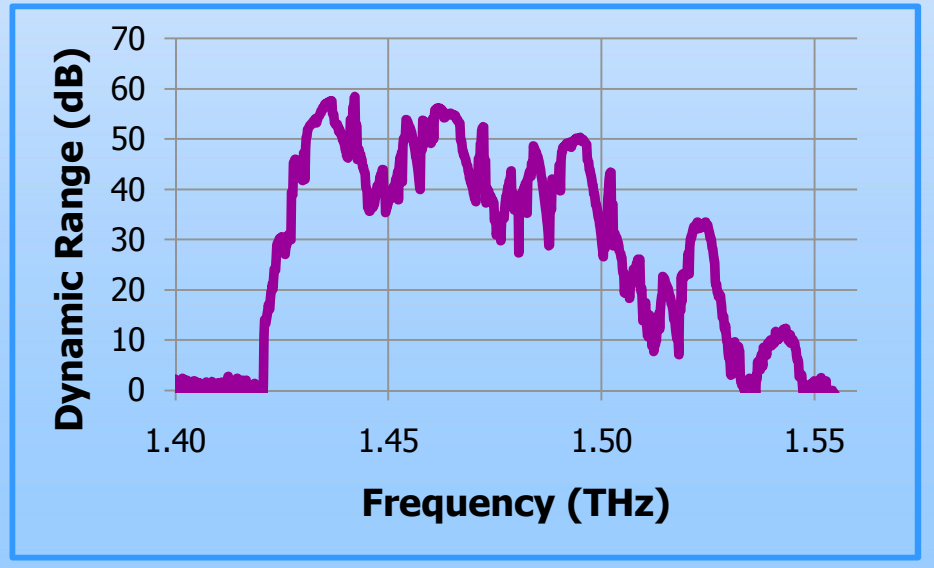




Conclusions

- VNA Measurements are crucial for upcoming THz developments
  - Wafer probing of THz transistors
  - General THz component characterization
- VDI VNA extenders have high output power and excellent dynamic range
  - Reconfigurable version available
    - Reuse lower frequency components → wide frequency coverage
    - Remove couplers to give high output power and dynamic range
      - e.g. for antenna measurements
- Now developing calibrated VNA to 900 GHz
  - Future developments to > 1 THz





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