

THz Vector Network Analyzer Development & Measurements

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www.vadiodes.com



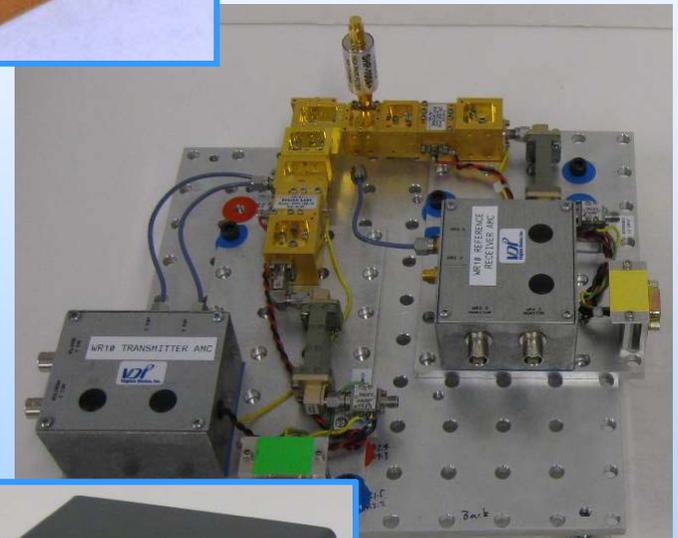
Abstract: Virginia Diodes has been developing a series of Vector Network Analyzer extenders to cover waveguide bands from WR-10 (75-110 GHz) up to WR-1.2 (600-900 GHz). This poster presents some of the challenges of performing THz VNA measurements, including calibration, flange issues, and the lack of 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

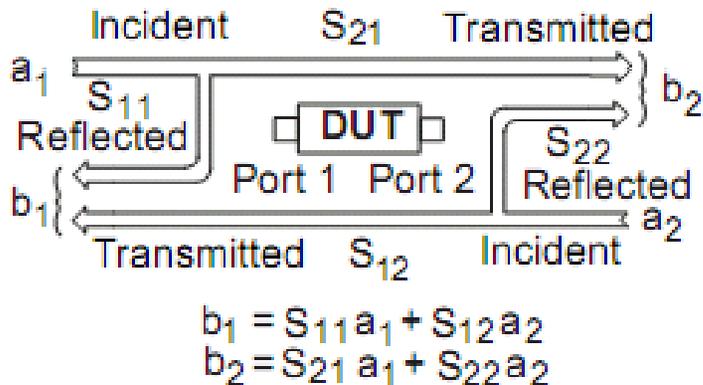
- VDI has developed a wide range of THz sources and receivers
 - State-of-the-art performance
 - Broadband
 - Electronically sweepable
- These components are now being used as the basis for high performance VNA extenders to THz
- Working on both Reconfigurable and Packaged systems
 - Reconfigurable system 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



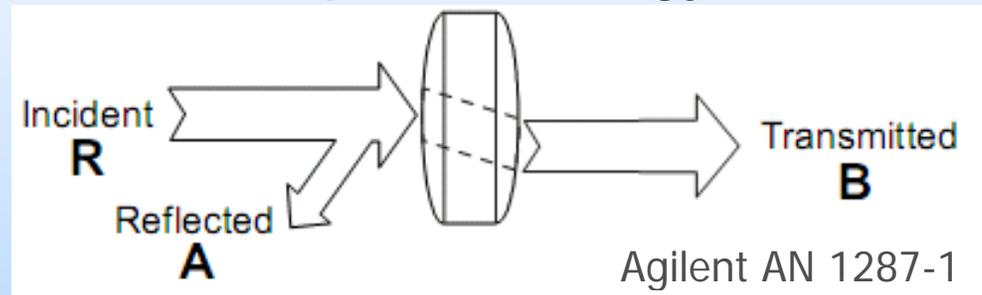
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VNA Extenders

- 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

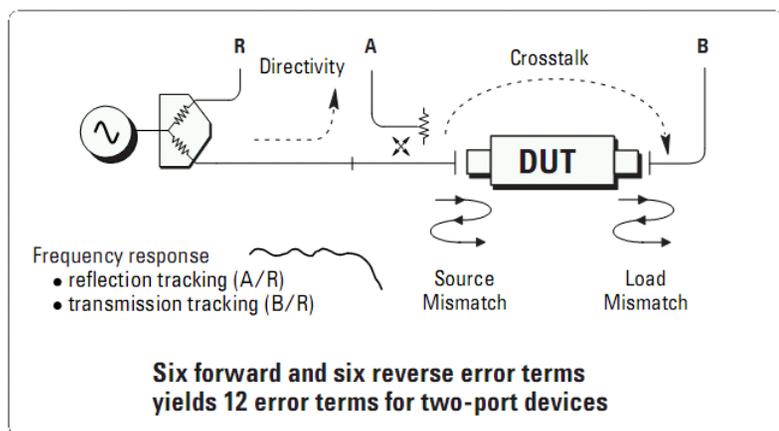


Figure 2. Systematic Measurement Errors

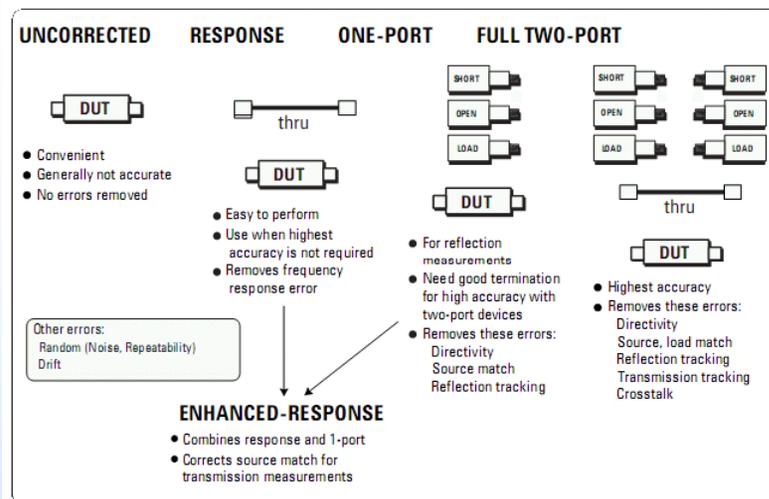
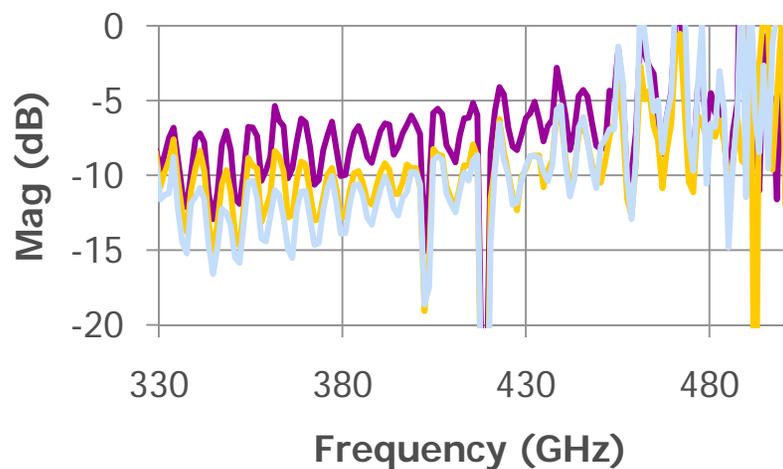


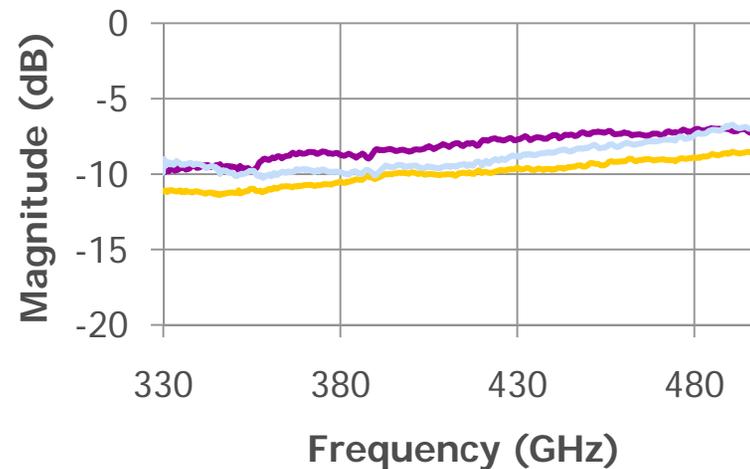
Figure 6. Errors and Calibration Standards

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, 1/4 Wave Delayed Short
 - Delayed Load
 - Zero, 1/8 & 1/4 wave delays
- 2-Port Calibrations
 - TRL Calibration
 - Flush Thru, Short & 1/4 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}, \dots)	Reflection tracking	Low to medium	Reflection measurements on any port.
Transmission Normalization	Through	S_{12}, S_{21} (or S_{13}, \dots)	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}, \dots)	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}, \dots)	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

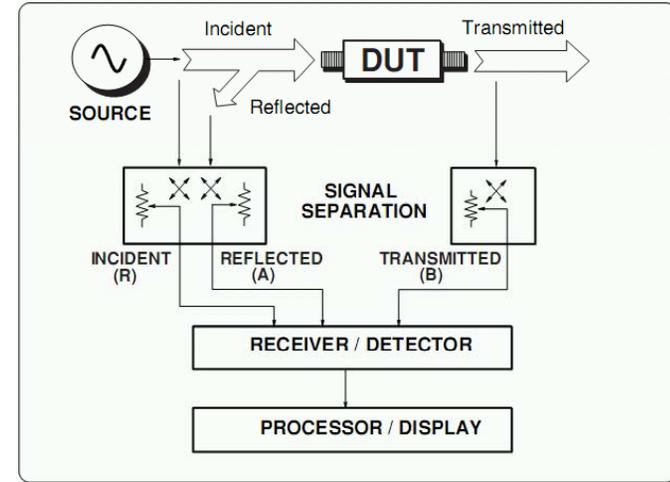
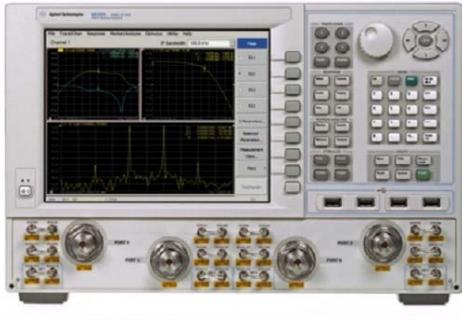


Figure 2. Generalized Network Analyzer Block Diagram

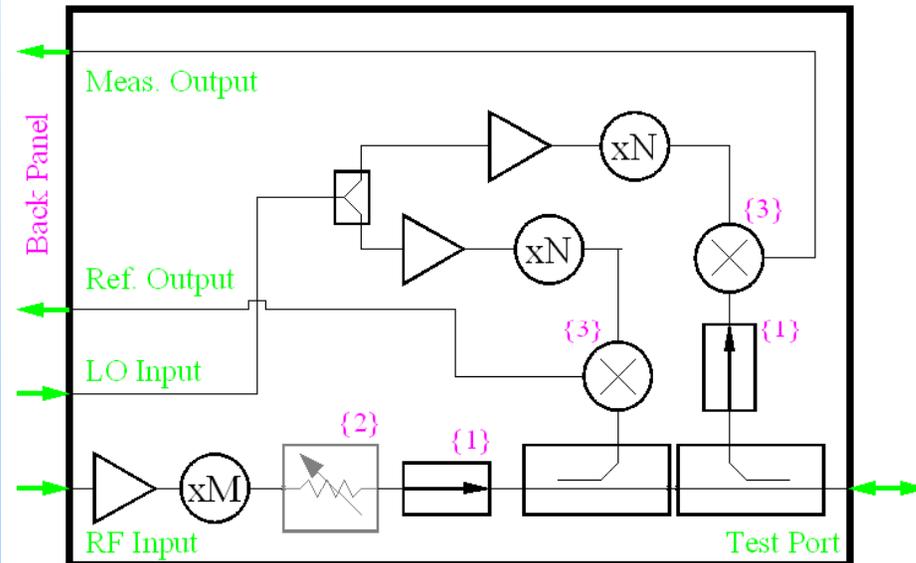
RF LO Ref. Meas.



Operation to THz



Full TxRx Extender

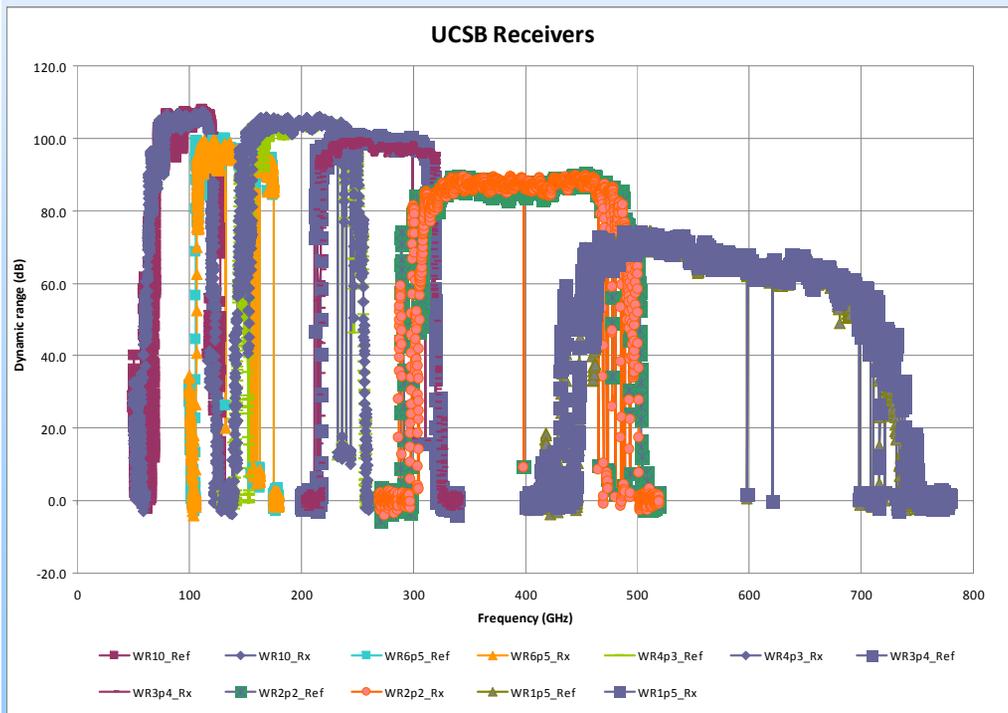
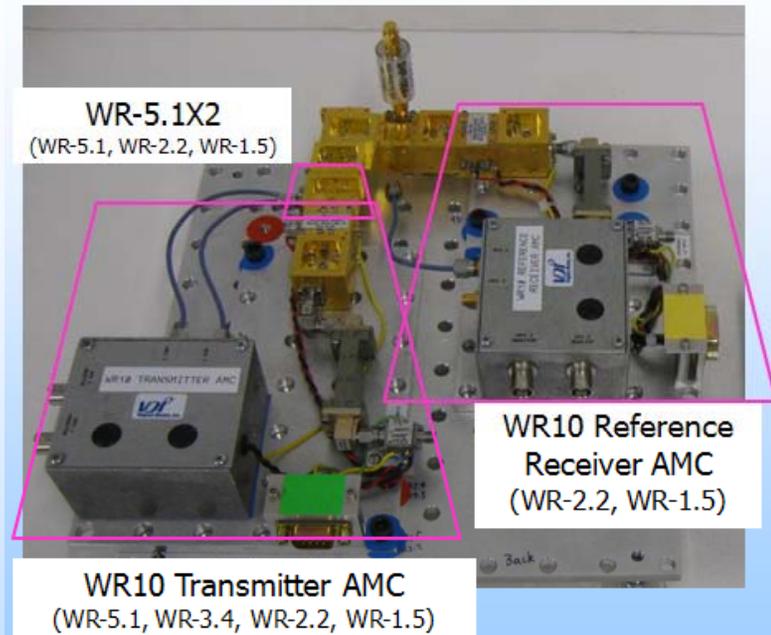


- {1} For WR-5.1 and higher bands an attenuator is used in place of an isolator
- {2} Optional variable attenuator
- {3} VDI uses subharmonic mixers which provide improved conversion when compared with Nth harmonic mixers

Reconfigurable Extender Systems

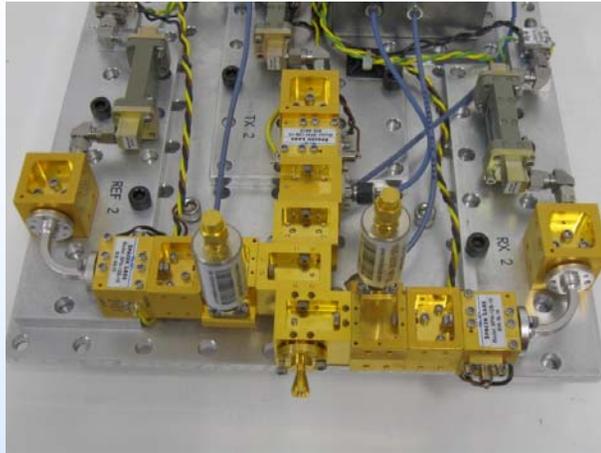
- A set of reconfigurable components to allow amplitude & phase measurements from 75 GHz up to 660 GHz
 - Coverage achieved in 6 bands
 - Reuse the base components
 - User must connect and disconnect components, and so rather complex to operate

WR1.5 (465-696 GHz) Extender

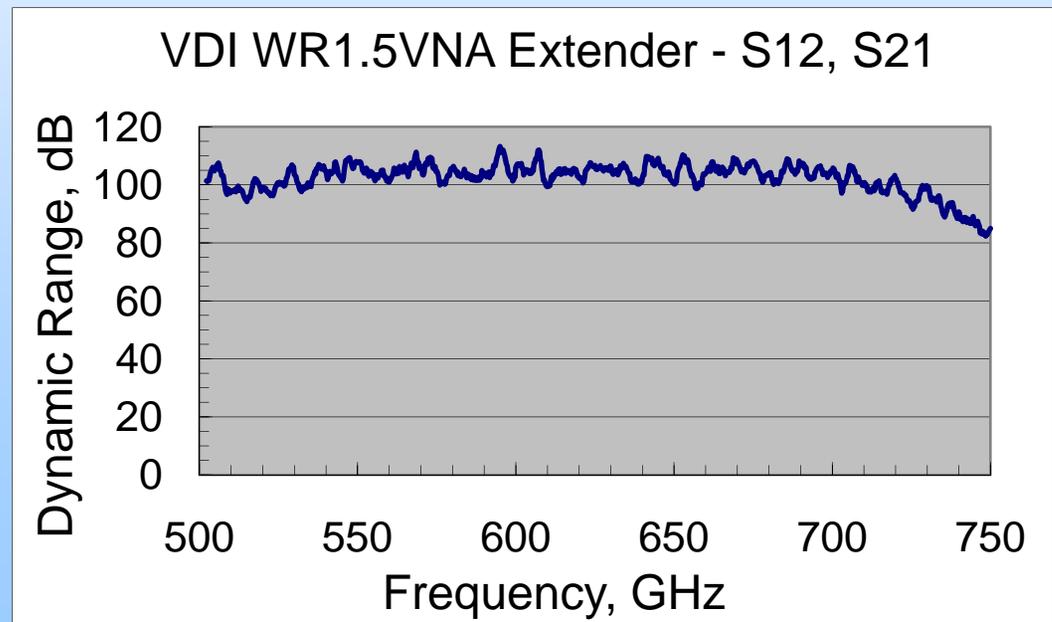
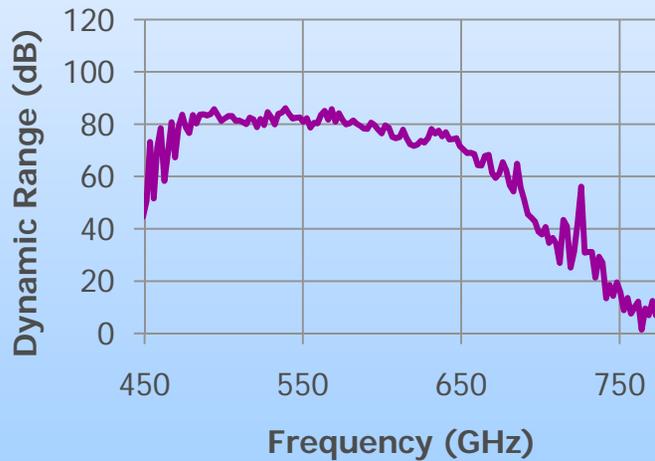


WR-1.5 VNA Extender

WR-1.5 Prototype



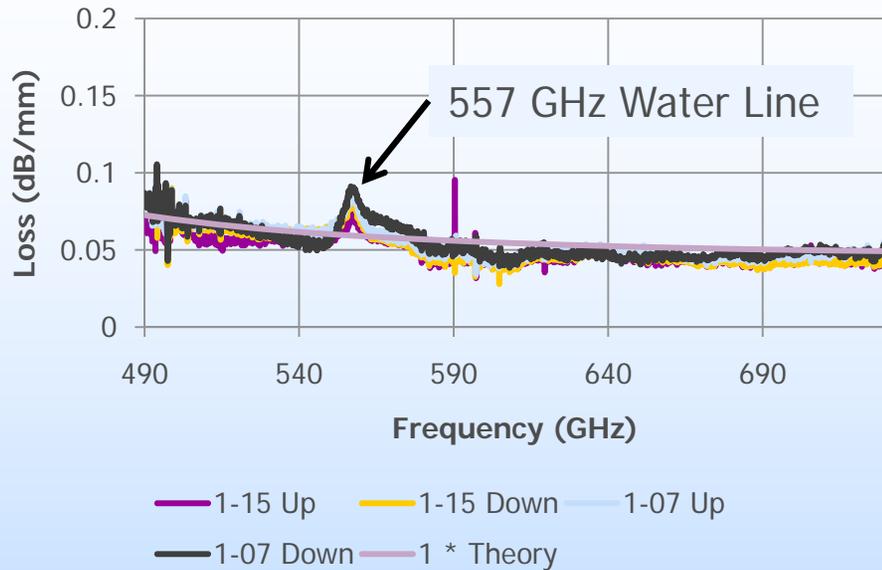
Packaged WR-1.5 Extenders



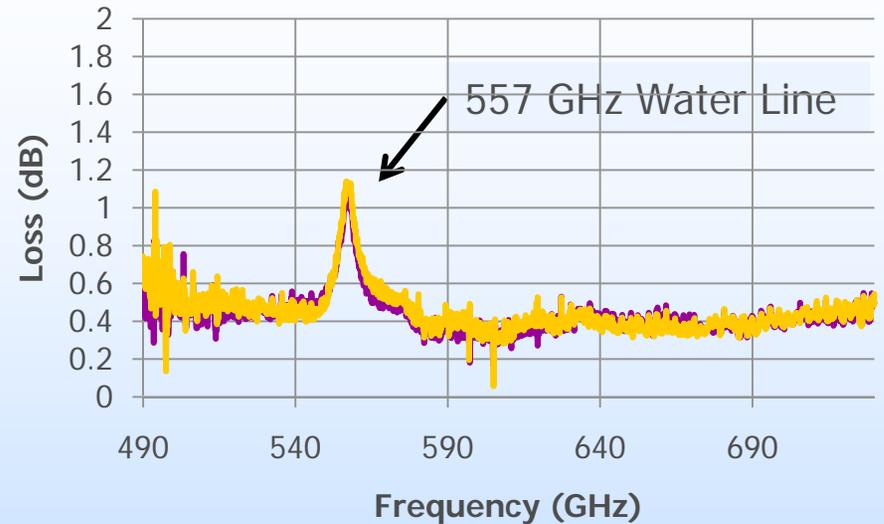
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WR-1.5 Measurements

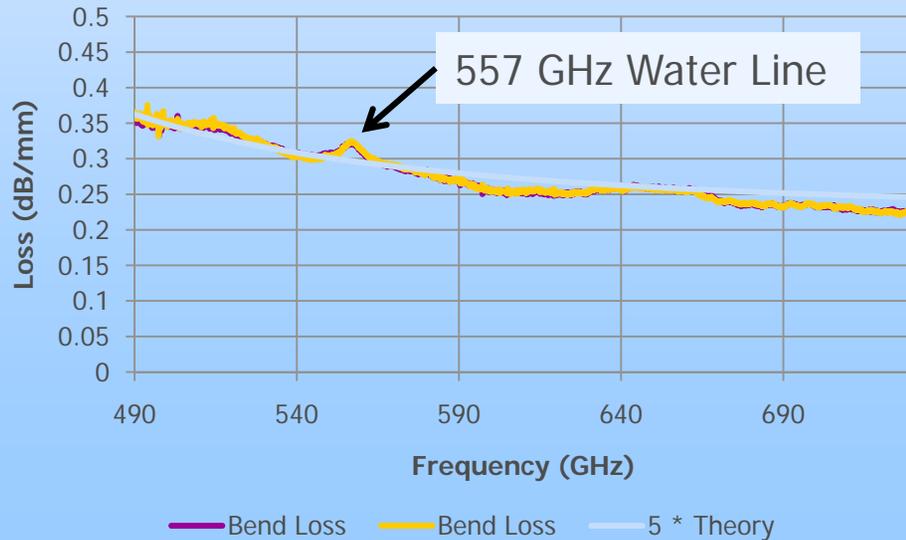
WR-1.5 Waveguide Loss (E-plane Split)



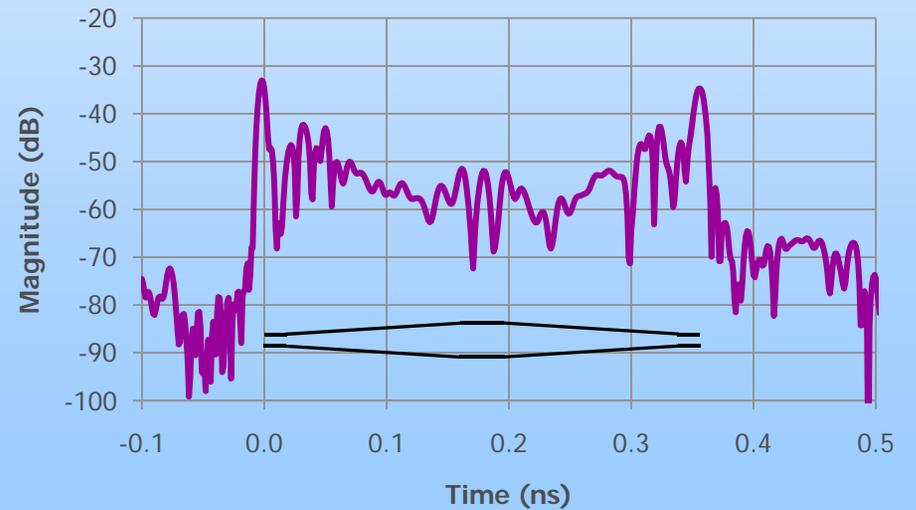
Loss for WR-1.5 to WR-10 Waveguide Taper



WR-1.5 Waveguide Loss (H-Plane Split)

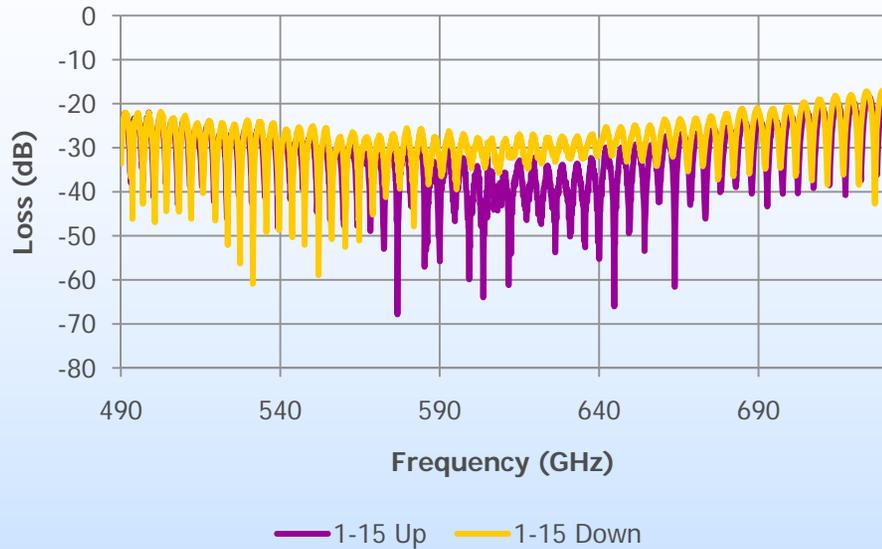


Time Domain Reflection for Back-to-Back Tapers

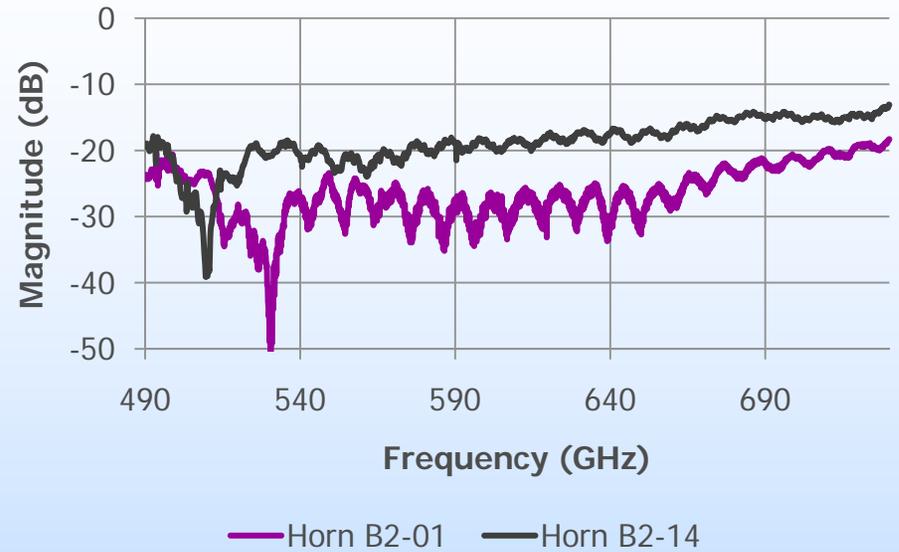


WR-1.5 Measurements

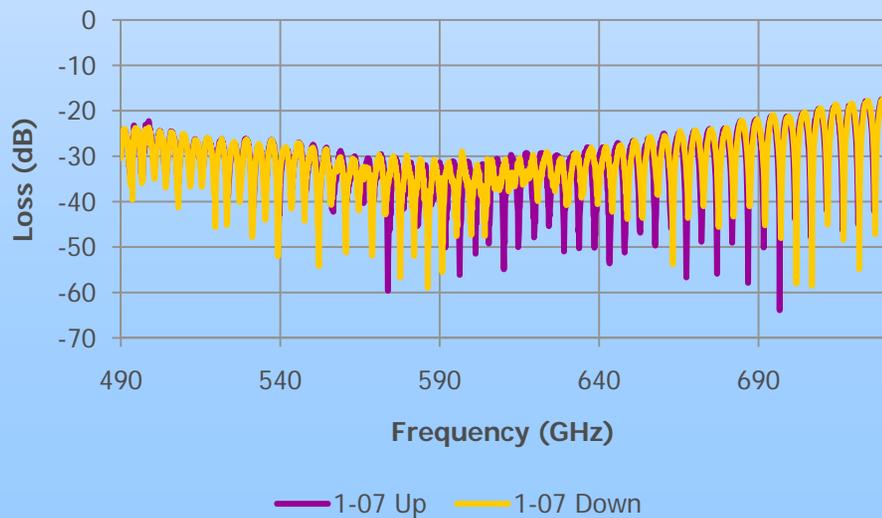
WR-1.5 Waveguide Reflection - B1-15



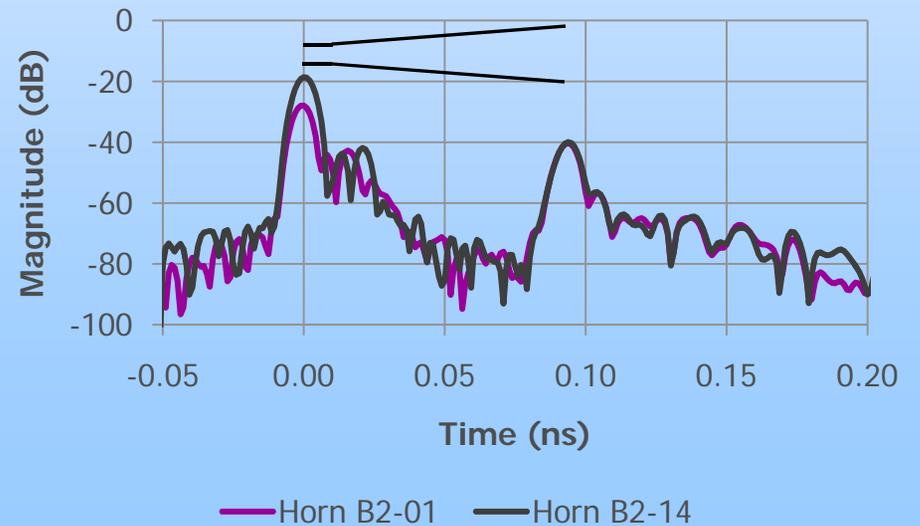
Diagonal Feedhorns



WR-1.5 Waveguide Reflection - B1-07



Time Domain Reflection for Horns

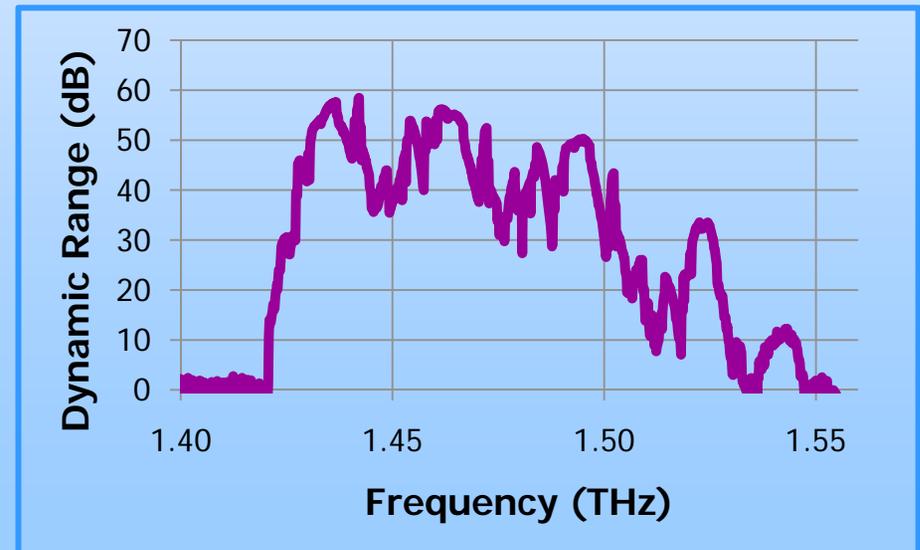
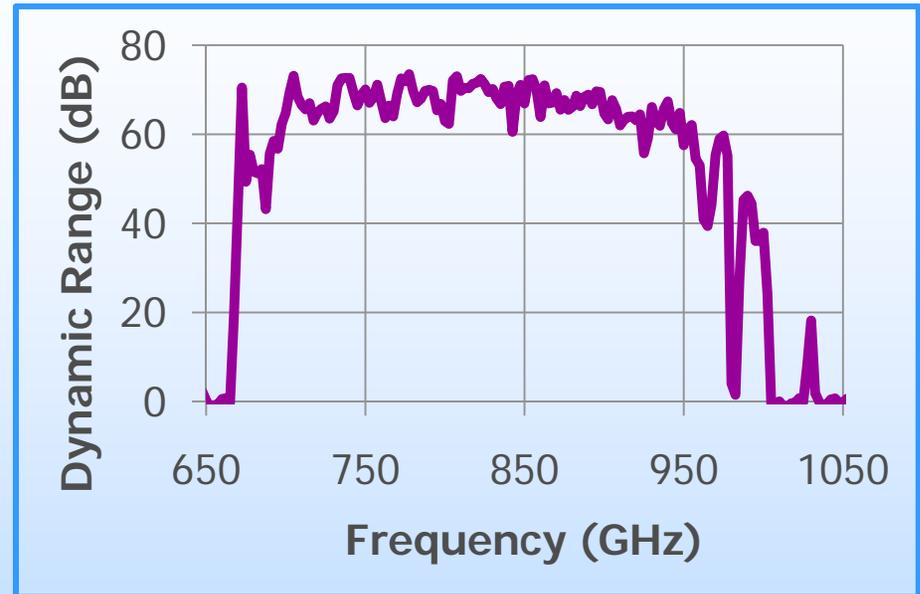


Conclusions

- 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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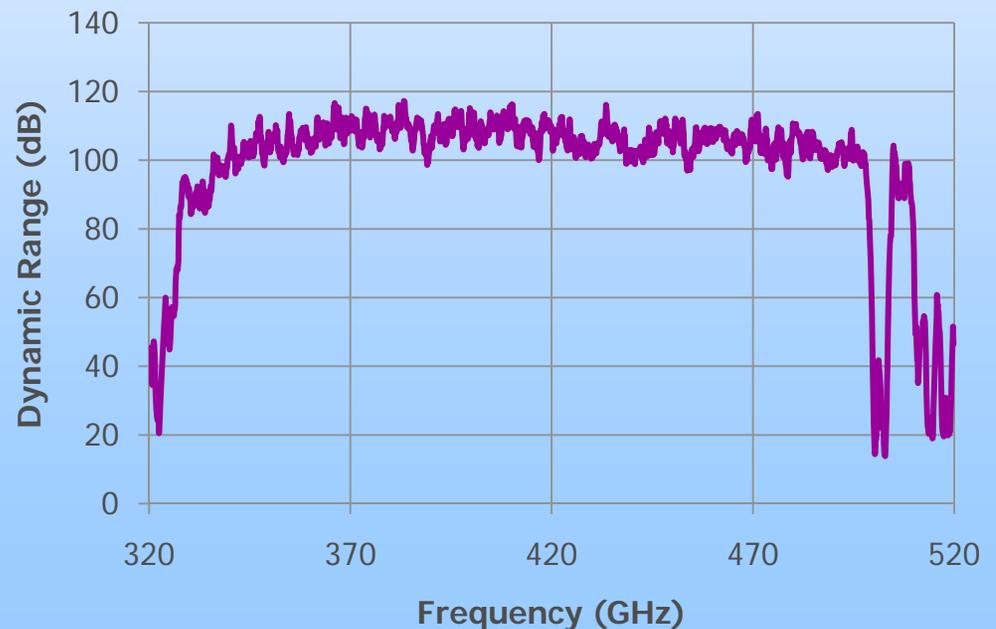
WR-2.2 VDI VNA Extender



- Dynamic range 100 dB typical
 - With 10 Hz IF Bandwidth
 - Output Power 10-20 uW typ.
- Excellent amplitude and phase stability
 - +/-4degrees and +/-0.4dB, under normal operating conditions

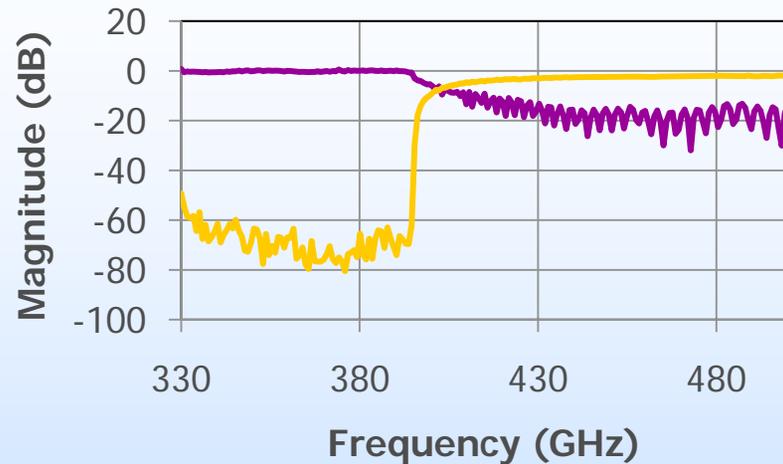


WR-2.2 Extender Dynamic Range (10 Hz)

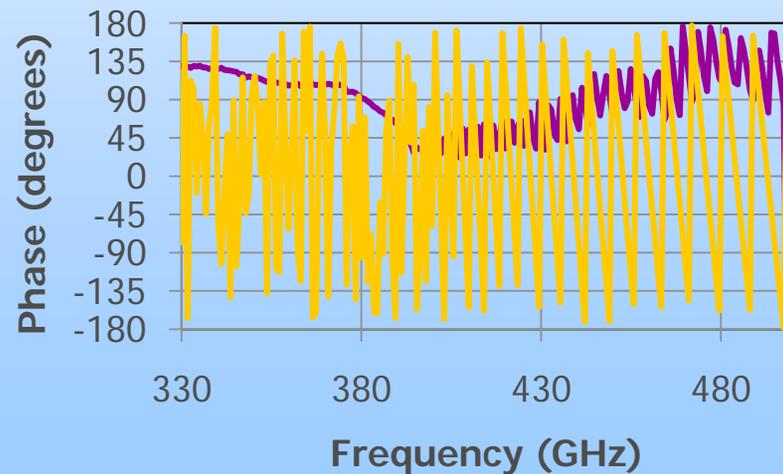


WR-2.2 Measurements

Measurement of Waveguide Cutoff

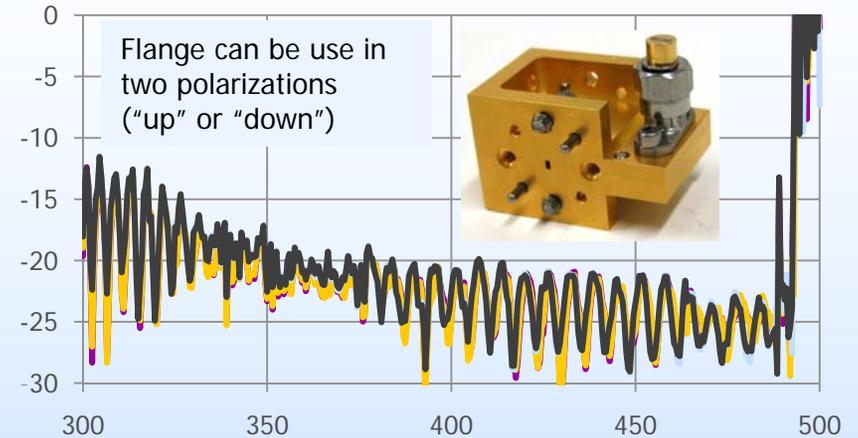


— S11 (dB) — S21 (dB)

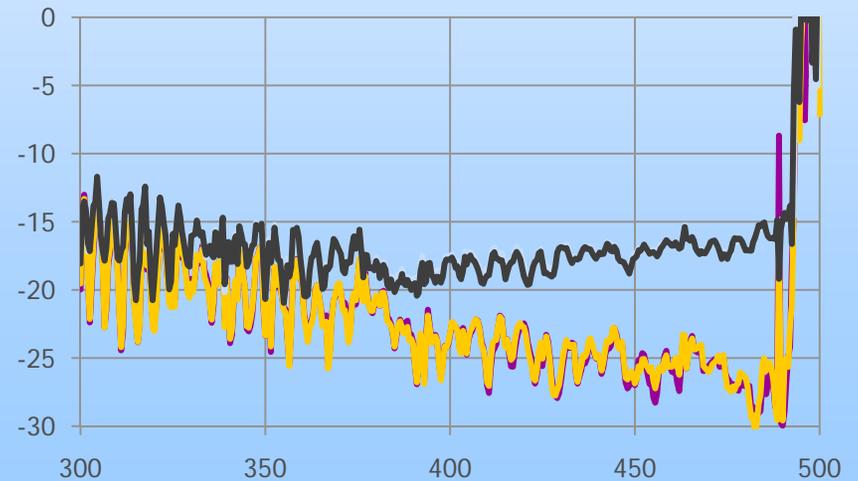


— S11 (deg) — S21 (deg)

Flange Orientation



— Load B106 Up (a) — Load B106 Up (b)
— Load B106 Down (a) — Load B106 Down (b)



— Load B107 Up (a) — Load B107 Up (b)
— Load B107 Down (a) — Load B107 Down (b)



VDI Extenders - Summary of Specifications

Waveguide Band (GHz)	WR10	WR8.0	WR6.5	WR5.1	WR4.3	WR3.4	WR2.8	WR2.2	WR1.5		WR1.2	WR1.0
	75-110	90-140	110-170	140-220	170-260	220-325	260-400	325-500	500-700	700-750	600-900	750-950
Dynamic Range (BW=10Hz,dB,typ)	110	105	100	100	95	95	90	85	60	50	50	50
Dynamic Range (BW=10Hz,dB,min)	95	95	90	90	85	85	80	75	50	40	40	40
Magnitude Stability (\pm dB)	0.15	0.15	0.25	0.25	0.3	0.3	0.5	0.5	0.8	0.8	1	1
Phase Stability (\pm deg)	2	2	4	4	6	6	8	8	10	11	12	15
Test Port Power (dBm)	3	0	0	0	-6	-9	-16	-17	-25	-25	-27	-30
Directivity (dB)	30	30	30	30	30	30	30	30	30		30	30
Max. Dimensions (LxWxH, in)	11x5x3	11x5x3	11x5x3	11x5x3	11x5x3	11x5x3	11x5x3	11x5x3	11x5x3		11x5x3	11x5x3

Notes:

- * These results assume a through measurement with two TxRx Heads.
- * Extenders are compatible with both Agilent (PNAX) and Rohde & Schwarz (ZVA) VNAs. Initial tests with Anritsu were promising.
- * Standard extenders assume available input frequency up to 42.5GHz.
- * Specifications quoted here are "expected," and subject to change. These values have been demonstrated to 750GHz, and solid laboratory data exists to 950GHz.
- * Stability is for 1 hr after 1 hr warm-up, in stable environment with ideal cables.
- * Extenders beyond 750GHz are under active development and full-band performance is not yet guaranteed.

Options Available (contact technical@vadiodes.com):

- 1) Reduce input frequency to below 24GHz.
- 2) TxRx and Tx extenders up to WR2.2 can include a micrometer driven variable attenuator.
- 3) Increase Test Port Power (in some bands or partial bands).
- 4) Non-standard frequency bands.
- 5) VDI will work with customers to reconfigure any extender to meet specific needs.

Head Configurations:

- TxRx:** Transmitter with two Receivers (Reference and Refl. Measurement), and two couplers.
Two TxRx heads are required for full two-port measurements
- Tx:** Transmitter with Reference Receiver and one coupler.
Rx: Measurement Receiver.

Notes:

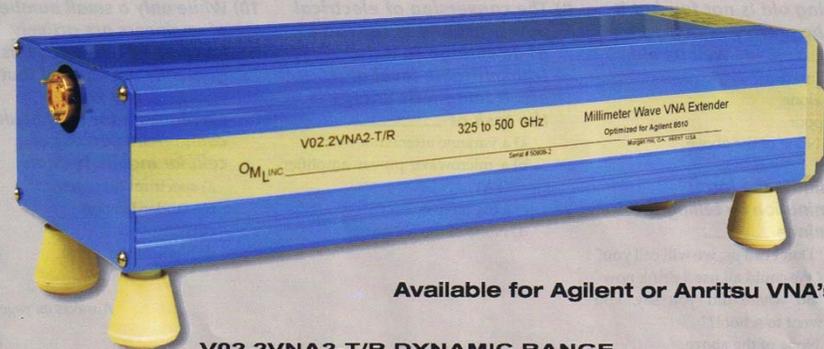
All extender heads include a precision Test Port.

Competitor #1

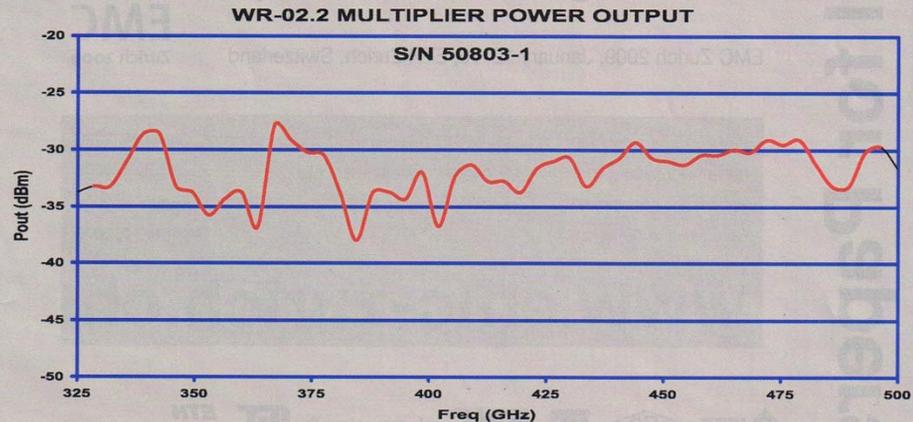
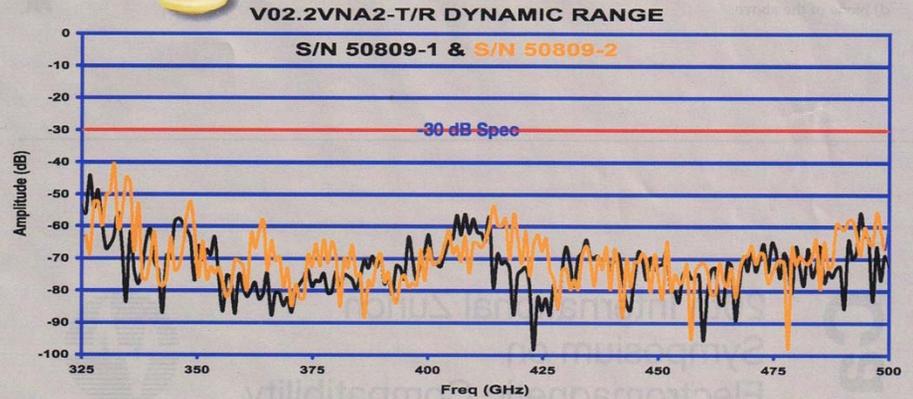


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Available for Agilent or Anritsu VNA's



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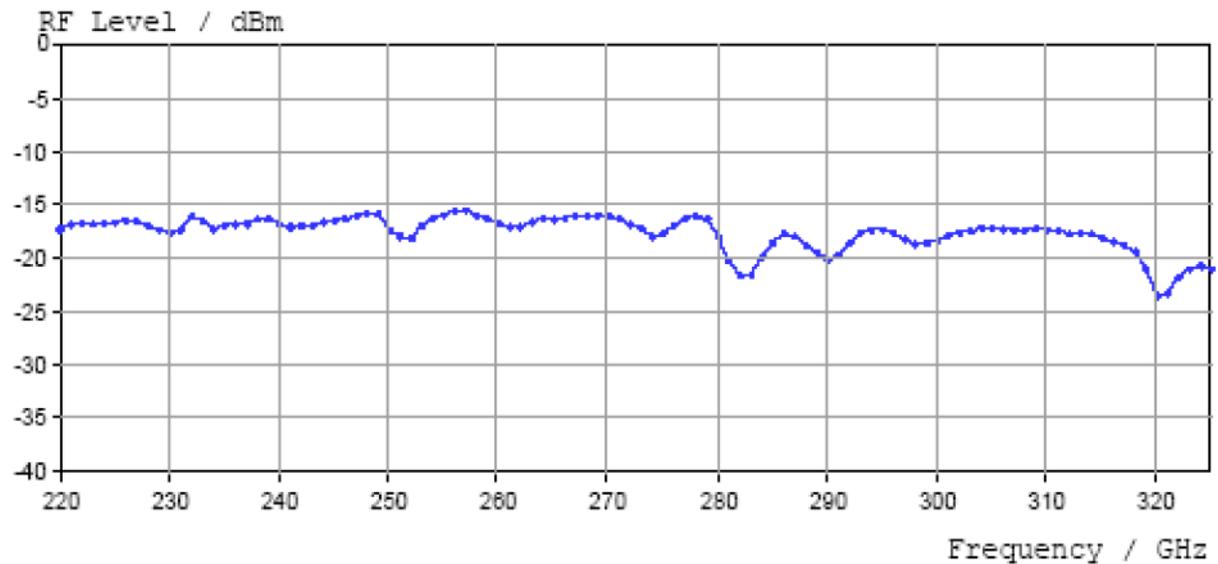
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Competitor #2

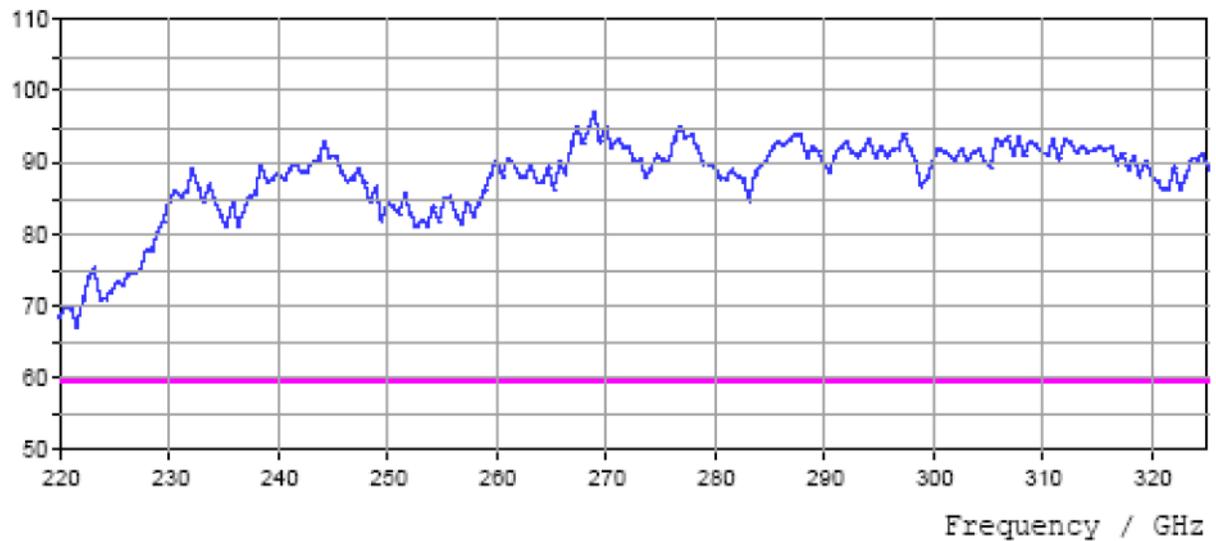
Published
performance
only to
325GHz



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Test port output power versus frequency of the R&S®ZVA-Z325



Dynamic range versus frequency of the R&S®ZVA-Z325

Uniqueness of VDI VNA Extenders

- 1) Owing to their use of advanced diode technologies and circuit designs, VDI achieves unprecedented transmit power and receiver sensitivity above 300GHz.
- 2) VDI's test-port power in the WR2.2 waveguide band (-17dBm) greatly exceeds that of OML, and is equal to that of R&S at WR3.4.
- 3) VDI's guaranteed minimum dynamic range at WR2.2 exceeds OML's typical dynamic range. Further, VDI has now increased their typical dynamic range to 100dB for WR2.2, greatly surpassing the competition.
- 4) VDI extenders to 750GHz also now achieve 100dB (typical), and laboratory prototypes achieve respectable performance (DR>70dB) to at least 950GHz. Extenders for WR1.2 and WR1.0 will be offered in the near future.
- 5) VDI meets or exceeds other manufacturer's specifications for magnitude and phase stability.
- 6) VDI's extenders are compatible with all modern VNA systems, and can connect directly to the front panel of a 4-port VNA, eliminating the need for a costly controller (VDI just needs access to both synthesizers and the IF inputs).

