Ultra High Frequency Measurements

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IEEE EMC – DC / N. VA Chapter
31 January 2012

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Overview

- We'll review Millimeter Wave Signal Measurement Systems (MSMS) necessary to measure in-band and outer-band radiated spurious emissions using Spectrum Analyzers (SAs) and Harmonic mixers
- We will only consider systems with a SA and a Harmonic mixer configuration in the 50GHz to 200GHz range, for several reasons:
  - SAs are readily available for direct coaxial measurements below 50GHz
  - The 50GHz to 200GHz range requires making measurements with external Harmonic mixers where there are measurement challenges
  - Most Regulator Agencies, especially the FCC, requires performing test measurements only up to the 5th harmonic of the carrier or to 200GHz, when the carrier operates above 30GHz

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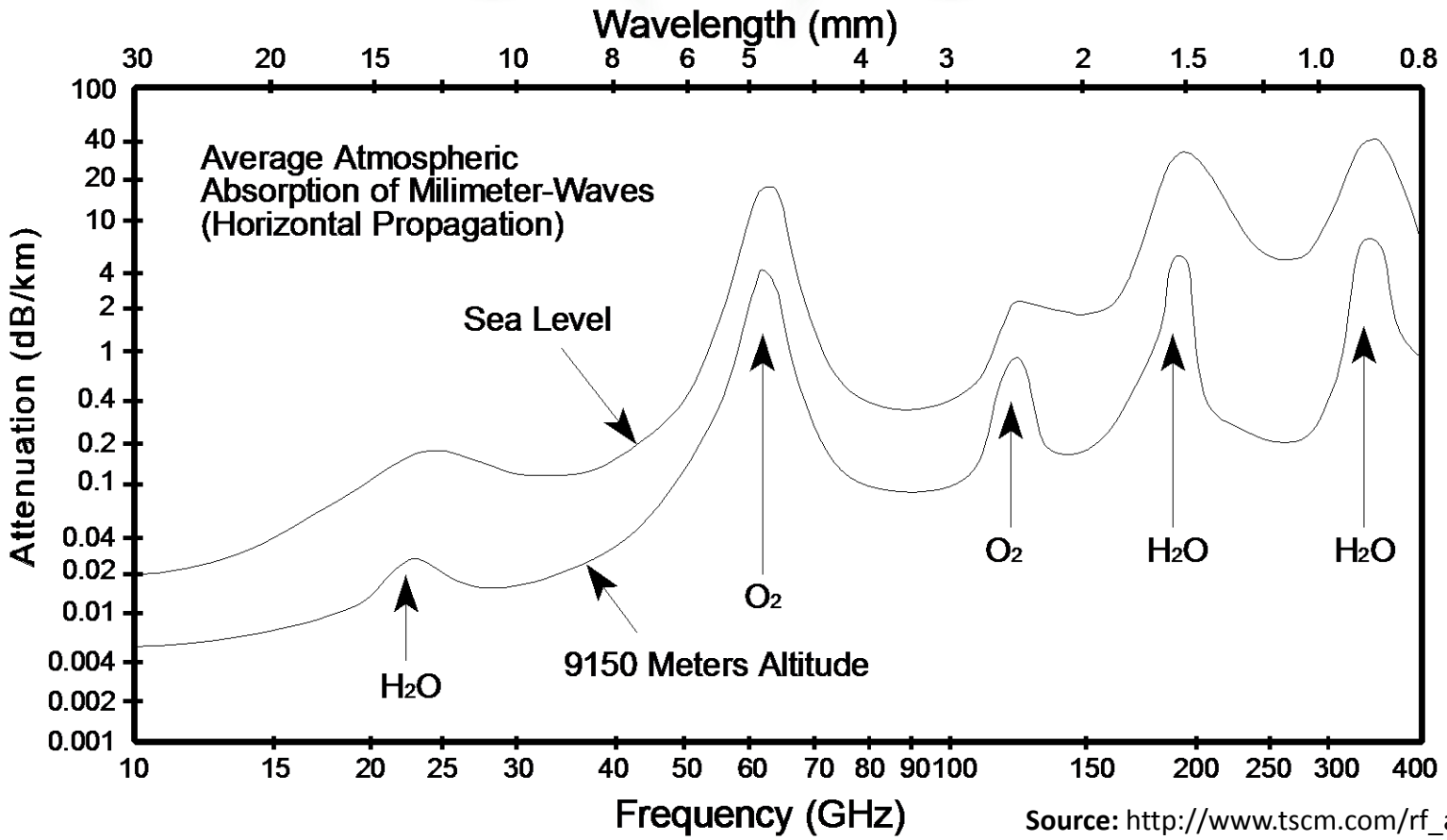
Frequency Range Definitions

- Microwave
  - Microwave frequencies covers the frequency ranges from 3GHz to 30GHz
- Millimeter Wave
  - Millimeter wave frequencies or Extremely High Frequencies (EHF) covers the frequency ranges from 30GHz to 300GHz with wavelengths from 10 millimeter to 1 millimeter
- Terahertz
  - Terahertz electromagnetic radiation or sub-millimeter range is from 300GHz to 3000GHz frequency range, with wavelengths from 1 millimeter to 0.1 millimeter

Transmission Characteristics of Millimeter Wave Signals

- Atmospheric Windows
  - Frequencies were gaseous attenuations are a minimum.
  - The main atmospheric windows are centered on 35GHz, 94GHz, 140GHz, 220GHz, etc.
- Atmospheric Absorption Bands
  - The regions with maximum atmospheric absorption.
  - The main absorption bands are around 60GHz, 120GHz, 182GHz, etc.
- Absorbing Characteristic
  - Gases that constitute the atmosphere attenuate millimeter wave signals at different rates for different frequencies.
  - Attenuation not only increases, but also is more dependent upon absorbing characteristic of H_2O, O_2 and other gases

Atmospheric Absorption of Millimeter Waves Signals



Source: http://www.tscm.com/rf_absor.pdf

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Millimeter Wave Measurement Systems

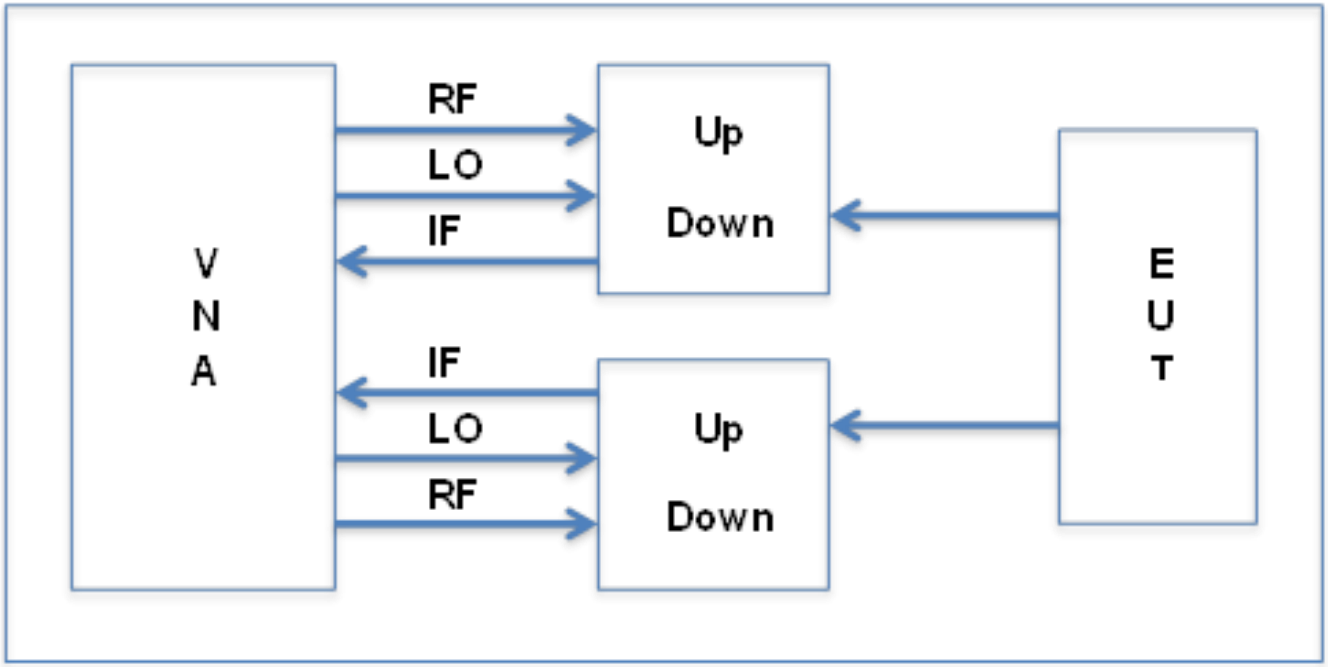
- Transmitter & Receiver based
  - Network Analyzers
  - Vector Network Analyzers
- Receiver based
  - Spectrum Analyzers
  - Signal Analyzers
  - Vector Analyzer

Transmitter & Receiver Based Measurement Systems

VNAs are configured with Up/Down Converters for various measurement applications including RCS and HRR radar applications.

- The first step in a VNA conversion is to multiply the microwave frequencies typically from below 20GHz for most manufacturers to the millimeter wave frequency band
- With VNAs the signal phase has to be determined and calibrated at the EUT's millimeter wave signal frequencies
- The Up/Down Converters (Head-ends) contain dual directional couplers and mixers in which the incident and reflected waves are down-converted to the VNA's IF input

Typical VNA Configuration



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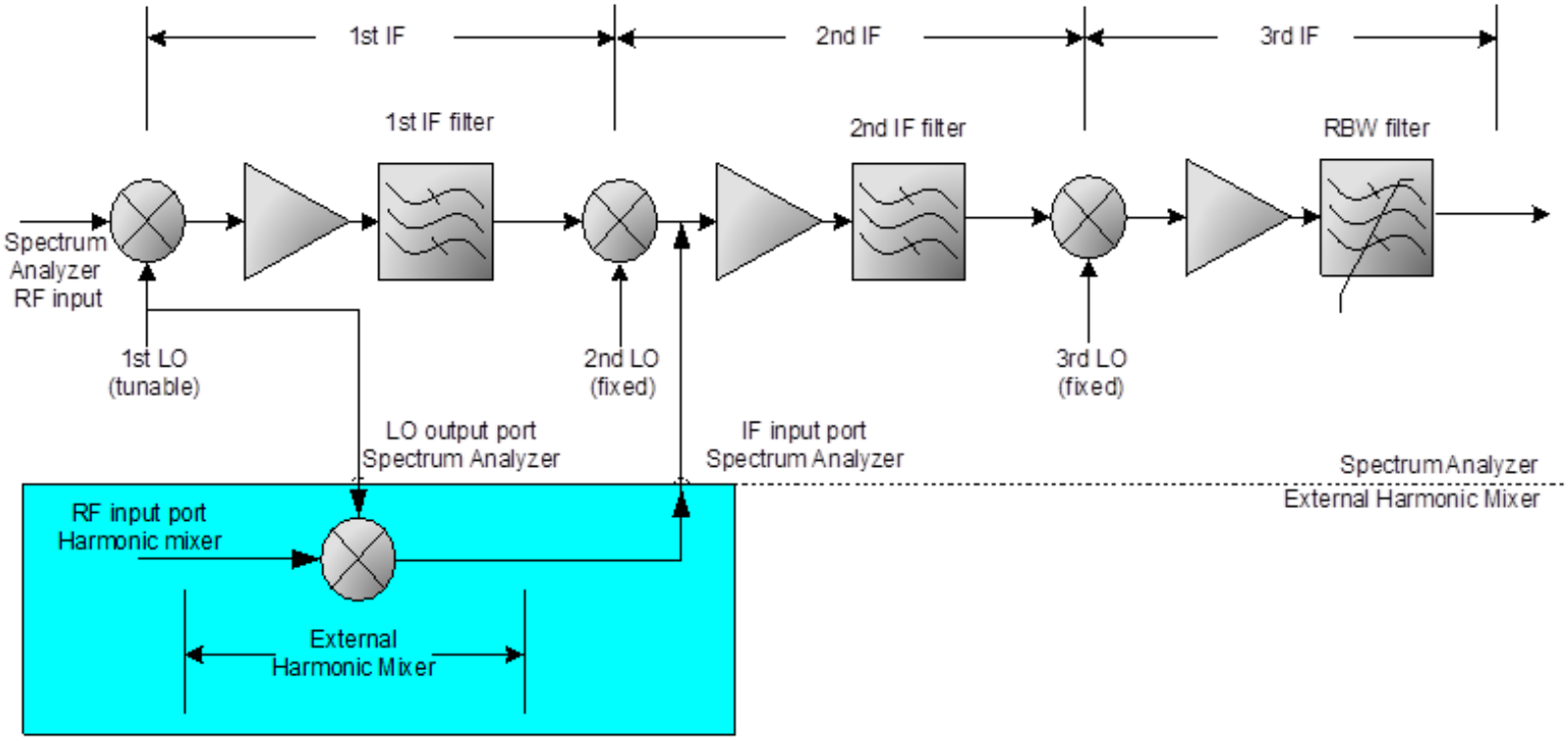
Receiver Based Measurement Systems

- Spectrum Analyzers (scalar), harmonic mixers are used to down-convert the millimeter wave signal to the SA's IF
- Vector Analyzers have wide bandwidth digital IFs
  - Typically 30MHz – 80MHz to analyzer vector modulations of millimeter wave signals (OFDM, LTE, etc.)

SA with Harmonic Mixer Measurement Systems



Source: Rhode & Schwarz

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Internal Mixing

- First element in a SA's signal path is the Internal Mixer
- Translates the input frequency into a range that the SA can use
  - Translated to the Intermediate Frequency stage
- Placed close to the input signal
  - To improve sensitivity and to avoid increase path loss with increasing frequency
  - Followed by attenuators and optional pre-amplifiers
- The SA controls all operations, including down conversion, digitizing and screen display
- Microwave and millimeter wave harmonic mixing
  - Requires a band-pass pre-selector (YIG) filter is tune to the frequency of the signal being measured to avoid the production or display of unintended mixing products

External Mixing

- First element in the SA's signal path is the external mixer
  - It typically does not include attenuators, an optional pre-amplifier or a pre-selector
- The SA provides the Local Oscillator (LO) and the external mixer provides an IF to the SA
- The IF result from mixing the frequency of the signal being measured and the LO's harmonics
- The external mixer typically connects to an antenna receiving the signal via a waveguide
  - Some mixers can be connected via coaxial cables

Some Waveguide Frequency Band Designation

Waveguide Standard	Band Designation	Frequency
WR-19	U band	40 - 60 GHz
WR-15	V band	50 - 75 GHz
WR-12	E band	60 - 90 GHz
WR-10	W band	75 - 110 GHz
WR-8	F band	90 - 140 GHz
WR-6	D band	110 - 170 GHz
WR-5	G band	140 – 220 GHz

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Harmonic Mixers

- Single Diode Mixers
  - Unbalanced and produce unsuppressed IF responses equal to the product of the RF input + LO for negative and positive products
  - This results in difficulty identifying the millimeter wave signal
- Double Diode Mixers
  - All recent Harmonic mixers are typically balanced with two diodes to suppress un-wanted harmonics mixing LO products

Double Diode Harmonic Mixers

- Using Even harmonic mixers
  - Odd LO harmonic mixing products are suppressed
- Using Odd harmonic mixers
  - Even LO harmonic mixing products are suppressed
- The degree of suppression is typically -20dBC
  - dependent on how well and “balanced” the mixer is designed.
- Cleaner Display
  - Higher order mixing products are suppressed because of lower unwanted IF energy levels, hence the signal is easier to identify
- Simpler to use
  - No need for bias
  - However, the two diodes increase the LO power requirement
- When using Harmonic mixers that are not from the same SA manufacturer, check the following:
  - Is the LO power from the SA to mixer within spec?
  - Does the mixer IF meet the SA’s IF input sensitivity?

IFs/LOs Incompatibilities from Known Manufacturers

Manufacturer	Series	IF (MHz)	LO (GHz)
Agilent/HP	HP8566B[1]	321.4	3.2 - 6.8
	E444XA	321.4	2.9 - 7.0
Rhode & Schwarz	FSV/FSVR	729.9	7.7 - 15.3
	FSEK/M	741.4	7.5 - 15.2
	FSIQ	741.4	7.5 - 15.2
	FSU/FSQ	440.4	7.0 - 15.5
	FSM/ESMI[2]	221.4	5.2 - 13.1
Anritsu	MS 2830A	1875.0	5 - 10

1. HP8566B requires the HP 11975A LO amplifier for proper operation of the HP11970X series mixers.
2. R&S FSM/ESMI requires the R&S FS-Z30 LO amplifier for proper operation of the R&S mixers.
3. Consult the SA's Operational Manual on how to set or change harmonic numbers including compatible mixers.

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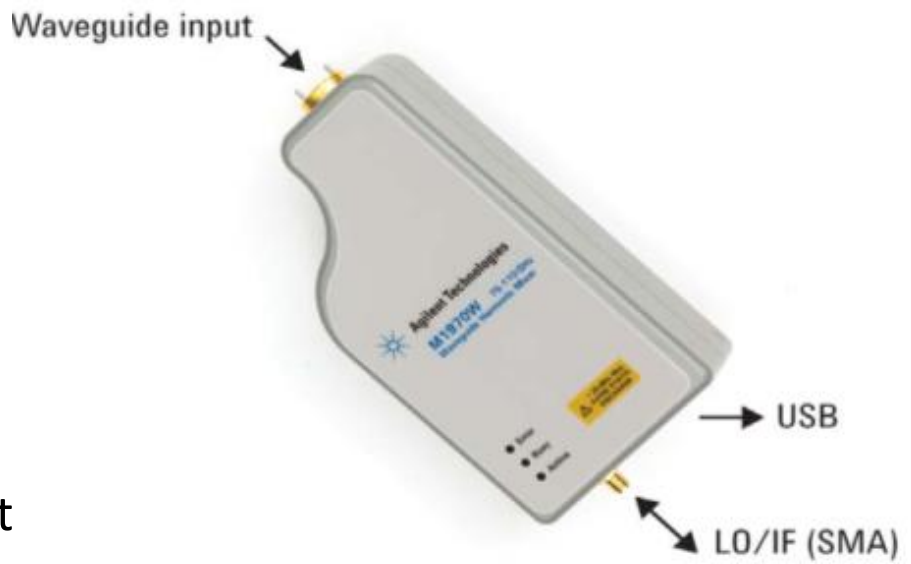
Smart External Mixers

- Improved Conversion Loss Value, DANL and accuracy
  - USB plug-and-play
  - Auto detection & parameter download
  - Auto configure frequency range, harmonic number
  - Auto amplitude correction
  - Auto LO power adjustment with up to 3m-cable loss
  - Single coaxial IF/LO interface



Source: Agilent

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Cables

- Use the appropriate RF cables at the right frequencies
- For measurements with SAs up to 50GHz, cables must be low loss at the interested frequencies
- Bends, kinks, poor connectors on cables cause are responsible for moding
- Moding (TE_{01}) is the excitation of the first circular waveguide propagation mode in the coaxial structure
- Dropouts are caused due to moding in which amplitude errors and phase errors are exacerbated

Connectors

- 2.92mm, 3.5mm and SMA connectors look similar; they are not 100% compatible
  - Small Impedance discontinuity: SMA connectors can be mated with both 3.5mm and 2.92mm connectors
- Differences: 3.5mm and 2.92mm (K) are precision connectors with air dielectric
  - SMA uses a PTFE (Polytetrafluoroethylene) dielectric, it is not a “precision” connector designed for repeated use
- Connector insertion loss repeatability is 0.002dB (DC to 1GHz), 0.006db (1 to 12GHz)
- Its very important to:
  - use torque wrench on connectors
  - use connectors from reputable manufacturers

Torque Values and Wrench Sizes

Connector	Coupling Torque (N-cm/in-lb)	Width Across Coupling Nut Wrench Flats	Agilent Torque Wrench #	Agilent Open Ended Wrench # & Size[1]	
7 mm	135/12	3/4"	8710-1766	8710-1770	1/2"
Type-N 50 ohm [2]	135/12	3/4"	8710-1766	8710-1770	9/16"
Type-N 75 ohm [2]	135/12	3/4"	8710-1766	8710-1770	9/16"
3.5 mm standard [3]	90/8	5/16"	8710-1765	8710-1761	7 mm
				8710-0510	5/16"(8 mm)
3.5 mm NMD [4]	90/8	20 mm	8710-1764	8710-1770	9/16"
				08513-20014	Spanner Wr.
2.92 mm standard	90/8	5/16"	8710-1765	8710-1761	7 mm
2.4 mm standard [3]	90/8	5/16"	8710-1765	8710-1761	7 mm
				8710-0510	5/16"(8 mm)
2.4 mm NMD [4]	90/8	20mm	8710-1764	8710-1770	1/2"
				08513-20014	Spanner Wr.
1.85 mm	90/8	5/16"	8710-1765	8710-0510	5/16"(8 mm)
1.0 mm	34/3	6 mm	8710-2079		
SMA [5]	56/5	5/16"	8710-1582		

Source: Agilent

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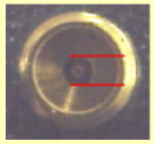
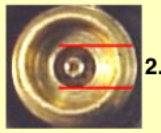
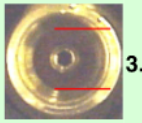
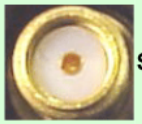
Mating Connectors

Connector Type	Frequency Range	Mates with...	Notes
 **1.0 mm**	To 110 GHz	1.0 mm	Much smaller connector than any of those below.
 **1.85 mm**	To 70 GHz	2.4 mm	The outer thread size of the 1.85 and 2.4 connectors is bigger than SMA, 3.5, and 2.92. This makes the area of the outer conductor mating surface look very large compared to the relatively small air dielectric.
 **2.4 mm**	To 50 GHz	1.85 mm	The 1.85 mm connector that is manufactured at Agilent has a **groove** in the male nut and female shoulder to distinguish these two connector types.
 **2.92 mm**	To 40 GHz	3.5mm and SMA	These two connectors use the same center pin.
 **3.5 mm**	To 34 GHz	2.92 mm and SMA	
 **SMA**	To 24 GHz	2.92 mm and 3.5 mm	Uses a Teflon dielectric.

Source: Agilent

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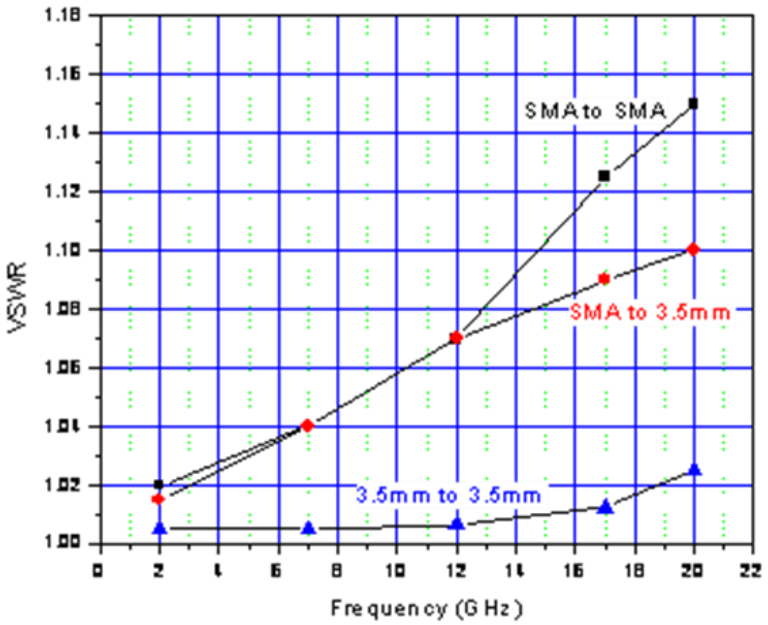
Mating Connector VSWR Test

- Small differences in the center conductor diameter of all three types
- SMA male with too long a center pin will damage a 3.5mm or 2.92mm connector, better to use a connector gauge
- Interesting tests indicates that SMA connectors mated with 3.5mm connectors might provide better overall performance than two mated SMA connectors



VSWR - Mating SMA-SMA and 3.5mm Connectors (Maury Microwave)

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Other Measurement Equipment

- Signal generator
  - Extending the frequency range by multiply or up-converting
  - Scalar modulation & measurements multiply the range from 10-20GHz $\rightarrow$ 75-110Gz
  - Vector modulation requires an up-converter to keep phase in millimeter wave relative to the original phase
- Power Meters
  - Millimeter wave power sensors required; Millitech makes an HP 432 compatible thermistor type (-20 to +10dBm) mount for W/G
  - Boonton has power meters with Millitech sensors up to 325GHz
  - Used Anritsu thermistor are still sought after, they are the most stable up to 220GHz

Calibration of Measurement Equipment

- Calibration of power sensors
  - Calibration is still a problem in millimeter wave signals
  - Harmonic mixers start to compress at -20dBm
  - NIST has traceability only to 110GHz, above 110GHz you are on your own as far as traceability
  - TRW and Hughes in CA may be a source but without traceability
- Millimeter Wave Signal Calibration
  - Ideally calibrate the spectrum analyzer/mixer combination with a know amplitude narrow bandwidth source at the frequency of interest

71GHz Gun Diode Demo

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Questions & Comments

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