The Advancement of THz Test & Measurement Equipment for 5G, 6G and Beyond

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Introduction : THz Applications

Basic Science has been a traditional driver of THz technology development

- Astronomy, Physics, Chemistry, Fusion Plasma, …

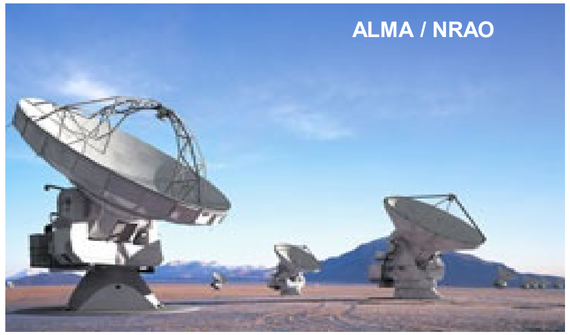
Commercial applications for THz are coming quickly, fueled by rapid progress in THz transistors

- SiGe, Si CMOS, GaN, InP, …
- THz transistors to > 1 THz

Application examples:

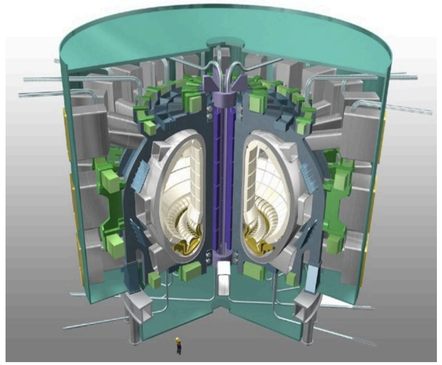
- Concealed Weapons Detection, Weather Forecasting, and
- Wideband & Secure Communication (5G, 6G, ….)

Radio Astronomy



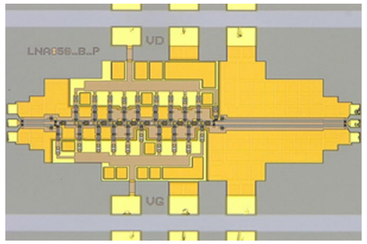
science.nrao.edu/facilities/alma

Fusion Plasma



ITER

850 GHz Amplifier



NGC

Concealed Weapons

thruvision.com

6G: Communications above 100 GHz

Steady growth in interest in 100+ GHz communications

Numerous companies (& countries) are pushing “6G”

- Ericsson, Intel, Sony, NTT, Intel, …
- US, China, EU, South Korea, Japan, …

Varied proposed applications

- Micro/Macro-Cell Backhaul, Events, Ports, Airports, Fiber Closure, …

World Radiocommunication Conference (WRC) November 2019

- Fixed and mobile allocations made up to 450 GHz

Note that we are in the early stages, with product not estimated to appear before 2030…

Beyond 5G: Sony, NTT and Intel to form 6G partnership

Advanced chips, plus phones that need just one charge a year, are on agenda

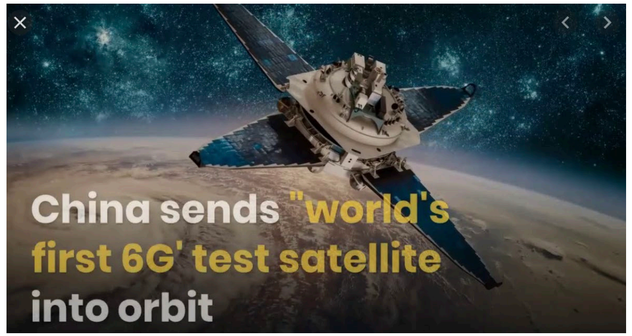
SONY NTT intel

6G WIRELESS SUMMIT
Levi • Lapland • Finland
24-26 March 2019

Nokia, Ericsson, and SK Telecom collaborate on 6G research

Race for 6G: South Korea and China off to early leads

Japan plays catch-up via infrastructure, and US tries to gain ground with chips



Test & Measurement above 100 GHz

Wide variety of devices under test

- Packaged devices, on wafer, differential, over-the-air testing, …

Wide variety of test needs

- S-parameters
- Noise Figure
- Intermodulation distortion
- IQ performance
- System level ACPR and EVM
- Antenna patterns
- Emissions testing
- …

How can the wide variety of available microwave test & measurement equipment be extended to mmWave & THz…

Microwave Test & Measurement Instrumentation

Spectrum Analyzer

Signal Generator

Vector Network Analyzer

Oscilloscope

VDI Core Technology

Use nonlinear Schottky diodes to extend the frequency range of traditional microwave electronics

Diodes fabricated at VDI

- Small captive cleanroom for the fabrication of devices

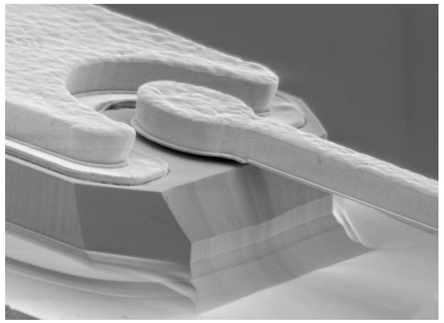
Waveguide-based components

- Waveguide have low loss line, e.g.:
  - Microstrip ~ 1 dB/mm @ 600 GHz
  - Waveguide ~0.08 dB/mm @ 600 GHz

Microwave Instrumentation

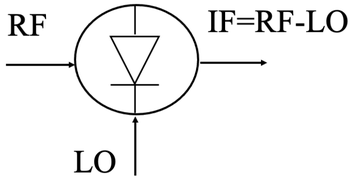
+

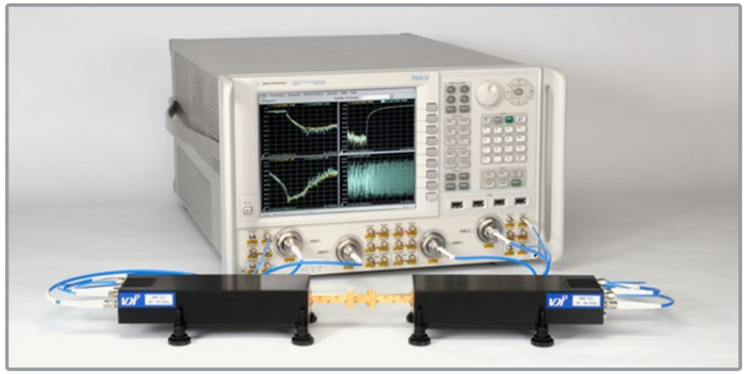
VDI Schottky Technology



Schottky Diode

Frequency Mixer





THz Instrumentation

THz Vector Network Analyzers (VNAs)

Extend the capability of microwave VNAs to THz

Enable measurements of S-parameters, compression, load-pull, …

VDI VNA Extenders available from 50 GHz to 1.5 THz

State-of-the-Art Test Port Power & Dynamic Range

Test Port Power: WR-10 (70-110 GHz) of 18 dBm

WM-3.4 (220-330 GHz) of 1 dBm

Dyamic Range: WR-5.1 (140-220 GHz) 120 dB

WR-1.5 (500-750 GHz) 100 dB

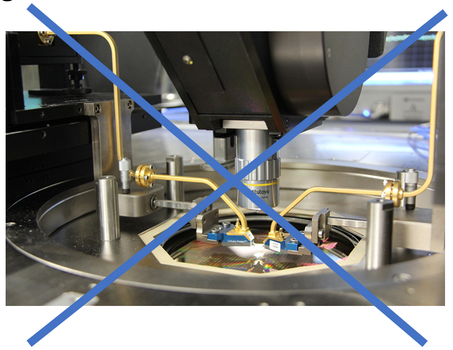
Compact form factor, suitable for probe stations

Enables close proximity to wafer

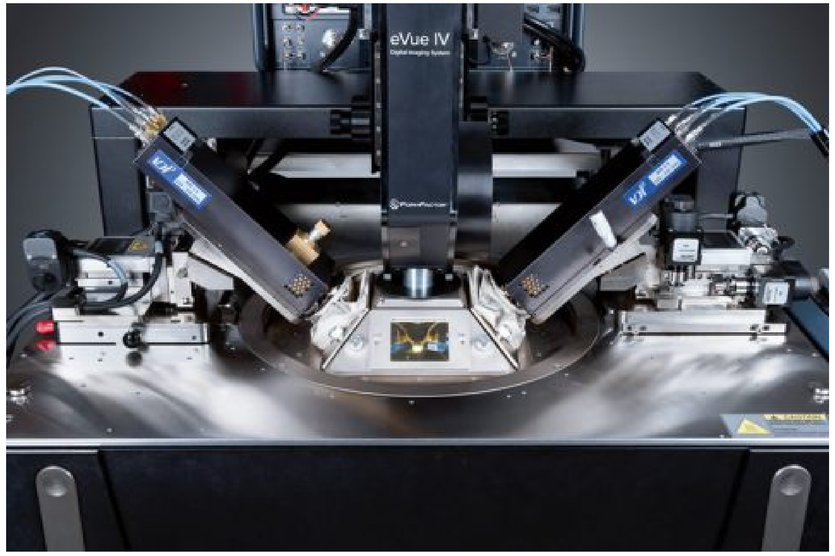
Lower losses → better performance

Mini-Extenders – 1.5” x 3” x 8.5”

Long Waveguide Runs → Reduced Performance



FormFactor Optimized On-Wafer Probing



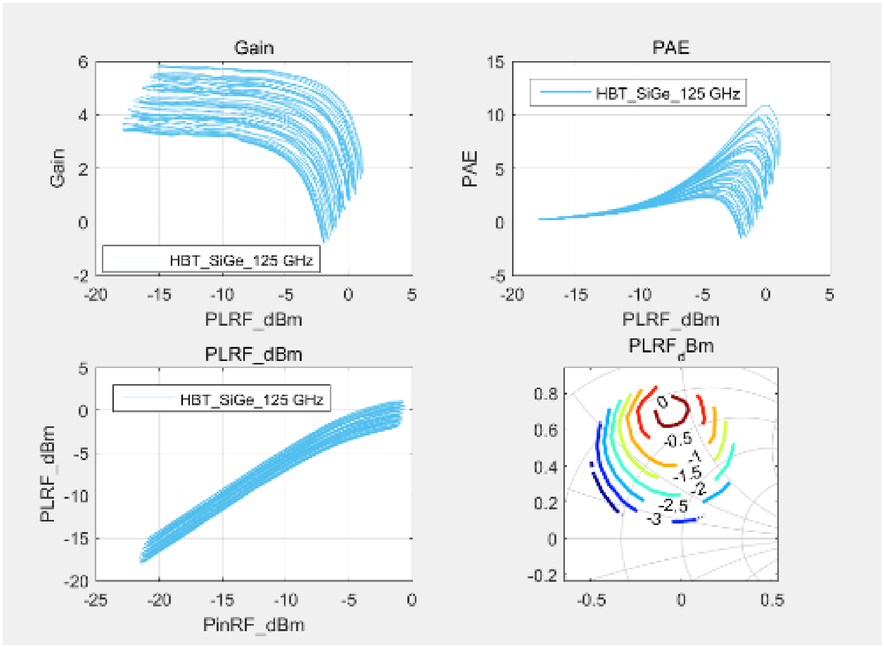
THz VNA Measurement Example - On-Wafer Load Pull with Maury

Improved test port power and compact size enable high performance active load pull with better impedance coverage

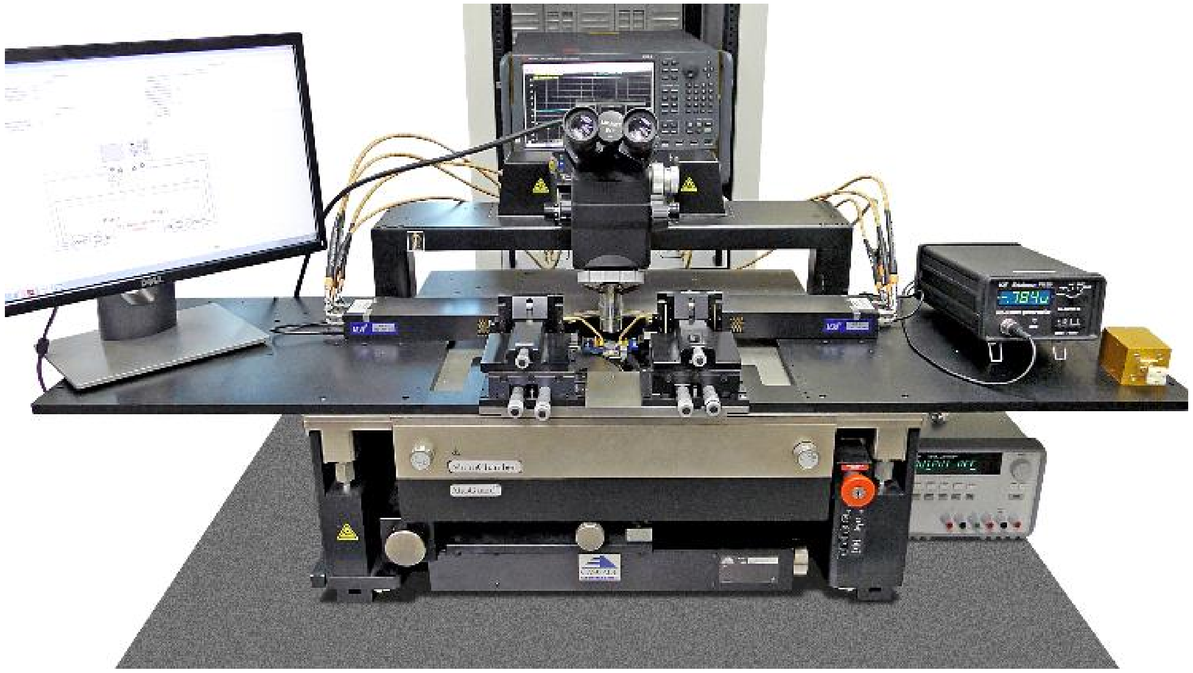
VDI Extenders with Maury Microwave and Vertigo Technologies enable high-resolution gain compression measurements and active load pull

Non-50Ω characterization and modeling, up to 1.1 THz!

SiGe 130 nm double finger HBT at 125 GHz (Maury/Vertigo)



Maury/Vertigo On-wafer Broadband Active Load Pull System



THz Spectrum Analyzer Extenders

THz Schottky mixers and multipliers allow the extension of spectrum analyzers into THz

- Excellent spectral purity & phase noise
- Low-order mixers → High sensitivy
  - Not a high harmonic mixer

Fullband down-conversion and frequency extension of microwave spectrum analyzers to 1.1 THz range

- Wide IF Bandwidth - up to 40 GHz

Compact Spectrum Analyzer Extenders – Mini-SAX & MixAMC-I

- Suitable for use on probe stations & over-the-air testing chambers
  - Can be mounted on e.g. robotic arms…
  - Lighter weight → faster scanning & less expensive motors

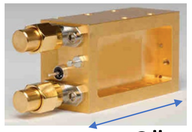
State-of-the-Art Displayed Average Noise Level (DANL)

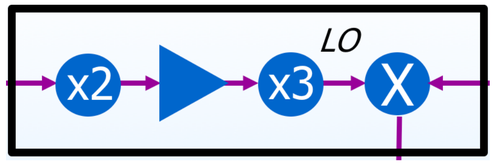
- 150 dBm/Hz to 750 GHz
- 135 dBm/Hz to 1.1 THz

Spectrum Analyzer

Mini-SAX

MixAMC-I





Wideband Signal Generation & Detection

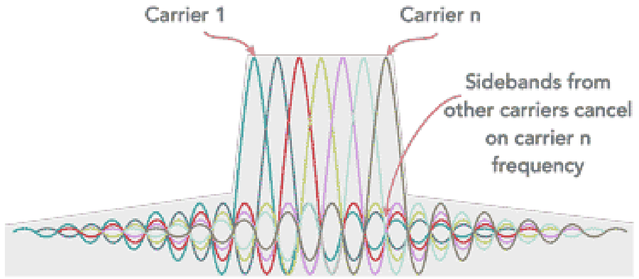
For digital communications the analysis and generation of wideband signals is crucial

- Channel bandwidths of 10+ Gbps
- Complex modulation schemes, e.g. OFDM, QAM, …

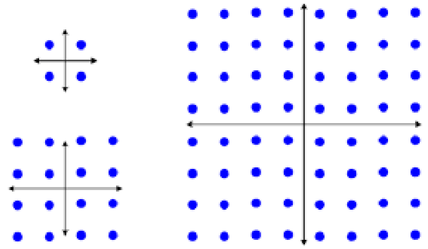
VDI has developed a series of compact up and down converters

- Receivers optimized to reduce distortion and intermodulation for wide band modulated signals.
- Excellent conversion loss and noise temperature performance.

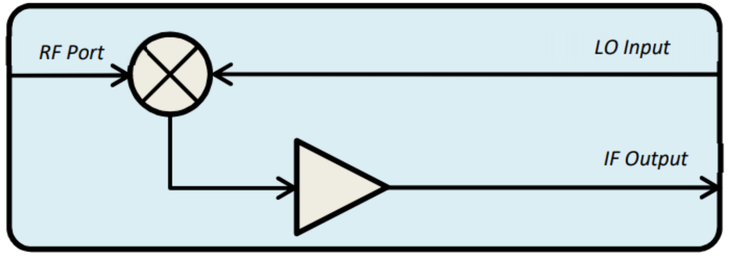
OFDM Signal



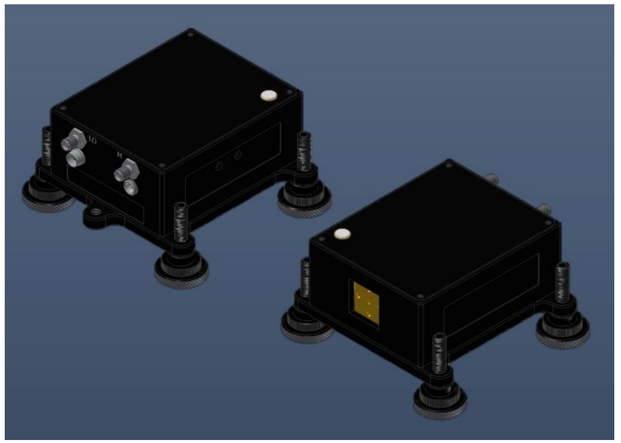
QAM Constellations



Compact Downconverter Schematic



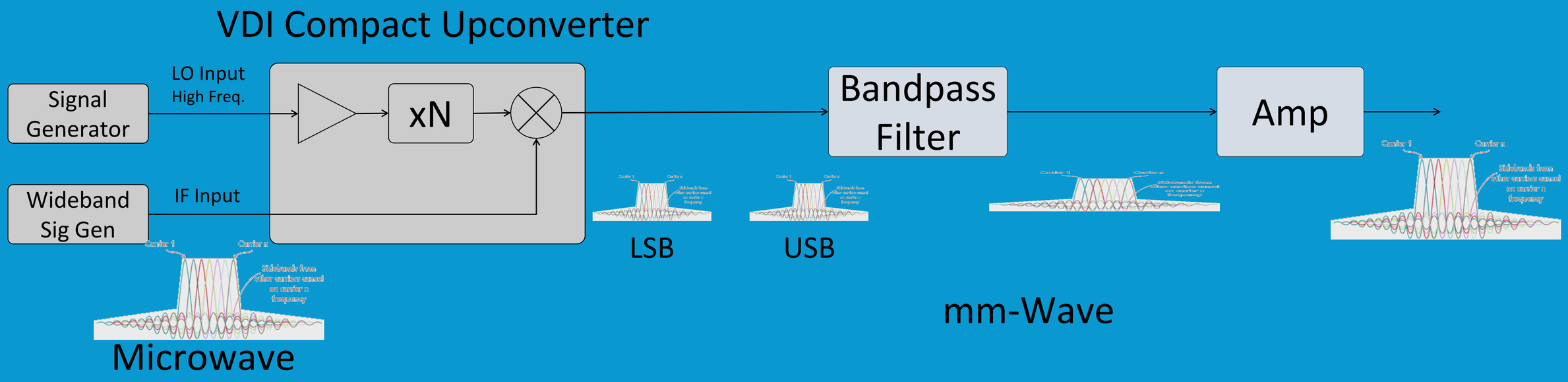
VDI Compact Converter



Wideband Signal Generation and Detection

Example of mm-Wave signal generation system

- Wideband microwave signal fed into mixer intermediate frequency input
- Mixer upconverts this signal to mm-Wave with low distortion
- Use mm-Wave bandpass filter to clean up signal
- Use mm-Wave amplifier to boost signal VDI has developed a set of waveguide filters and amplifiers to be used for these applications



Bandpass Filters for Comm Links

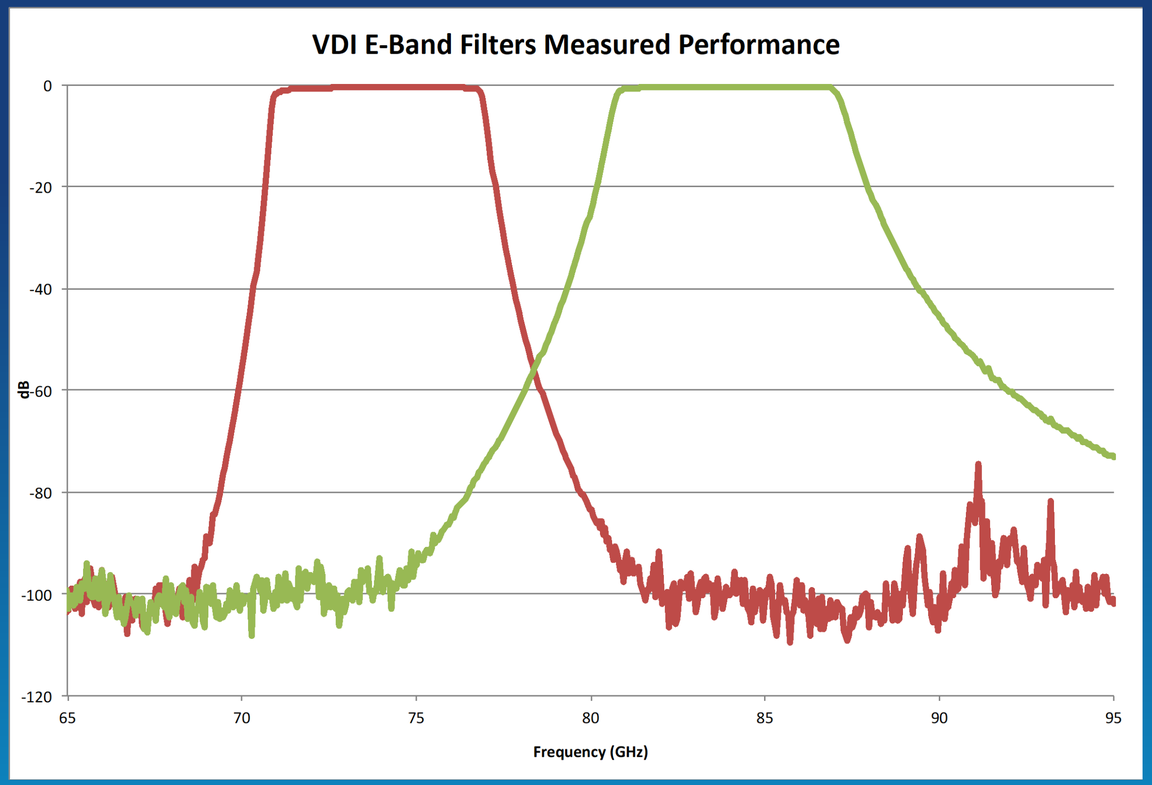
Waveguide-based bandpass filters

Low pass band insertion loss (<1dB)

High out of band rejection

Available at a variety of bands under consideration for 5G & 6G

Filters have been successfully developed up to 600 GHz!



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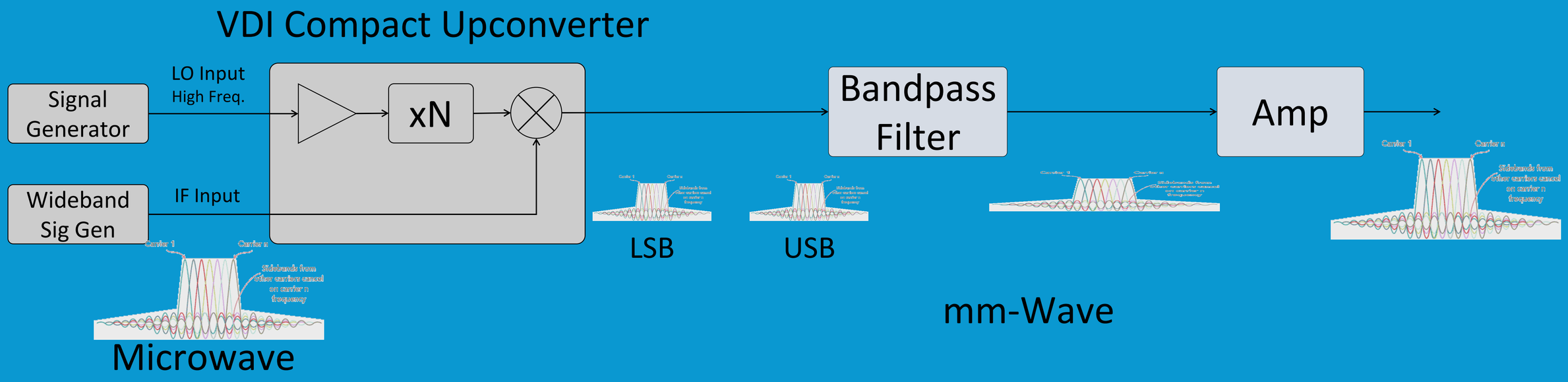


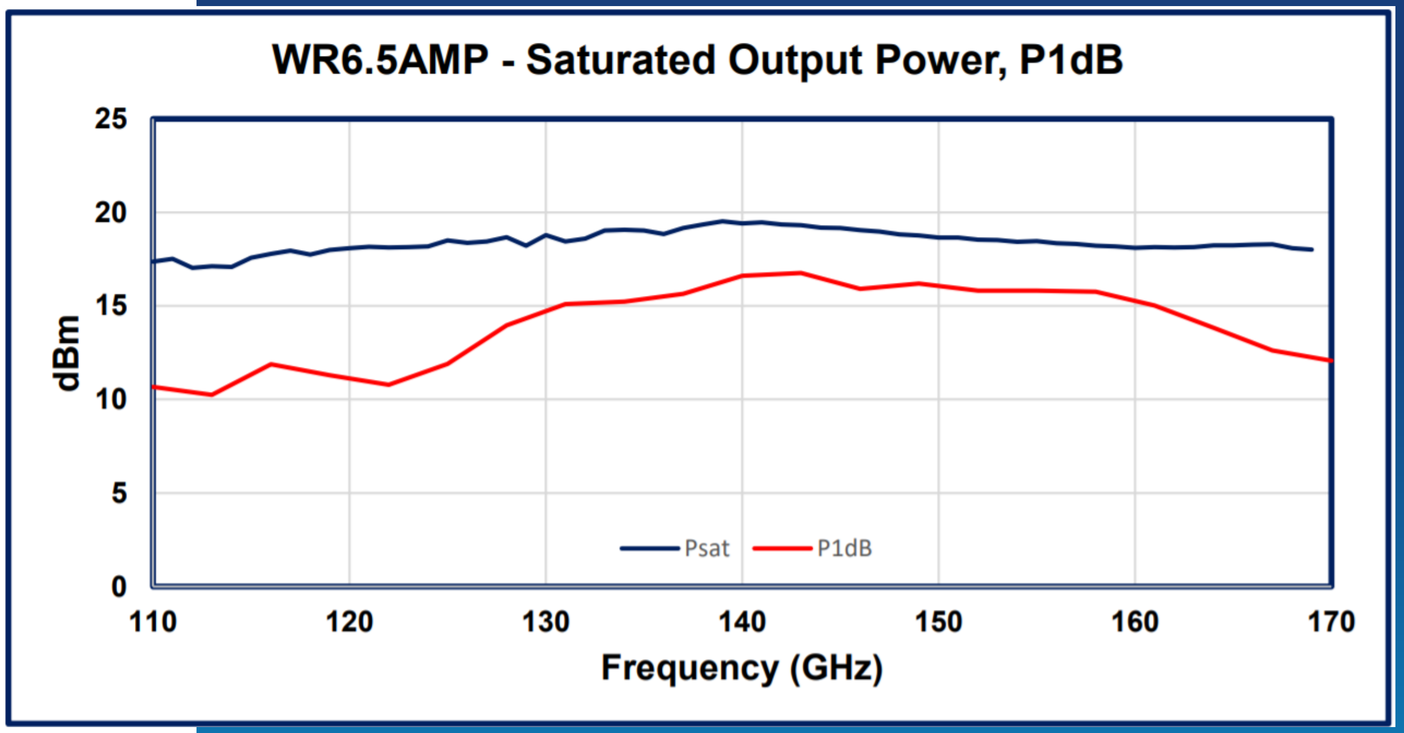
Medium Power Amplifiers

Waveguide Amplifiers from WR-15 (50-75 GHz) to WR-4.3 (170-250 GHz)

High gain and saturated output power

20 dBm at WR-12 to 16 dBm at WR-4.3

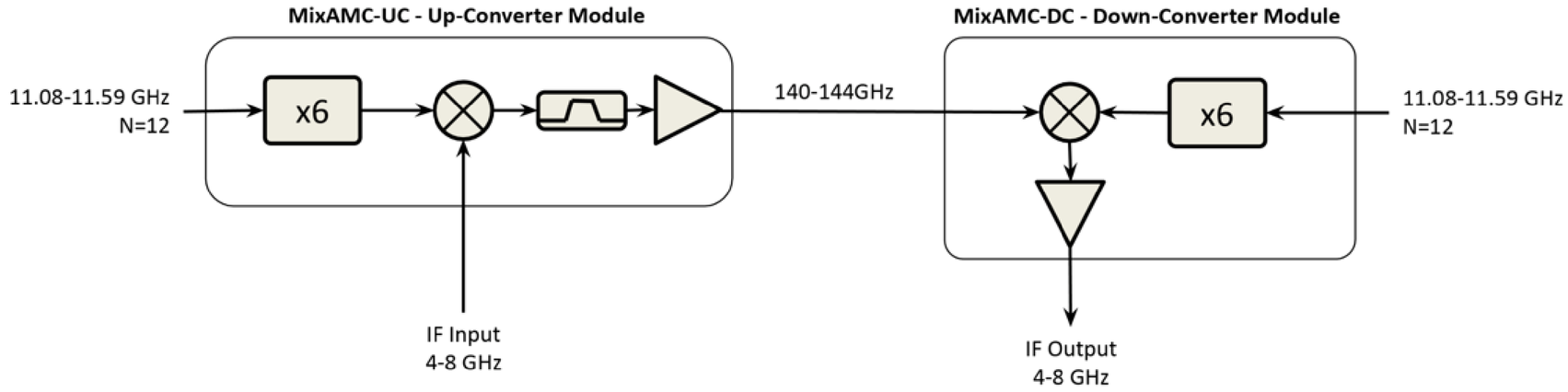
Full waveguide band coverage.



VDI 140 GHz Comm-Link Demo

Demo in operation at the Brooklyn 5G Summit in 2019

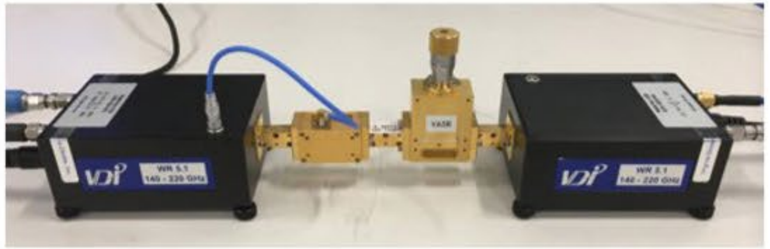
System is being used by NYU (Rappaport) for channel sounding experiments



Sub-Terahertz Testbed for 6G Research

This testbed is scalable across various frequency bands:

- V-band (50–75 GHz)
- E-band (60–90 GHz)
- W-band (75–110 GHz)
- D-band (110–170 GHz)
- G-band (140–220 GHz)



VDI Compact Upconverter (CCU), Amp, Bandpass Filter, Variable Atten, Compact Downconverter (CCD)

www.keysight.com/us/en/assets/7120-1082/white-papers/A-New-Sub-Terahertz-Testbed-for-6G-Research.pdf

Sub-Terahertz Testbed for 6G Research

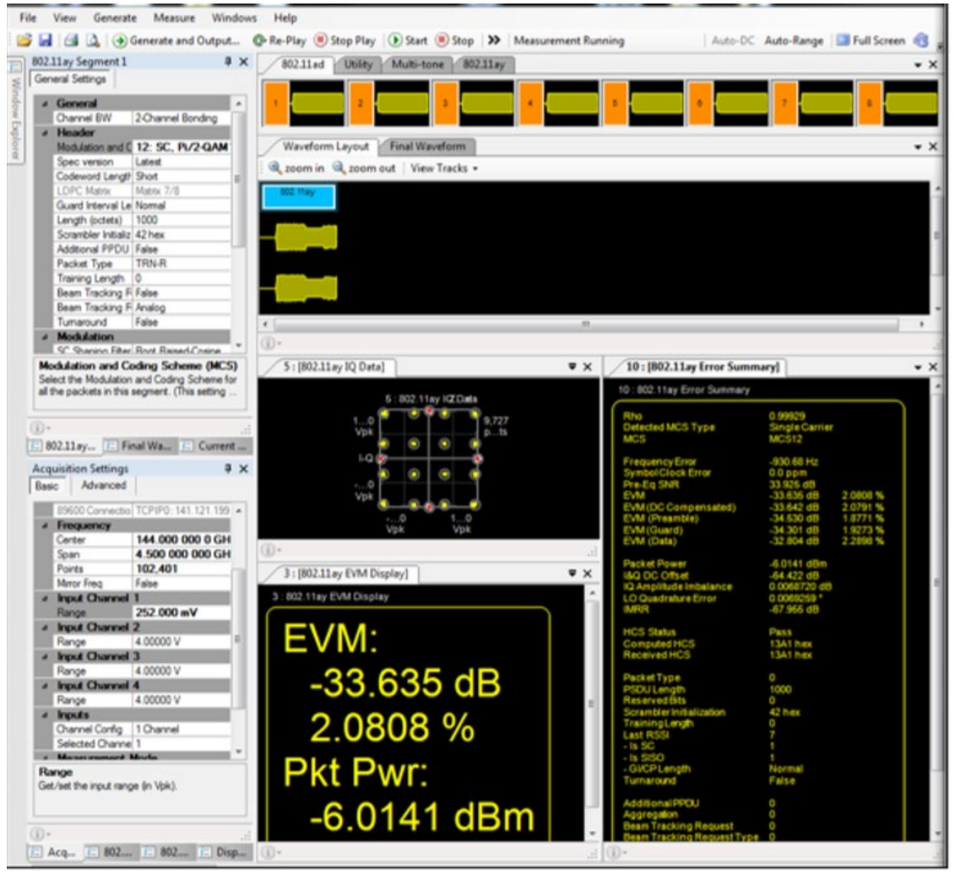
16QAM Measurements at 144 GHz

Simulated radio measurement using VDI up and downconverters

Channel bandwidth 4.32 GHz

EVM 2.1%

Measurements with 64QAM signals performed similarly



www.keysight.com/us/en/assets/7120-1082/white-papers/A-New-Sub-Terahertz-Testbed-for-6G-Research.pdf

Sub-Terahertz Testbed for 6G Research

Extreme Bandwidth Result

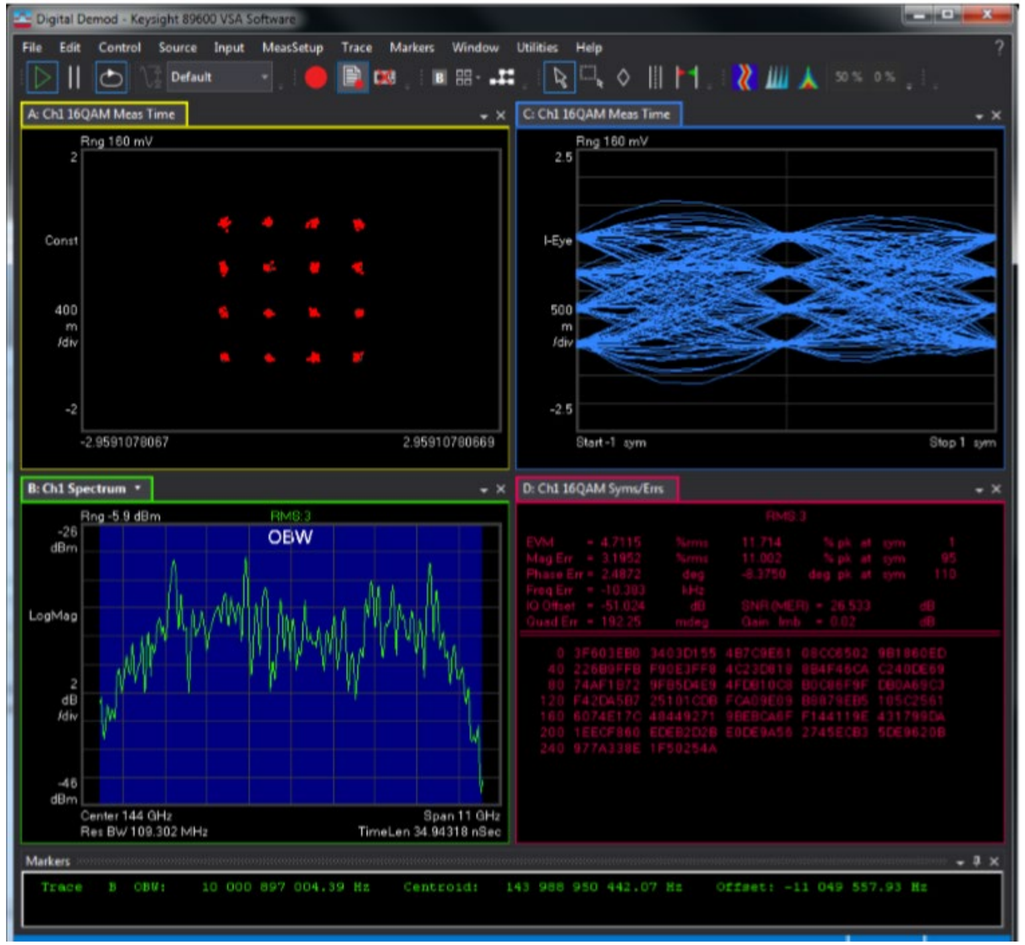
10 GHz of occupied bandwidth

16QAM measurements performed at 144 GHz

4.7% EVM

Using VDI G-band VDI converters

Measurements to 128 QAM…



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Summary

Terahertz technology is an emerging field with many established applications in basic science, as well as a host of commercial applications that are now under development.

A primary need is fast, convenient and accurate Test & Measurement tools.

“If you can measure it, you can improve it”

mmWave Test Takeaways

Existing equipment can be leveraged

True mixers over high harmonic mixers

Cable loss matters

Put the test probe near the DUT

Test probes can be small form factor

High dynamic range matters

THANK YOU