



Trends in Aerospace & Defense ***including what's new from Agilent***

Jong-hwan Keum, Agilent Technologies

Categorizing Radar



Architectures

Monostatic
Bistatic
MultiStatic (Netted)
Angle / Time / Freq (Doppler)
Space-Time Adaptive (STAP)
MIMO
Adaptive/Cognitive

Imaging / Non-Imaging

Synthetic Aperture
(SAR/ISAR/CSAR)
Synthetic Impulse and Aperture
(SIAR)

Active / Passive

Multi-Mission:
Multi-Function (MPAR or MFAR)
Time Scheduled
Freq Scheduled (OFDM)
Non-Radar (e.g.Comms)

Antenna

Mech. Steered
Passive Steered Array
Electronic Steered Array
Digital Array
Digital Beam Forming
Co-located
Distributed
Tube / GaAs / GaN / SiGe
Photonics

Active Signals

CW / FMCW / Pulsed / Chirped
Frequency Hopped
Coded/Spread (e.g. Barker)
Impulse / UWB
OFDM
Correlated / Uncorrelated
Orthogonal

Signals of Opportunity

Broadcast AM/FM/TV
Cellular

Deployment

Fixed Ground
Airborne
Land Mobile
Naval
Space
Co-located
Distributed
Man Portable

Application

Surveillance: Air/Sea/Land/Space
Air Traffic Control
Fire Control
Ground Moving Target (GMTI)
Imaging / Mapping
Navigation & Guidance
(altimeters, terrain following, auto,
autonomous ground vehicles, etc.)
Weather
Wall/Ground Penetrating
Perimeter Security
Law Enforcement
Sports

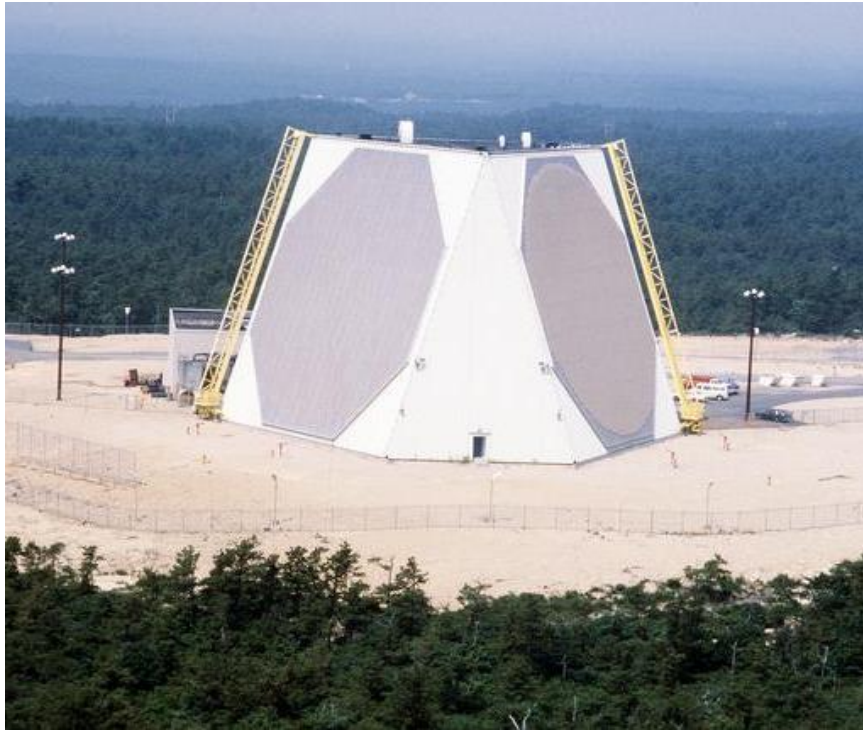


How Many Antenna Array Elements



PAVE PAWS - 31 Years Old

1,792 Passive Elements



Airborne 1000-3000+
Active Elements

AN/APG-77 (F-22)





Digital continues to move closer to the antenna

Mechanically Steered > Electronically Steered Phased Array

Passive ESA (PESA) > Active ESA (AESA) > Digital Array Radar (DAR)

Steered Beams giving way to Digital Beam Forming (DBF)

Architectures support multiple functions

Search, track, fire control, weather

Synthetic Aperture

Communications

Electronic Warfare (spectral environments becoming more complex)

Frequency, bandwidth, resolution and capability are increasing

Phase Shifters being replaced by true-time delay elements

More sophisticated algorithms and signals

Signals tailored to detected targets and conditions



Spatially distributed radar systems are more common

Elements of the radar system are at different locations

MIMO (may be co-located)

Passive Radar

Multi-static radar

Density of array elements is increasing

Cost, size and power of elements are decreasing (T/R modules are inexpensive)

Analog T/R modules giving way to fully digital ones

Vacuum electron devices giving way to solid state

Higher performance (GaAs, GaN, SiC)

MMIC, SoC, Radar-on-a-chip

Lower cost, smaller size, less power consumption

SBX

“8th Wonder of the World”

RADOME: 103 FT HIGH

ANTENNA DIAMETER: 72 FT

45,056 T/R MODULES

RADAR: X-BAND PHASED ARRAY

22 January 2006

The SBX-1 in the Pacific Ocean adjacent to the Hawaiian island of Maui.



Approximately 45,000 transmit/receive modules operate together to form the radar beam. The radome surrounds the radar and protects it from the weather.



9th Wonder of the World?

DARPA ISIS

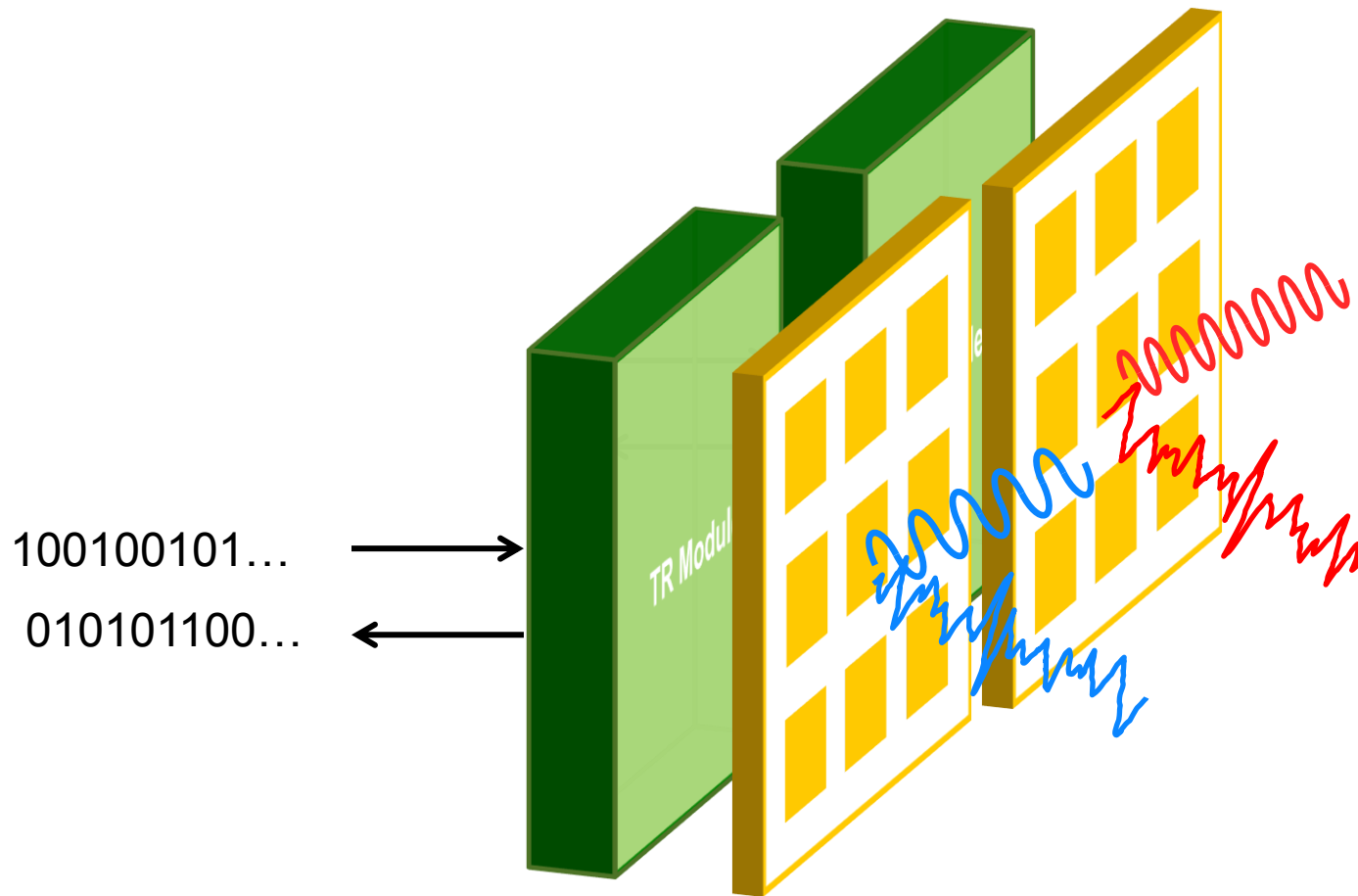


Table 1 – ISIS Demonstration and Objective Systems

	DS	OS
Altitude	20 km	21.3 km
Airship Length	150 m	300 m
Airship Diameter	50 m	100 m
Antenna Height	8 m	36 m
Antenna Diameter	22 m	50.5 m
UHF Aperture Area	530 m ²	5725 m ²
UHF Elements	3,922	42,365
X-Band Aperture Area	98 m ²	5725 m ²
X-Band Elements	347,500	20,300,000
First Launch	2013	2020

The OS is launched like a satellite; once aloft it never lands until the end of its 10+ year lifetime. Within ten days it autonomously deploys to any designated worldwide location. The OS can maintain its station year-round within latitude bounds of -37° South to +55° North.

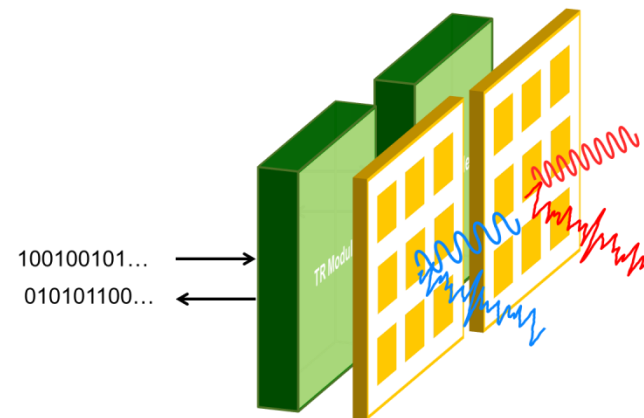
Digital Moving Closer to the Antenna



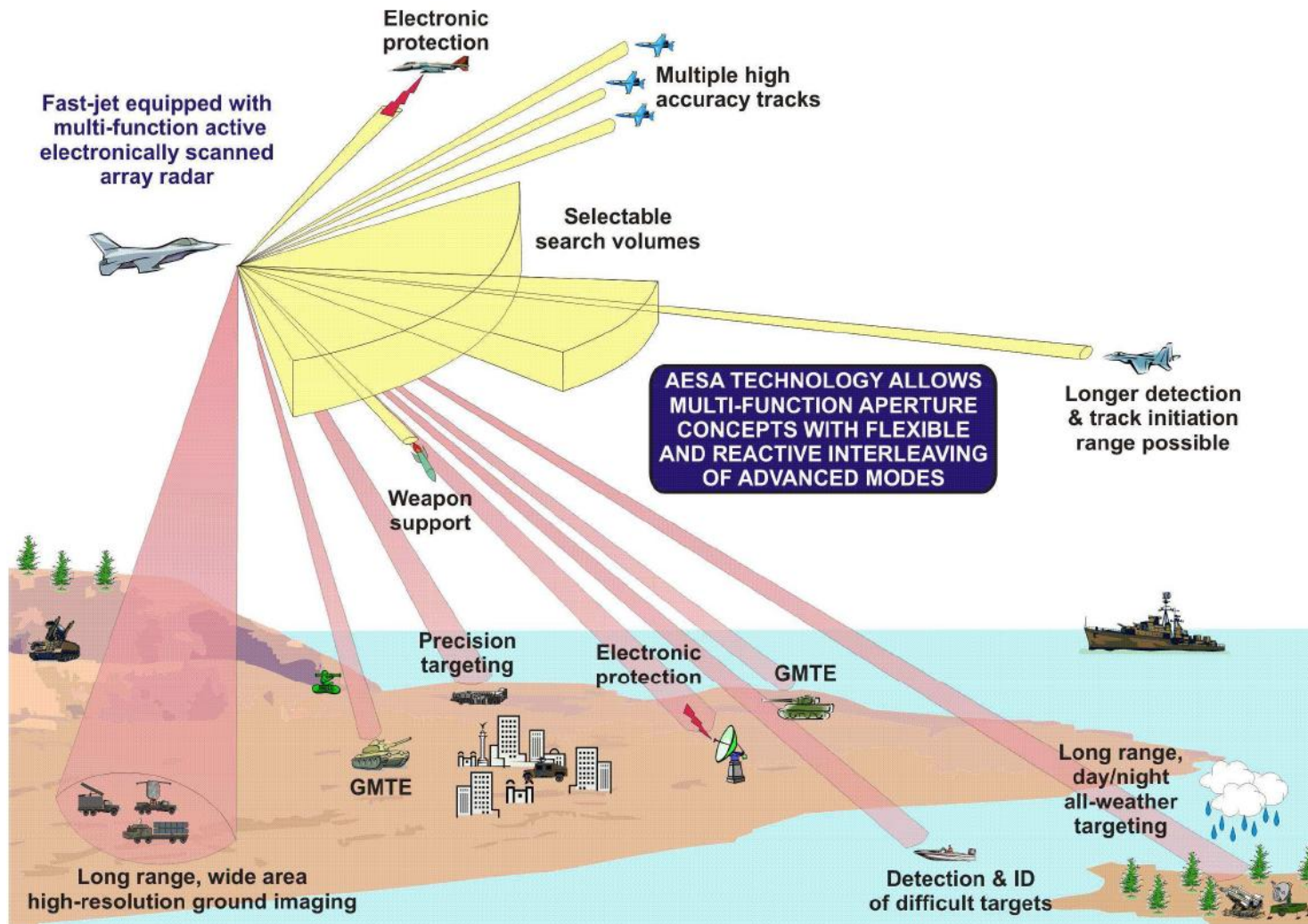
Impact of Digital Moving Closer to the Antenna



- **Functionality becoming software defined**
 - New capabilities added to existing designs
 - Upgrades to deployed equipment (no return to factory for test)
 - May need to verify performance drivers, not specific implementations
- **Signals are not fixed by design, and may not be fixed during operation**
(adapt to target and conditions)
 - Change with function
 - Pre-compensate based on channel
(target, clutter, jamming, etc)
- **Signals convey information**

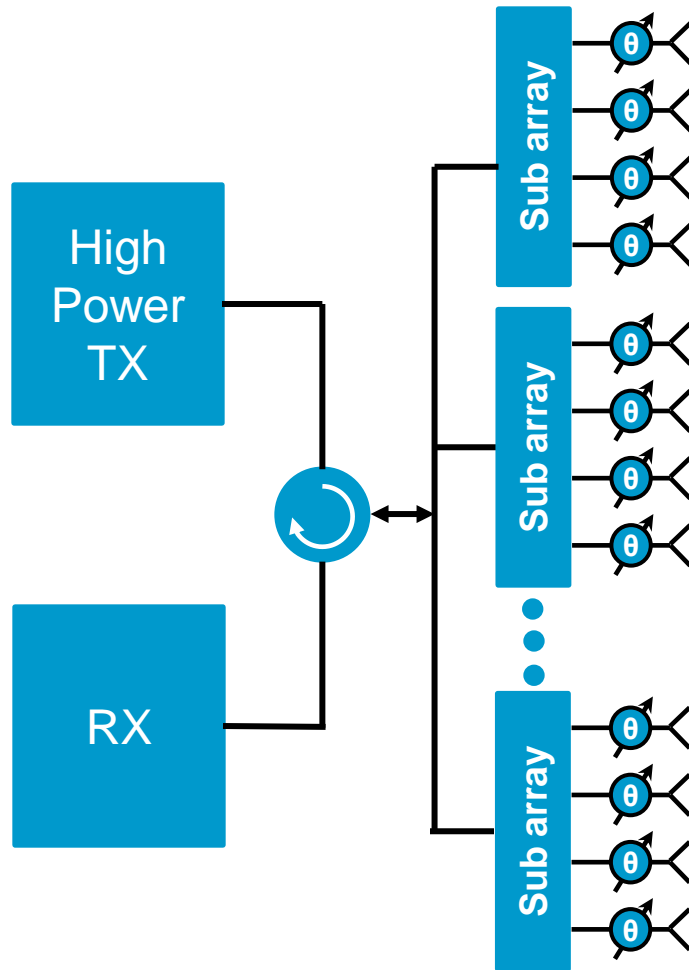


One Driver for Change: Multi-Function Radar



“UK AIRBORNE AESA RADAR RESEARCH”, Dr. Stephen Moore, Radar Team Leader, Dstl, UK

Passive Electronically Steered Arrays (PESA)



- **One Source of RF Energy**
 - Klystron
 - Single Point of Failure
 - High Voltage Requirements
- **TR Isolation**
 - Circulator
 - Duplexer
 - Switch
- **Power Distribution**
- **Phase Shifters**
- **One Receiver**
 - High Dynamic Range Requirements
 - Single Point of Failure

Active Electronically Steered Arrays (AESA)

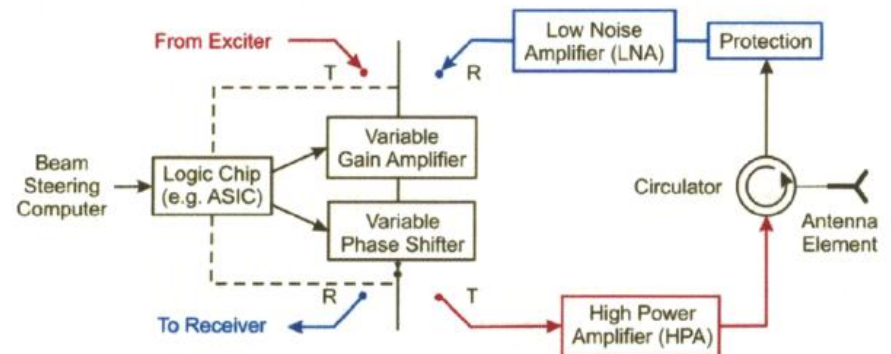
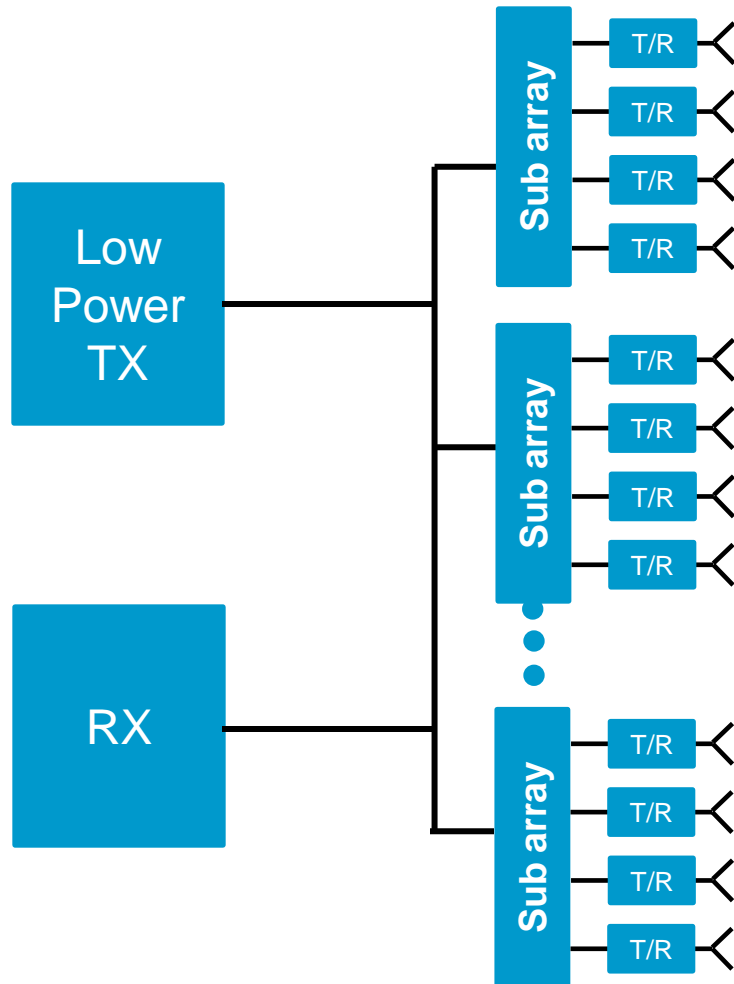
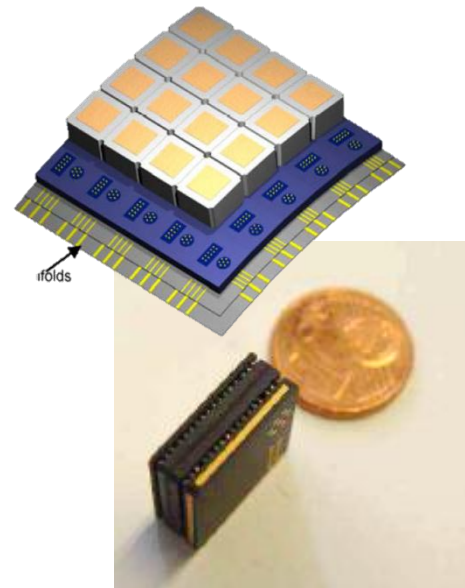
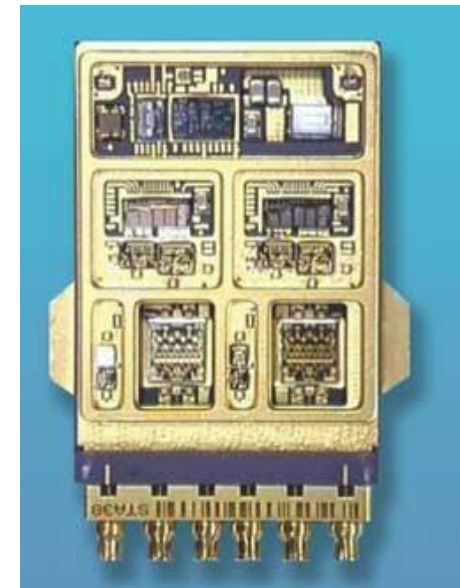


Figure 11 – Typical Transmit/Receive Module design

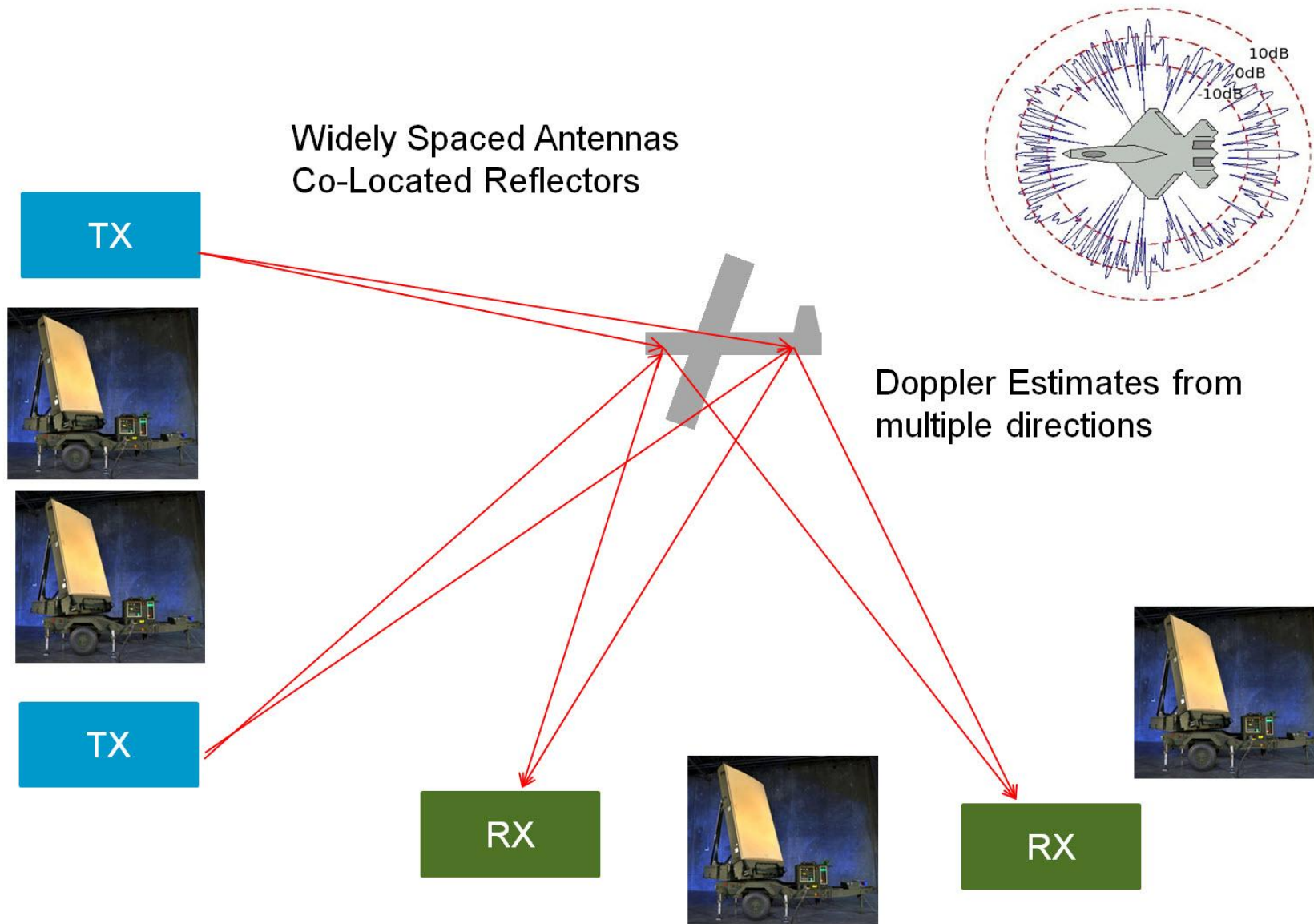


Tile Style



Brick Style

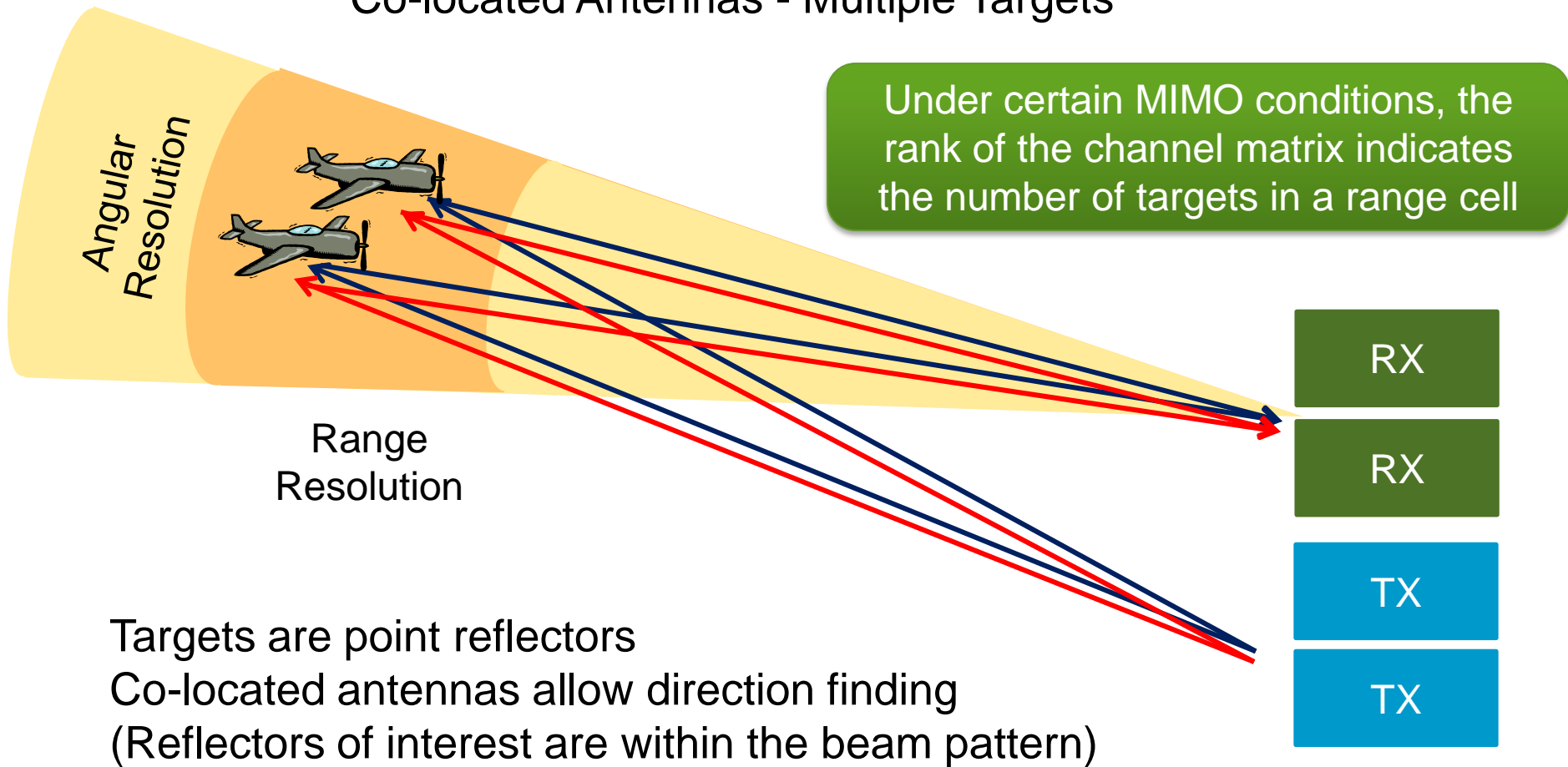
MIMO Radar



MIMO Radar: Co-Located Antennas



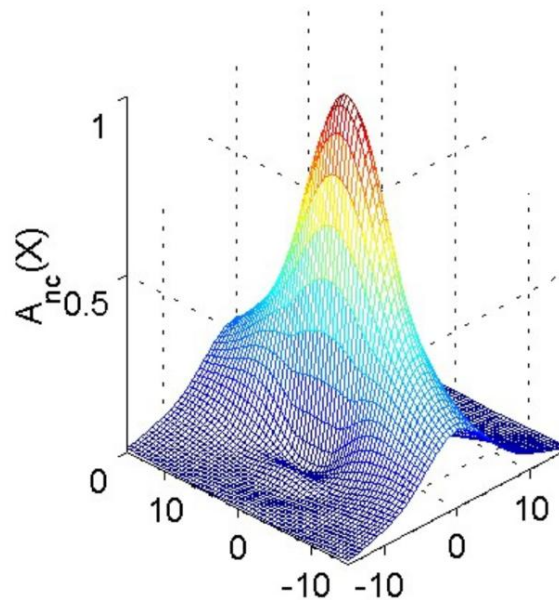
Co-located Antennas - Multiple Targets



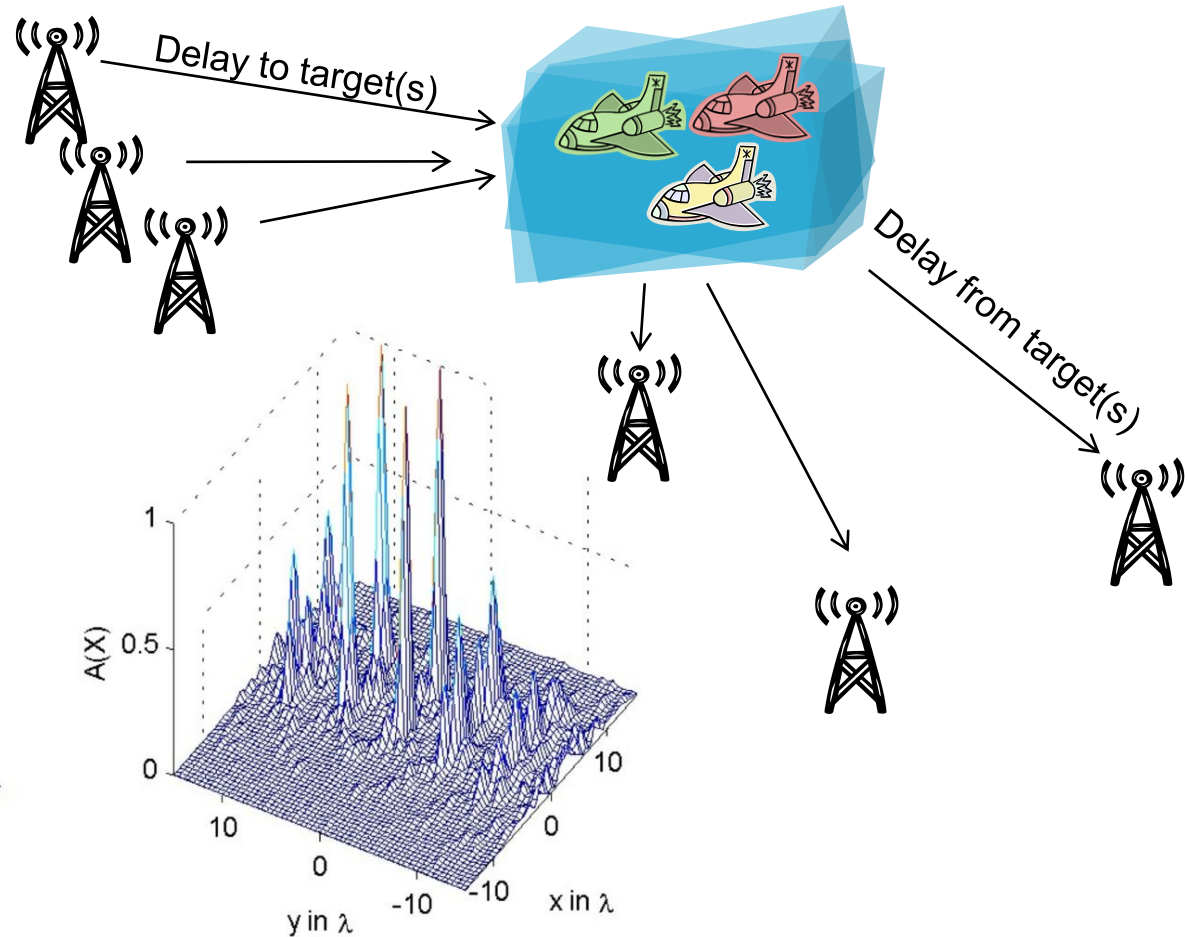
MIMO: Improved Resolution



Range resolution is a function of the signal and the geometry



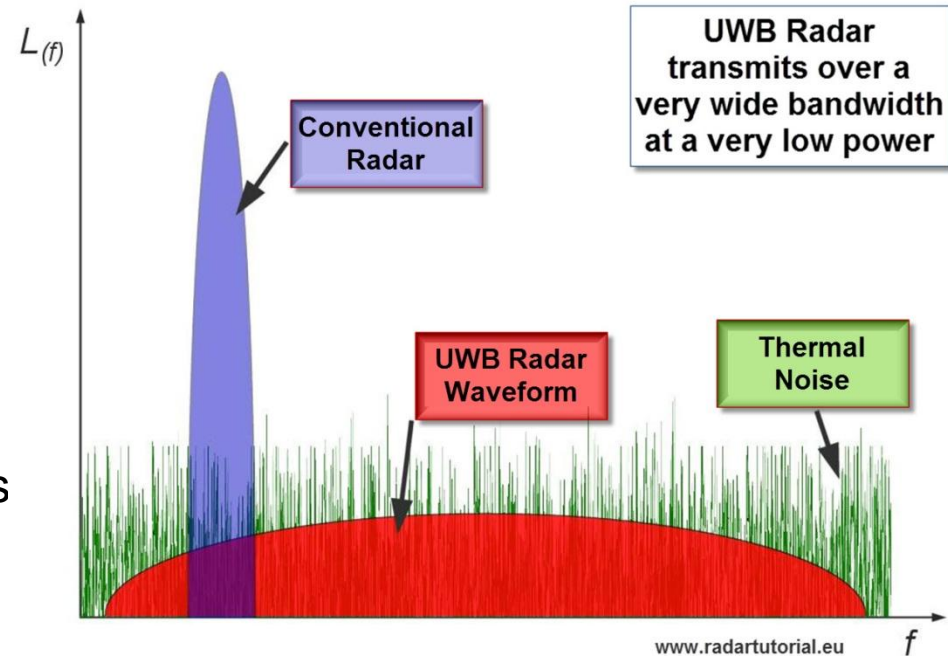
Non-coherent 9x9



Coherent 9x9 MIMO with 4 targets

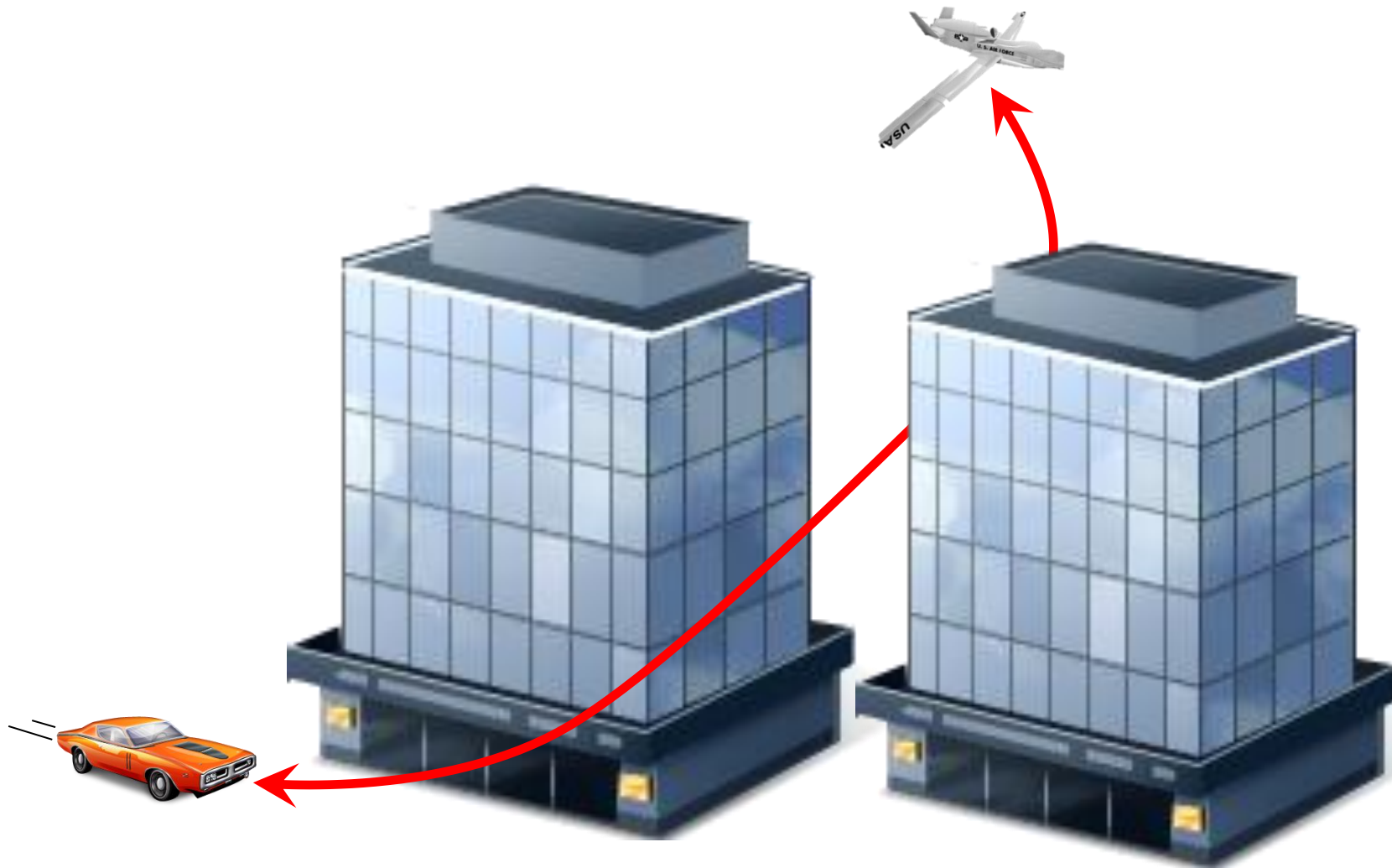


- **Ultra-wideband definition:**
 - Bandwidth greater than 0.5 GHz
or
 - Bandwidth greater than 25% of central frequency
- **Four types of pulses: UWB, LFM UWB, Noise UWB, OFDM UWB**
- **Advantages**
 - See through walls and obstacles for object location and positioning
 - High accuracy for target detection
 - Ease of signal generation and processing architectures
 - Multipath immunity
 - Low cost
 - Low detectability
 - Low interference with other signals

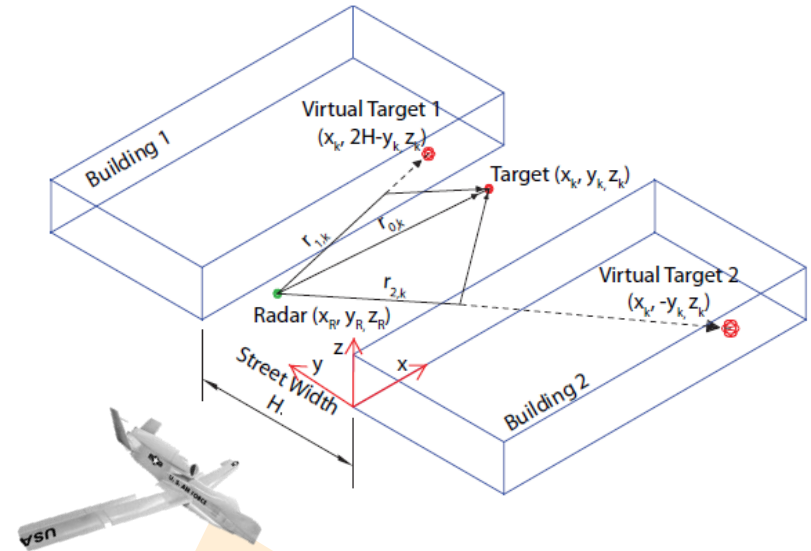
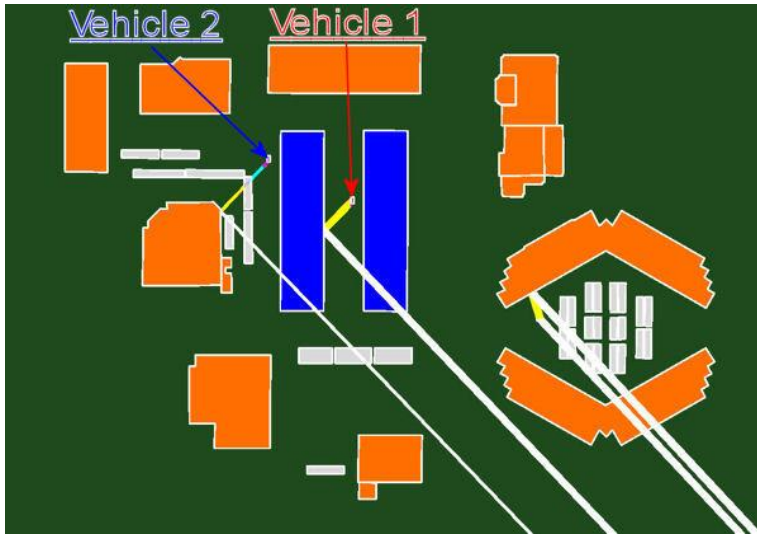


www.radartutorial.eu

Wanted: Radar That Can See Around Corners



Solution: Multipath Exploitation Radar (MER)





Satellite Market Trends

Commercial Satellite Market trends



- **Market trends - Commercialization and "New Space"**
 - Lower launch vehicle costs = smaller & more satellites
 - New companies & new countries building satellites
 - Private Satellites, joint development, hosted payloads
- **Technological trends**
 - Regenerative vs. Bent Pipe = digital solutions
 - Spot beams & Beamforming = multi-channel
 - COTS, reusable and standard = use SW tools
- **Political – ITAR, US opening up Satellite Mfg and sales**

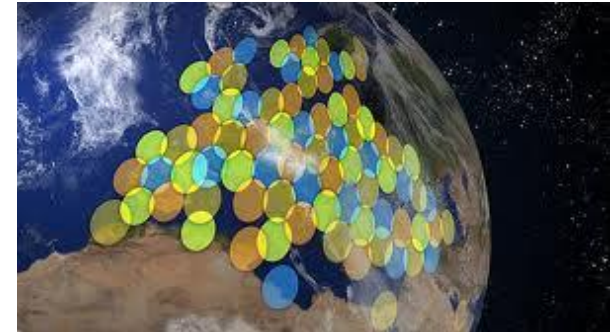
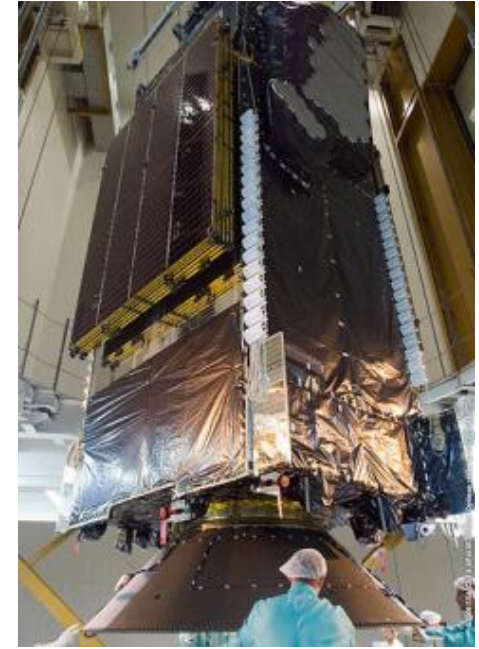


Satellite Technological Advancements



- **Technological Advancements**

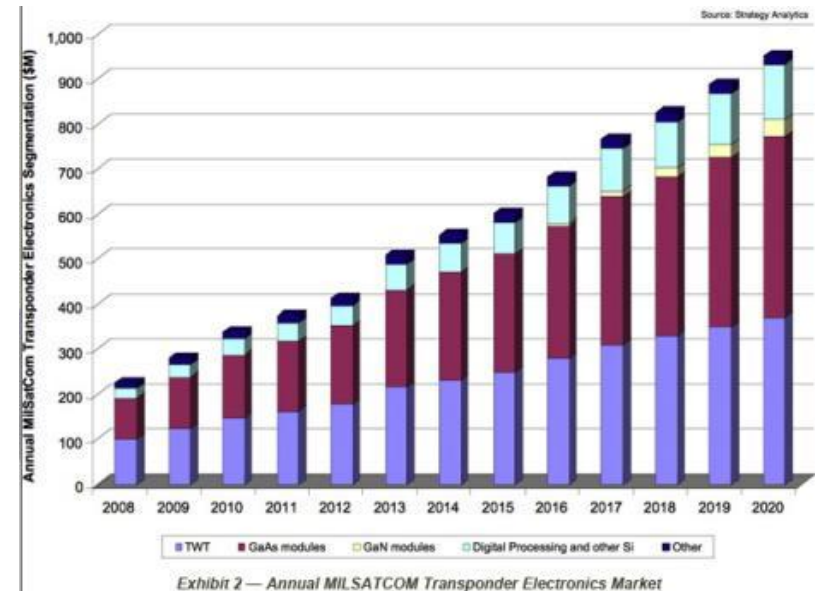
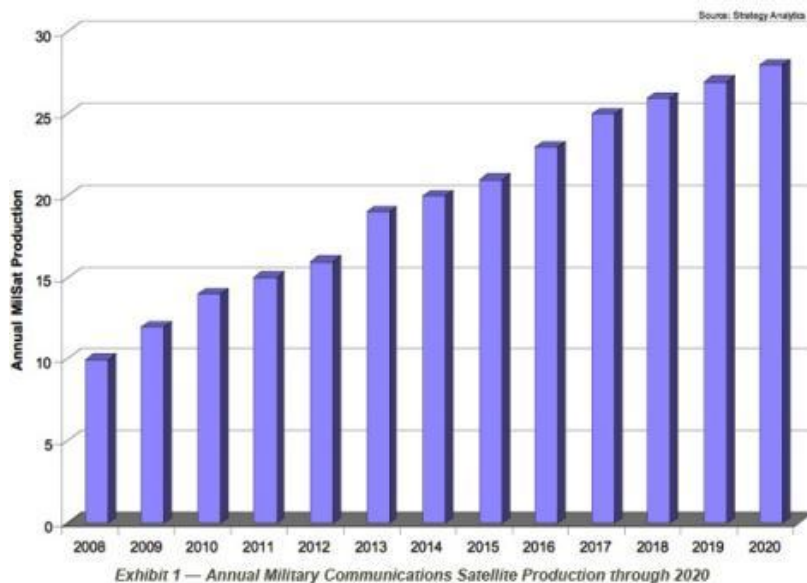
- Increased power = more antenna's
- More than one frequency band per antenna
 - PIM-free multiband antennas: tri & quadruplexers
- Ku and Ka bands to wider bandwidths
 - 250 & 500 MHz BW in orbit 1 GHz in R&D and V-Band
- Reconfigurable satellites = test full performance
- TRM based antennas = AESA Radar solutions



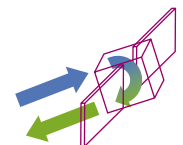
Military Satellite Market trends



- Increasing demand for Military communication bandwidth
- Military is now leveraging commercial service providers
- Laser data transfer, crosslink and ground link
- Sequestration will have short-term impacts



Regenerative Satellite Challenges



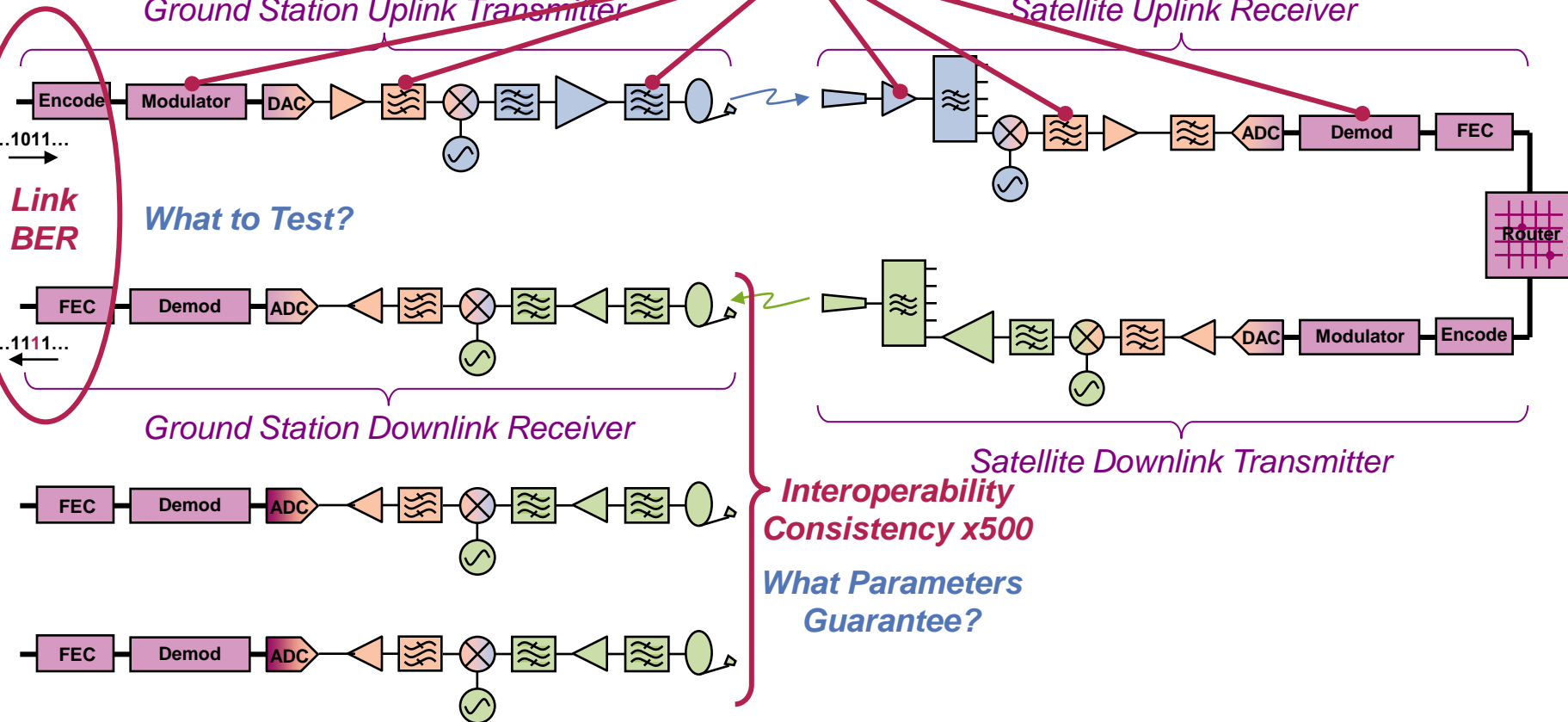
Consistent
Characterization?

Different Signal Formats
(Digital, BB, IF & RF)

Ground Station Uplink Transmitter

Satellite Uplink Receiver

What to Test?



Interoperability
Consistency x500

What Parameters
Guarantee?





What's New from Agilent





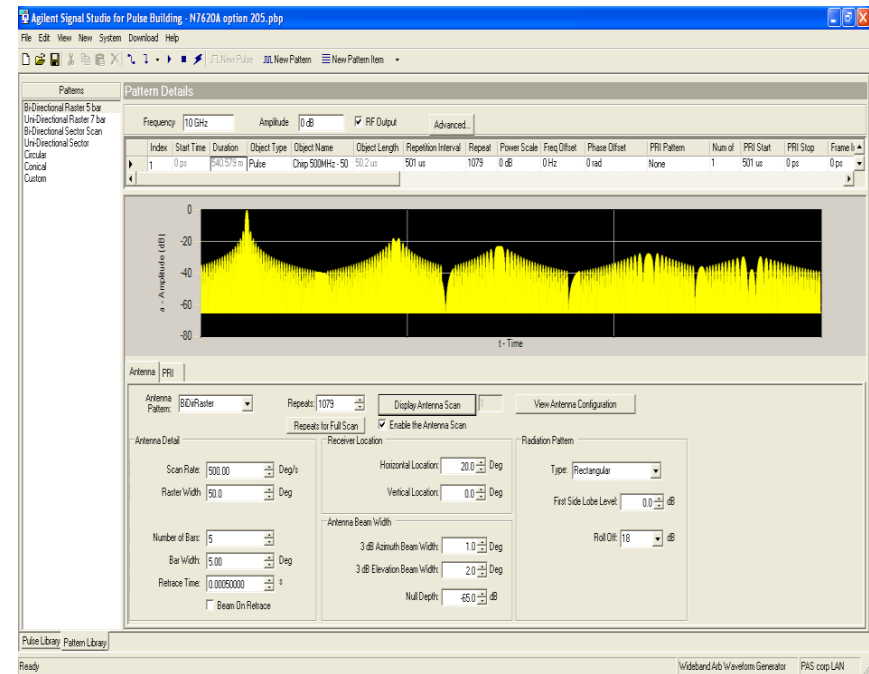
Emitter Simulation Software from Agilent



Agilent N7620A Signal Studio for Pulse Building Software

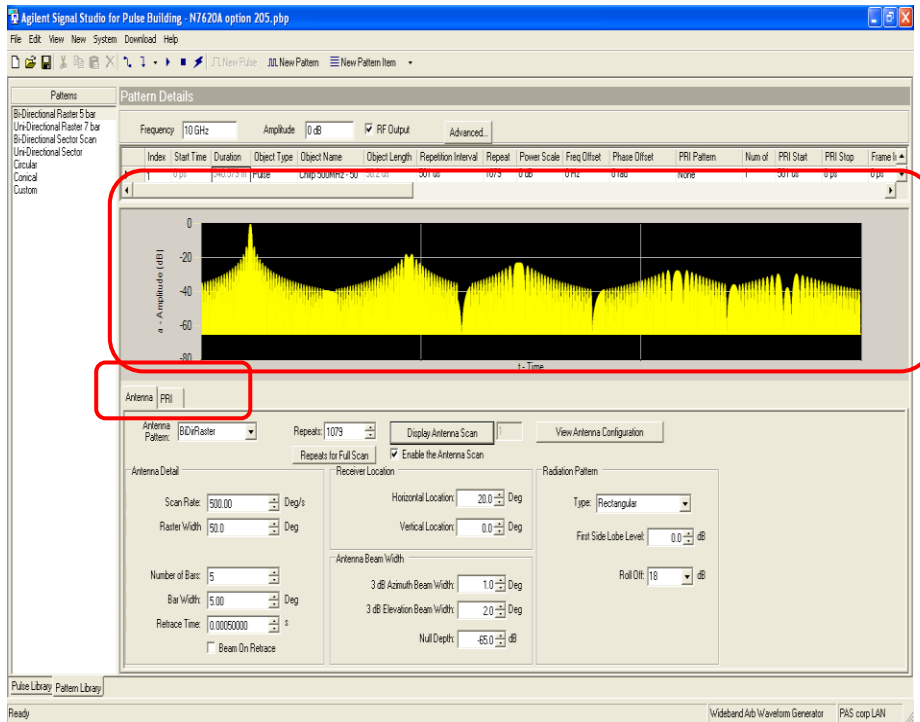


- Graphical displays
- Pulse timing patterns parameters
- Antenna patterns
- Antenna scanning
- Scenario database import/export

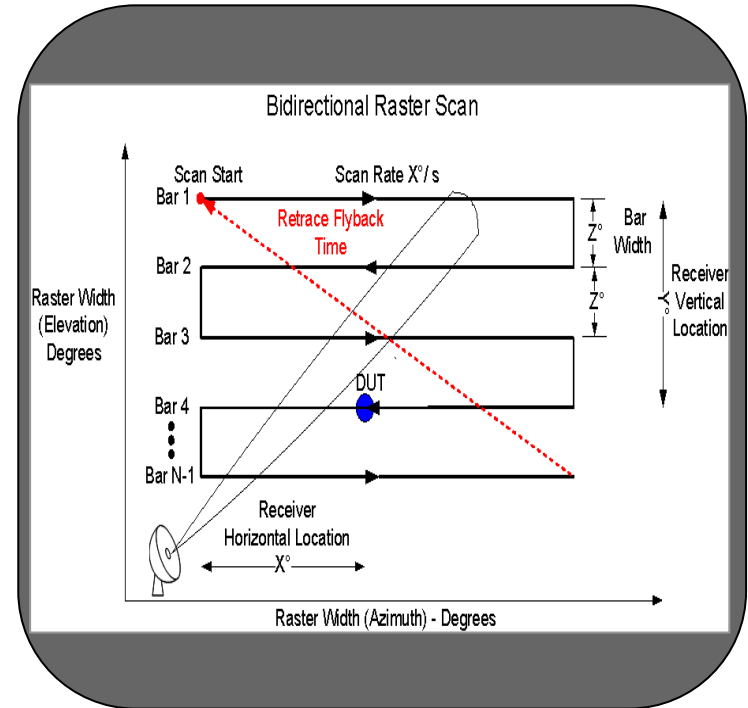


The User Interface

- Two pattern tabs: PRI and Antenna
- Graphical window displaying antenna scanning & timing patterns
- Graphical windows documenting antenna & timing patterns properties
- Flexible pattern table



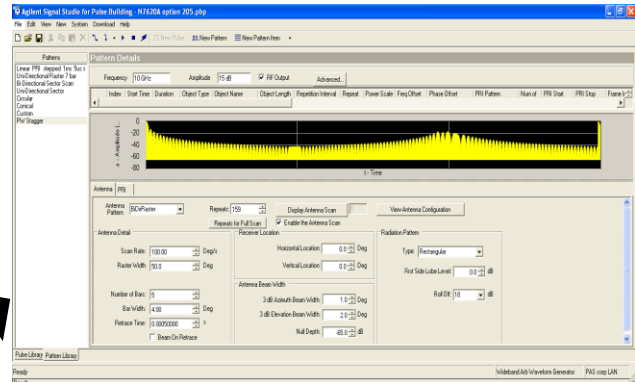
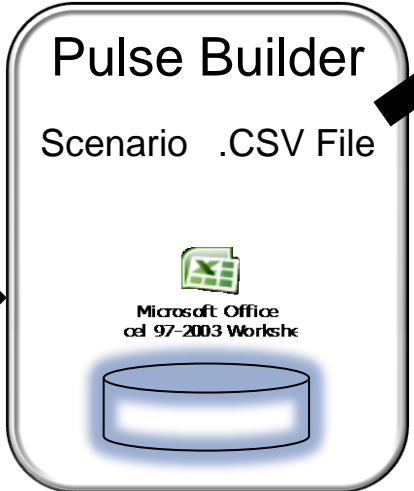
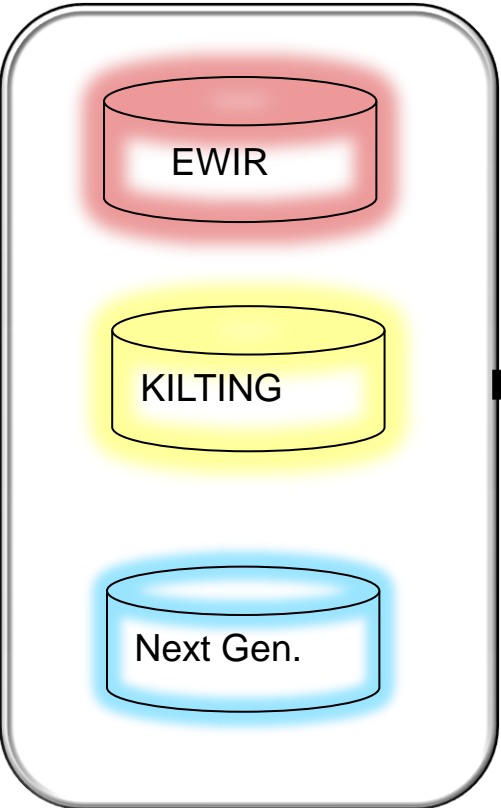
N7620A Signal Studio



Scenario Data Base Import/Export



Threat Data Bases



Evaluating Hardware Under Realistic Signal Scenarios for EW



- Today's military theater spectral environment may contain many sources of interference:

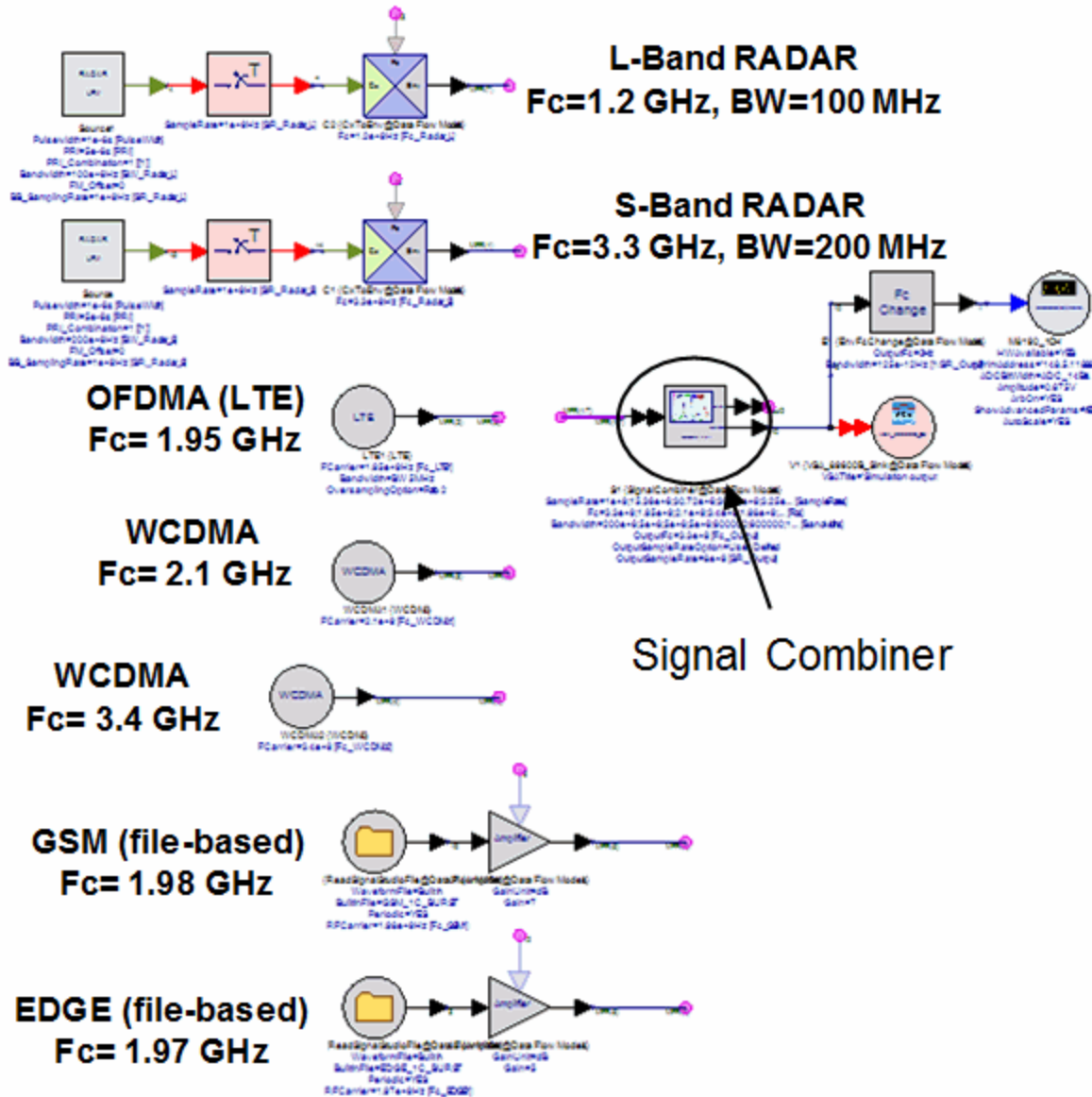
Intentional jammers

Unintentional: Wireless infrastructure (ships in port), military assets, Radars, EW, other

- May need to capture offending signals in the military theater environment
- May need to generate mixed Radar and communications signals to evaluate hardware under different scenarios



Multi-Emitter Signal Creation with SystemVue



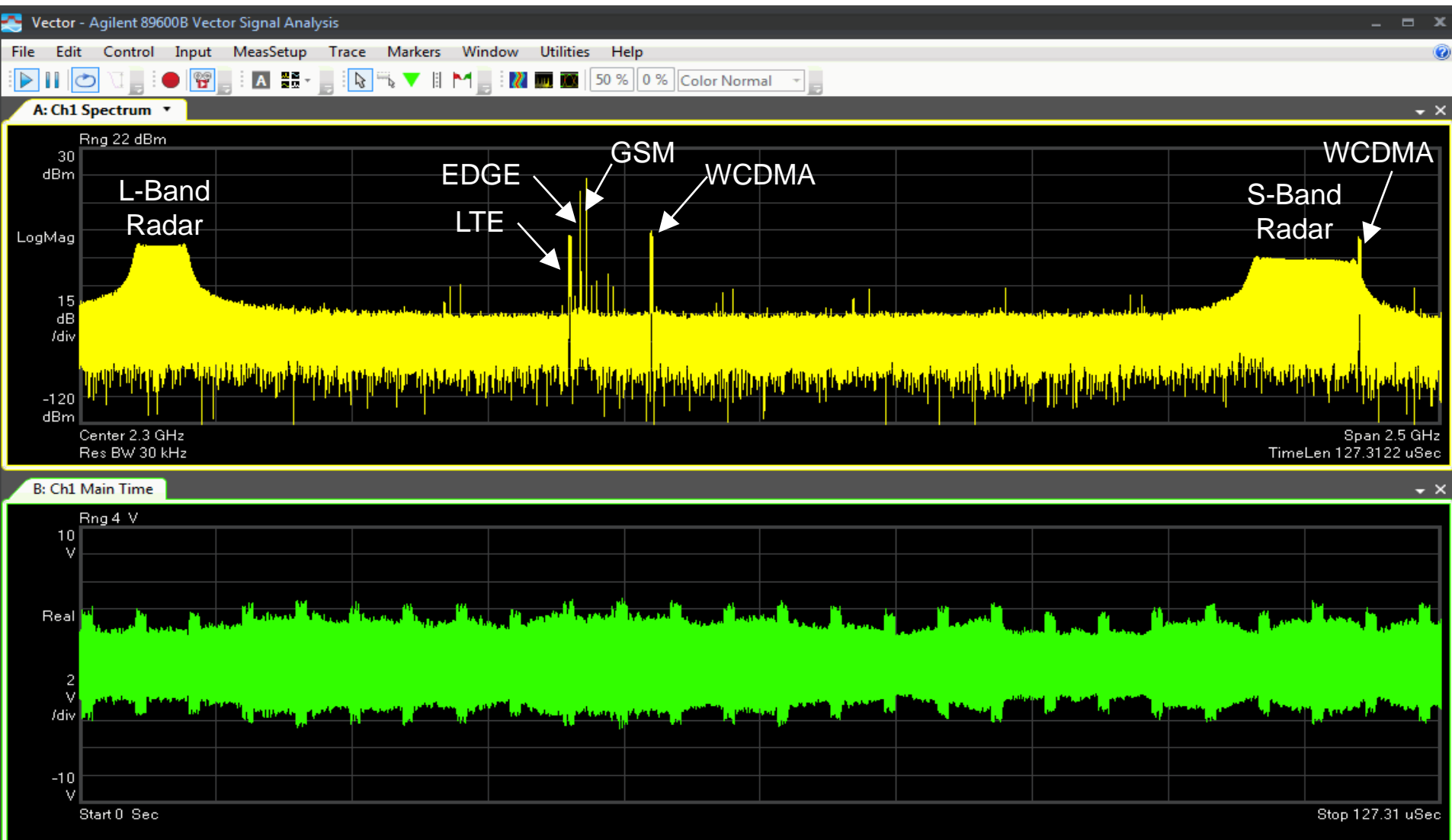
Download Waveform
to M8190A AWG



Multi-Emitter
Test Signal



Measured Waveform on DSA91304A and VSA





Arbitrary Waveform Generation (AWG)



Advanced AWG Solutions

M8190A Arbitrary Waveform Generator



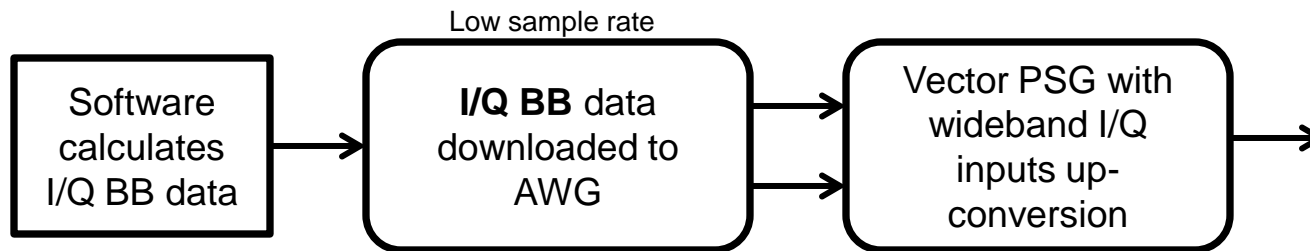
- ✓ 14 bit up to 8 GSa/s
- ✓ 12 bit up to 12 GSa/s
- ✓ Up to 5 GHz analog bandwidth per channel
- ✓ Up to 2 GSa memory per channel
- ✓ Signal Studio for Pulse Building and SystemVue support
- ✓ AXIe form factor
- ✓ DC and AC amplifier
- ✓ SFDR: -80 dBc typical / Harmonic distortion: -72 dBc typical
- ✓ Advanced sequencing scenarios define stepping, looping, and conditional jumps of waveforms or waveform sequences
- ✓ 2 markers per channel (does not reduce DAC resolution)
- ✓ ISO 17025 or Z54 calibration



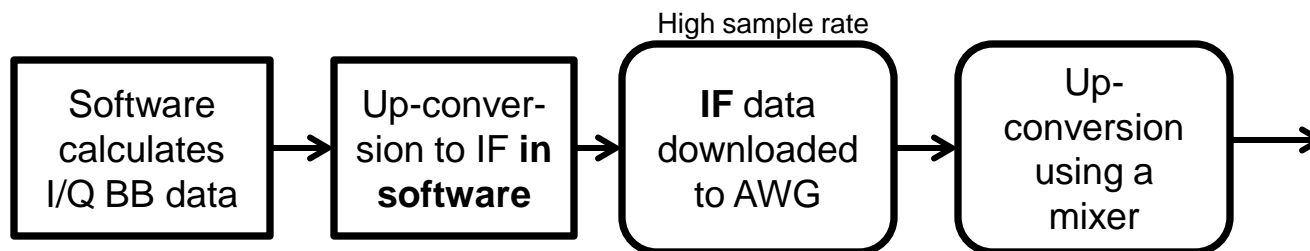
www.agilent.com/find/M8190



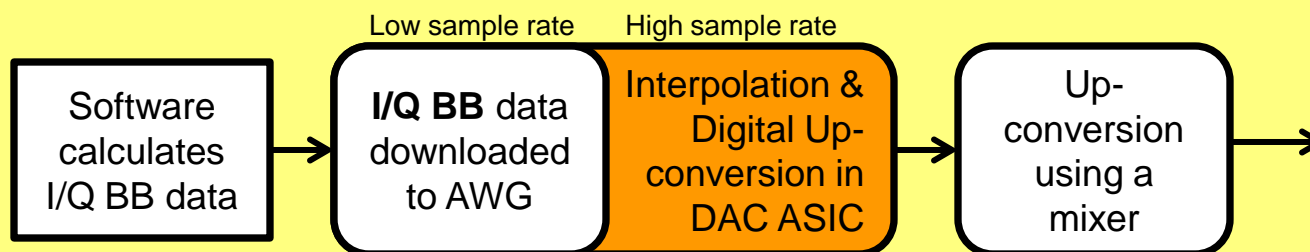
Comparison of Different Up-Conversion Methods



Analog I/Q upconversion causes distortions, Vector PSG is expensive

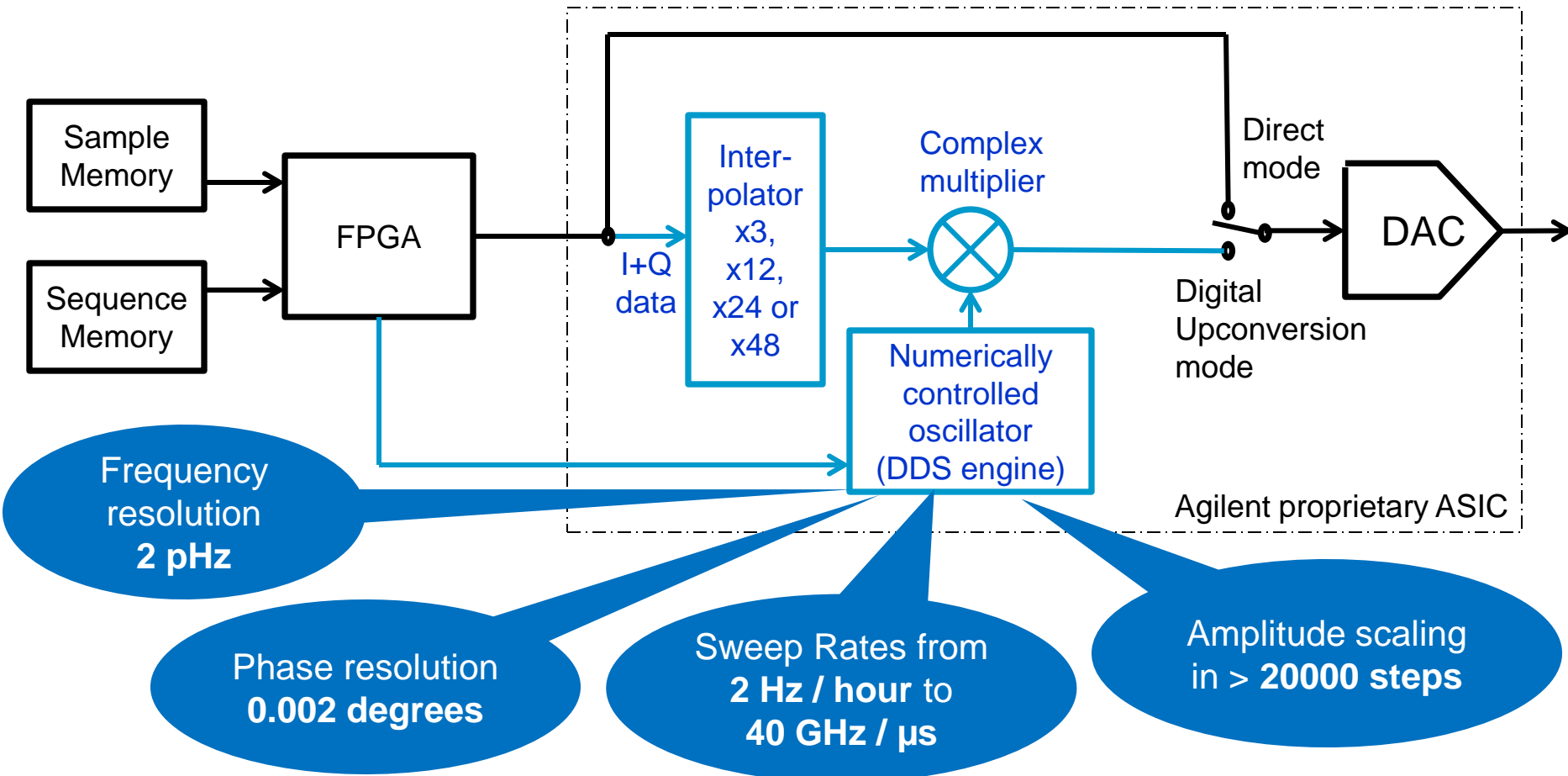


IF in software requires high sample rate → eats up memory; poor freq resolution



Digital up-conversion in hardware combines the benefits of both approaches

Combine Precision AWG with Digital Up-Conversion



Carrier frequency, phase, amplitude and frequency sweep can be controlled in real time under sequence control



Signal Analysis Platforms



Infiniium Q-Series Oscilloscopes



DSO/DSA Models	92004Q	92504Q	93304Q	95004Q	96204Q
Bandwidth (2 channels)	20 GHz	25 GHz	33 GHz	50 GHz	63 GHz
Bandwidth (4 channels)	20 GHz	25 GHz	33 GHz	33 GHz	33 GHz
Maximum sample rate	80 GS/s	80 GS/s	80 GS/s	160 GS/s	160 GS/s
Probe bandwidth	30 GHz to the probe tip				
Maximum acquisition memory	2 Gpts per channel				

Lowest noise floor and jitter measurement floor available on an oscilloscope

Agilent M9703A High-Speed Digitizer



*Reduce measurement time with the new M9703A.
Higher number of synchronous acquisition channels, wider signal
capture and best accuracy.*



AXIe



Key Features

- 12 bit Resolution
- 8 channels @ 1.6 GS/s
- Interleaving option to get 4 ch @ 3.2 GS/s
- DC to 2 GHz analog 3 dB bandwidth
- **Optional real-time digital downconversion (DDC) on 8 phase-coherent channels**
- Up to 256 MS/ch memory and segmented acquisition
- > 650 MB/s data transfer
- **Agilent 89600 Software support**

M9703A OS support

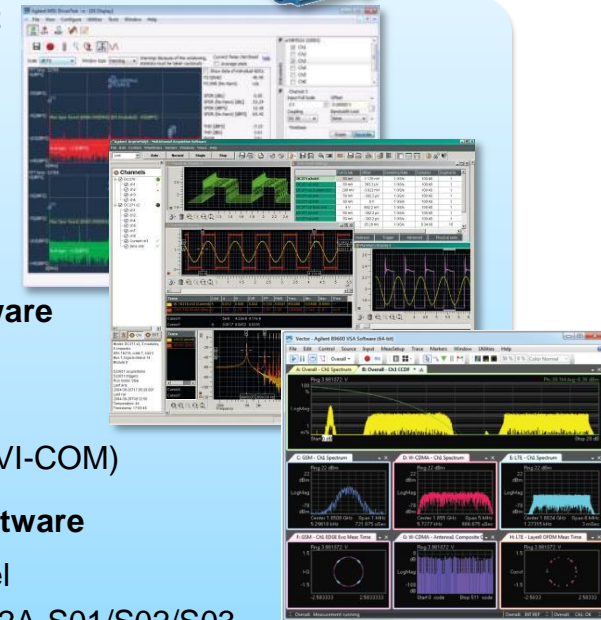
- Windows
- XP (32-bit)
- Vista (32/64-bit)
- 7 (32/64-bit)
- Linux

Drivers – MD1 software

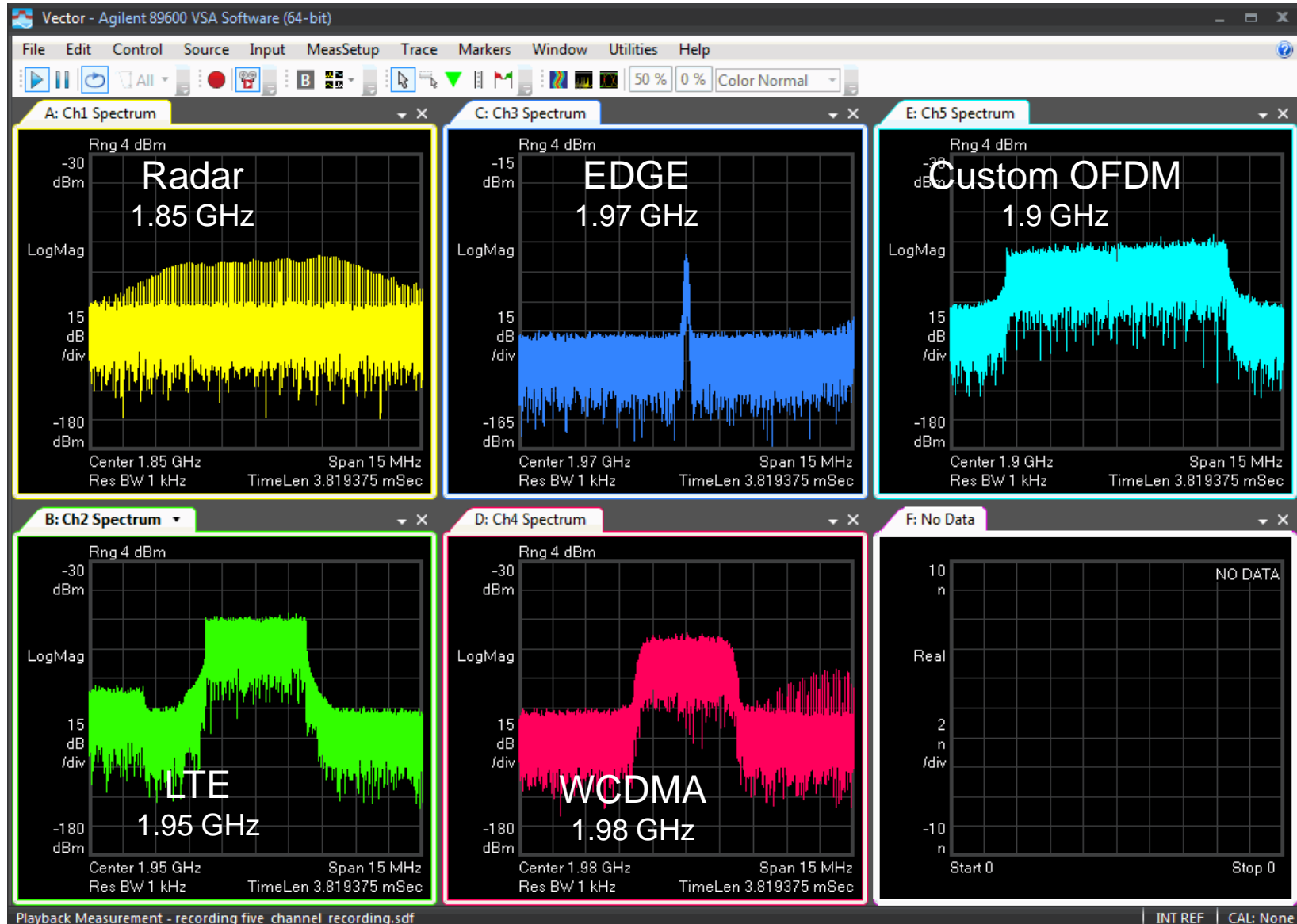
- IVI-C, IVI-COM
- LabVIEW
- MATLAB (through IVI-COM)

OTS application software

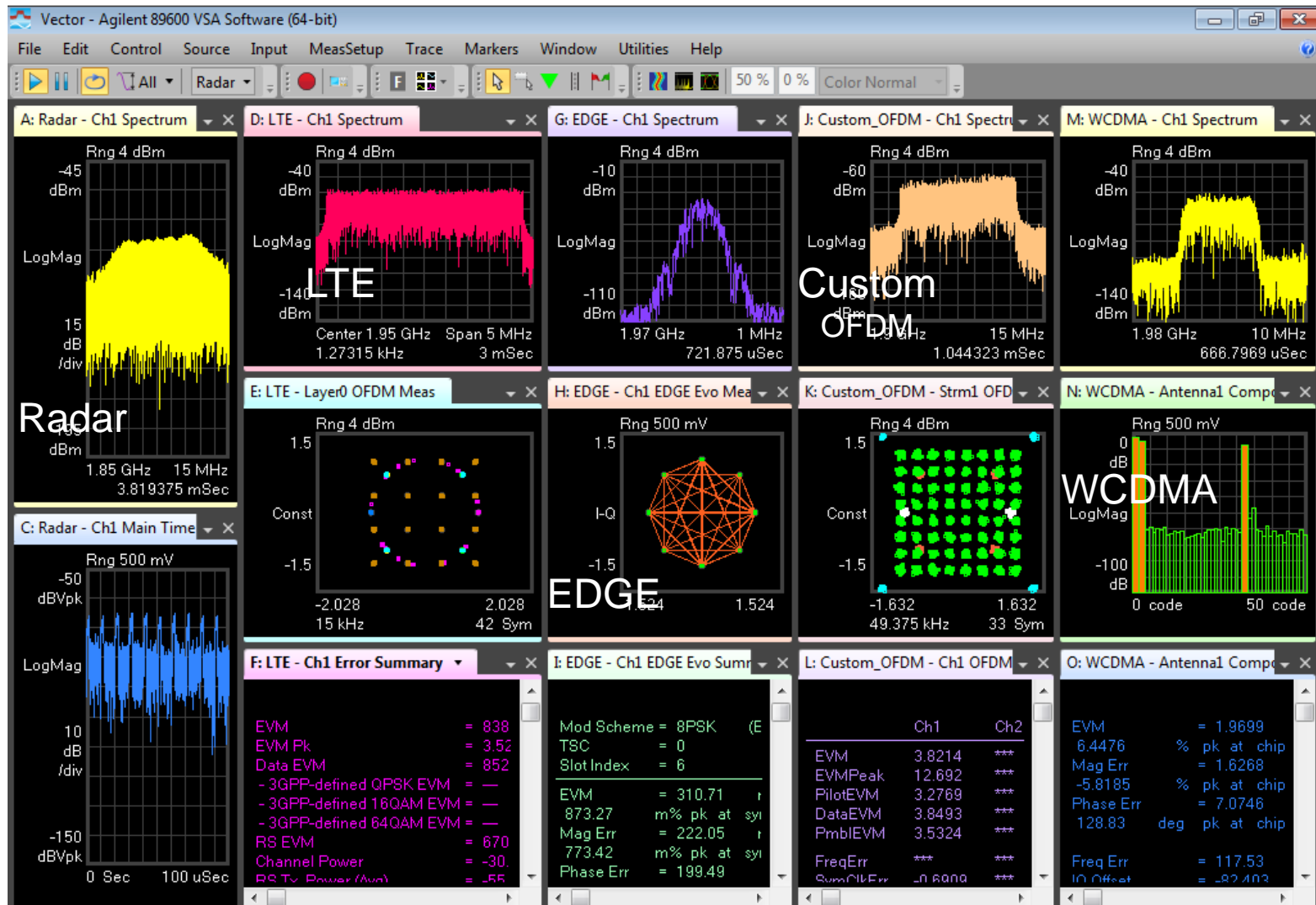
- MD1 soft front panel
- AcqirisMAQS U1092A-S01/S02/S03
- 89600 VSA software



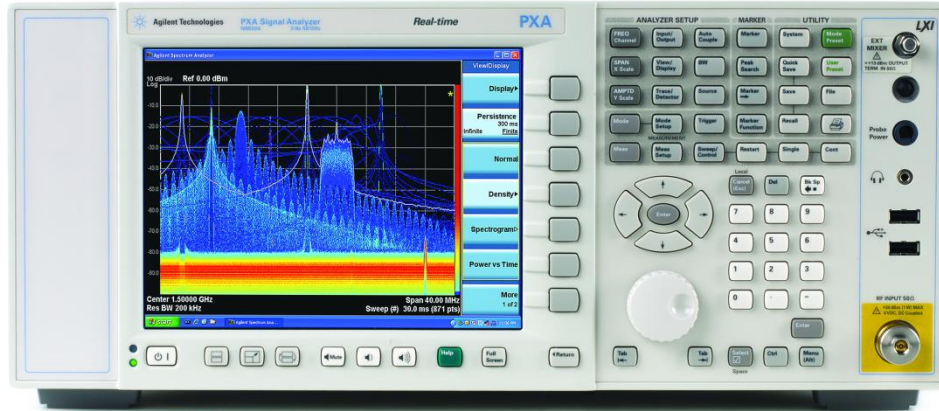
5 Channel IF Signals Captured with M9703



5 Channel Demodulation Performed with M9703 and VSA Software



Agilent's Real-Time Spectrum Analysis



See, capture and understand the most elusive signals—known or unknown

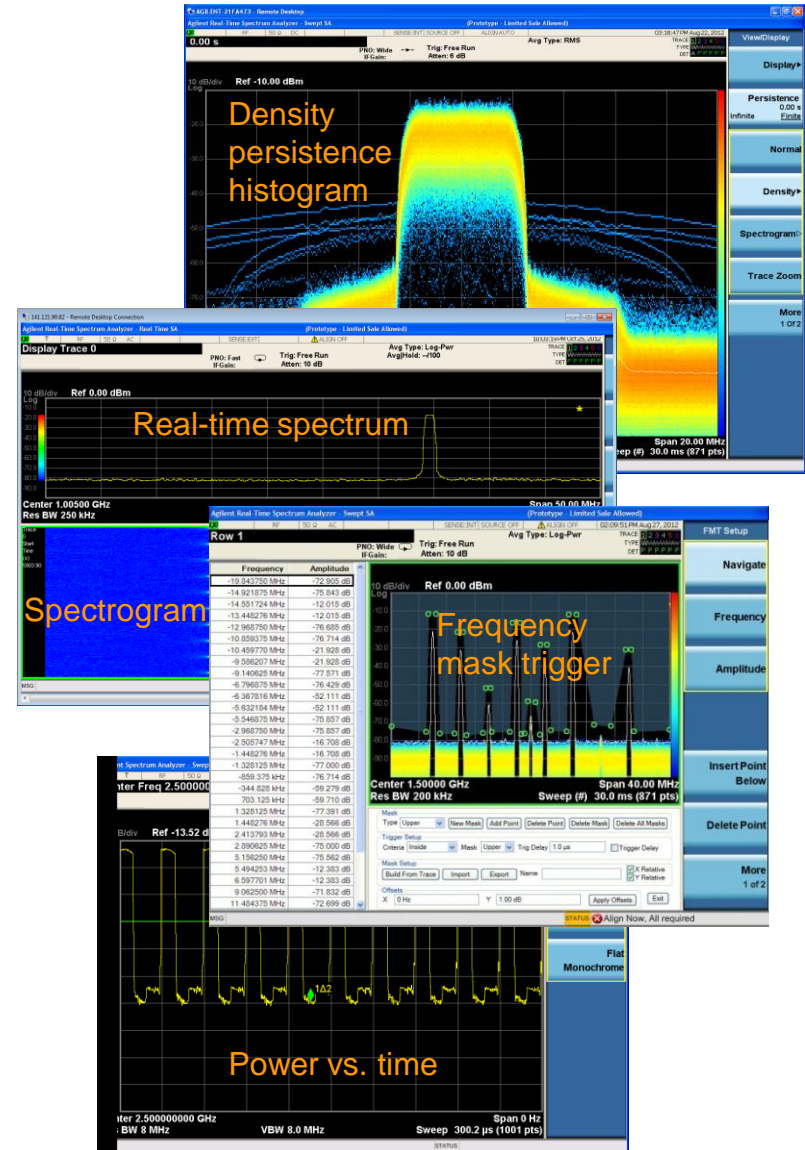
- **Provides highest-performance real-time spectrum analysis**
- **Adds real-time to industry-leading PXA signal analyzer**
 - *Upgradable option to new and existing PXAs*
- **Supports thorough analysis of complex signals**
 - *Seamless integration with 89600 VSA software*

Agilent's Real-Time Spectrum Analysis



Key features

- Detect signals with durations as short as **3.57 μ s** with 100% POI
- Use FMT to identify or record culprit signals
- Lowest noise floor of **-157 dBm/Hz @ 10 GHz** (no preamp) enables improved POI
- Scan wide spans of spectrum with **160-MHz real-time bandwidth** up to **50-GHz** frequency range
- See small signals in the presence of large ones with up to **75 dB SFDR** across 160 MHz bandwidth
- Eliminate need for specialized/dedicated instrument by adding real-time capabilities to the PXA





Signal Analysis Software



Agilent Vector Signal Analysis

89600 VSA software is an evolutionary approach to vector signal analysis that spans instrumentation and measurements



X-Series Signal Analyzers

PXA High-performance
MXA Mid-performance
EXA Economy-class
CXA Low cost



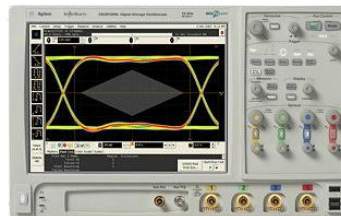
Modular Products

Signal Analyzer &
Digitizer



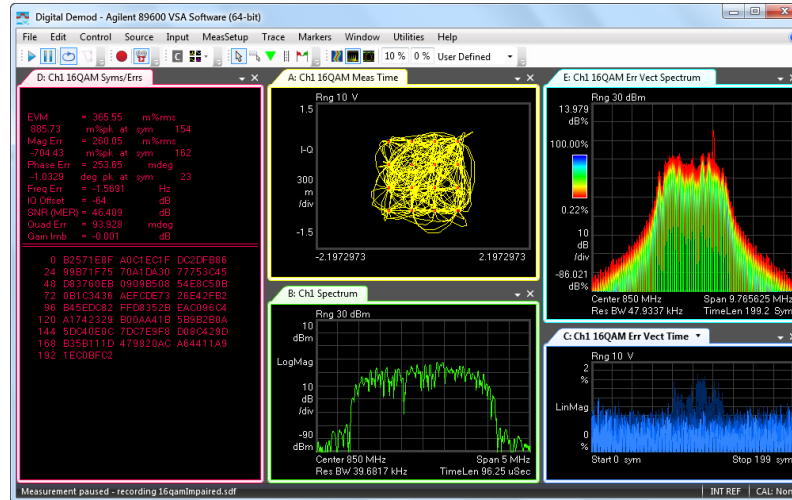
Oscilloscopes

Infiniium & InfiniiVision

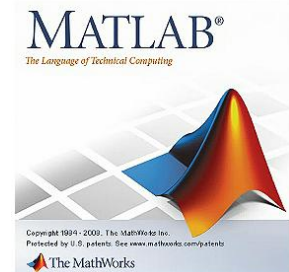


Logic Analyzers

16800/16900 series



89600 VSA Software



Example: Cross Correlation of Measurements

Time sidelobe analysis

Compressed
measured pulse

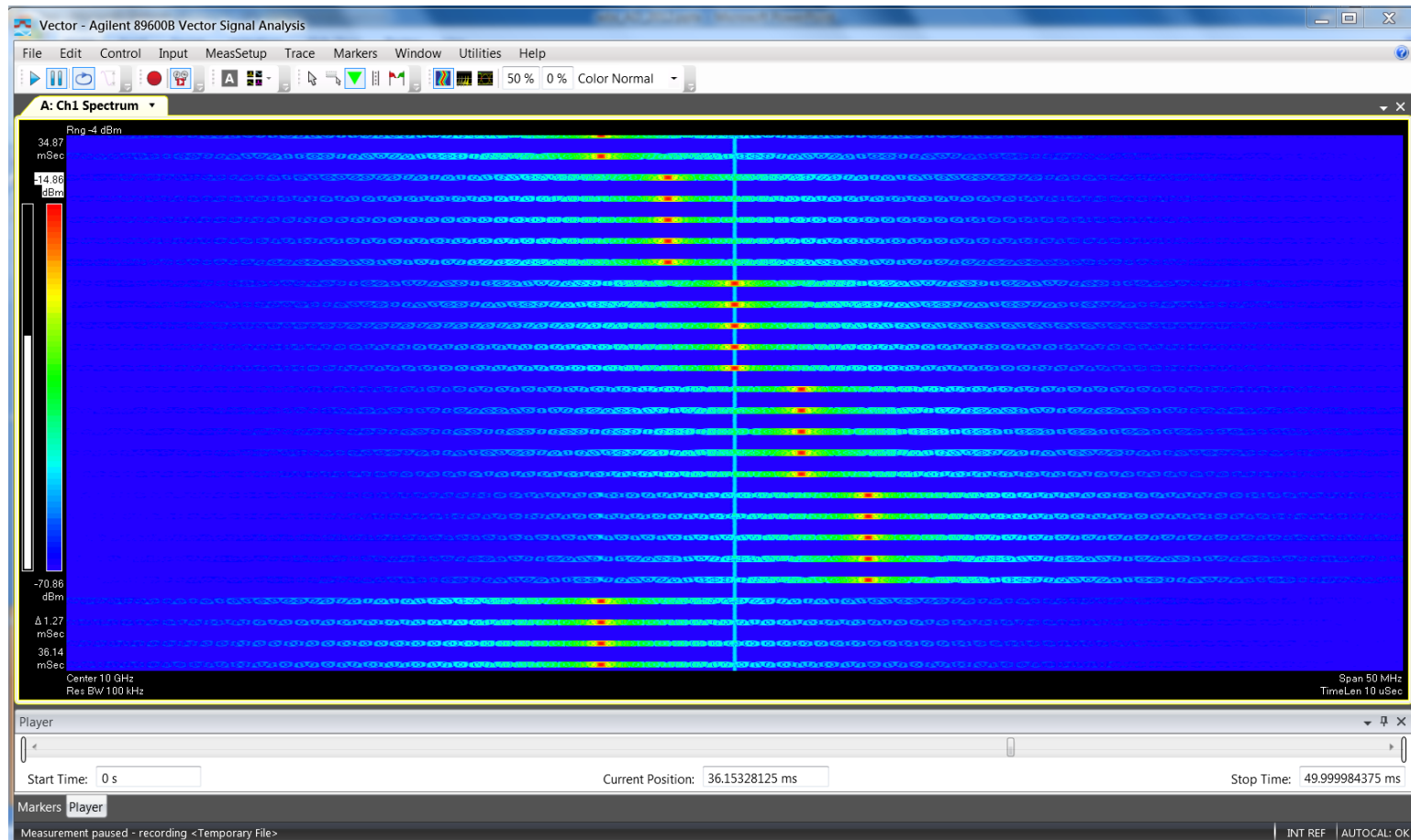
Chirp pulse
spectrum



Pulse envelope

Compressed Ideal
pulse (MATLAB)

VSA Spectrogram Display



Spectral activity over time



Capture & Playback



PXI Dual-Channel Wideband Data Streaming



Problem:

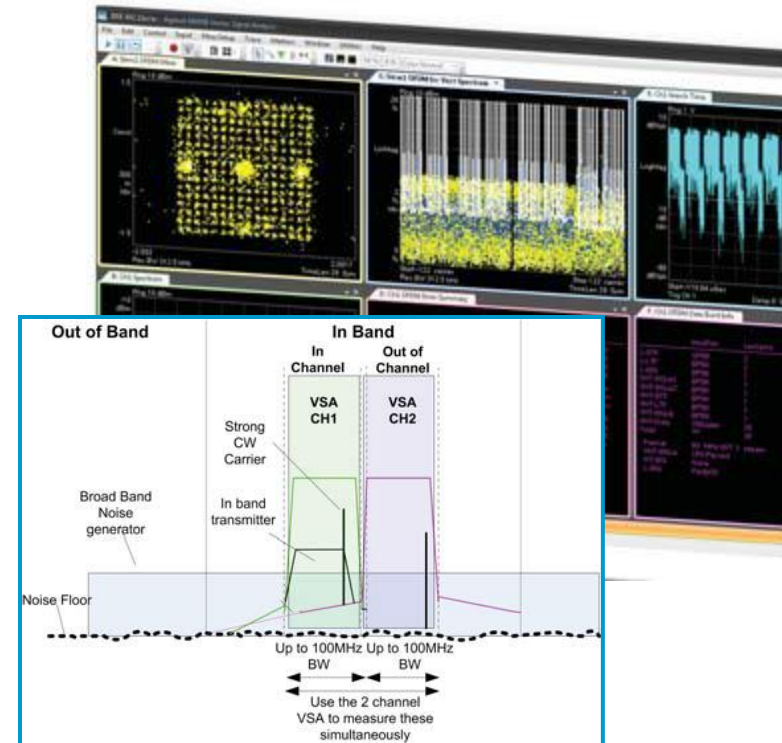
Need to make continuous wide bandwidth RF and microwave measurements in two different frequency spans over extended periods without signal loss

Solution:

Industry's **widest bandwidth dual channel** PXI Vector Signal Analyzer with continuous, gapless capture of RF/uW signals up to 100 MHz BW

Benefits:

- Greater than **6 hours** of gapless capture of RF & Microwave signals on 2 channels
- Up to **2 synchronized channels** with **100 MHz BW** for environment recording
- Create coherent recordings using post processing technique
- Captured digitizer data format is open for customer analysis tools
- Small Form Factor – 2 channels in 1 chassis



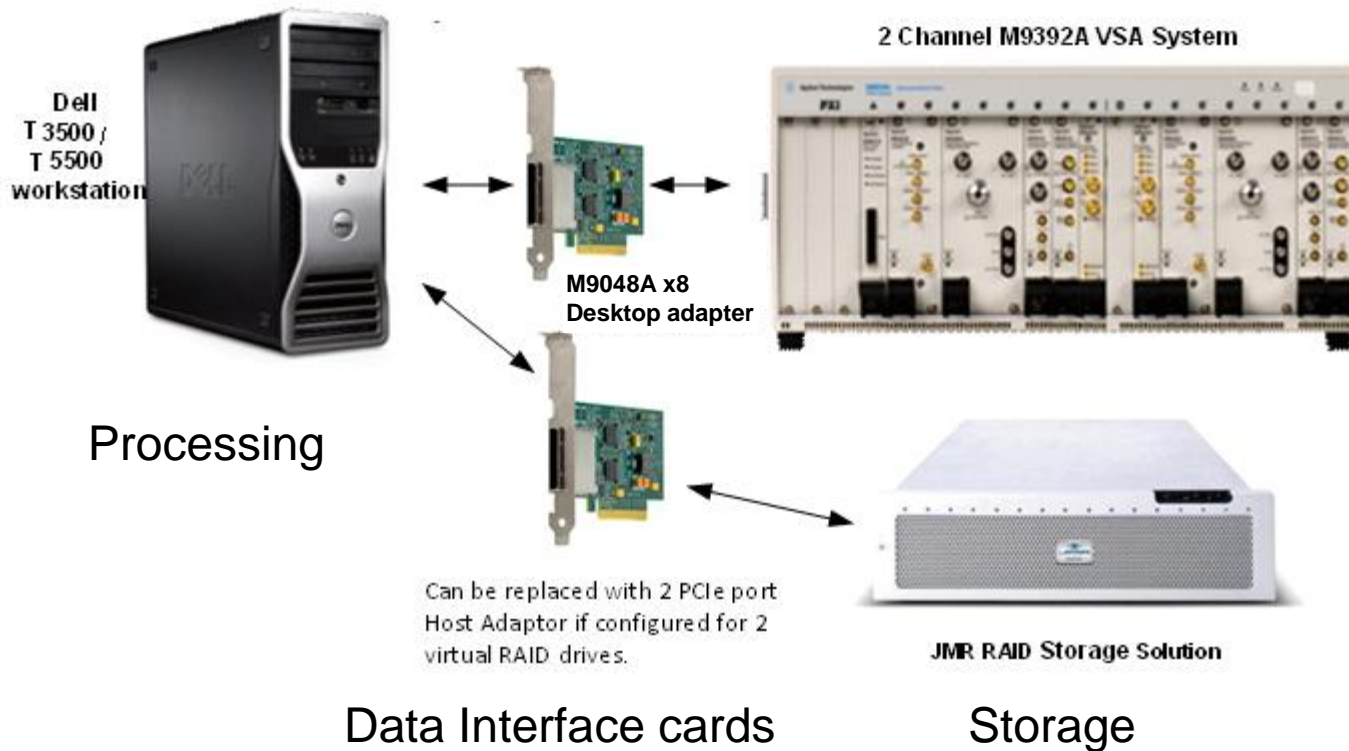
www.agilent.com/find/pxi-vsa-dualchannel



Gapless Recording Hardware Solution

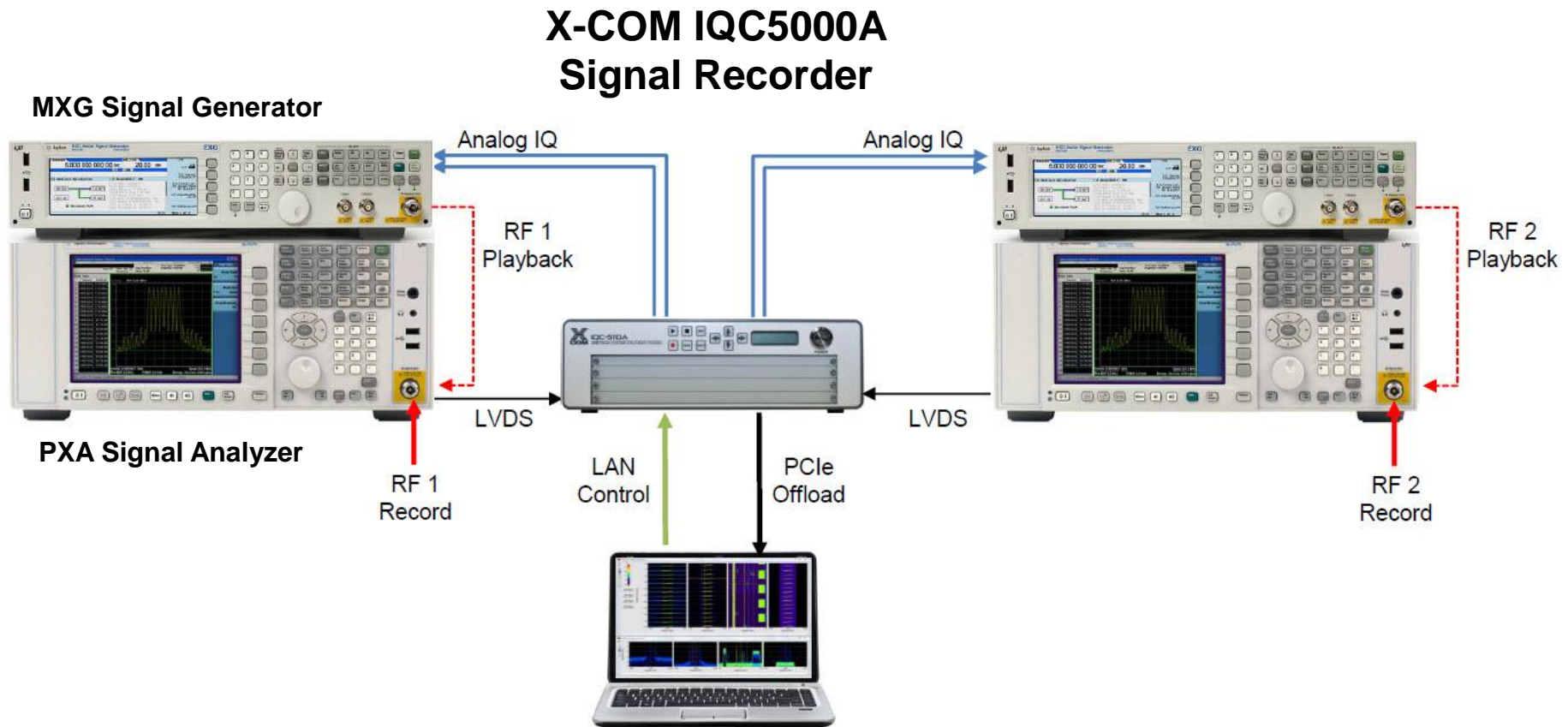


Measurement Hardware



- 2 x M9392A PXI VSA
- M9018A PXI Chassis
- M9021A Interface
- 10 MHz - 26.5 GHz
- 100 MHz Recording Bandwidth
- Single Controller / Dual Controller
- 8, 16, 32 TB

Agilent / X-COM Solution for Gapless Capture and Streaming Playback



- Record and Playback 40 MHz through 50+ GHz
- Store over 20 hours at 40 MHz bandwidth

Wideband Capture & Playback Solution



Agilent's New M8190 Arbitrary Waveform Generator Combined with Agilent's New M9703 Digitizer



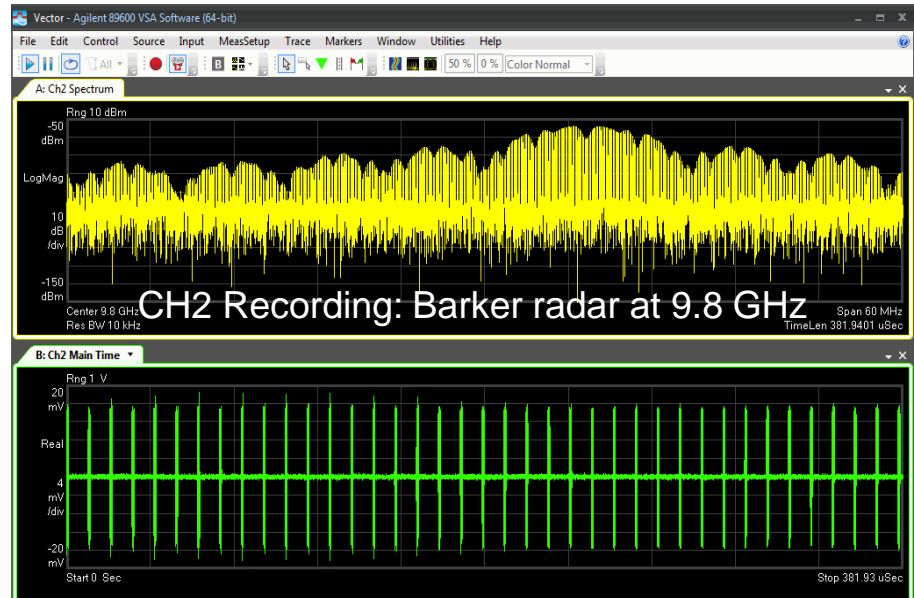
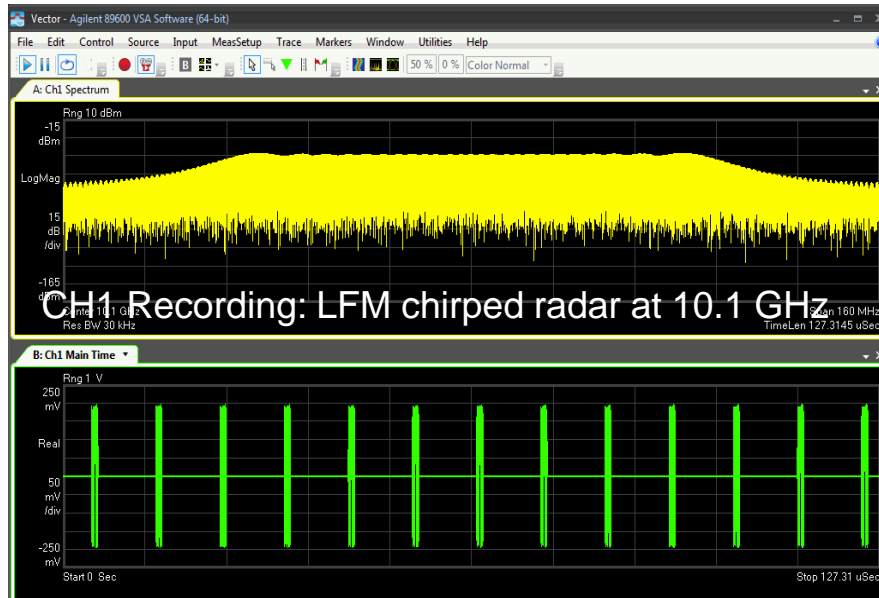
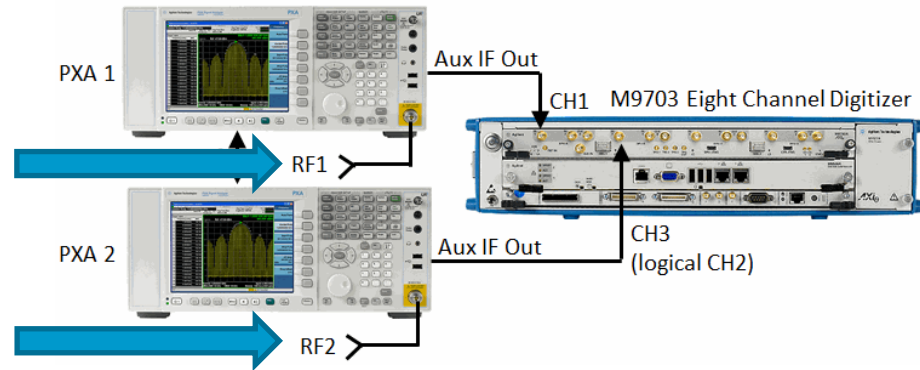
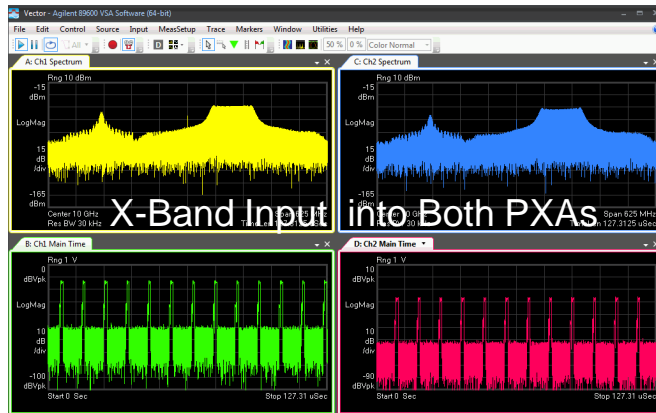
World Class Digitizer Features:

- ✓ 12 bit Resolution
- ✓ 8-4 coherent channels at up to 1.6-3.2 GS/s
- ✓ DDC option
- ✓ DC to 1 GHz analog bandwidth
- ✓ 650 MHz bandwidth limit
- ✓ 1 V / 2 V selectable input voltage FSR (Full Scale Range)
- ✓ $\pm 2 \times$ FSR Input voltage offset range
- ✓ Up to 256 MS/ch
- ✓ Segmented memory mode
- ✓ 3 Trigger inputs, 1 Trigger output
- ✓ Internal clock, external ref, backplane ref, and external clock modes
- ✓ PCIe x4 Gen2 back-plane connectivity (> 650 MB/s sustained transfer rate)

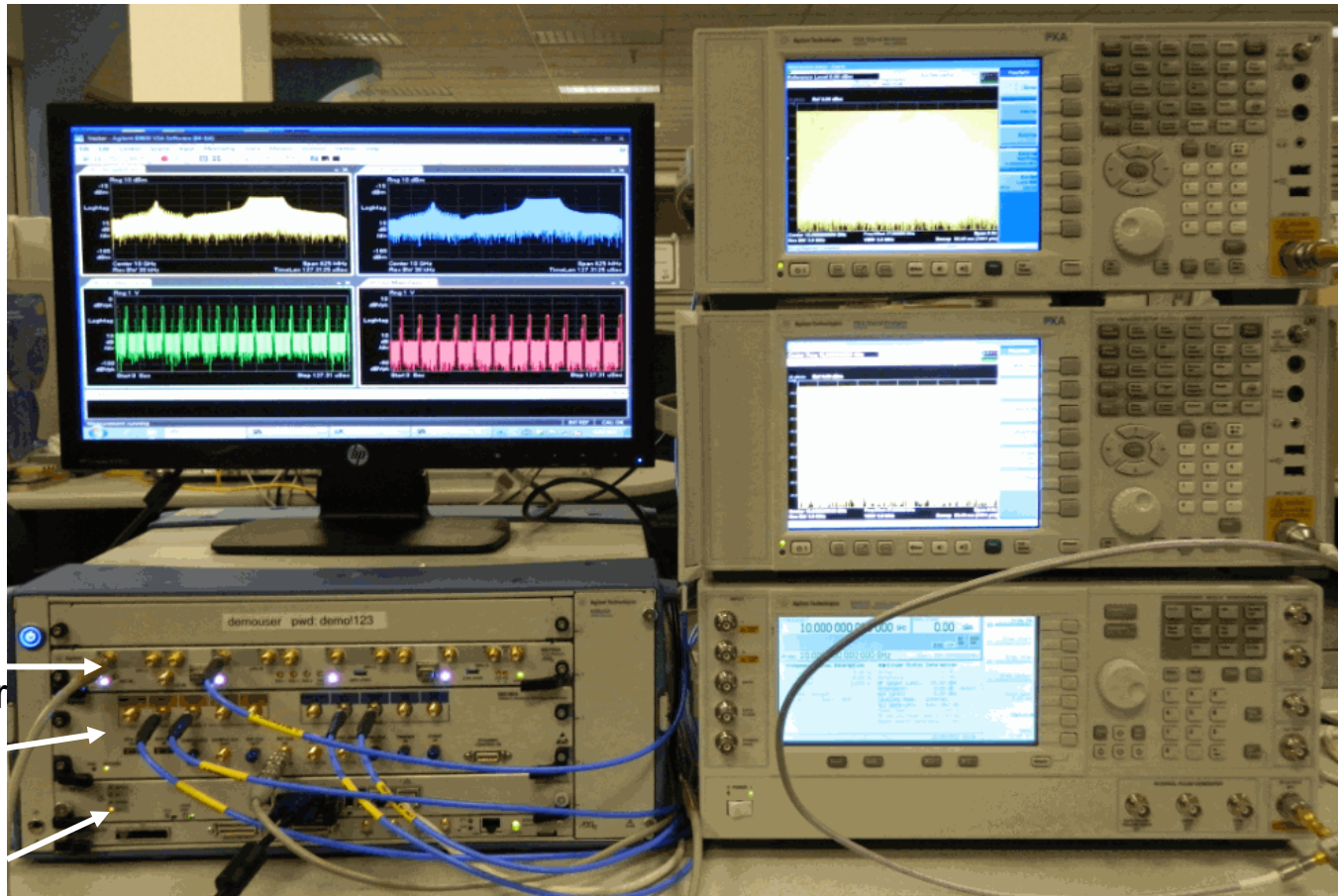
Precision AWG with DAC resolution of:

- ✓ 14 bit up to 8 GSa/s
- ✓ 12 bit up to 12 GSa/s*)
- ✓ Up to 2 GSa Arbitrary Waveform Memory per channel
- ✓ Up to 5 GHz analog bandwidth per channel
- ✓ 3 selectable output paths: direct DAC, DC *) and AC*)
- ✓ SFDR: -80 dBc typ. ($f_{out} = 100$ MHz, $F_s = 7.2$ GHz, 14 bit mode)
- ✓ Harmonic distortion: -72 dBc typ. ($f_{out} = 100$ MHz, $F_s = 7.2$ GHz)
- ✓ Advanced sequencing scenarios define stepping, looping, and conditional jumps of waveforms or waveform sequences*)
- ✓ 2 markers per channel* (does not reduce DAC resolution)

Capture Two X-Band Signals with VSA Software and M9703 Digitizer



Picture of Capture/Playback Test Setup



PXA 1
(Down-
converter)

PXA 2
(Down-
converter)

PSG
(Test
Signal)

M9703 Multi-
Channel Digitizer

M8190A Multi-
Channel AWG

SystemVue
(installed on controller)



Calibration Refresh Module (CalPod)



CalPod Calibration Refresh Modules



A new and unique way to quickly and easily refresh a network analyzer calibration with the push of a button, and without disconnecting the DUT.



Public introduction: June 2, 2013 at IMS-MTT Conference, Seattle, WA

Agilent has not previously publically introduced these products, but has been selling these products to targeted customers for 2+ years. Purpose was to get an installed base before competitors.

Benefits CalPods Offer Customers:



CalPods can remove effects of:

- Amplitude & phase variations due to test cable movement
- Thermal variations in test cables & connectors
- Connector repeatability errors
- Switch matrix repeatability errors
- Different cables being added to the test system

Key message:

CalPods can provide assurance of a current & valid 'fresh' calibration at the push of a button

Types of CalPods



Ambient temperature CalPods

- For bench top and ambient measurement applications
- 85530A 20 GHz ambient CalPod module
- 85540A 40 GHz ambient CalPod module



Temperature compensated CalPods

- For hot plate & temperature chamber applications
- 85531A 20 GHz ambient CalPod module
- 85541A 40 GHz ambient CalPod module



Thermal Vacuum CalPods

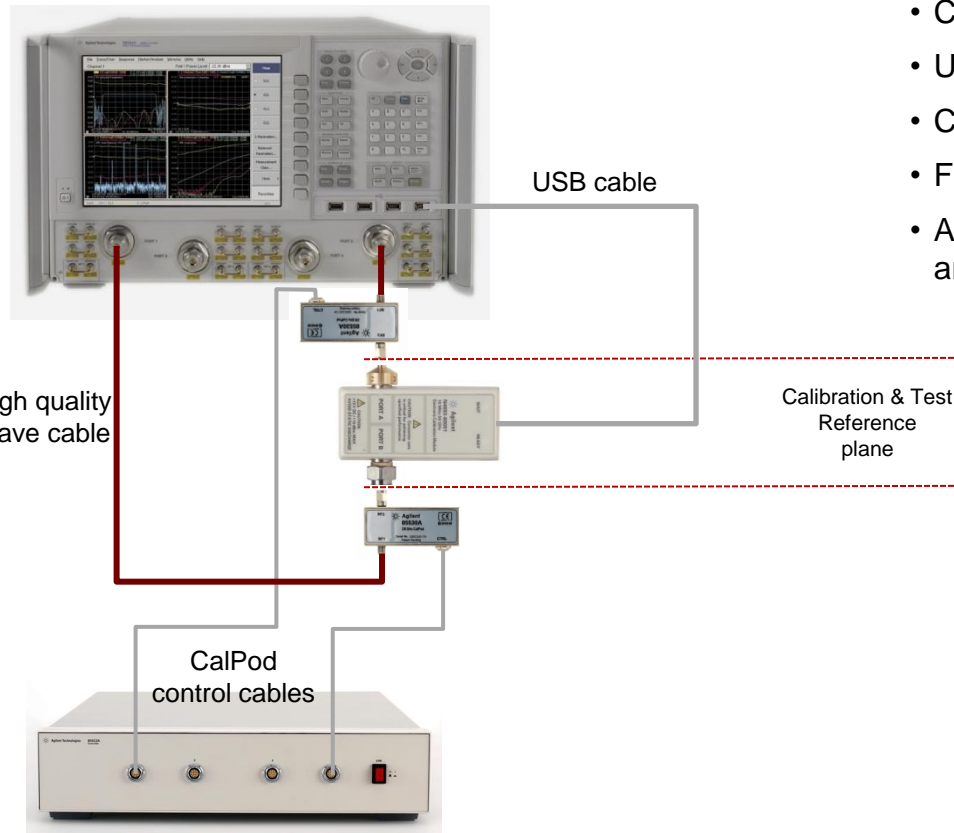
- For thermal vacuum chamber applications
- 85532A 20 GHz CalPod (thermal-vacuum environments)
- 85542A 40 GHz CalPod (thermal-vacuum environments)



Initial Calibration



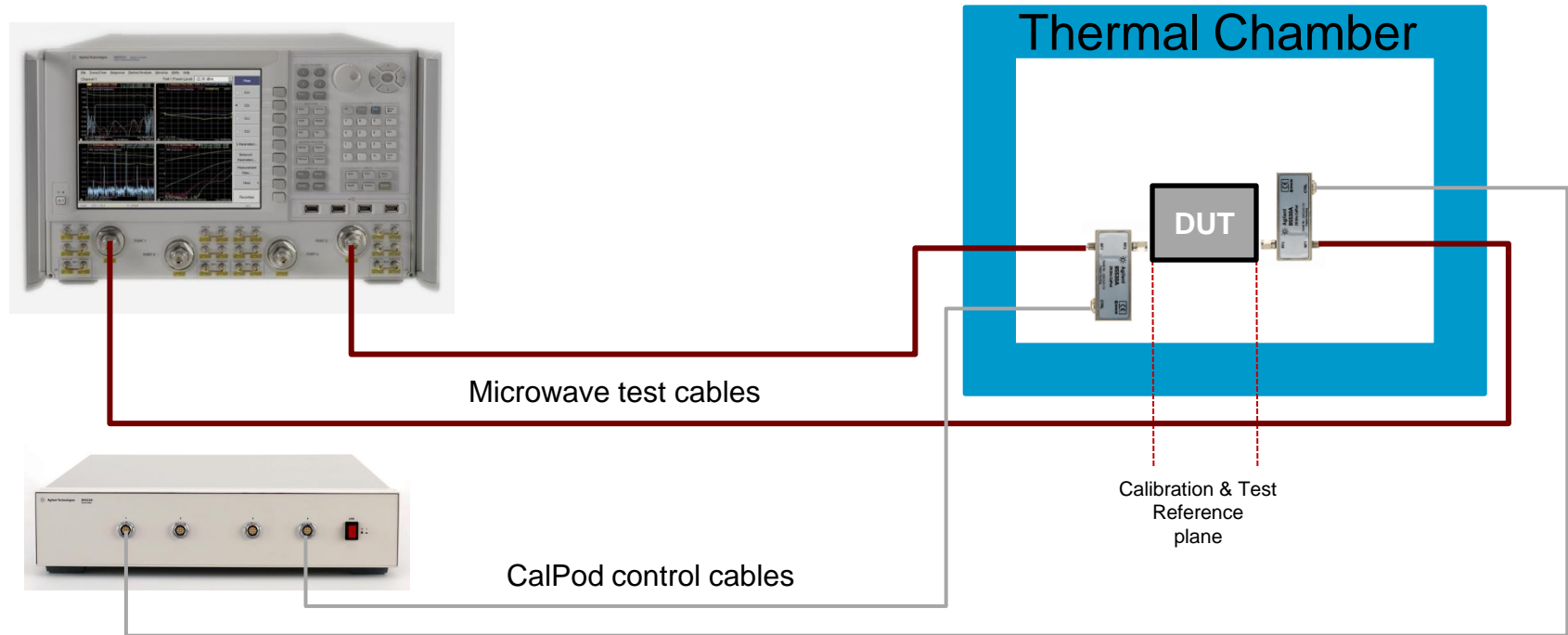
Initial calibration is performed only once!



- Configure as shown
- Use short, high quality microwave cables
- Calibrate using an ECal module or mechanical cal-kit
- Final calibration connection should be a through
- After ECal is complete, do not touch setup until calibration array is transferred to the CalPod module correction array

Initial calibration is performed at ambient temperature.

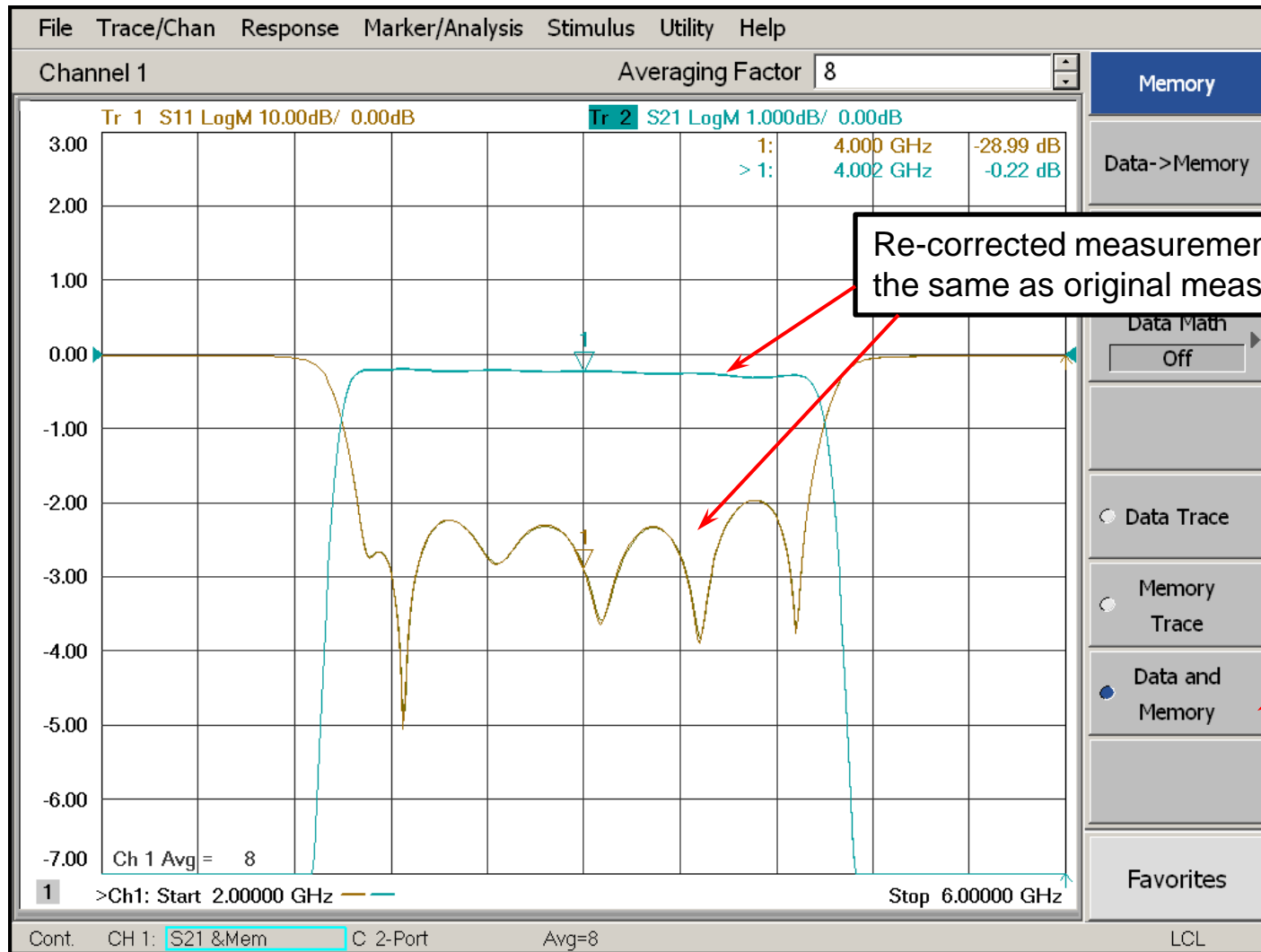
Reconfigure the Measurement System



- Longer cables can be added to reach the DUT location.
- Can add different cables, connectors, adapters, and reconfigure anything between the PNA and the CalPods.
- A CalPod calibration refresh can be done at any time, and will provide a valid fresh calibration at the test reference plane at the DUT interface.

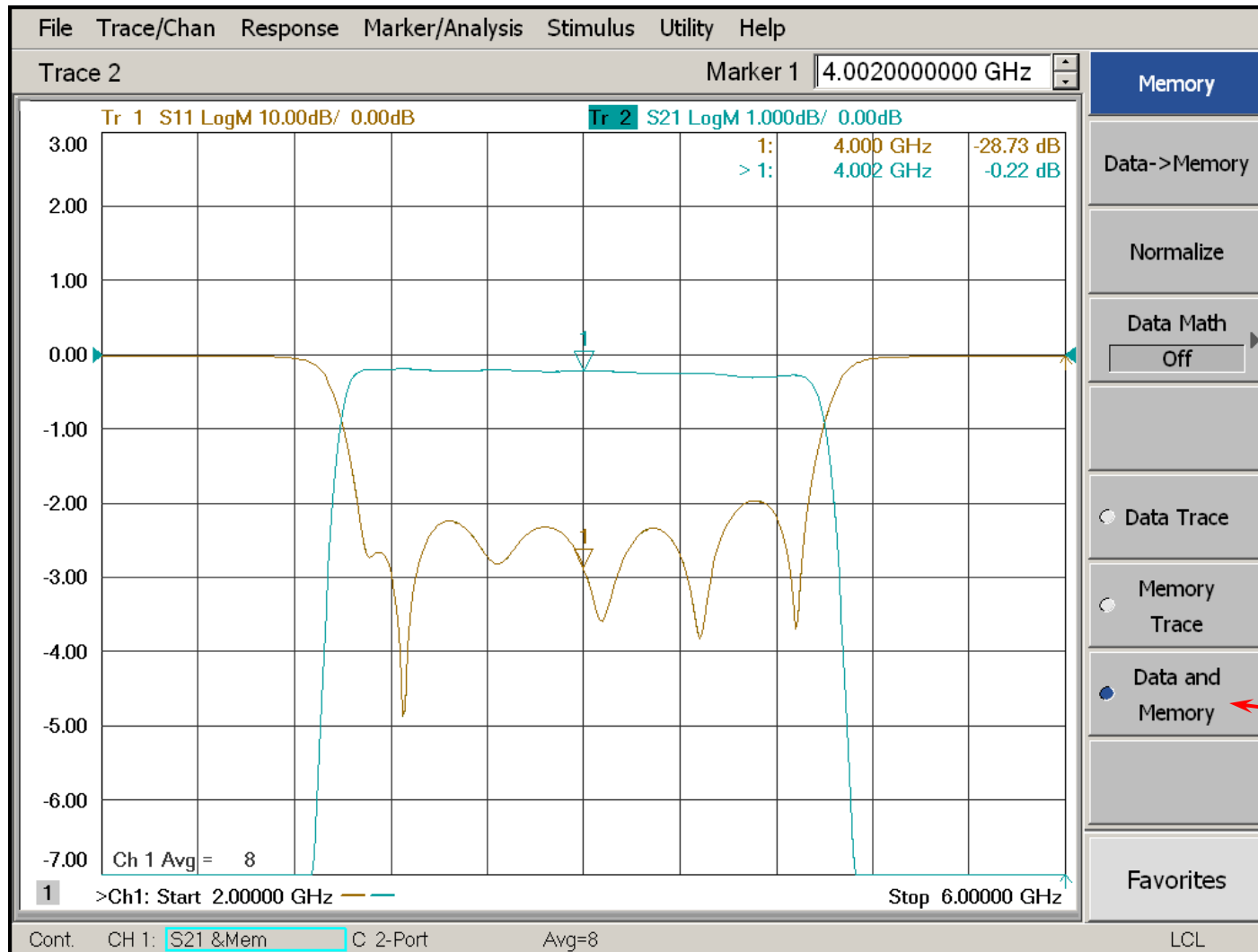
Filter Measurement

– After CalPod Re-correction With loose connector still in measurement system



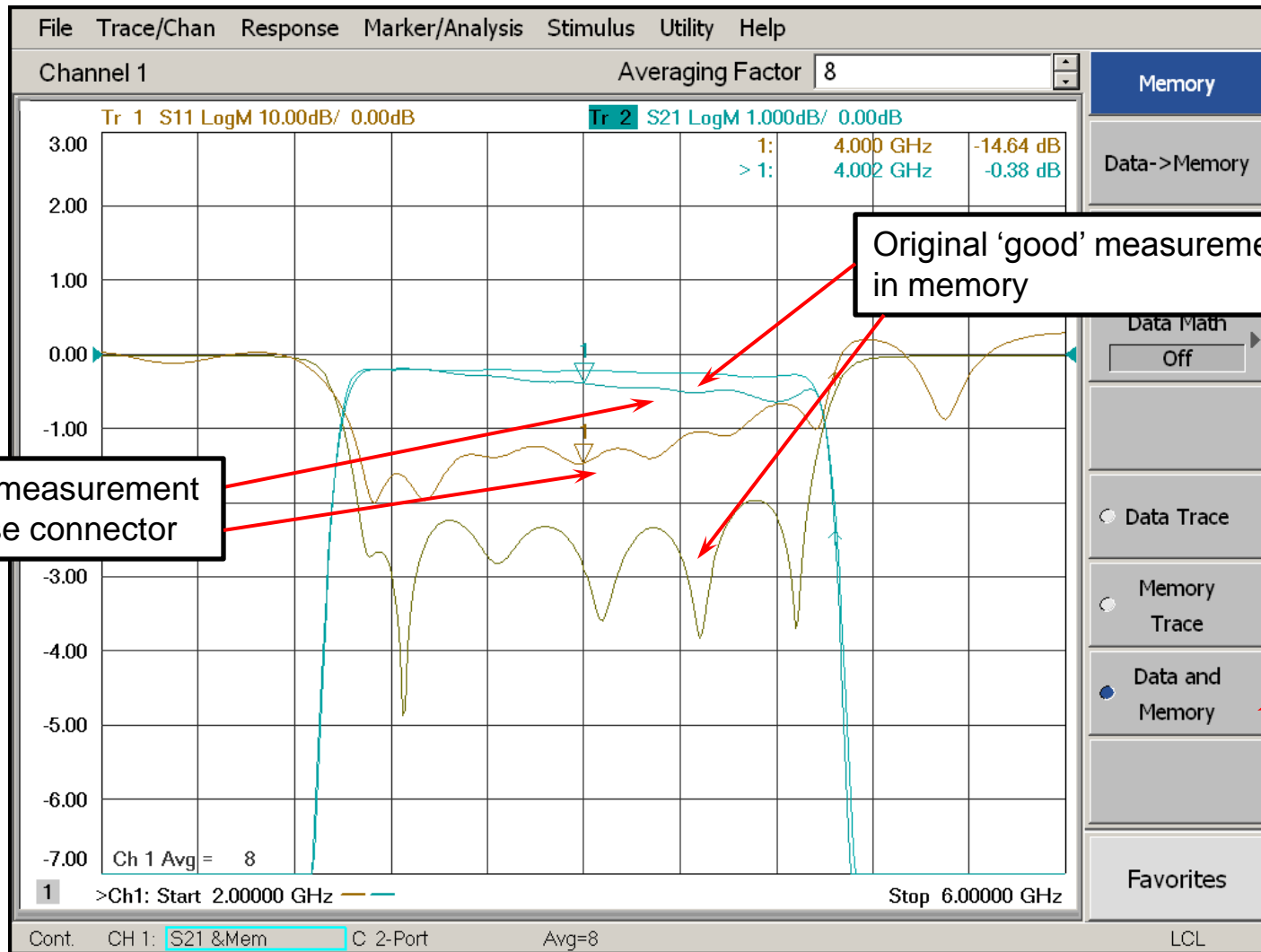
Filter Measurement

- Data and memory traces exactly the same



Filter Measurement

- With loose connector in measurement system

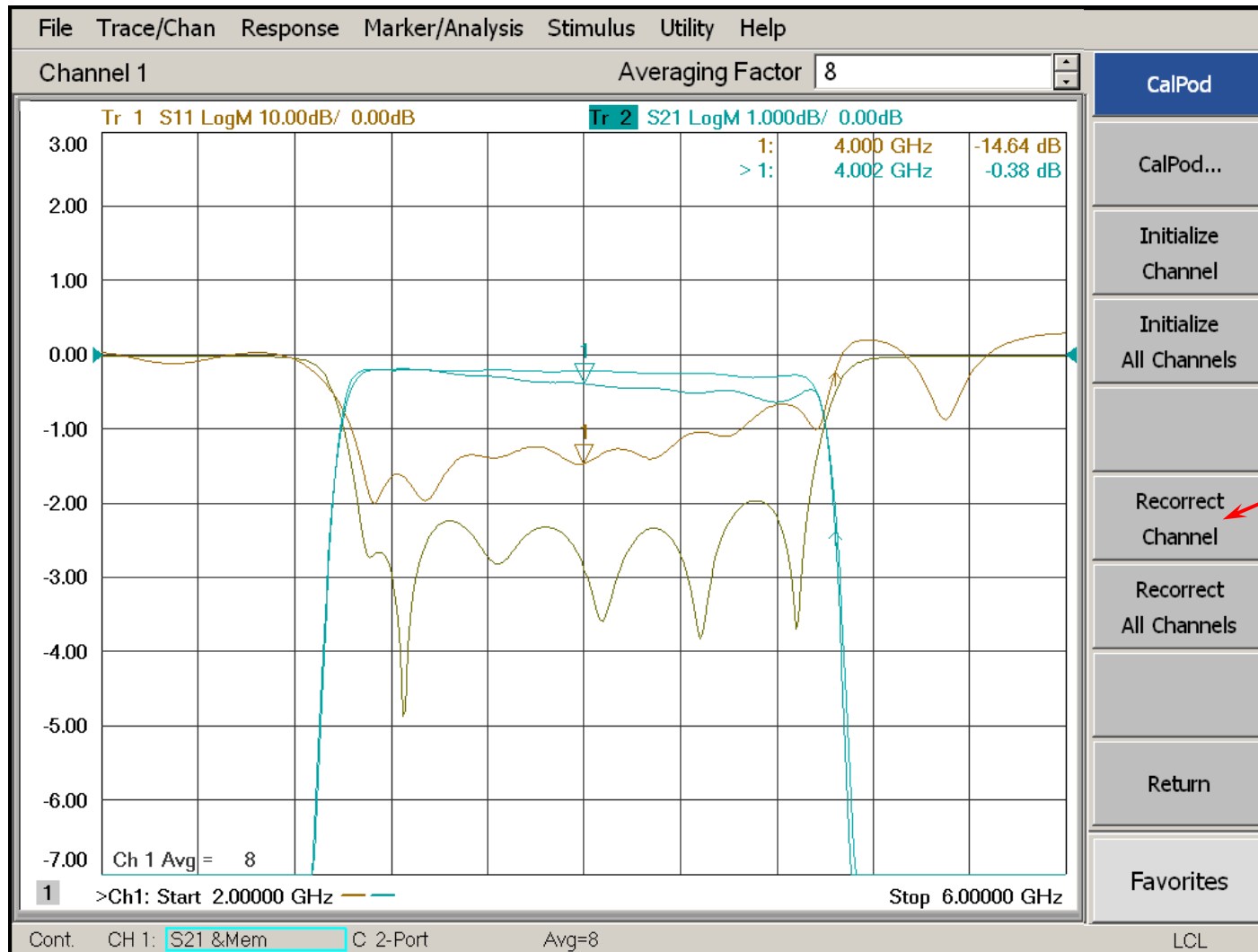


Degraded measurement
due to loose connector

Original 'good' measurement
in memory

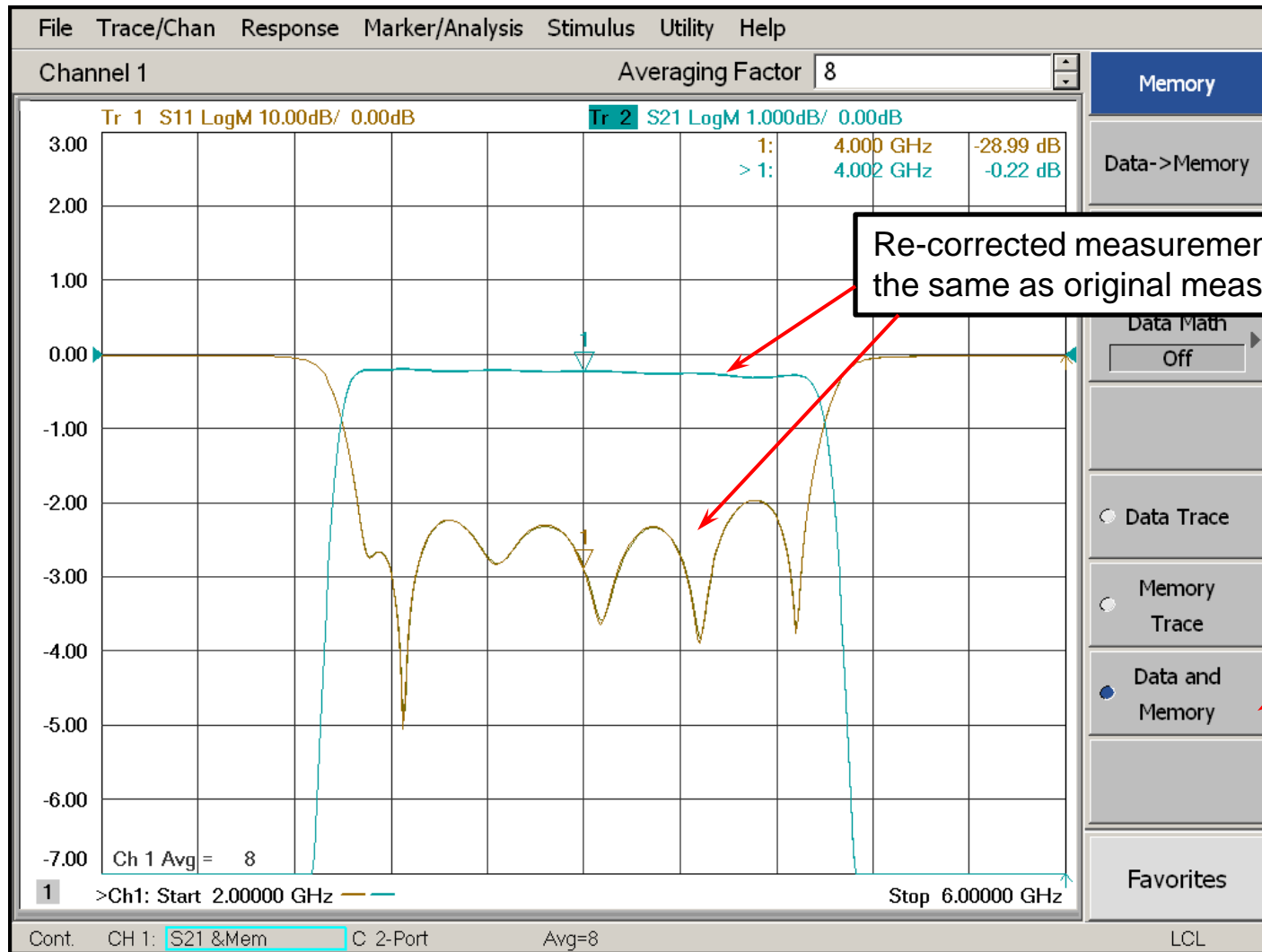
For a Calibration Refresh

- Press **Cal**, [CalPod], [Recorrect Channel]



Filter Measurement – After CalPod Re-correction

With loose connector still in measurement system



Thermal or Thermal-Vacuum Chamber Testing



- Application: Thermal or thermal-vacuum chamber testing. Long duration tests that are very expensive.
- Challenge: Thermal variations inside the test chamber can affect the reflection coefficients of the test cables and connectors.

It is expensive and time consuming to stop the test sequence to recalibrate.

- Solution: Temperature compensated and TVAC compatible CalPods placed inside the chambers.

With CalPods, you only measure the variations in the DUT, and not the variations in the test cabling, connectors, and switch matrices.



Measuring Installed Cables

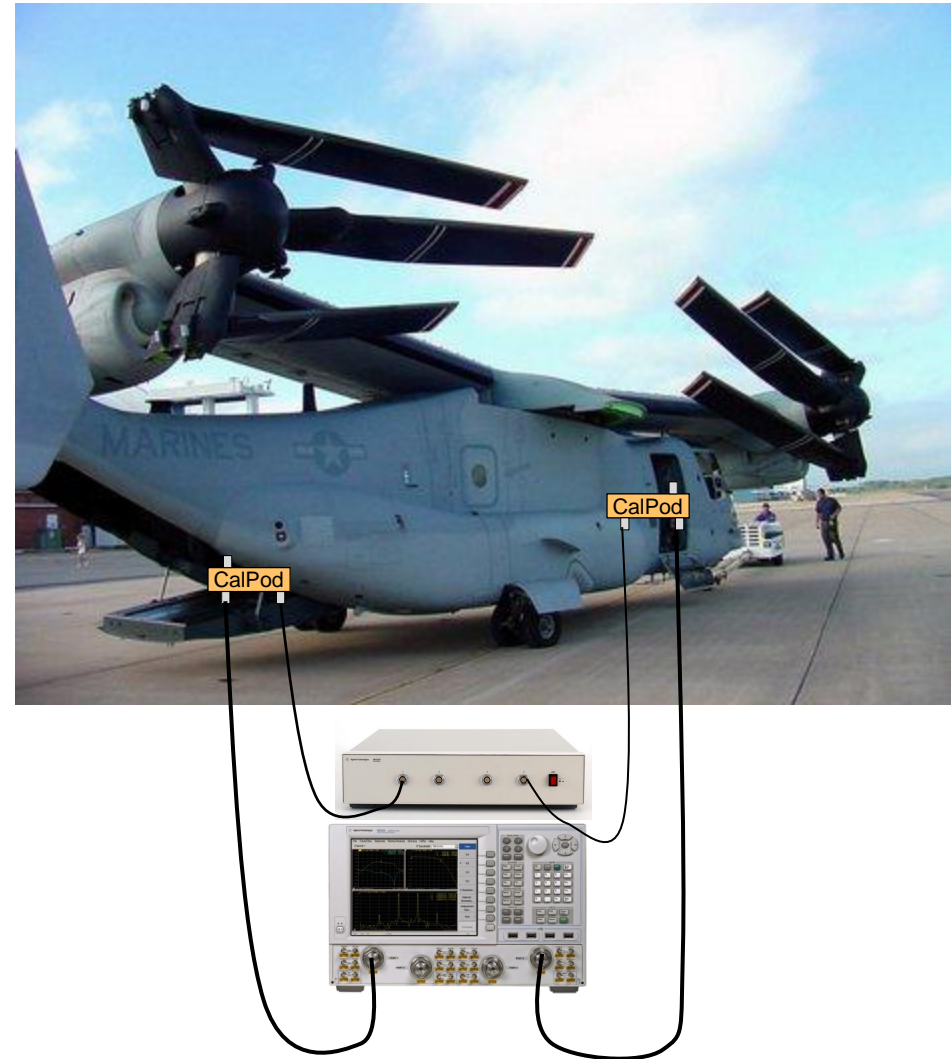


Application: Accurately measuring installed cables.

Challenge: The long test port cables will have more amplitude & phase variations than the cable being tested.

Solution: Use CalPod calibration refresh modules.

Calibration refresh modules can assure that you are only measuring the variations in the aircraft cables, and not the variations in the test port cables.

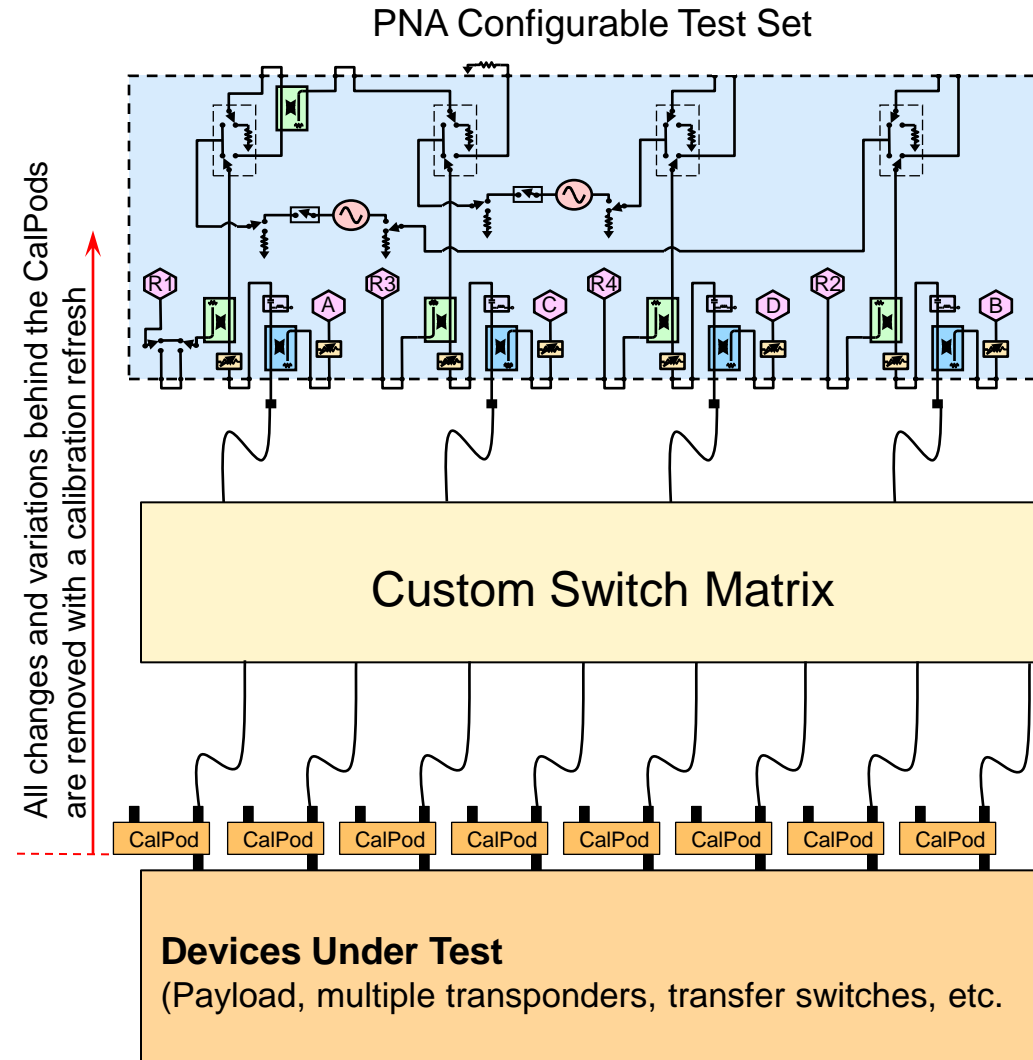


V22 Osprey photo courtesy U.S. Marines

Remove Switch Matrix Repeatability Errors



- Application: ATE test systems with complex signal paths.
 - Challenge: Switch matrices and disconnecting and reconnecting cables adds measurement uncertainty due to changes in reflection coefficients.
 - Solution: CalPods at the DUT interface will remove all signal variations behind the CalPods.
- No need to recalibrate after configuration changes, just refresh the calibration.



Accurate Measurements of Phase & Low-loss Devices



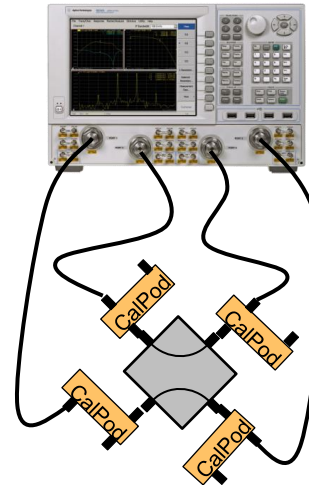
Example DUT: Measuring the insertion loss of a transfer switch

Application: Accurately measuring phase and low-loss devices.

Challenge: Cable movements between the calibration and measurement may affect the measurement of small phase and amplitudes.

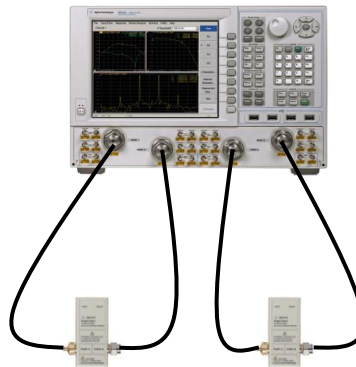
Solution: Use CalPod calibration refresh modules.

CalPods remove the variations of cable movement from the measurement.



With CalPods:

1. Connect cables,
2. Refresh calibration
3. Accurately measure DUT

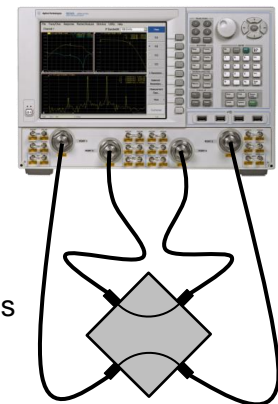


1. Calibration; S12, S34, S13, S24

Without CalPods:

Cables are repositioned between calibration and measurement

Moving the test cables may change the amplitude response of the cables



2. Measurement

Applications that Require Frequent Calibrations



Frequent Re-calibrations:

- Challenge: Applications that require frequent re-calibrations.
- Solution: Calibrate once, and refresh often; quickly and easily at the push of a button.

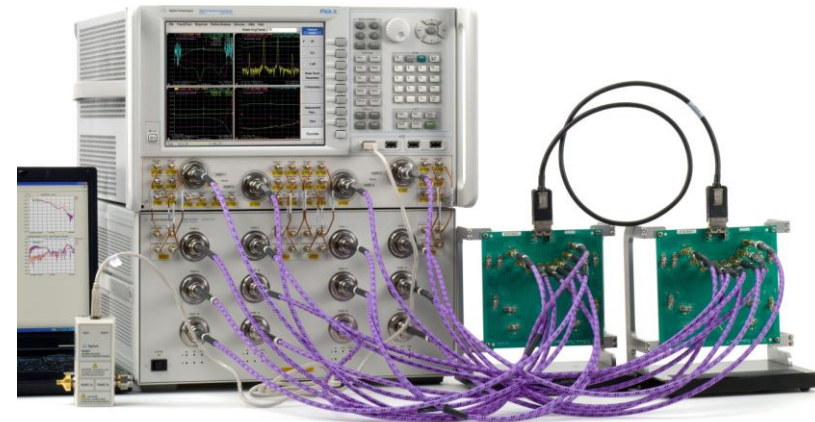
No need to spend time reconnecting calibration standards



Lengthy and Complex Calibration Sequences:

- Challenge: Applications that have long calibration times.
- Solution: Calibrate once, and refresh when necessary; quickly and easily at the push of a button.

No need to repeat long and time consuming calibration sequences.



Providing the closest device tolerances in production testing



Application: Production testing of DUTs.

- Challenges: Operators may not be calibration experts.
- Cable movement and connection repeatability may increase guard band tolerances.

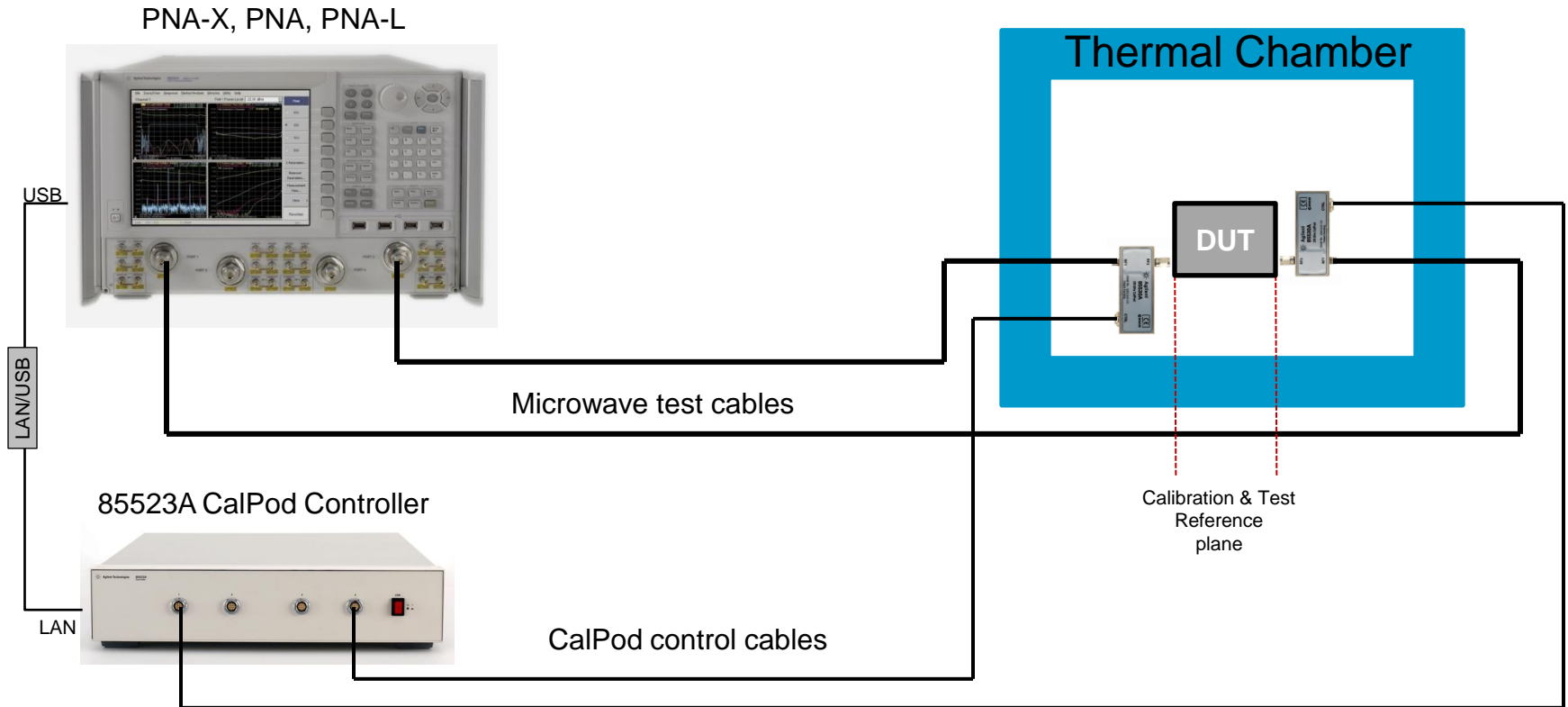
Solution: CalPod calibration refresh modules.

- Engineer or technician can perform initial calibration, operator can push button to refresh calibration.
- Cable movement and connector repeatability errors are removed, so smaller measurement guard bands are achievable.



Improve productivity, tighten tolerances, & confidence in calibration and measurements!

Basic Configuration for a two-port DUT



Re-correction 'accuracy' is dependent on loss of microwave test cables

- 16-20 dB of one-way test cable loss provides good re-correction capabilities

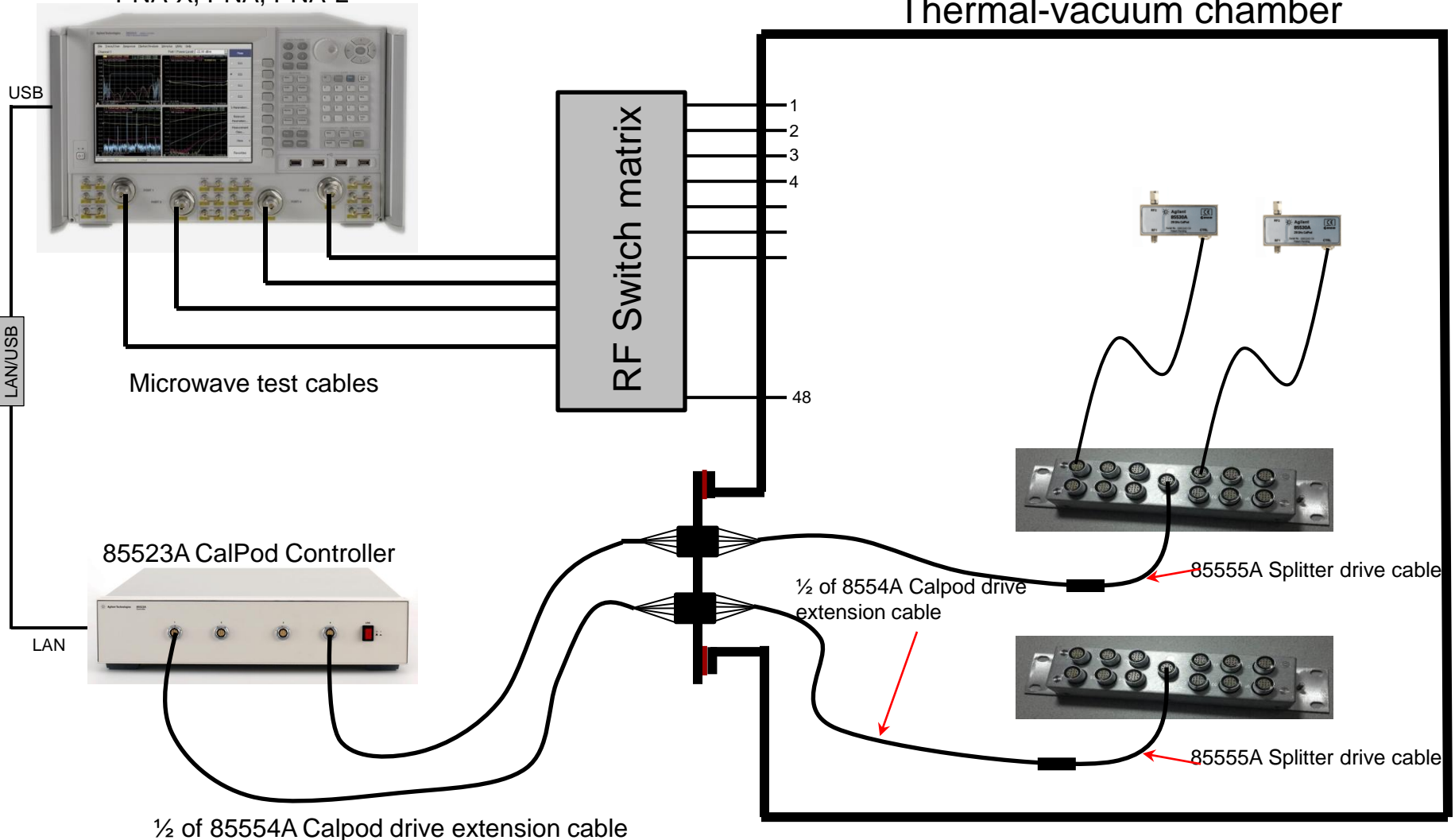
CalPods in Thermal Vacuum Chambers



Up to 48 CalPods Can be Controlled

Thermal-vacuum chamber

PNA-X, PNA, PNA-L





Thank You