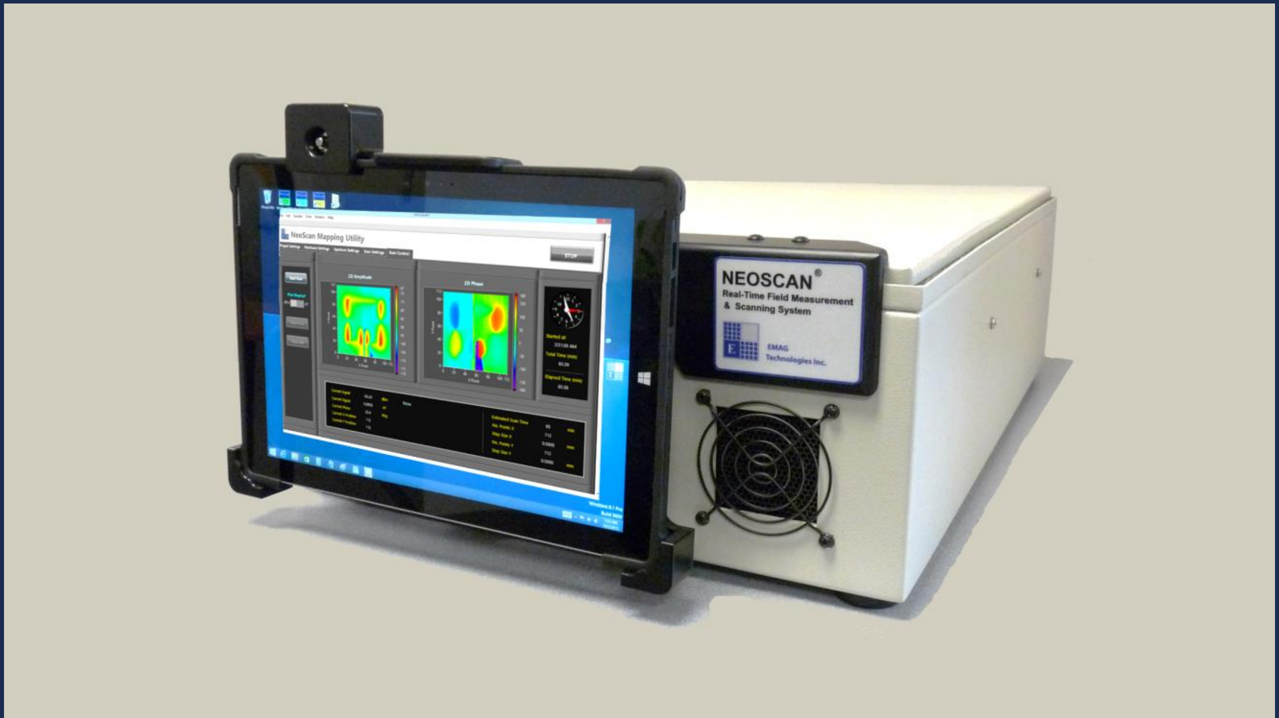
Capture the Invisible™




# NEOSCAN®

## Turnkey Field Measurement System

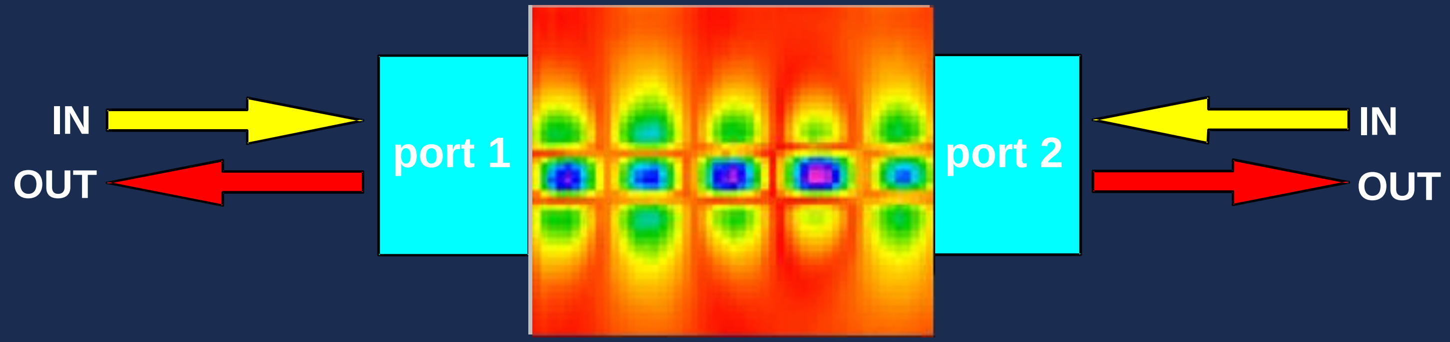
### EMAG Technologies Inc.

# Characterizing RF Circuits & Devices

Conventional port-based measurement systems like vector network analyzers measure the relationship between input and output port quantities. They do not shed light on the internal field behavior of the device under test (DUT) and cannot identify faulty areas in a direct manner.

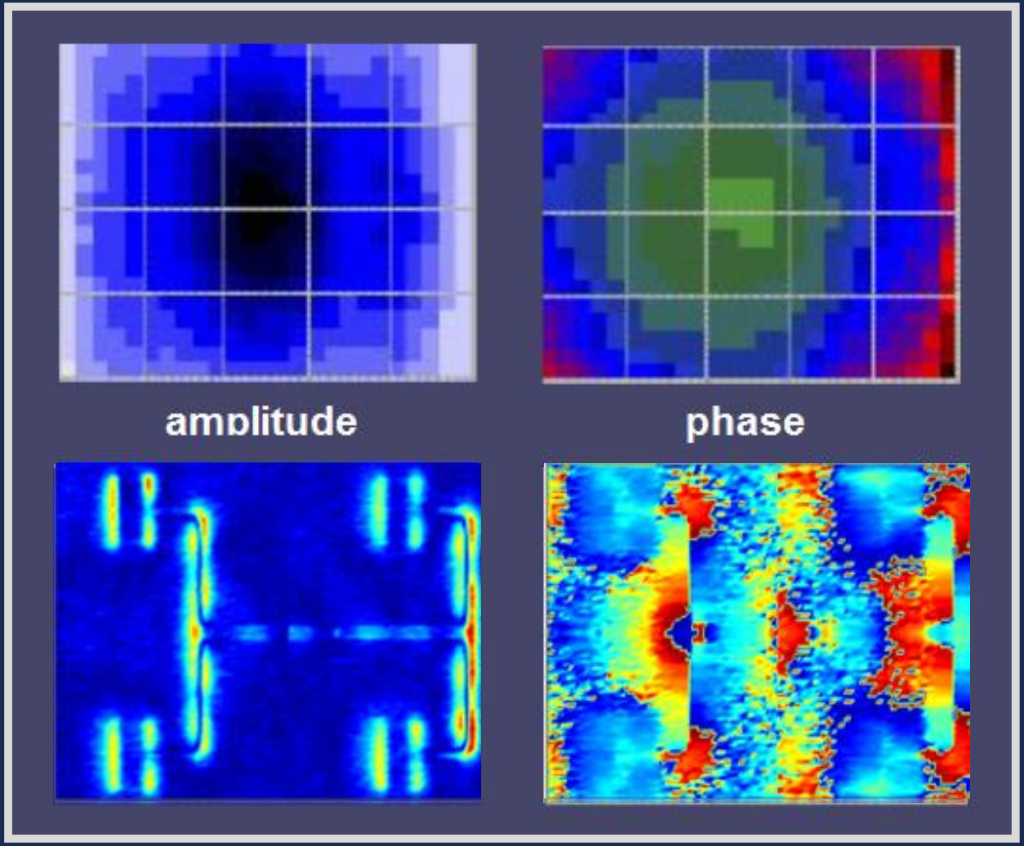
*Conventional port-based measurement*


*NeoScan's electro-optic near-field measurement*



# Characterizing Antennas & Arrays

Conventional near-field scanning systems cannot get close to the surface of the antenna under test (AUT) because their metallic parts disturb the aperture fields. They have limited bandwidth and coarse spatial resolution.



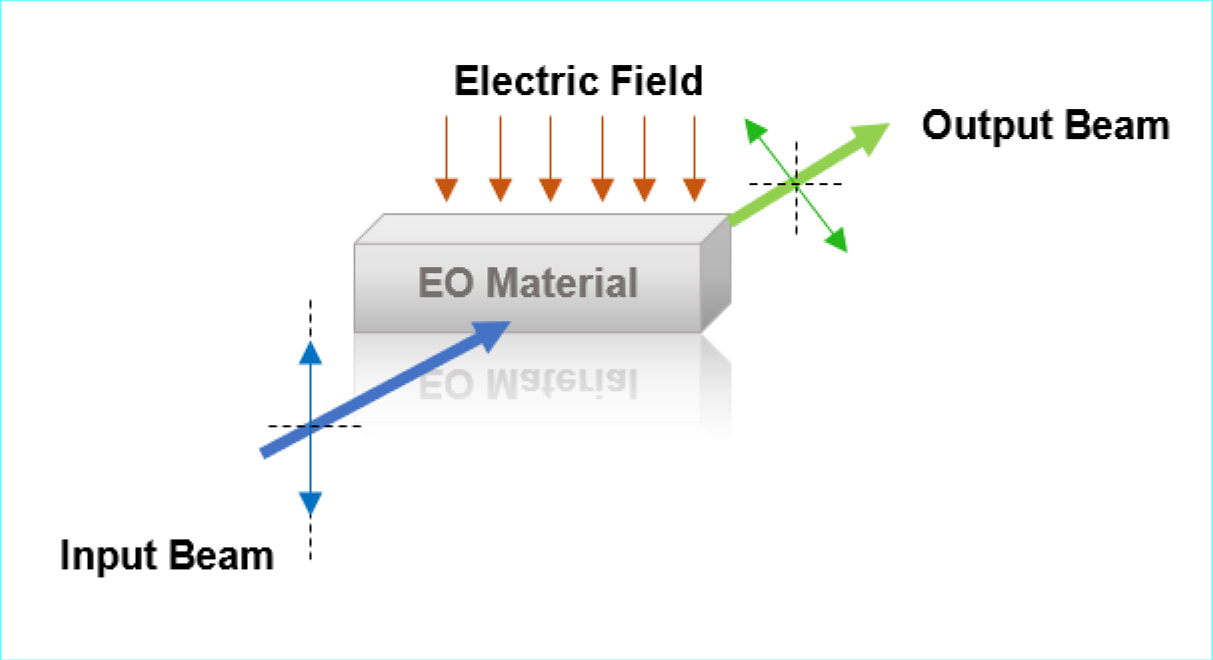

*Conventional open waveguide near-field measurement*

*NeoScan's electro-optic near-field measurement*

# The Electro-Optic (EO) Effect

## RF Electric Field Measurement Based on Pockels Effect

Imposing an external electric field on an electro-optic (EO) crystal induces a change in refractive index, which leads to a change in polarization (*linear birefringence*), which in turn produces a measurable change in optical intensity at a polarization analyzer.

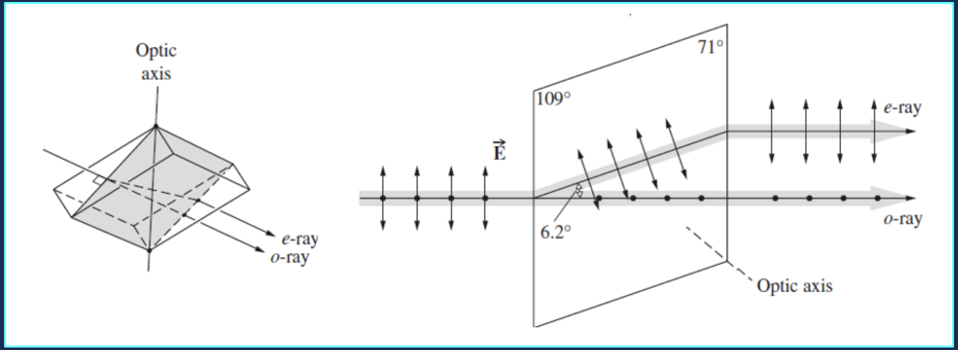


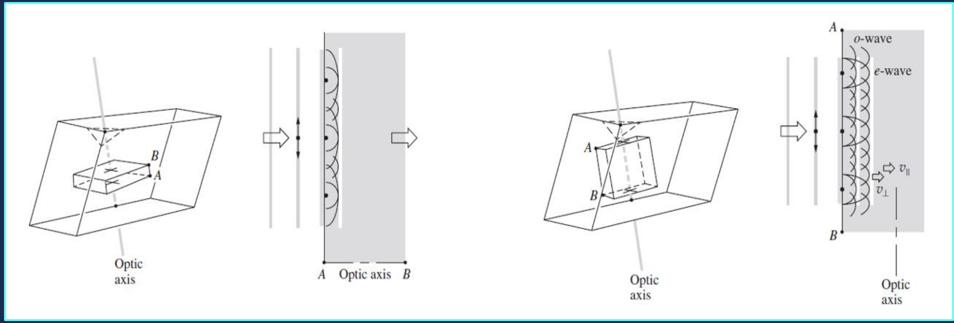
# The Electro-Optic (EO) Effect

## RF Electric Field Measurement Based on Pockels Effect

The phenomenon of birefringence occurs when the components of a wave propagating inside an anisotropic material see different refractive indices (and hence have different phase velocities) depending on the orientation of the polarization.

A propagating plane wave can be decomposed into to orthogonally polarized components along the ordinary and extraordinary axes of the EO crystal with the corresponding refractive indices $n_o$ and $n_a$.



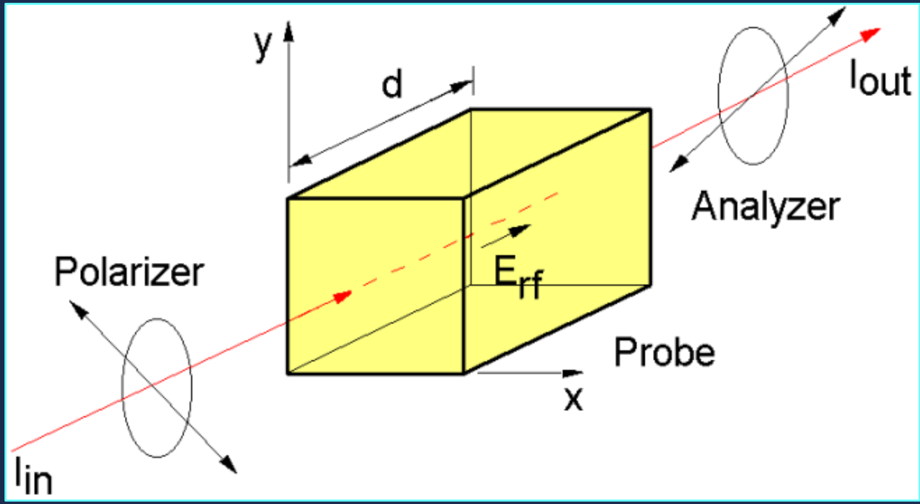

Crystal cut perpendicular to optic axis

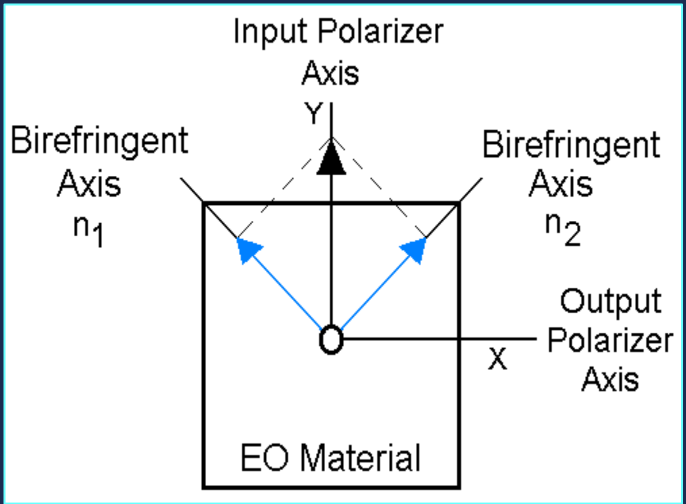
Crystal cut parallel to optic axis

# The Electro-Optic (EO) Effect

## RF Electric Field Measurement Based on Pockels Effect

### Pockels Effect in a Normal EO Crystal

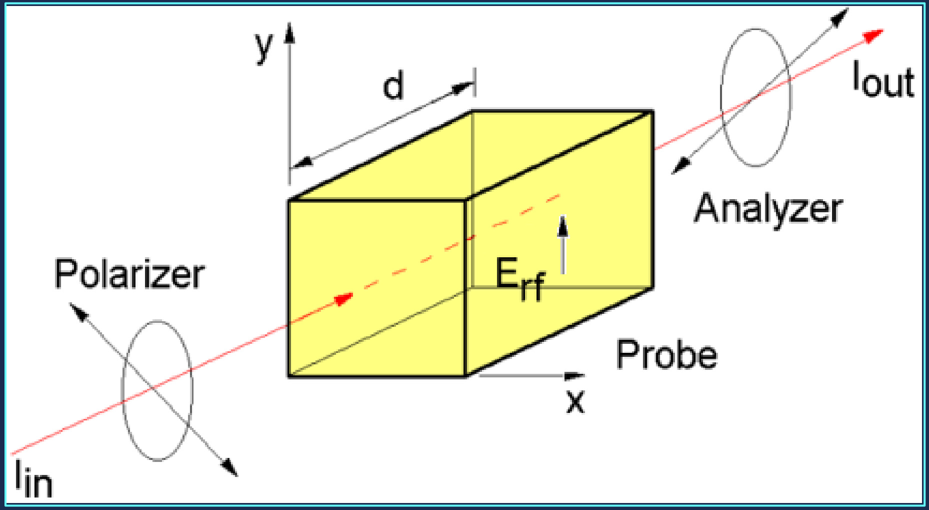


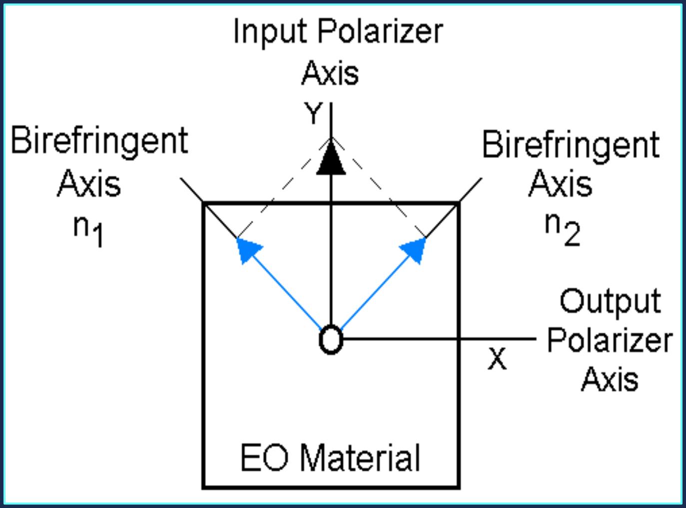




$$\Gamma \equiv \frac{2\pi}{\lambda_o}(n_1 - n_2)d = -\frac{\pi}{\lambda_o}(n_o^3 r_{41} E)d \qquad T = \sin^2\frac{\Gamma}{2}$$

## RF Electric Field Measurement Based on Pockels Effect

### Pockels Effect in a Tangential EO Crystal

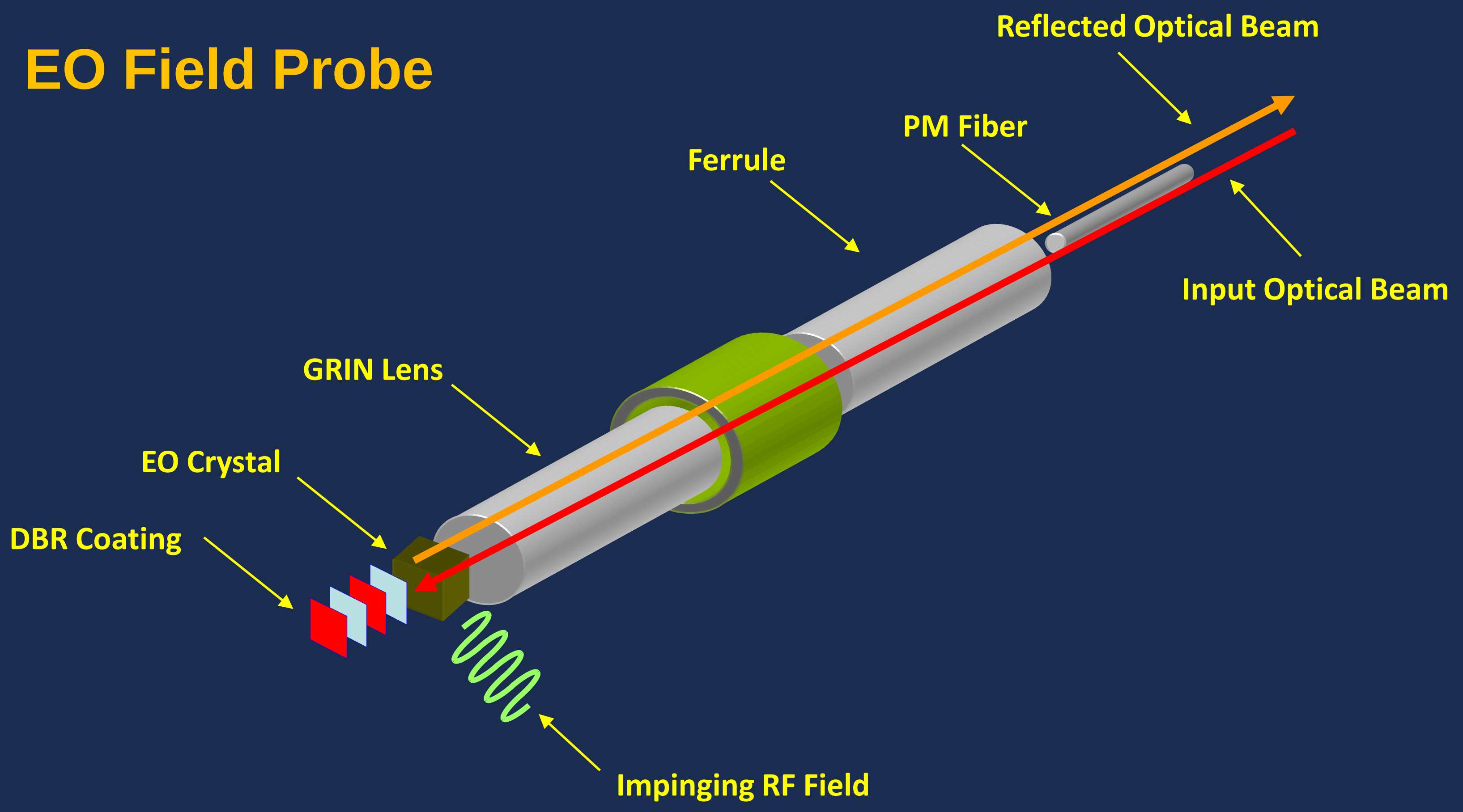



$$\Gamma \equiv \frac{2\pi}{\lambda_o}(n_1 - n_2)d = \frac{\pi}{\lambda_o}[(n_e^3 r_{33} - n_o^3 r_{13})E]d \qquad T = \sin^2\frac{\Gamma}{2}$$

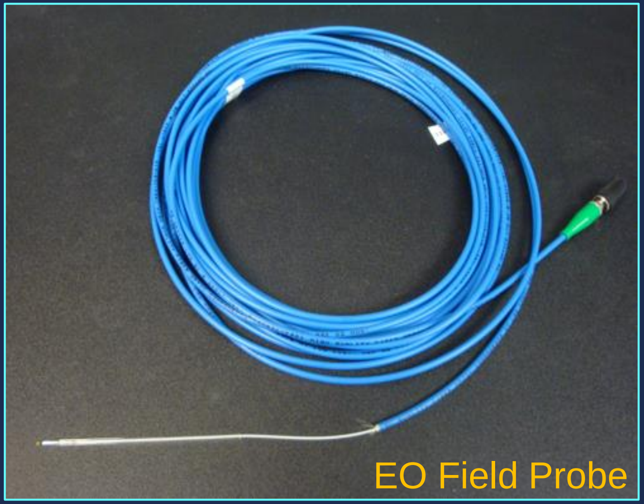
# Field Probe with Bulk EO Crystal

## EO Field Probe



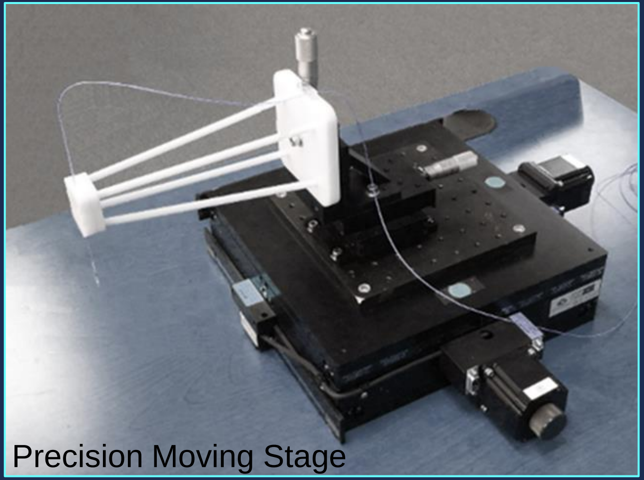
# Fiber-Based Electro-Optic Field Probe System

## Third-Generation NeoScan



EO Field Probe

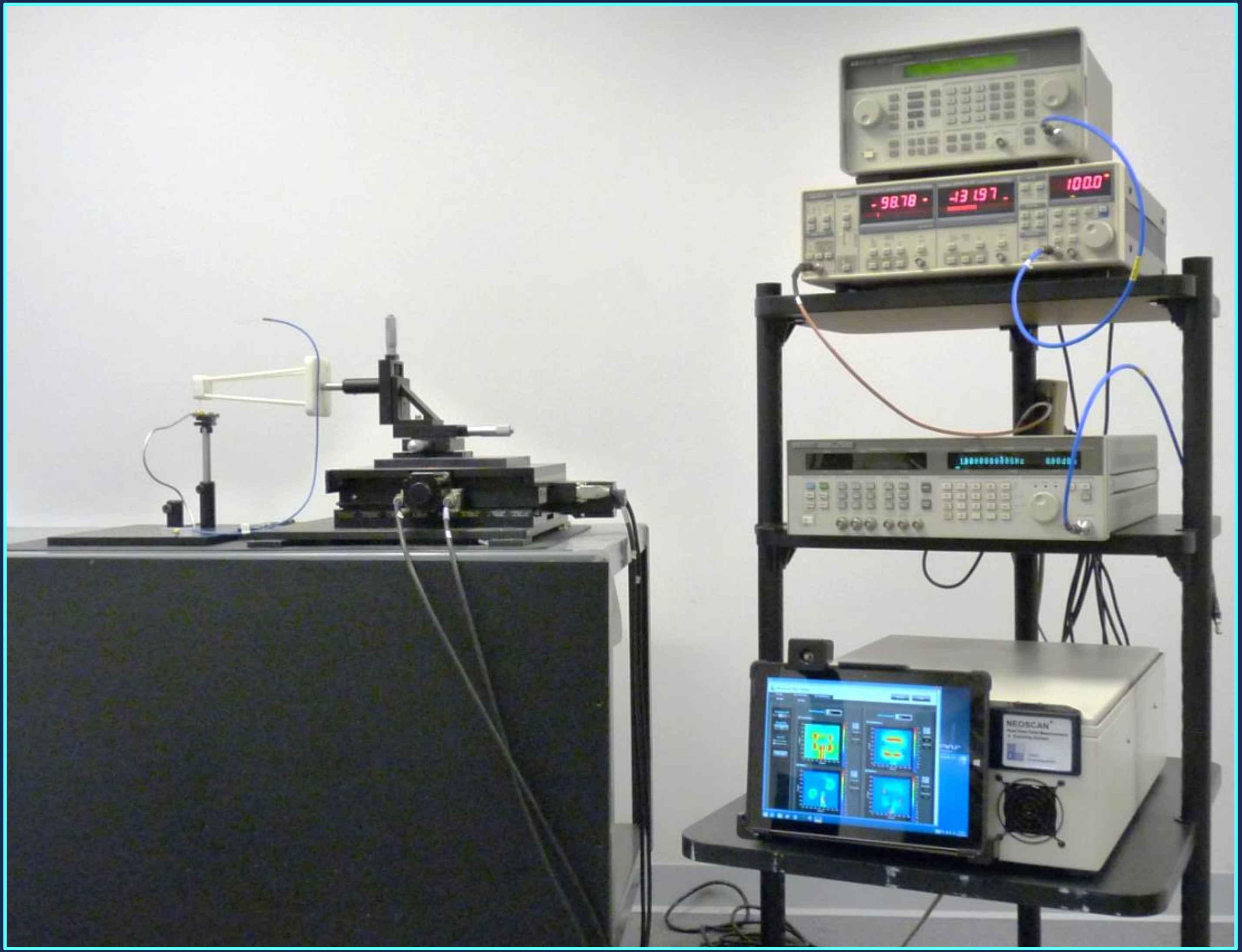

Optical Mainframe System



Precision Moving Stage

# Fiber-Based Electro-Optic Field Probe System

## Third-Generation NeoScan



# Electro-Optic Field Measurement: Key Features

- Ultra-wide Measurement Bandwidth: 10 kHz – 40 GHz
- Simultaneous Amplitude and Phase Measurement
- Vectorial Component Measurement with Cross Polarization Suppression Better than 25 dB
- Measurement Dynamic Range > 70 dB
- Minimum Detectable Signal < 1 V/m RMS
- Maximum Detectable Signal > 2 MV/m RMS
- Non-Invasive Testing: No metal parts in the probe structure
- Extremely High Spatial Resolution: Scan steps as small as 50 $\mu$m or less. Typical probe tip size: 1 $mm^3$, Laser beam spot size: < 10 $\mu$m
- DUT Proximity: As close as 100 $\mu$m
- Standoff Distance (of Mainframe Box): Up to 50 m

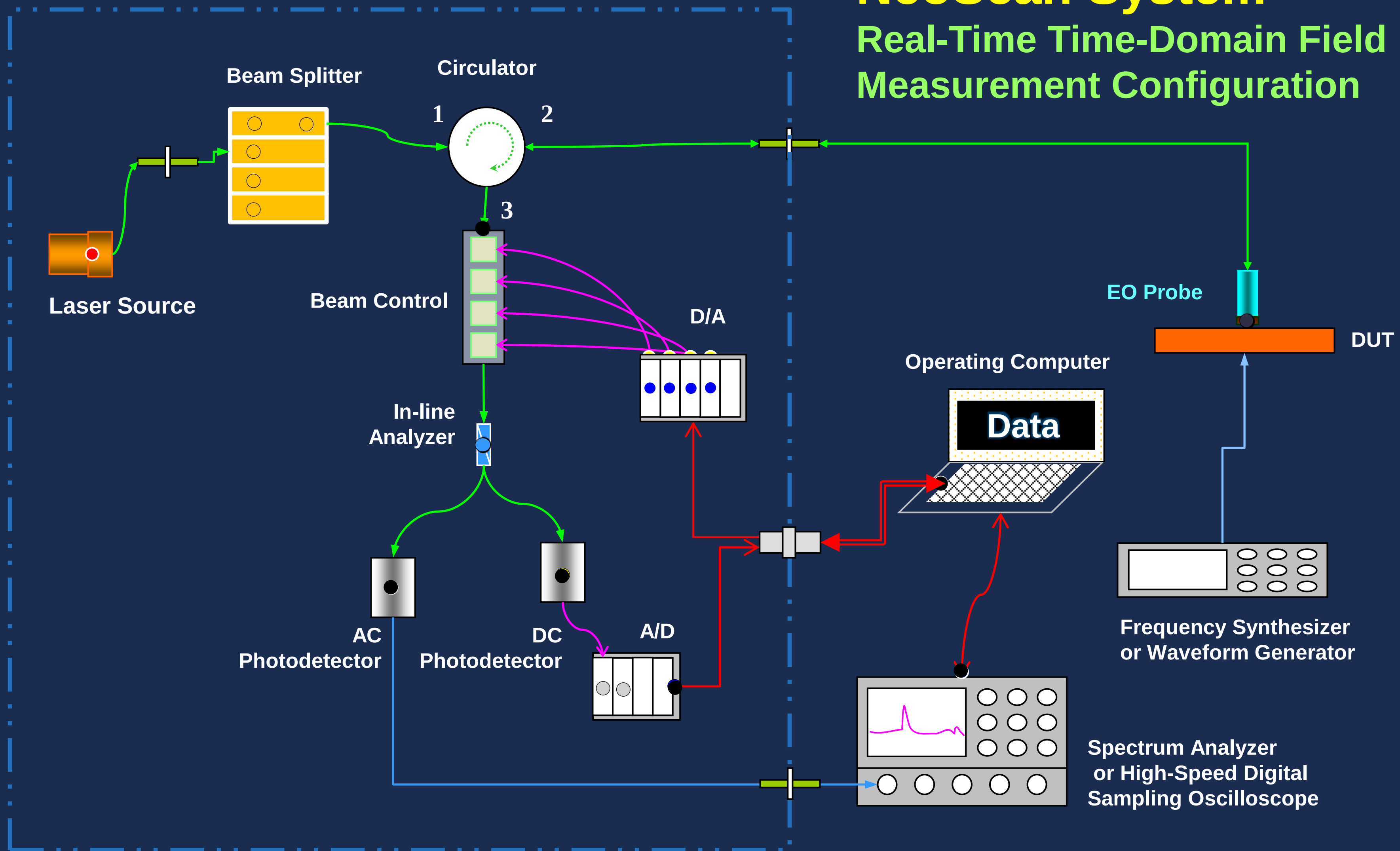
# Electro-Optic Field Measurement: Applications

- High-Resolution Near-Field Scanning
- Compact Antenna Range Alternative
- Phase Calibration of AESA Arrays
- RF Test & Characterization
- RF Circuit & Device Diagnostics
- Real-time Field Detection
- EMC/EMI Testing & Certification
- Ultra-wideband Pulse Waveform Probing
- High-Power Microwave System & Weapons Evaluation
- Field Monitoring in Medical Devices and Biological/Saline Environments
- Non-Contact, Non-Invasive, Remote Field Sensing & Evaluation
- Model Verification & Validation (V&V)

# Electro-Optic Field Measurement: Time-Domain Mode

## NeoScan System

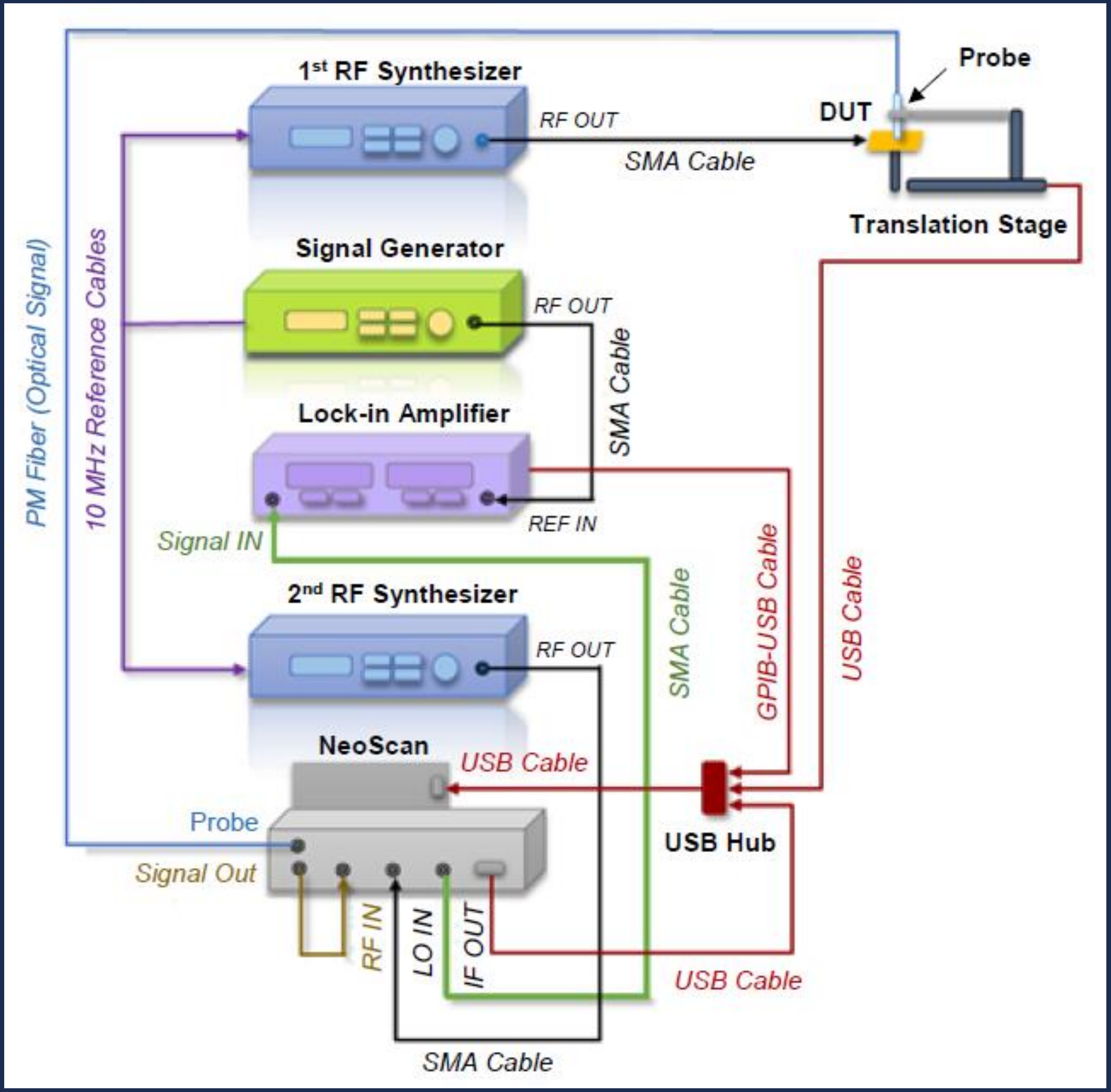
### Real-Time Time-Domain Field Measurement Configuration



# Electro-Optic Field Measurement: Near-Field Scanning Mode

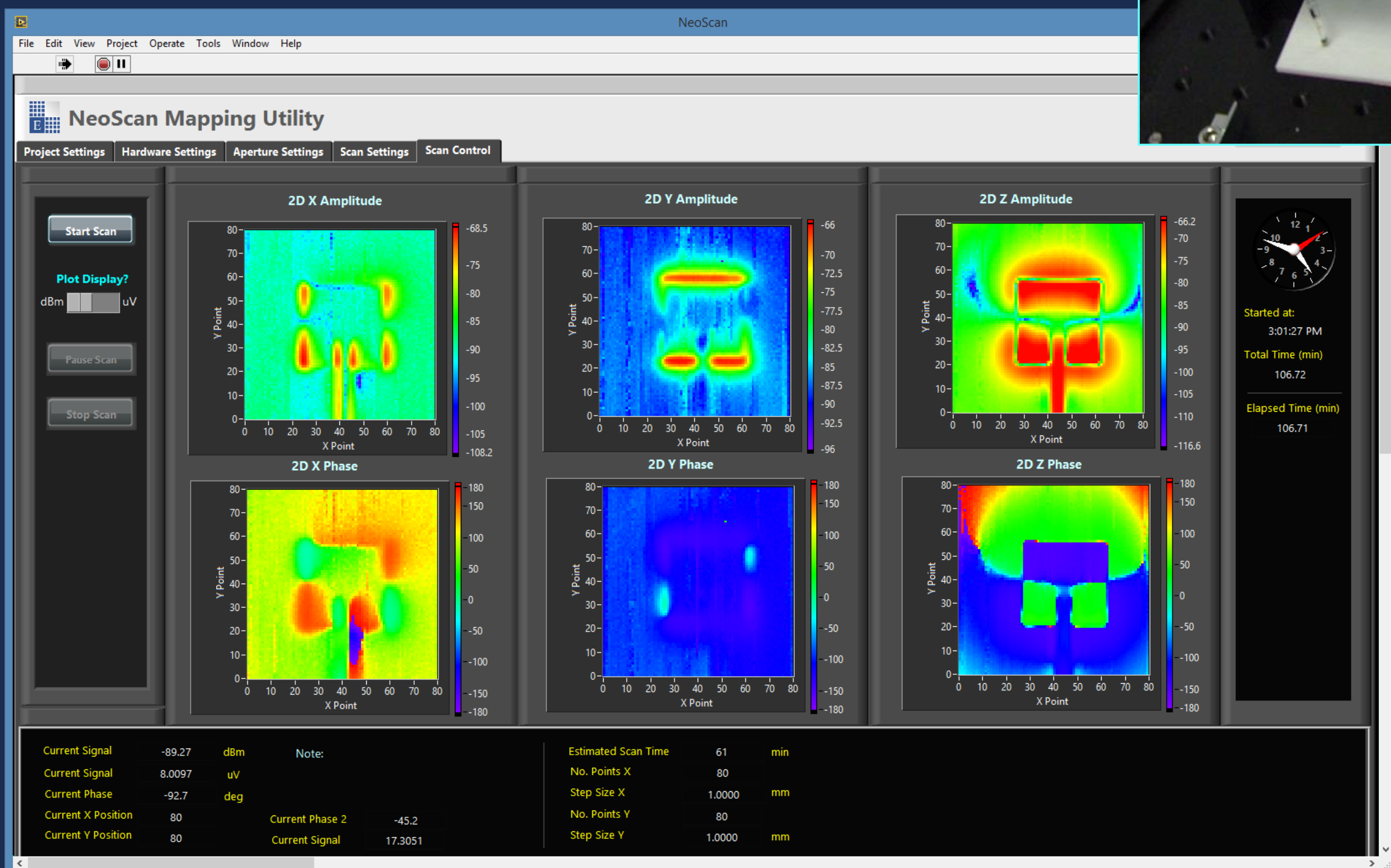
## NeoScan System

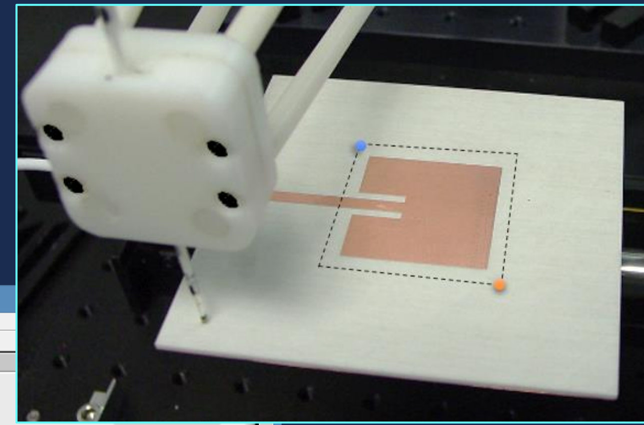
### Frequency-Domain Near-Field Scanning Configuration



# Antenna Characterization System

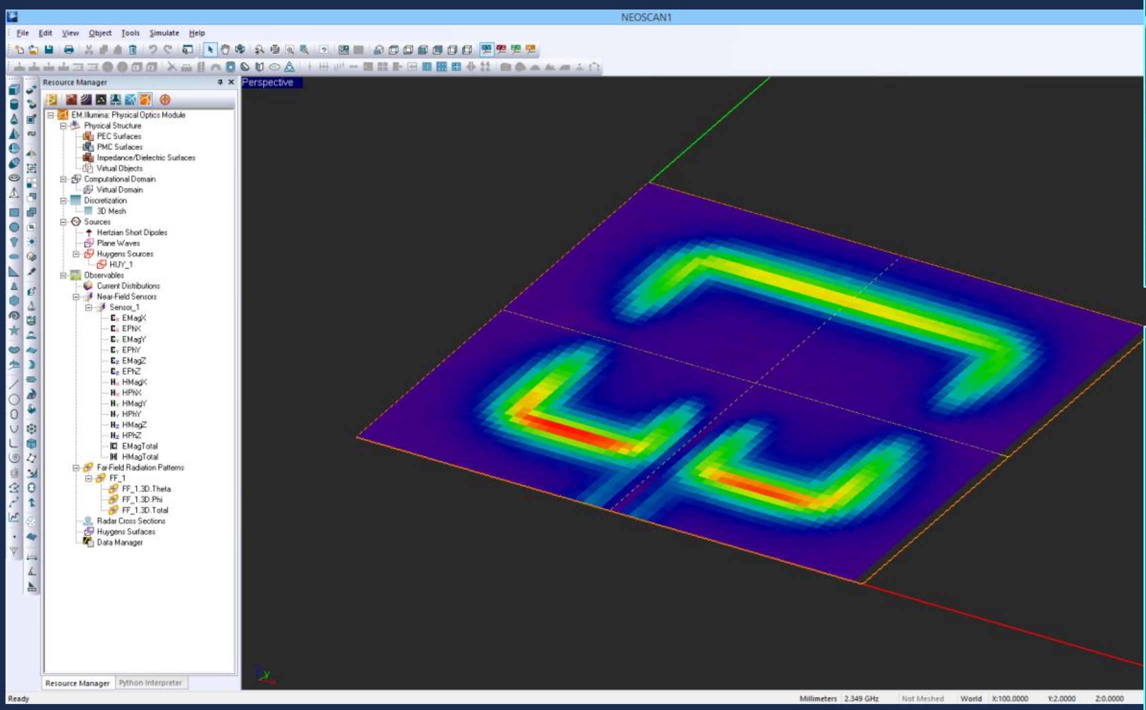
Near-Field Maps of a Microstrip-Fed Patch Antenna at 2.4GHz

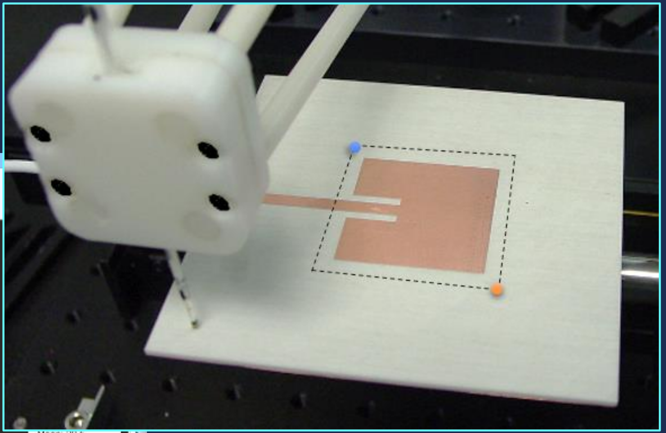


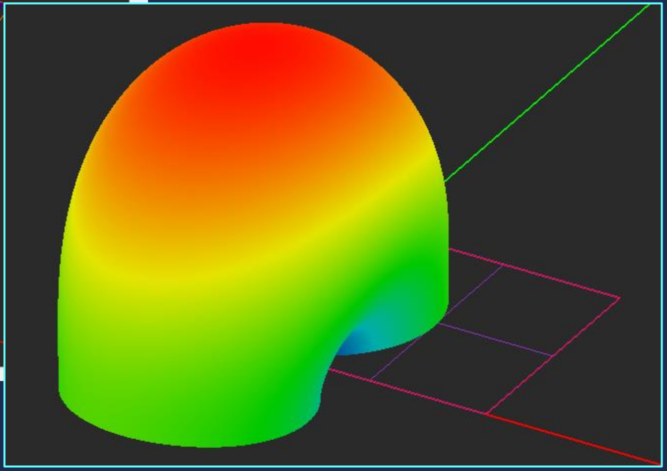



# Antenna Characterization System

NeoScan has been fully integrated with EM.Cube, our modular integrated 3D electromagnetic modeling suite. NeoScan's measured near-field maps are imported to EM.Cube as Huygens sources for both visualization and far-field radiation pattern calculation.

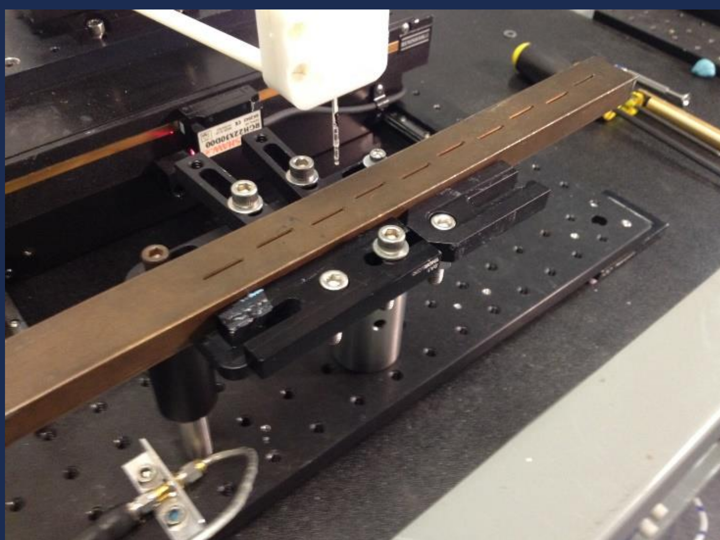


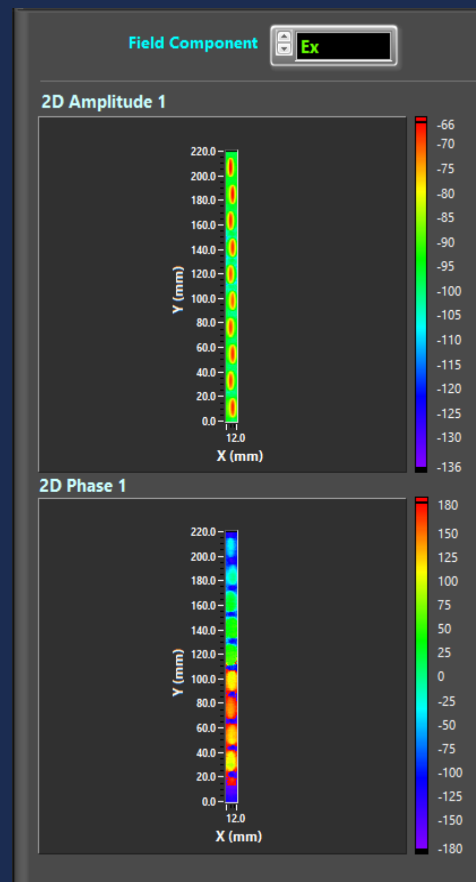



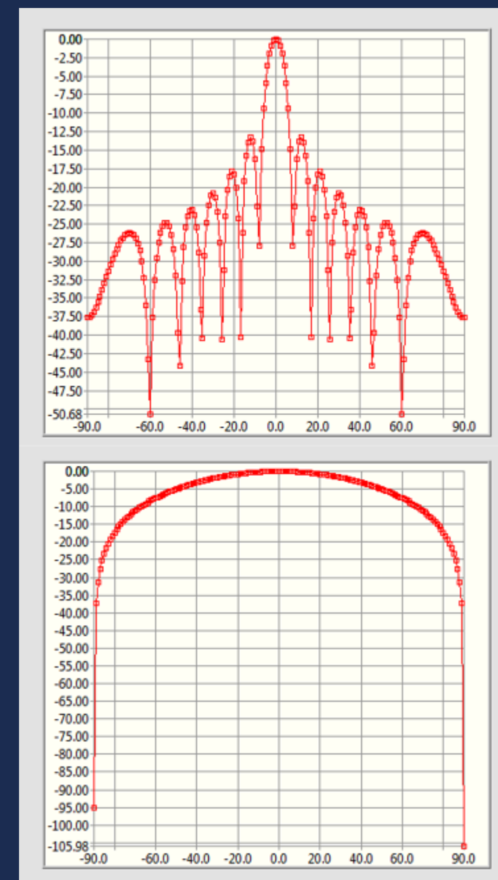


# Antenna Characterization System

Near-Field Maps & Far-Field Radiation Patterns of a Linear X-band Slotted Waveguide Array measured at 9.5GHz

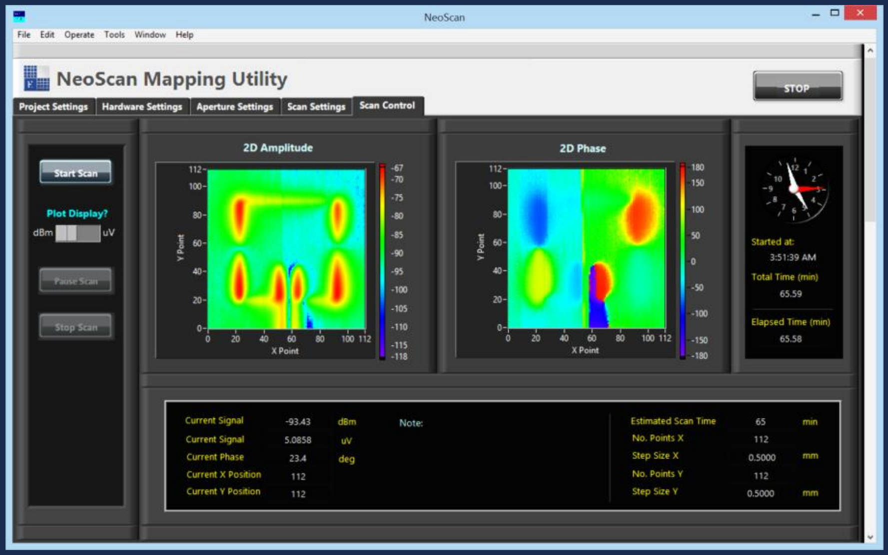


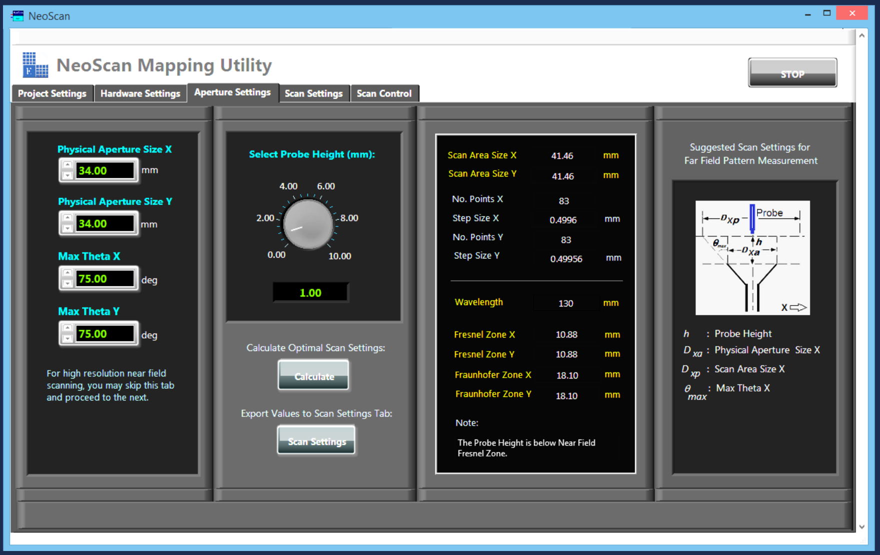


# Automated Operational Software & Control Interface

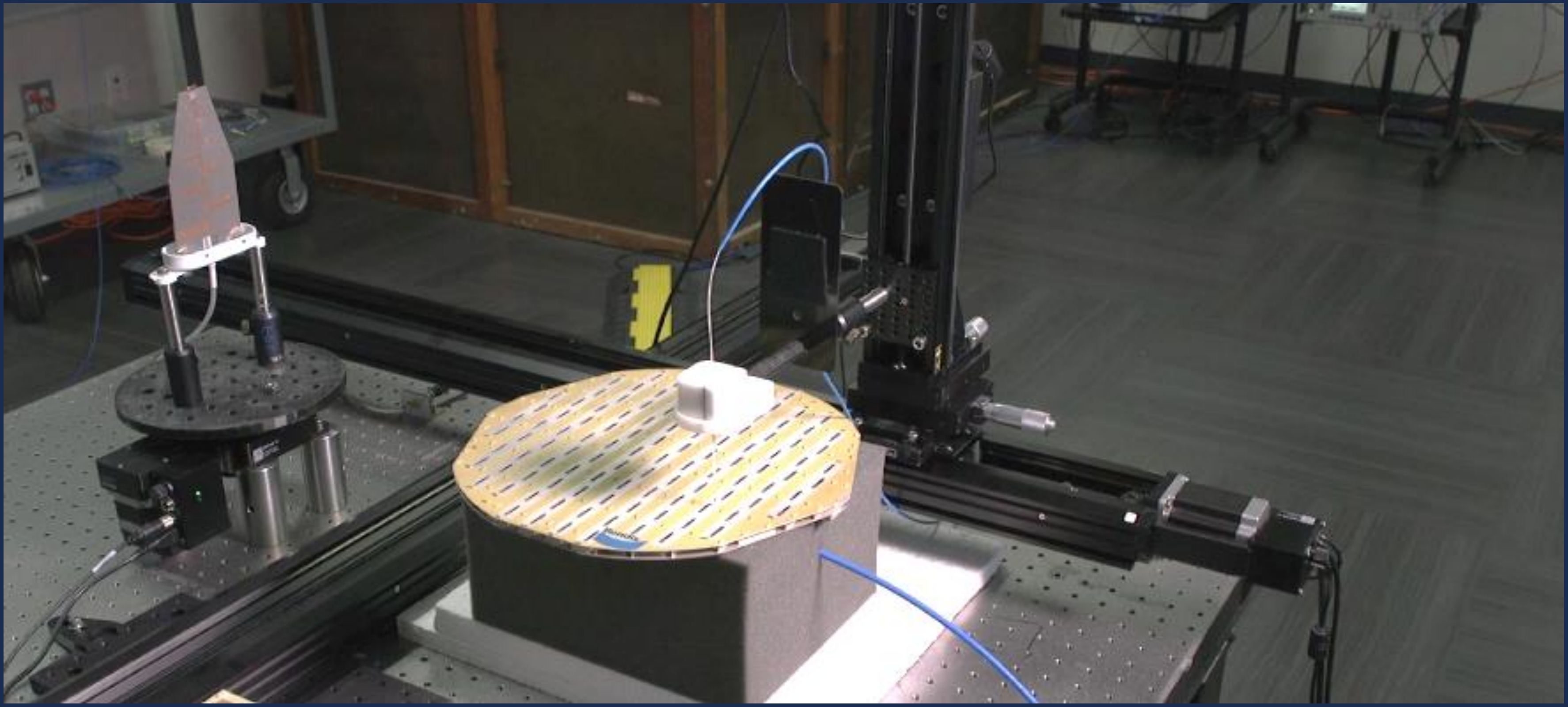
A comprehensive operating software module automates the system setup, optimization, calibration and data visualization. It also recommends the scan surface area and scan steps (spatial resolution) for the optimal far-field pattern measurement.

# Fiber-Based Electro-Optic Field Probe System

## Third-Generation NeoScan

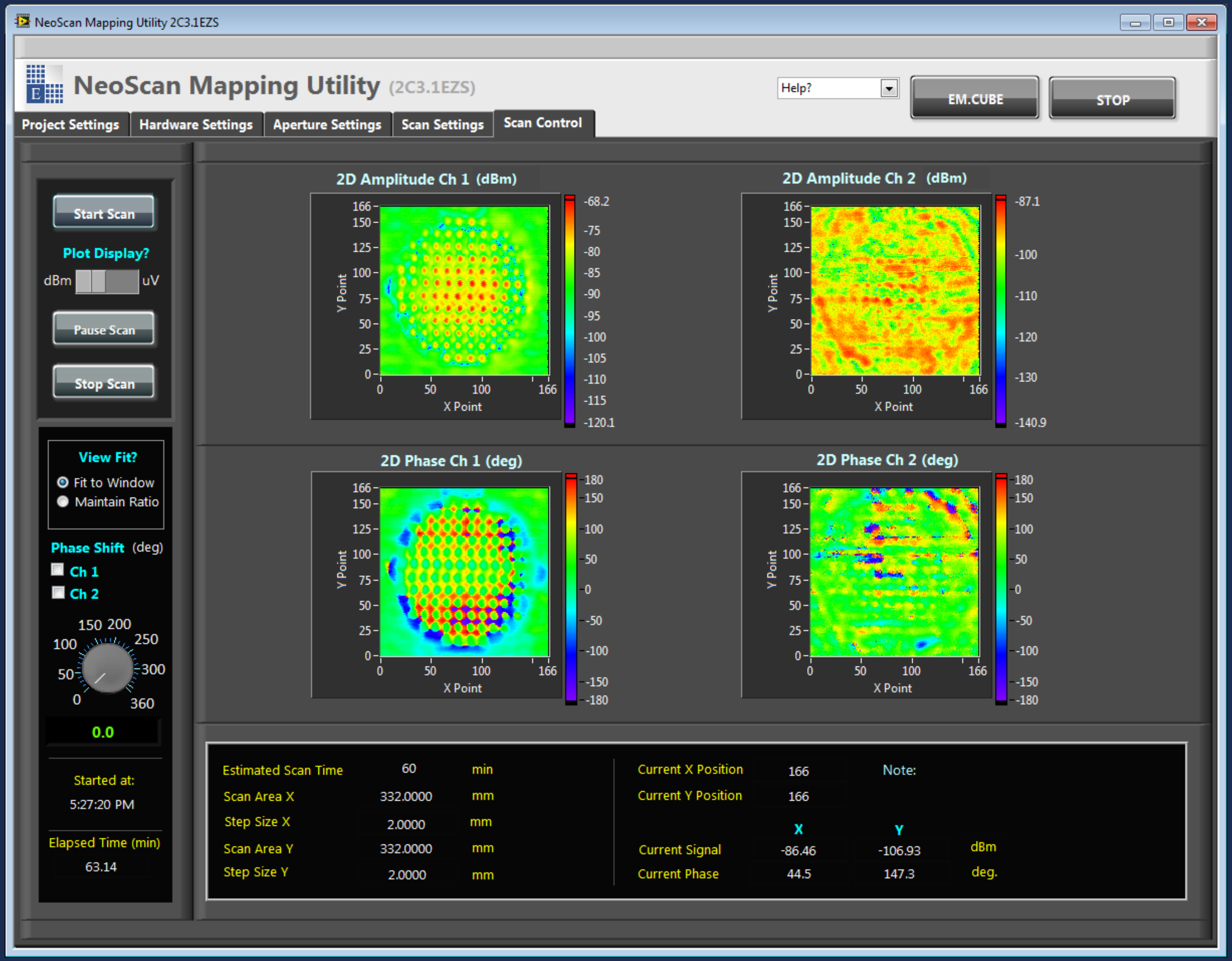


# Antenna Characterization System

Near-field maps of X-band Slotted Waveguide Array measured at 10 GHz

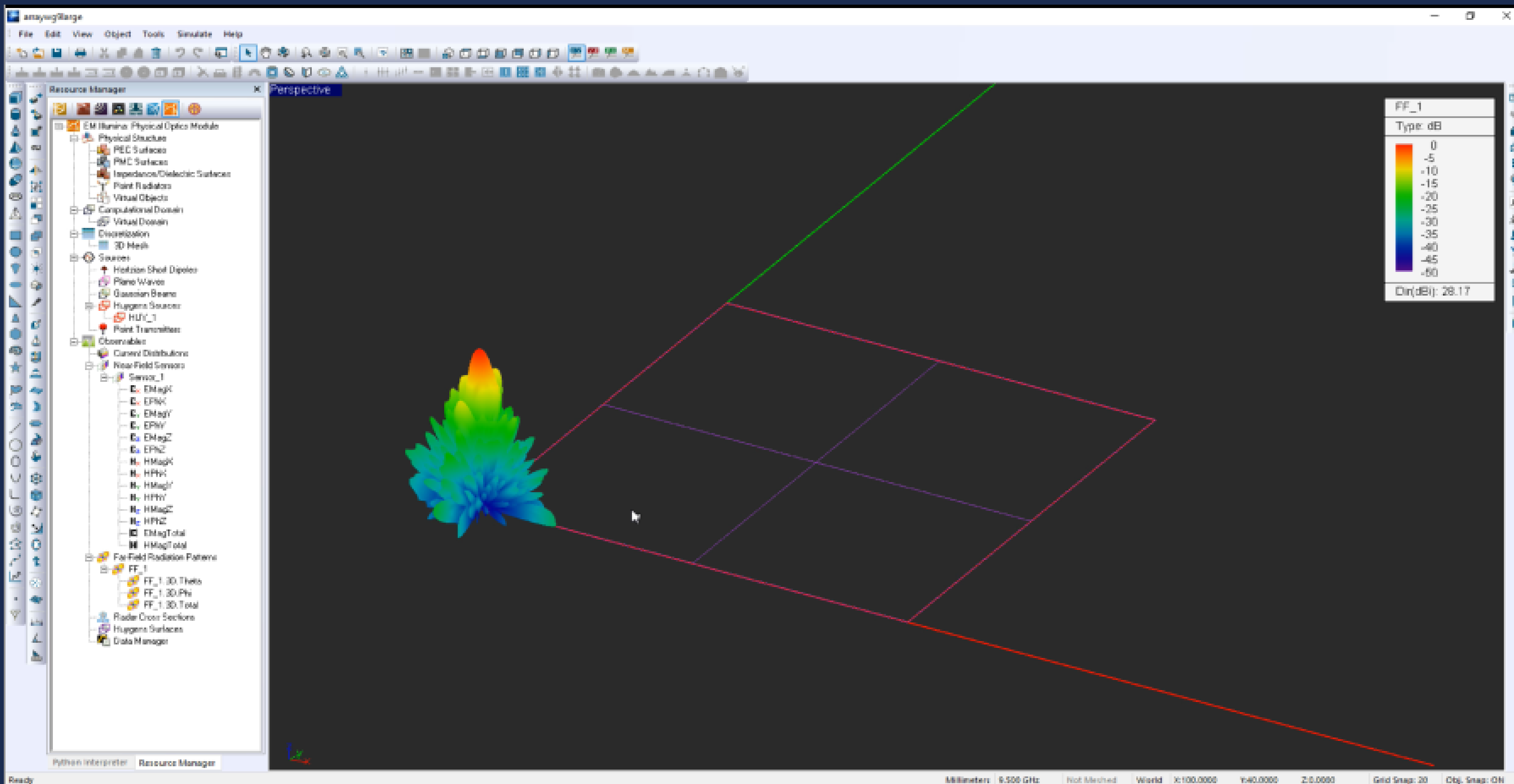
# Antenna Characterization System

Near-field maps of X-band Slotted Waveguide Array measured at 9.5 GHz



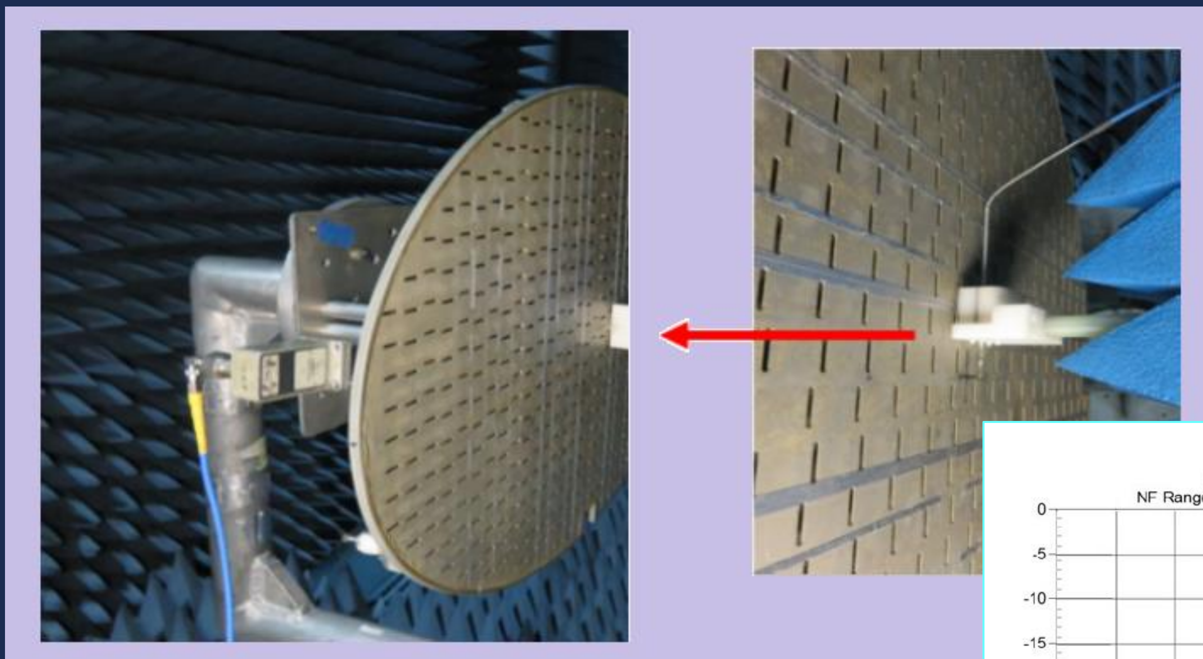
# Antenna Characterization System

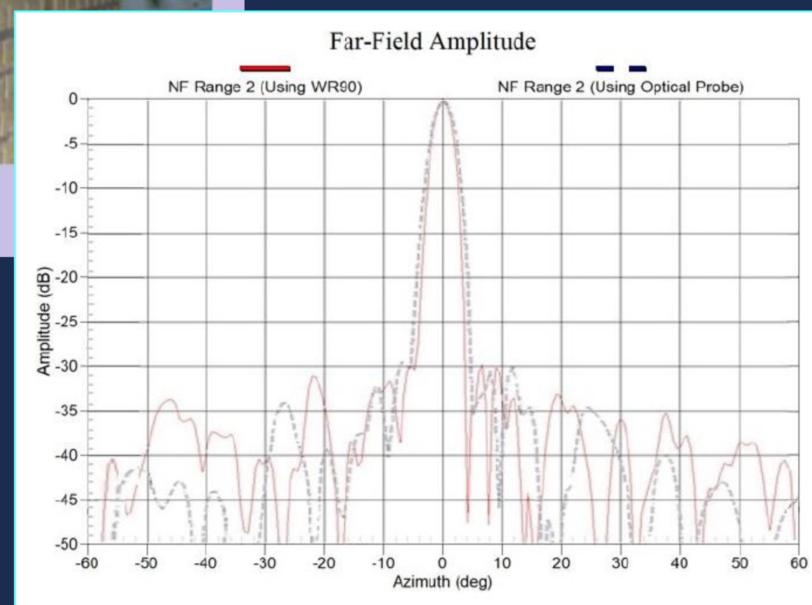
3D Far-field Radiation Pattern of X-band Slotted Waveguide Array Measured at 9.5 GHz



# Antenna Characterization System

Far-field radiation pattern of Raytheon’s X-band Slotted Waveguide Array





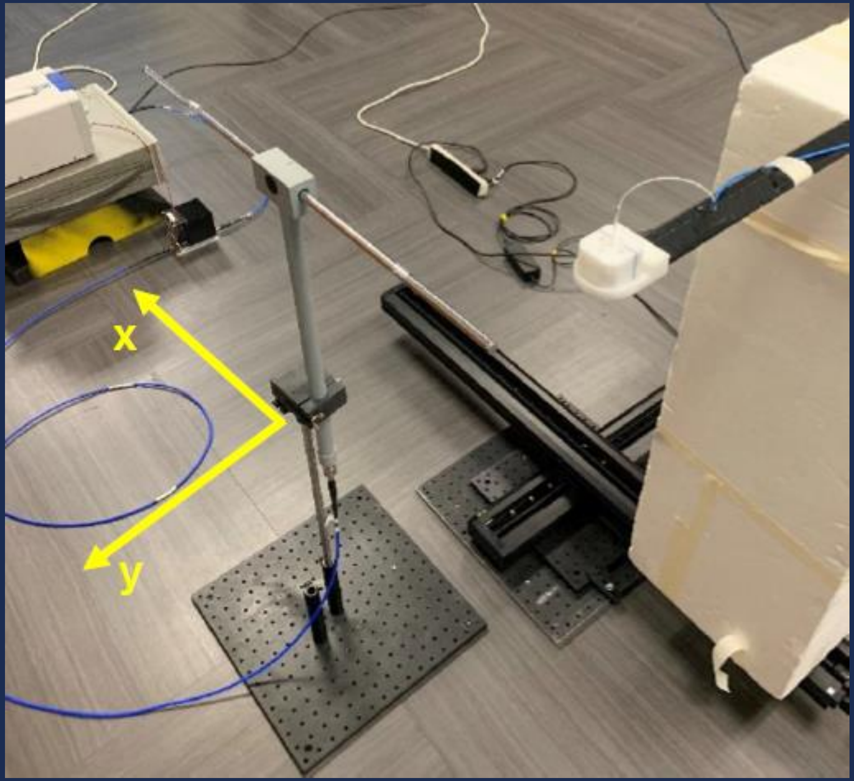

W. Dykeman, B. Marshall, D. Canterbury, C. Garner, R. Darragh and Ali Sabet, “Comparison of Antenna Measurements Obtained Using an Electro-Optical Probe System to Conventional RF Methods”, AMTA Conference Digest, San Diego, CA, October 2019.

# Characterizing Low-Frequency Antennas

## JPL's 66 MHz Spacecraft Antenna Measured by Neoscan

# Characterizing Low-Frequency Antennas

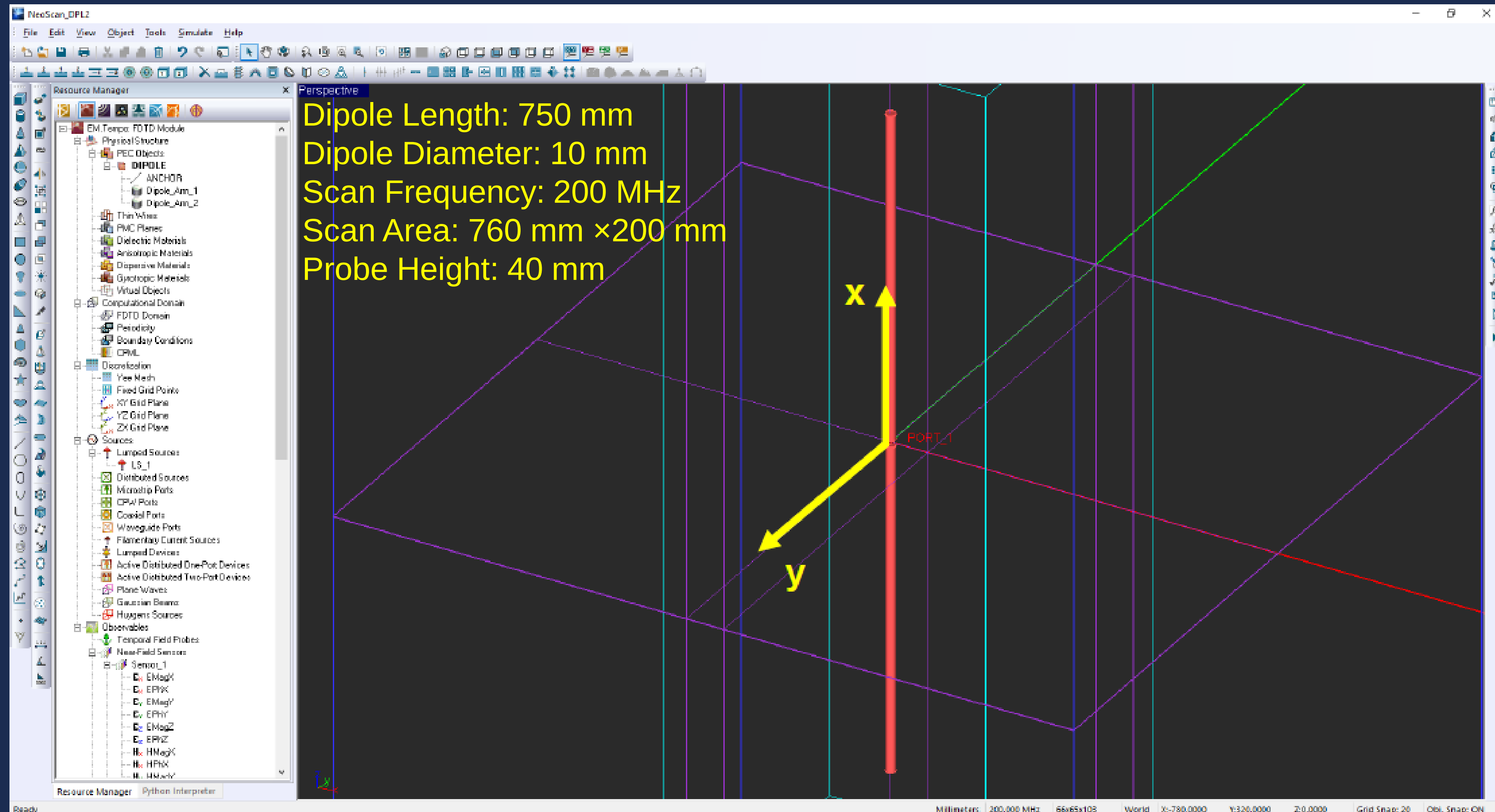
## 200 MHz Dipole Antenna with a Balun




Dipole Model: ETS Lindgren 3121C
Dipole Length: 750 mm
Dipole Diameter: 10 mm
Scan Frequency: 200 MHz
Scan Area: 760 mm ×200 mm
Probe Height: 40 mm

# Characterizing Low-Frequency Antennas

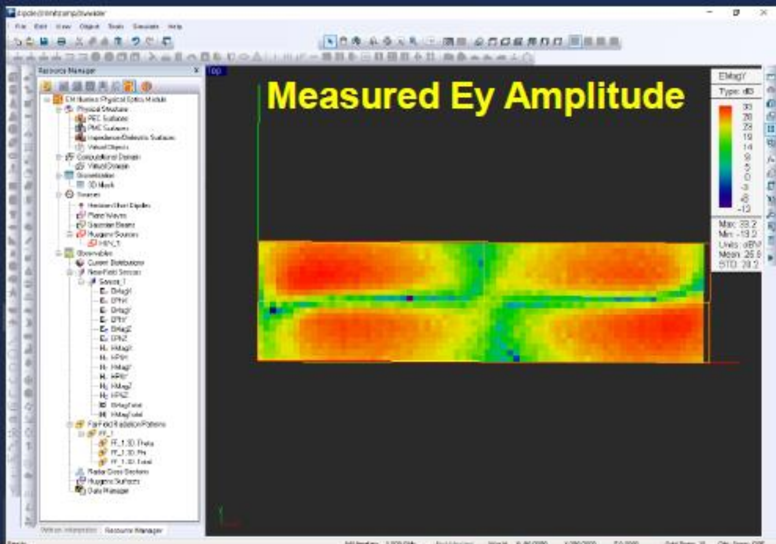
## 200 MHz Dipole Antenna with a Balun

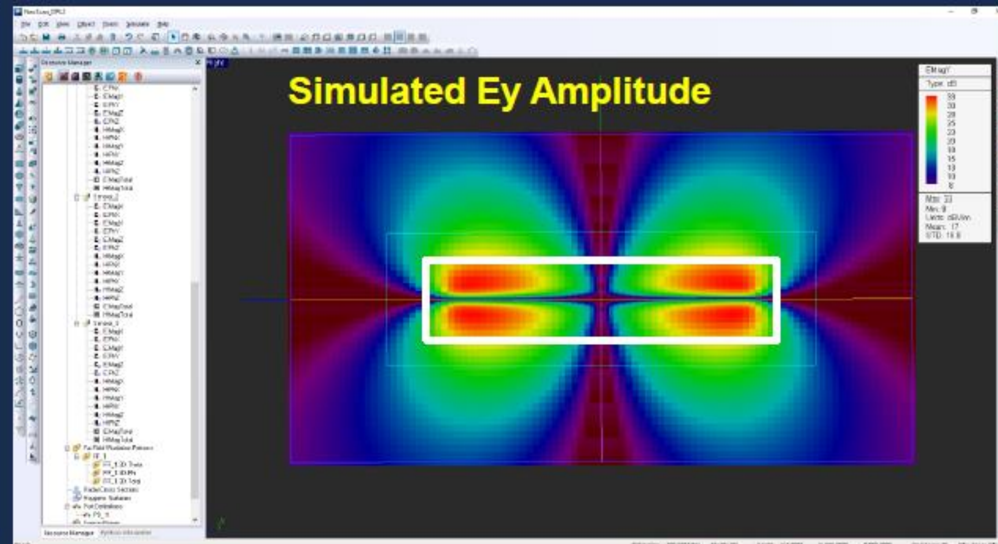


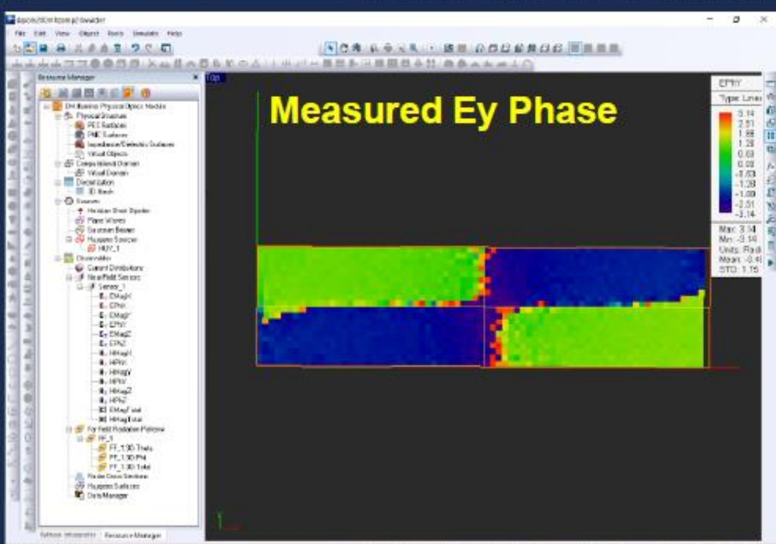

Model Setup in EM.Cube

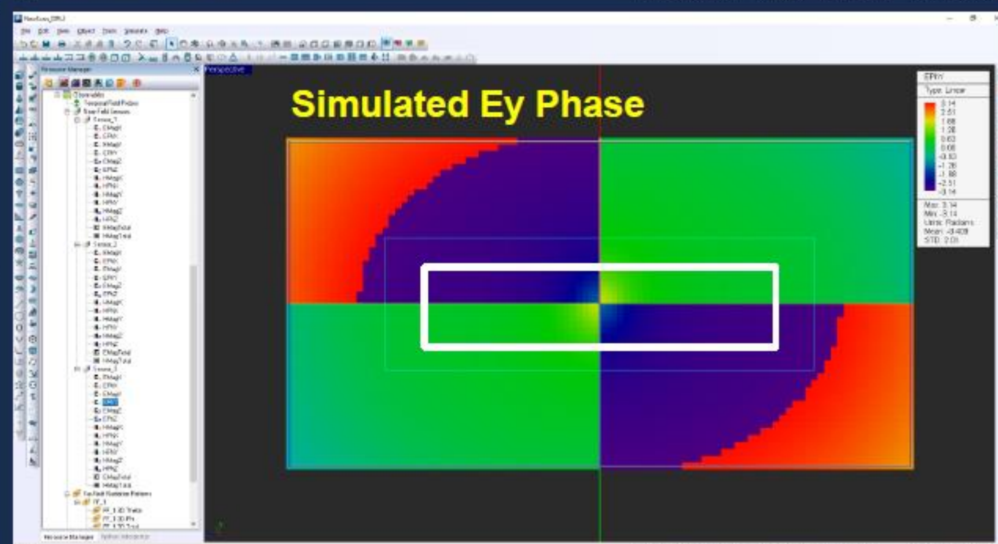
# Characterizing Low-Frequency Antennas

## 200 MHz Dipole Antenna with a Balun



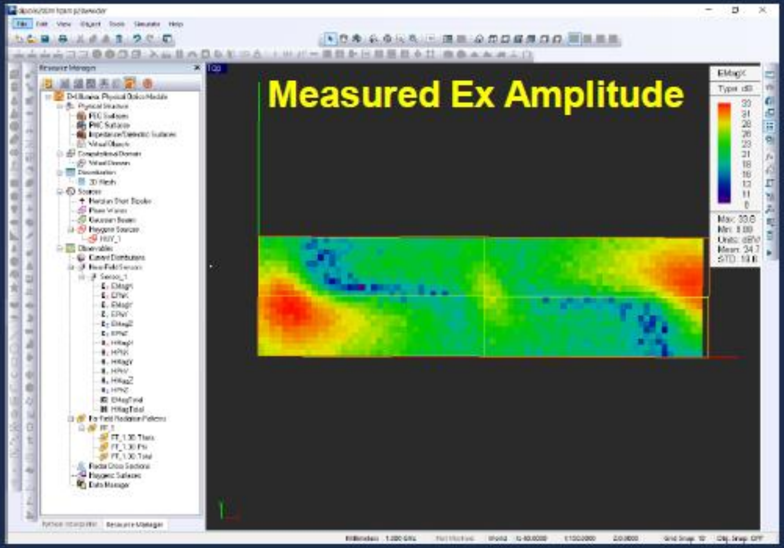



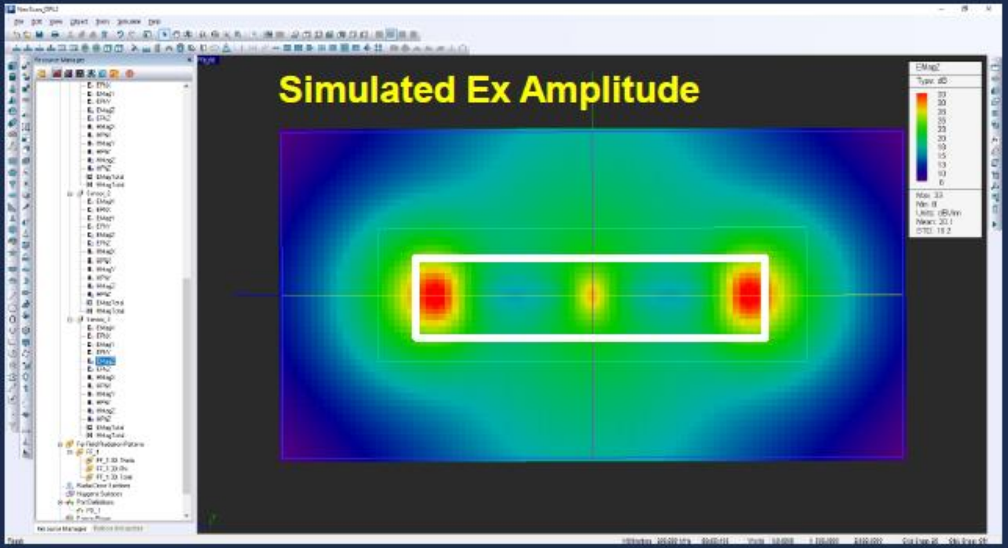



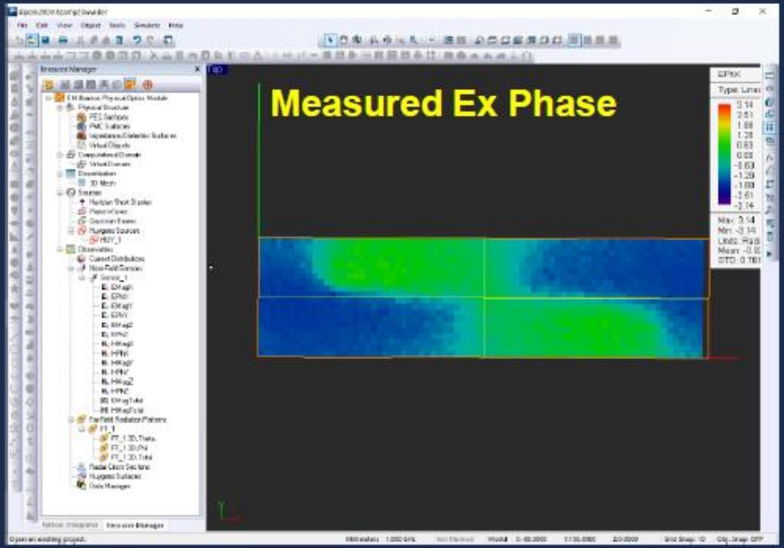



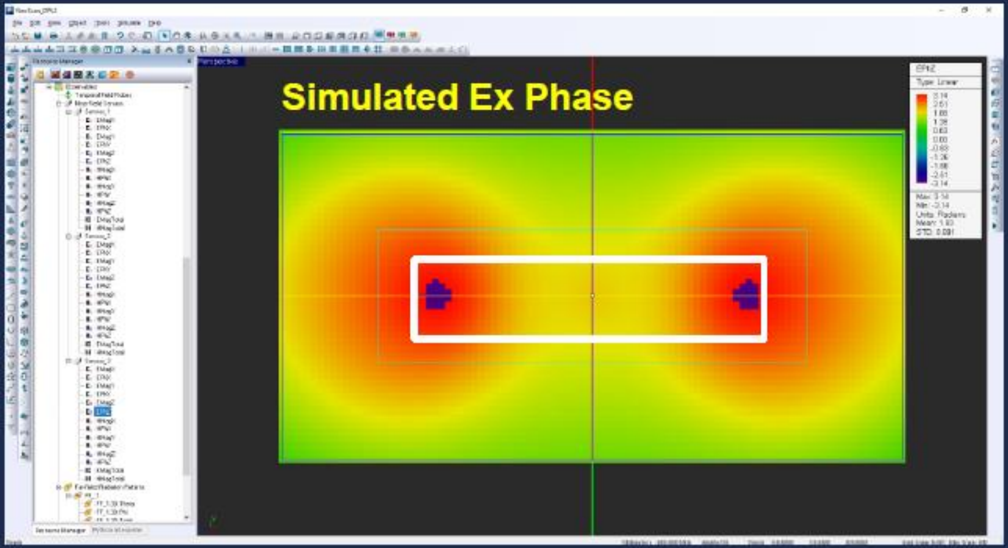
# Characterizing Low-Frequency Antennas

## 200 MHz Dipole Antenna with a Balun



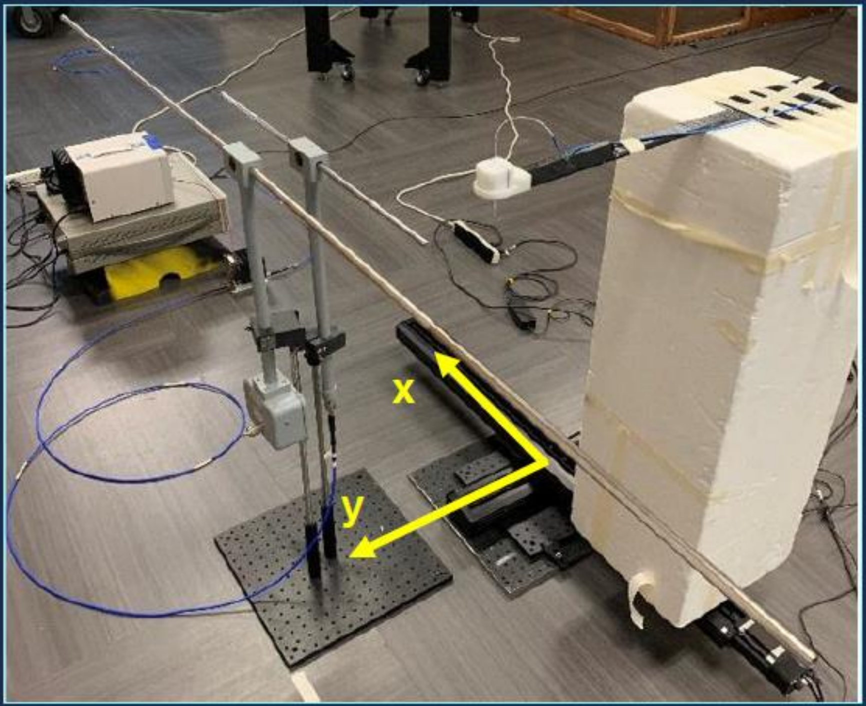



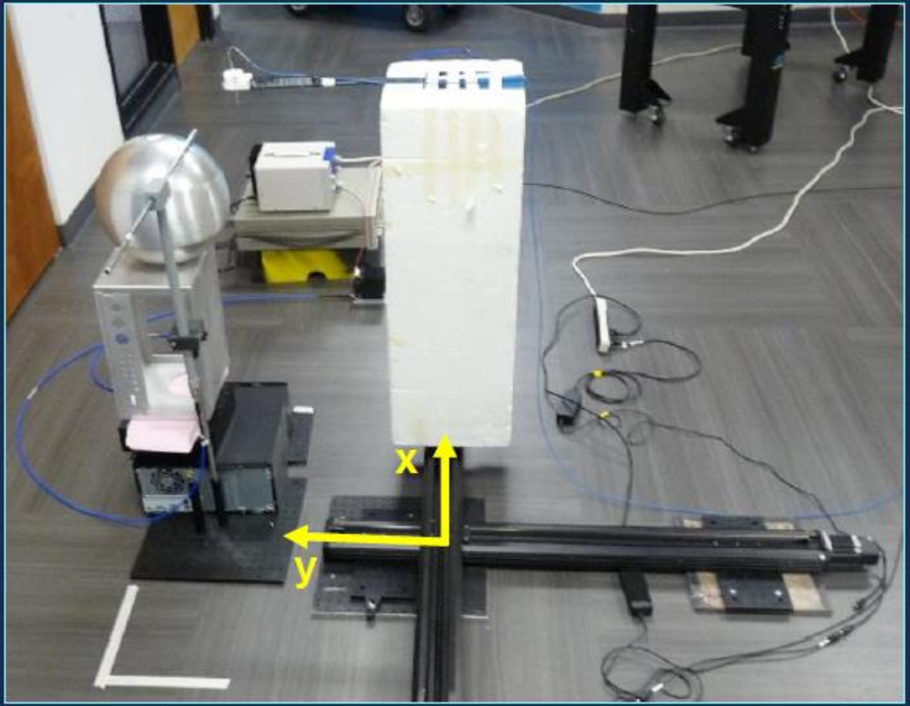



# Characterizing Low-Frequency Antennas

## 200 MHz Dipole Antenna with a Balun



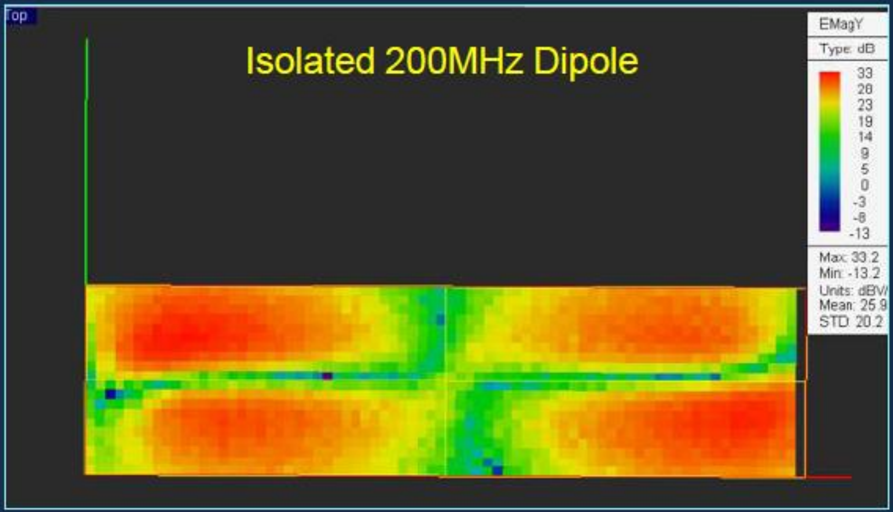

Parallel 66 MHz Dipole (2.02 m Length)

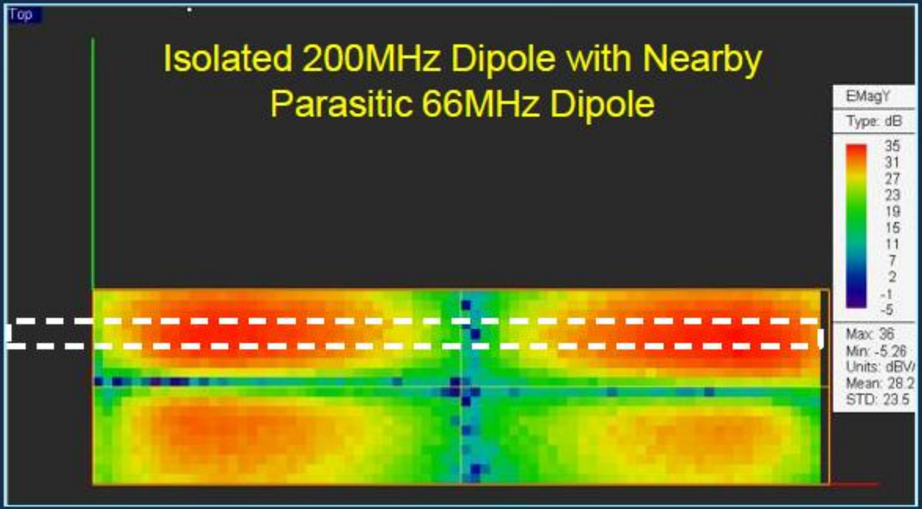



Aluminum Sphere of diameter 30 cm

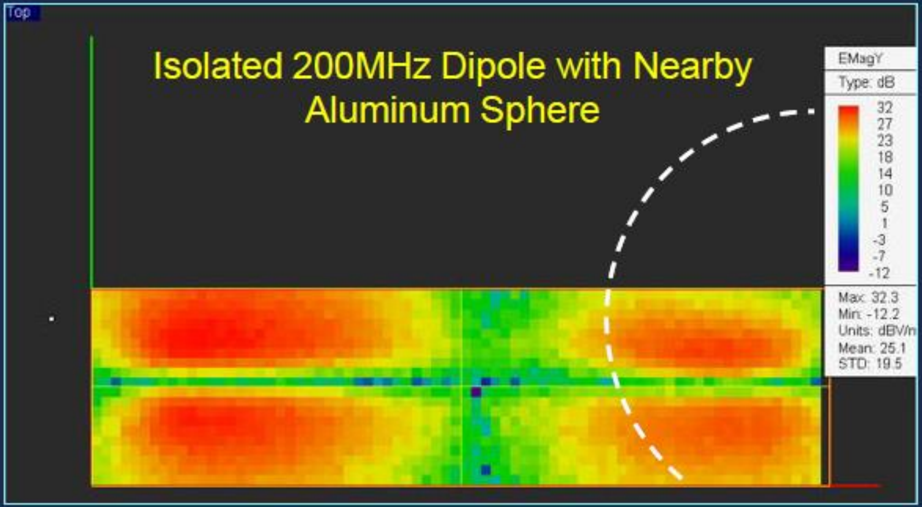
# Characterizing Low-Frequency Antennas

## 200 MHz Dipole Antenna with a Balun



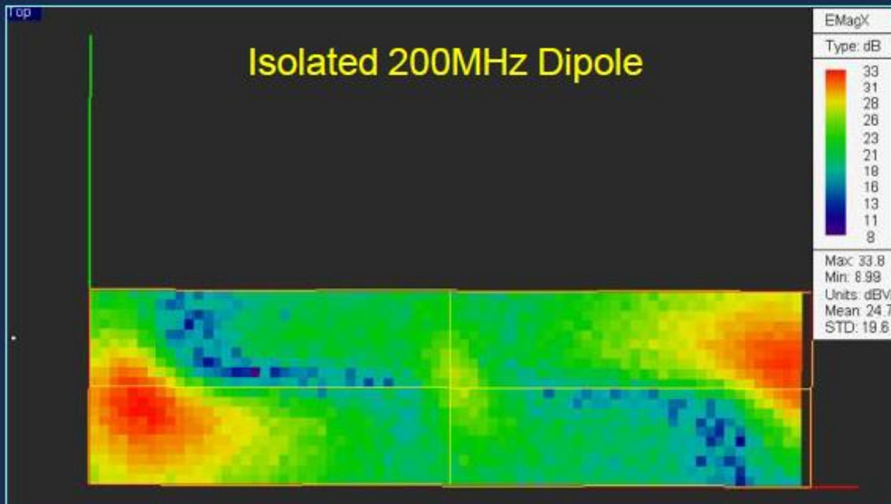



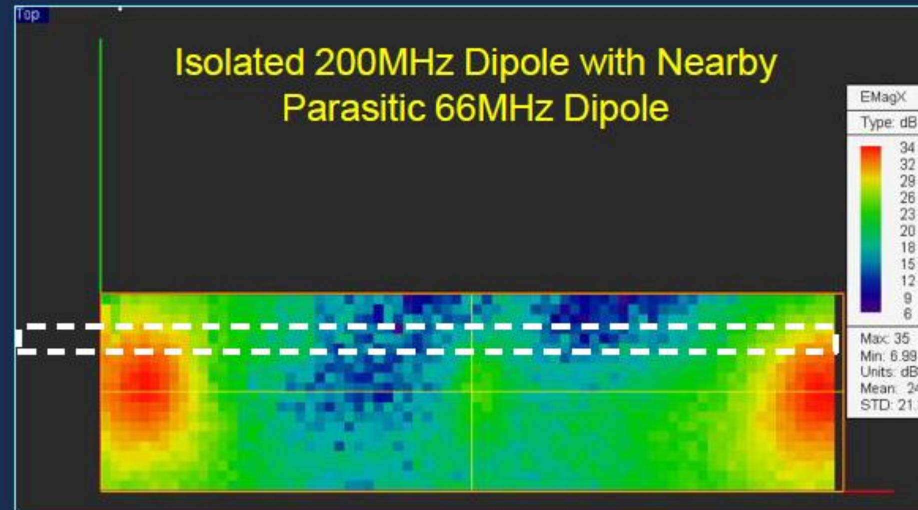

**Measured Ey Amplitude (Normal to the Dipole)**



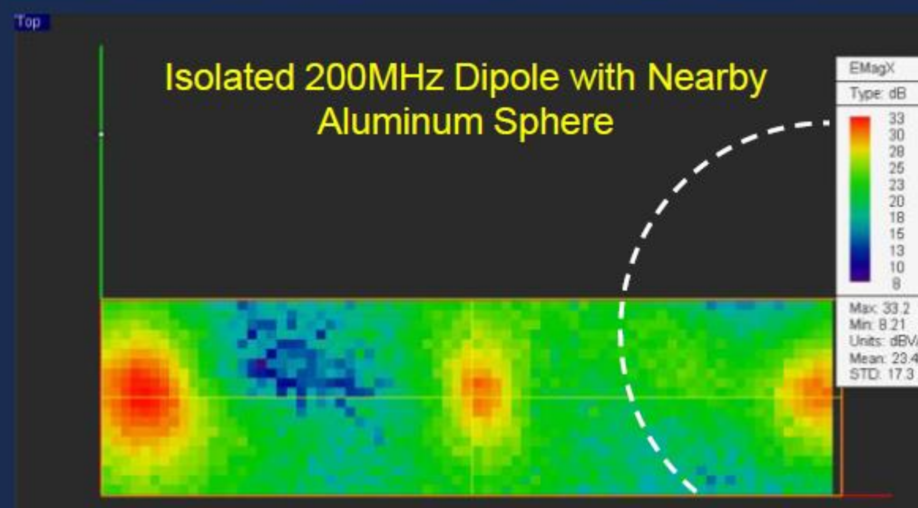
# Characterizing Low-Frequency Antennas

## 200 MHz Dipole Antenna with a Balun




**Measured Ex Amplitude (Parallel to the Dipole)**

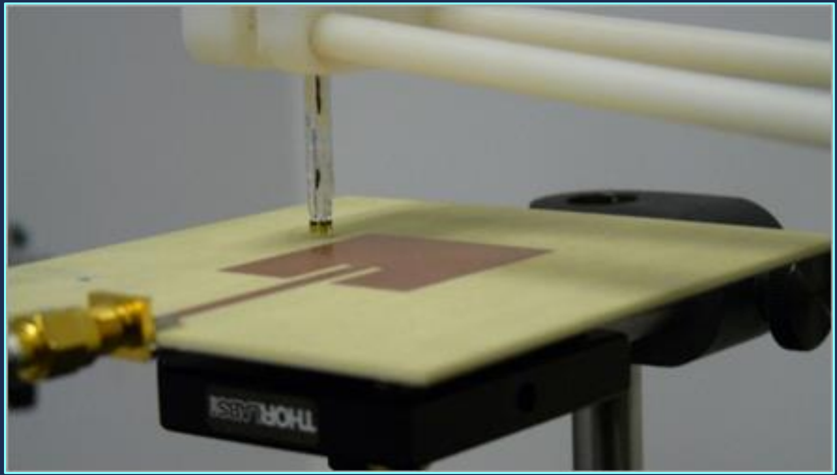


# Antenna Characterization System

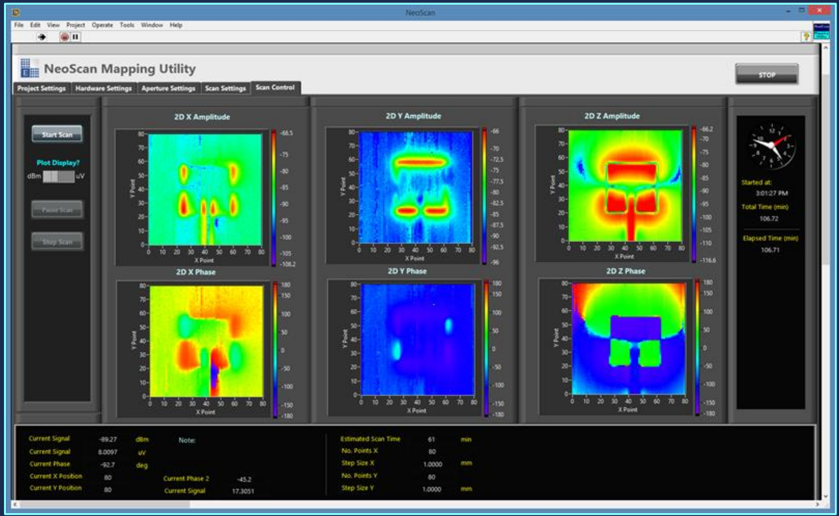
## 3 m x 3 m Translation Stage for Large and Platform-Installed Antennas

# Antenna Characterization System

## EO Field Measurement System with Three Coherent Channels



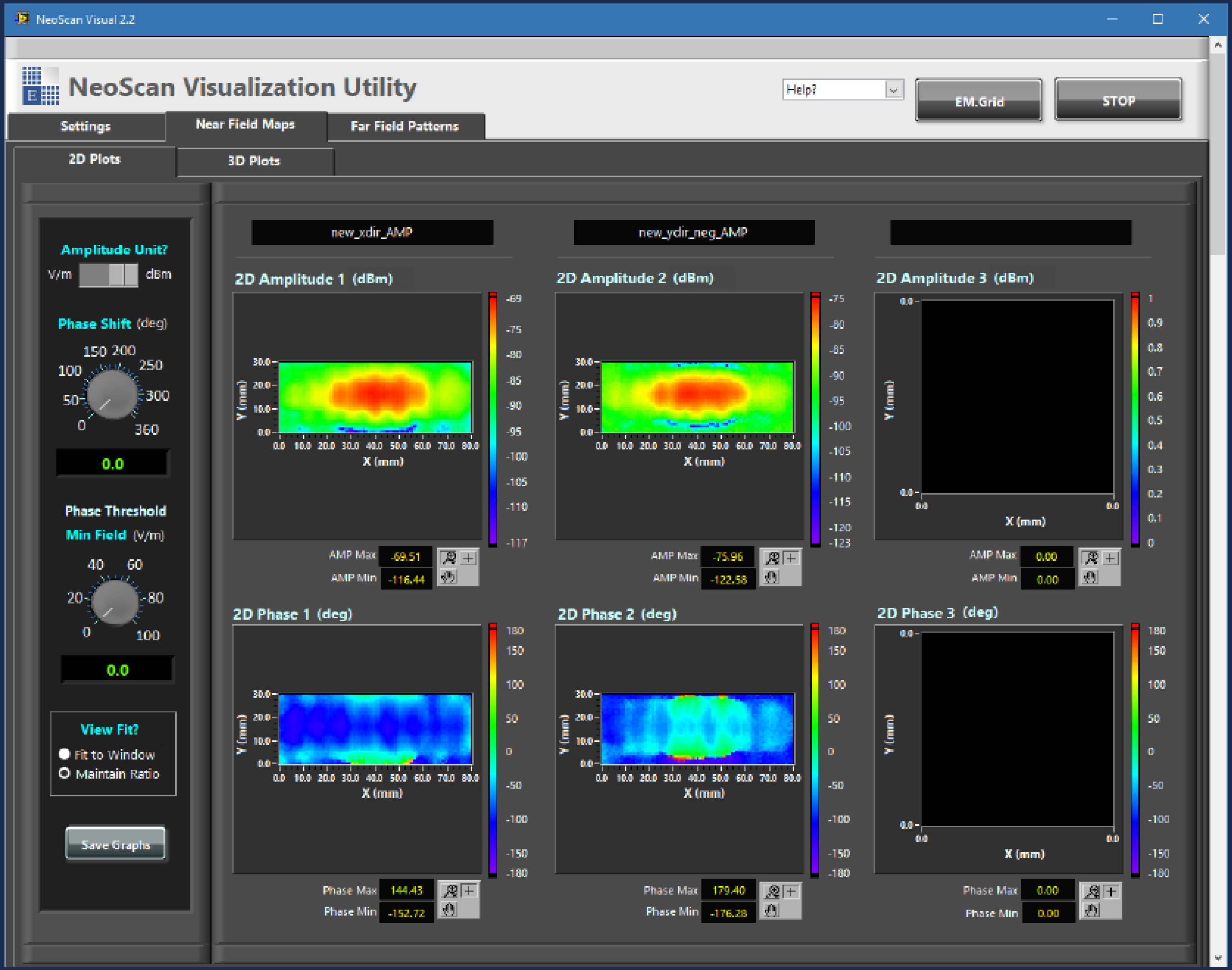


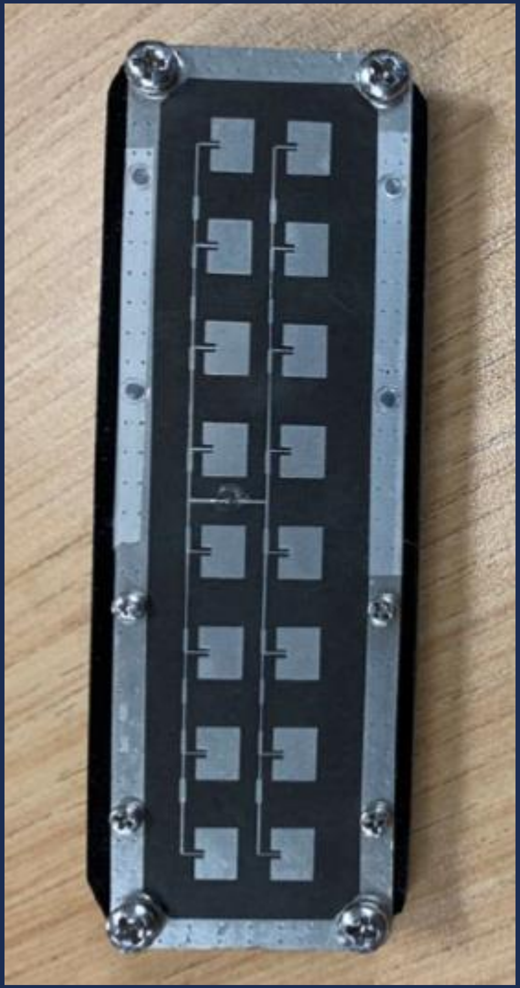



# Antenna Characterization System

## 24 GHz Patch Array for Automotive Radar

Measured Field Maps

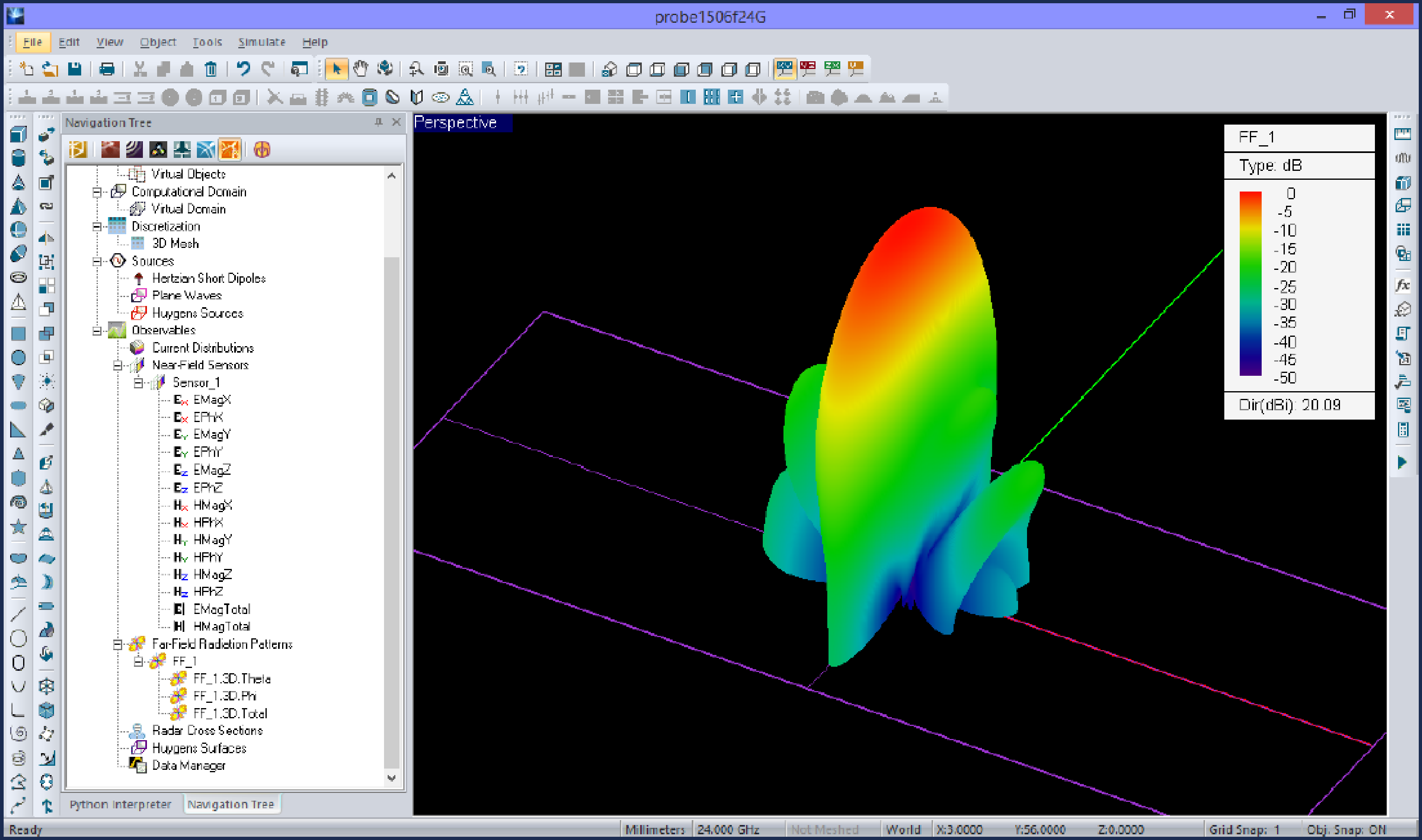


# Antenna Characterization System

## 24 GHz Patch Array for Automotive Radar

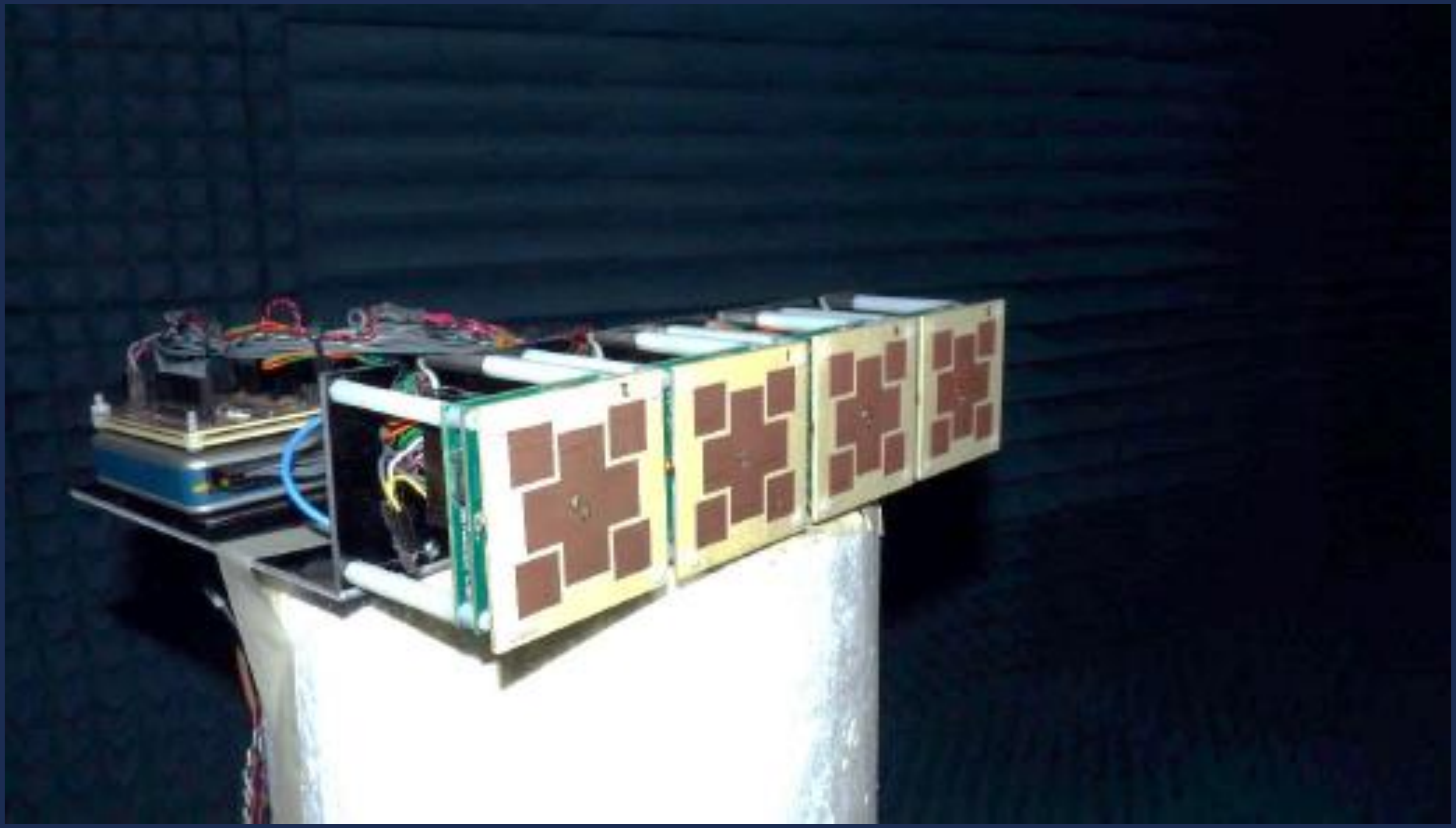
Measured Field Maps



# Active Phased Array Characterization System

## EMAG's Dual-Band (S/C) Circularly Polarized Half-Duplex AESA for Nanosatellite Ground Station

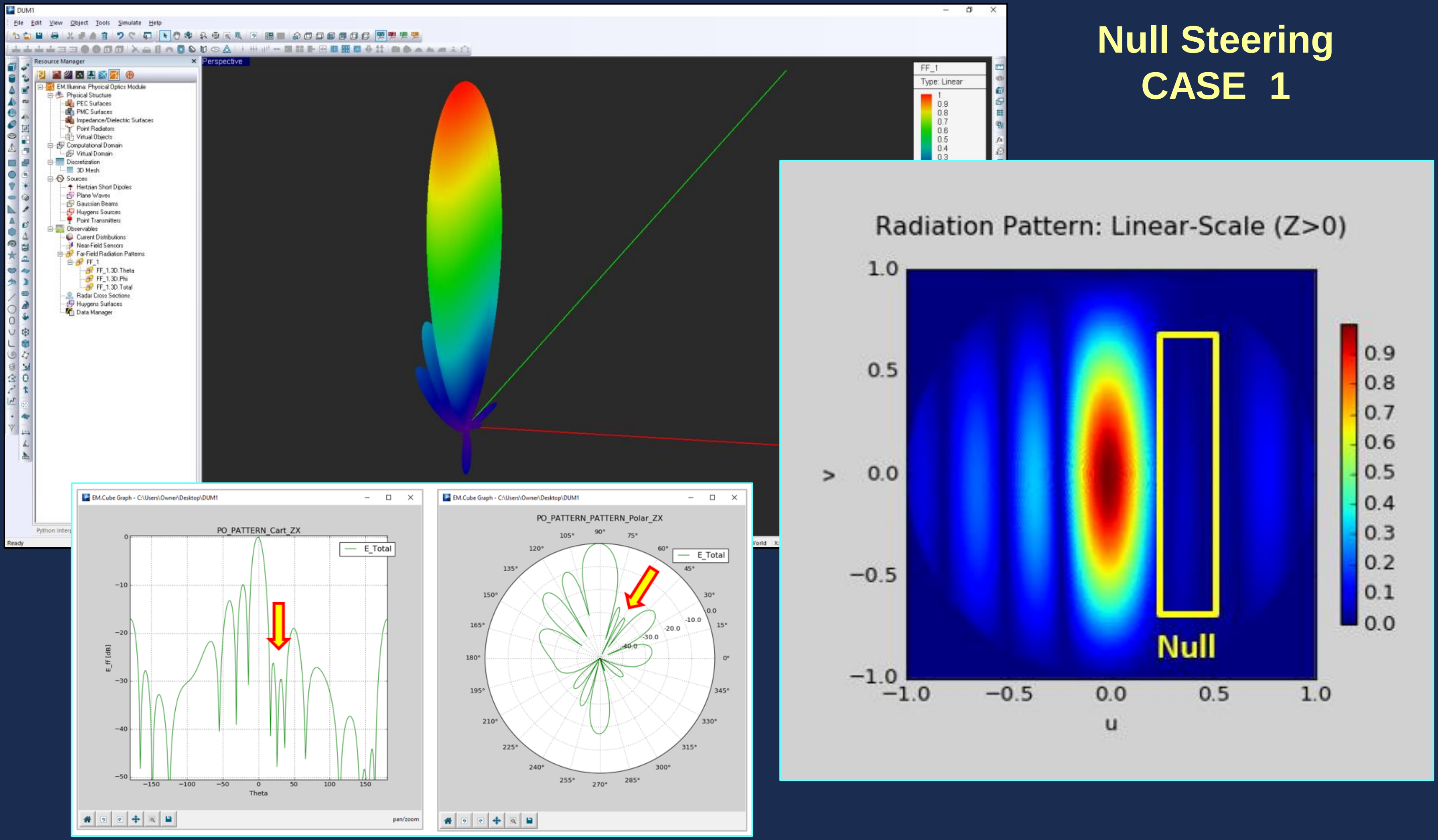
### Using Particle Swarm Optimization (PSO) for Phase-Only Null Steering



# Active Phased Array Characterization System

## Dual-Band (S/C) Circularly Polarized Half-Duplex AESA for Nanosatellite Ground Station

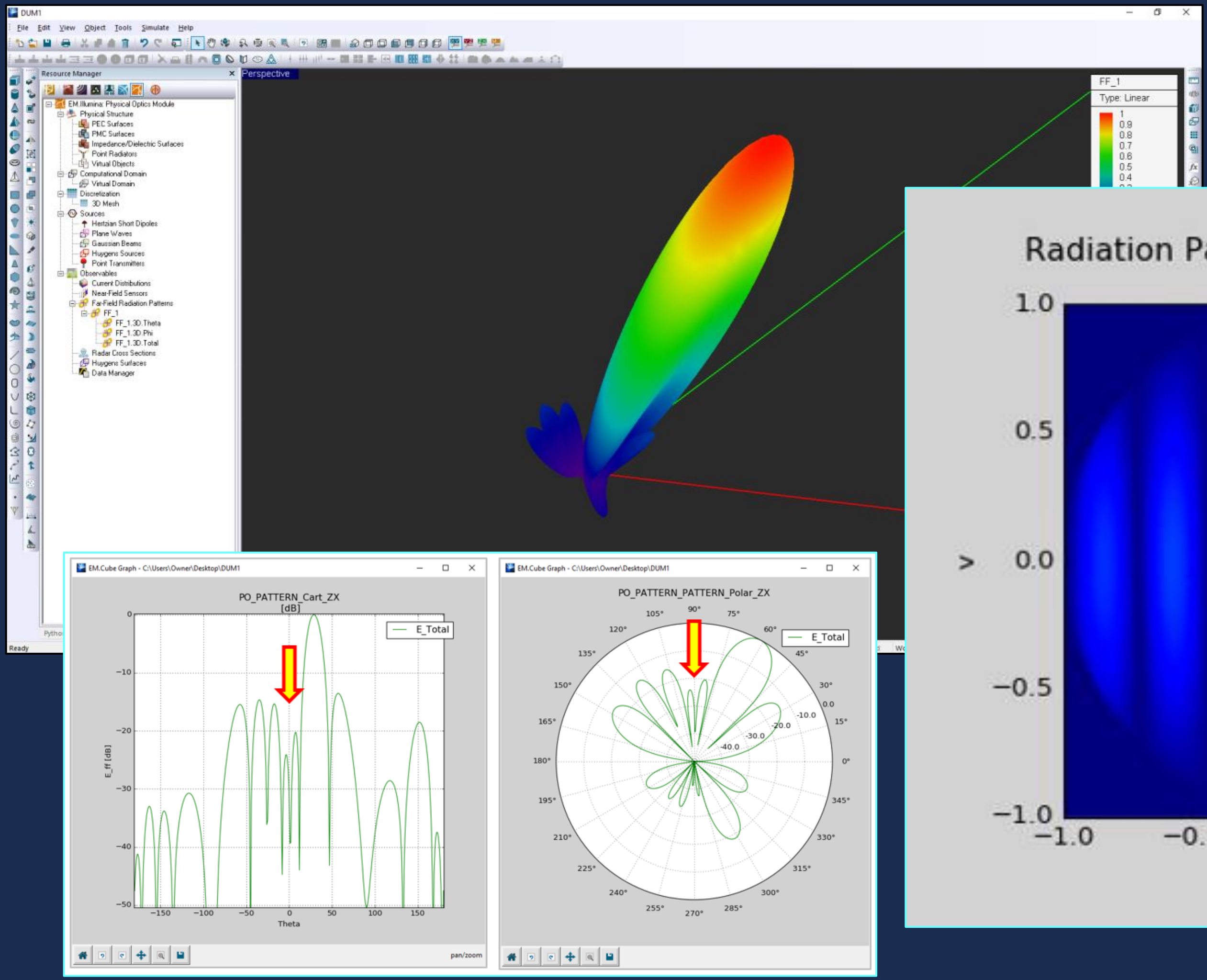
**Null Steering**
**CASE 1**

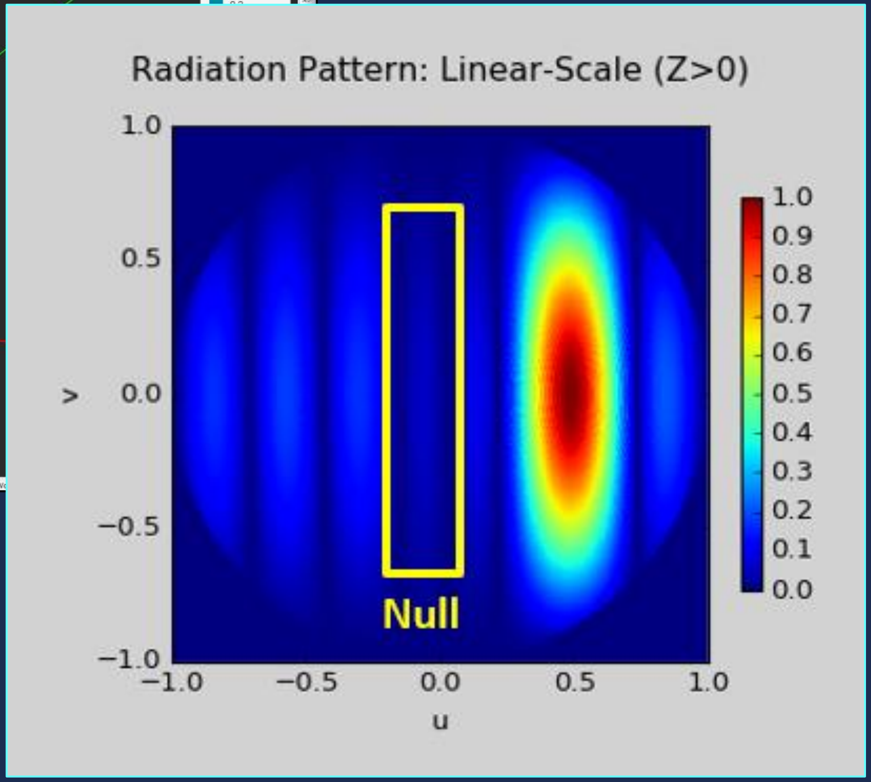


# Active Phased Array Characterization System

## Dual-Band (S/C) Circularly Polarized Half-Duplex AESA for Nanosatellite Ground Station

**Null Steering**
**CASE 2**

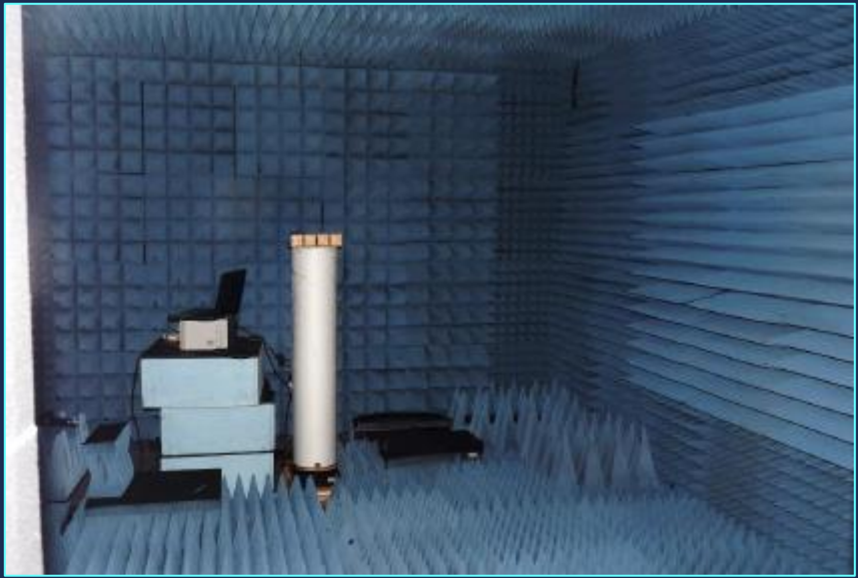


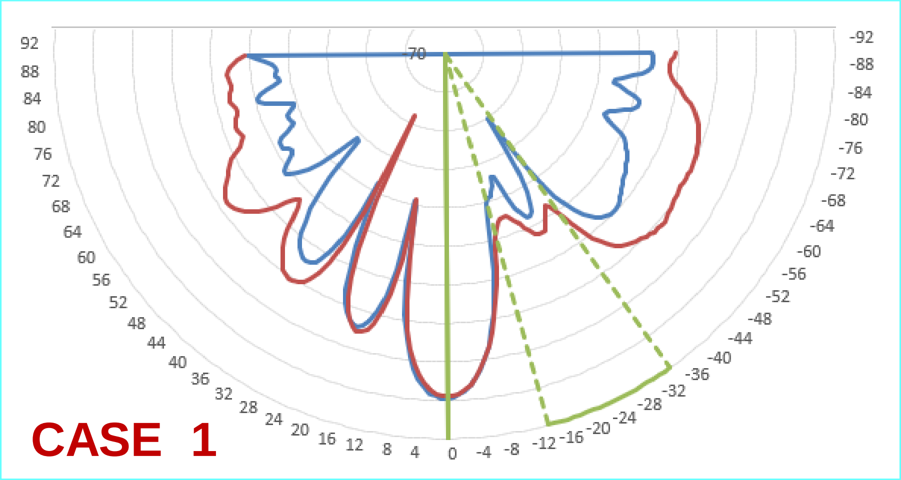



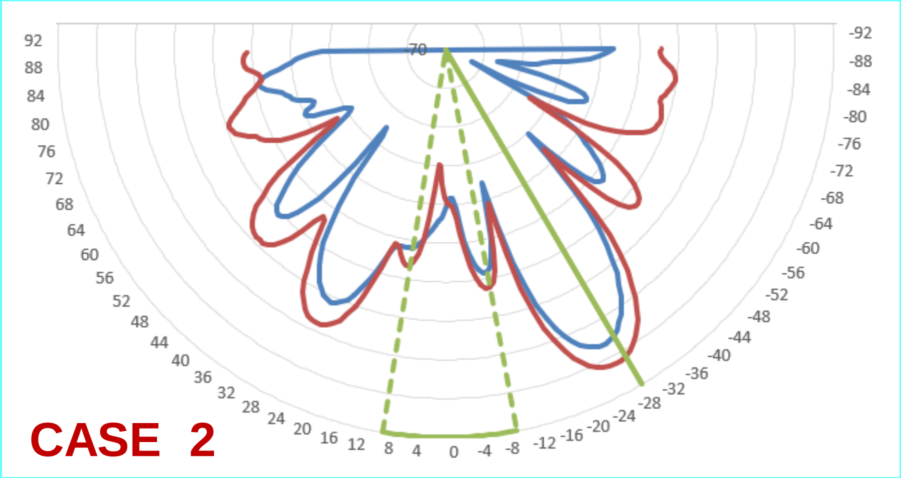
# Active Phased Array Characterization System

## Dual-Band (S/C) Circularly Polarized Half-Duplex AESA for Nanosatellite Ground Station

### Anechoic Chamber Measurements

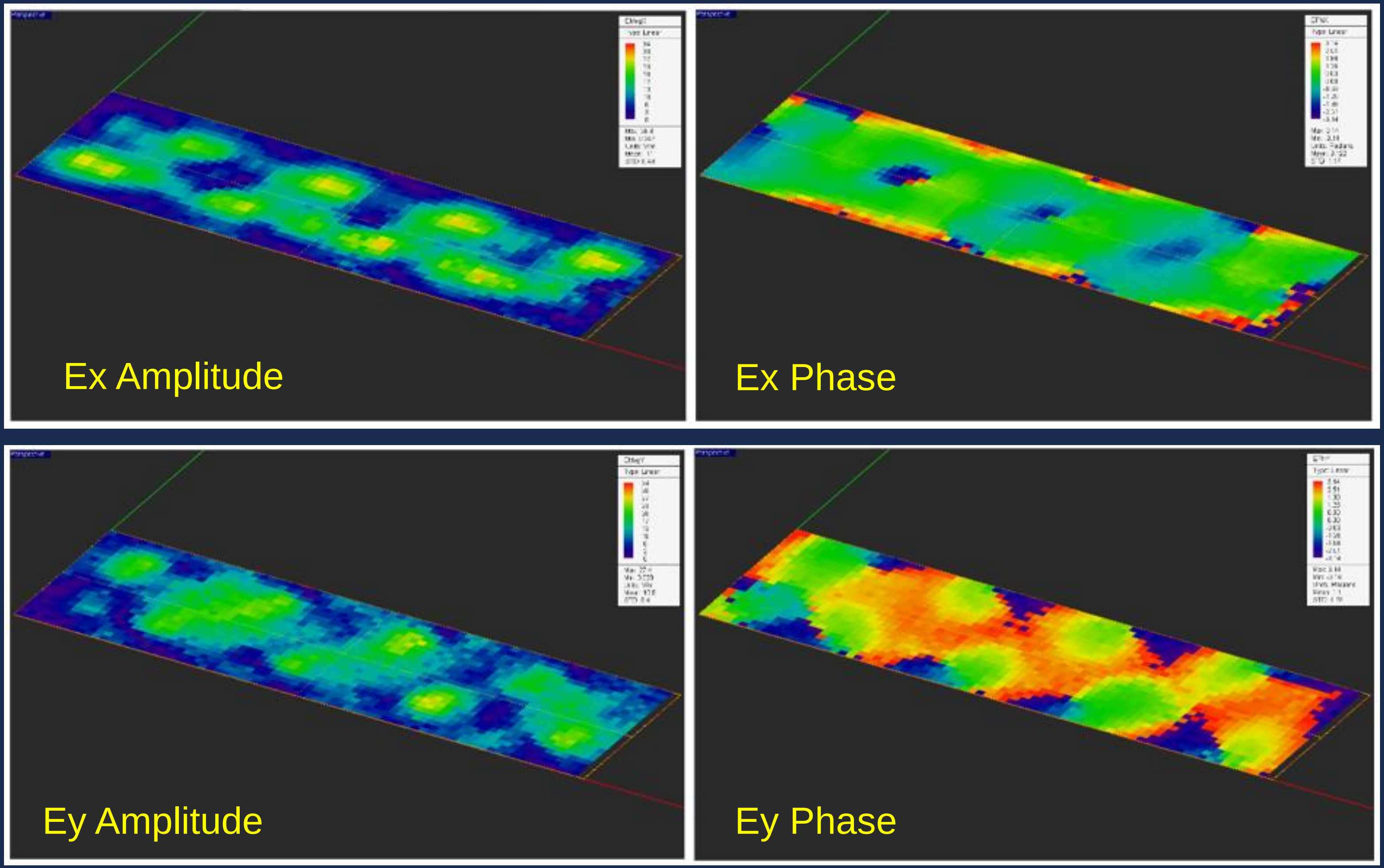




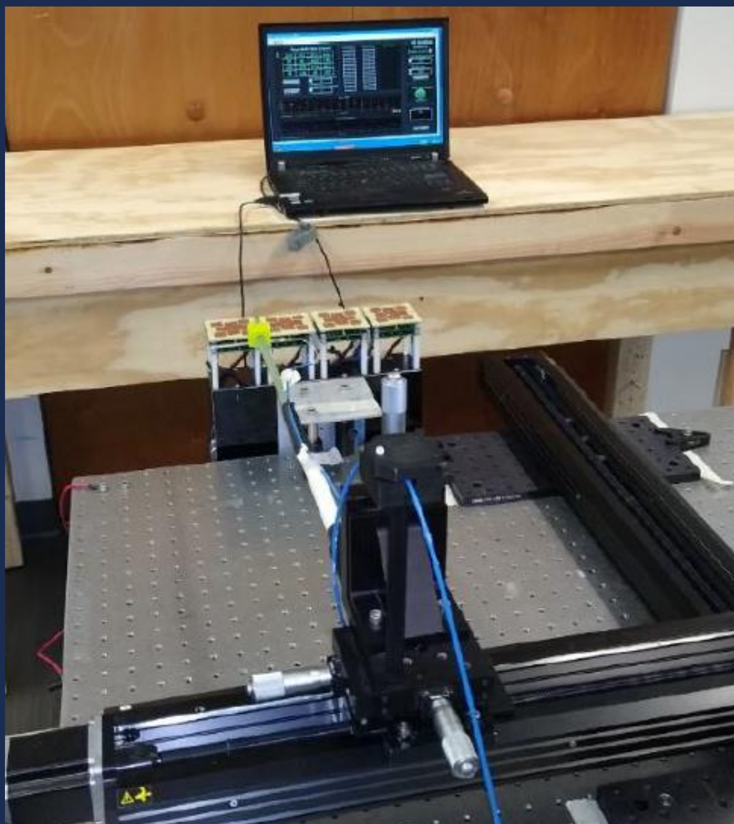
# Active Phased Array Characterization System

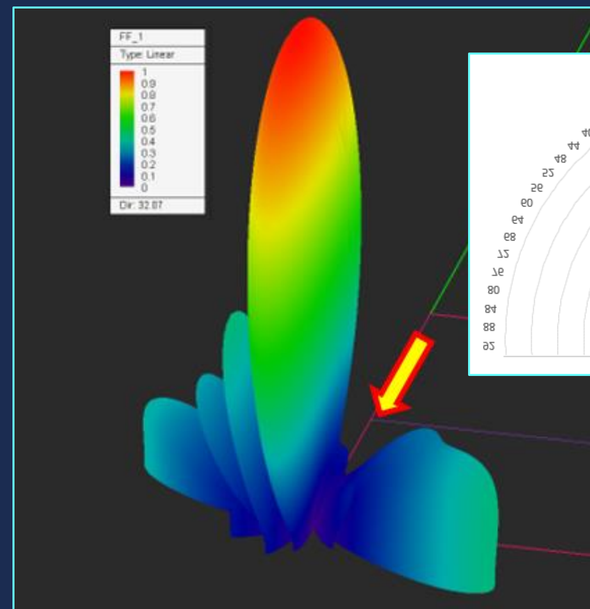
## Dual-Band (S/C) Circularly Polarized Half-Duplex AESA for Nanosatellite Ground Station: NeoScan Near-Field Maps

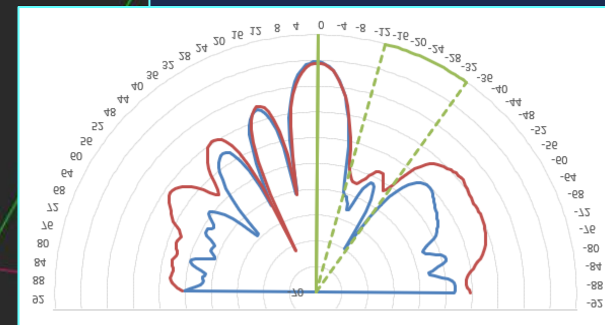


# Active Phased Array Characterization System

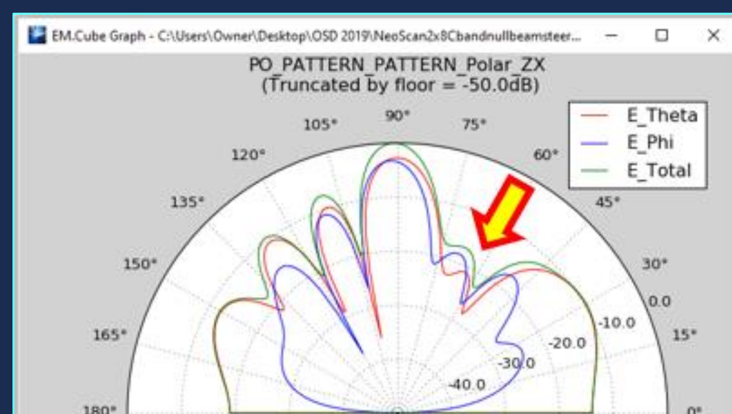
## Dual-Band (S/C) Circularly Polarized Half-Duplex AESA for Nanosatellite Ground Station: Radiation Pattern





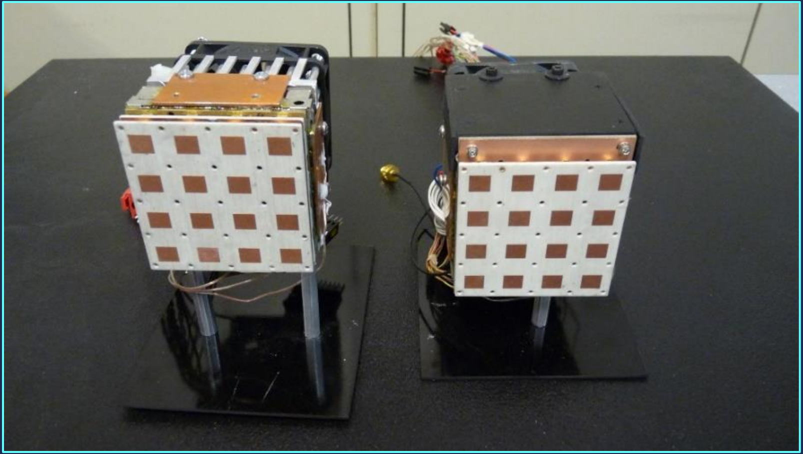
Chamber Data

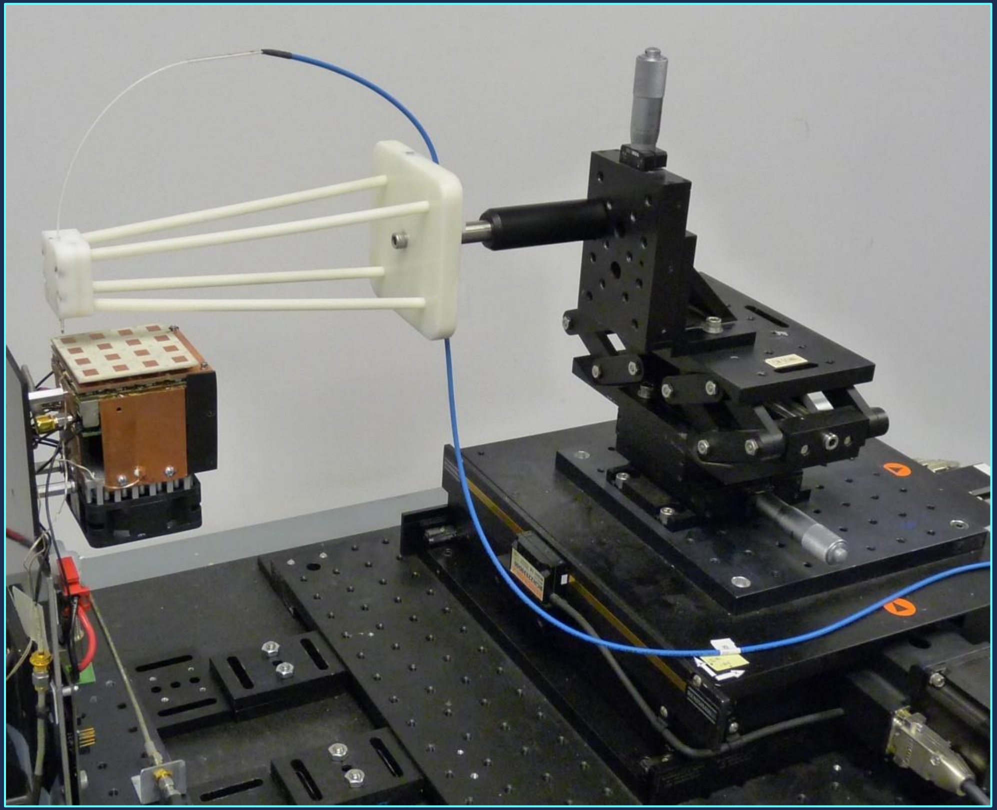



NeoScan Data

# Antenna Array Diagnostic Tool

## EMAG's Vertically Integrated Scalable X-Band AESA with Thermal Management System



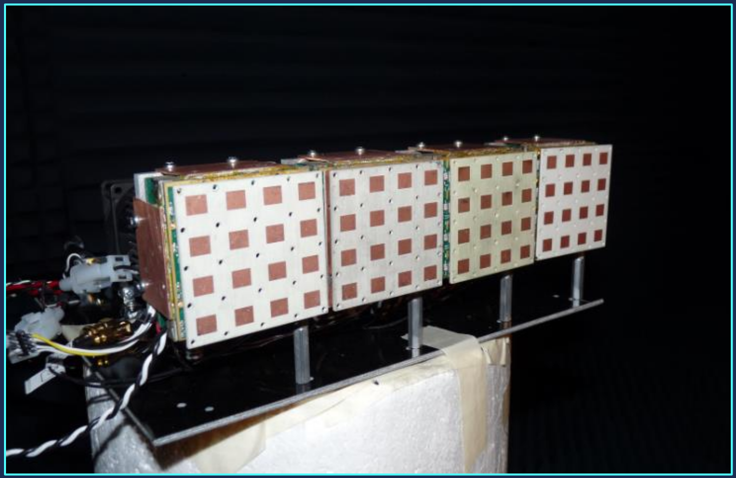


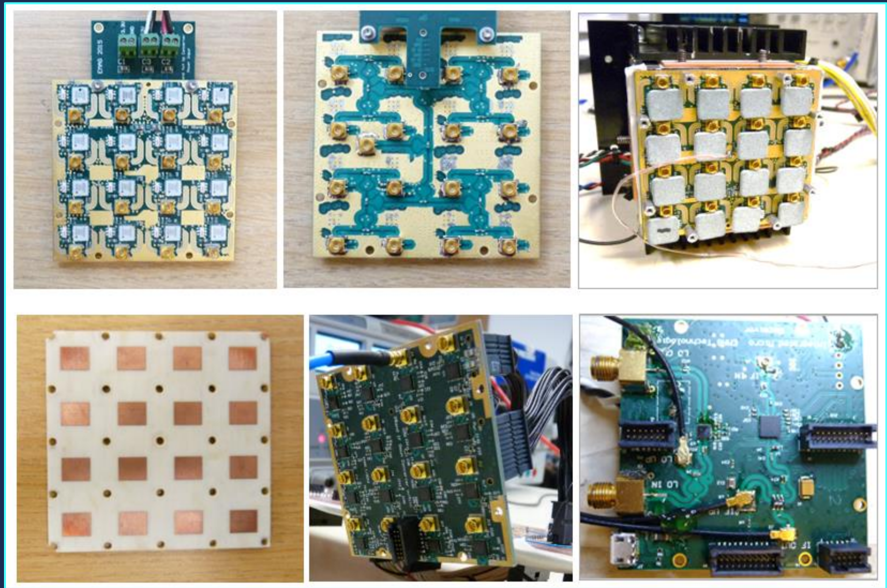
### Multilayer Architecture:

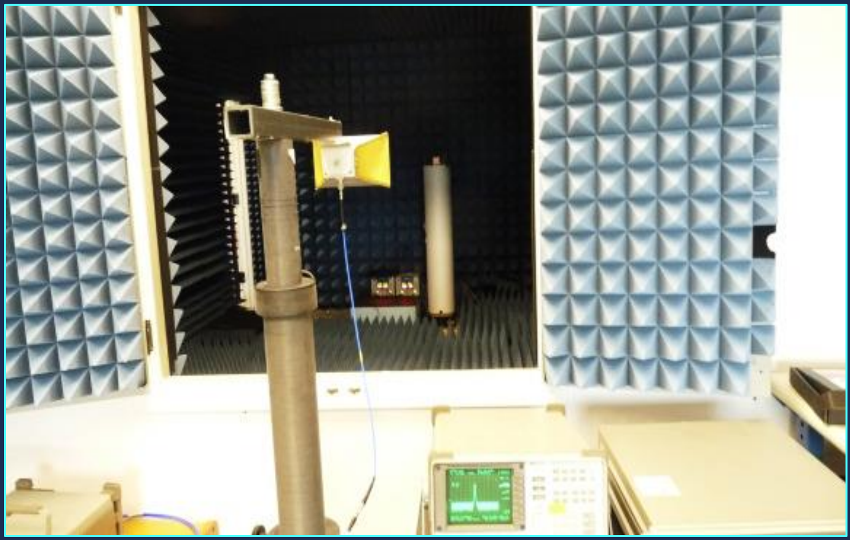
- Antenna Layer
- Frequency Conversion and Amplification Layer
- Digital Phase Shifters & Attenuators Layer
- Microcontroller, DC Regulators & Daisy Chain Logistics Layer

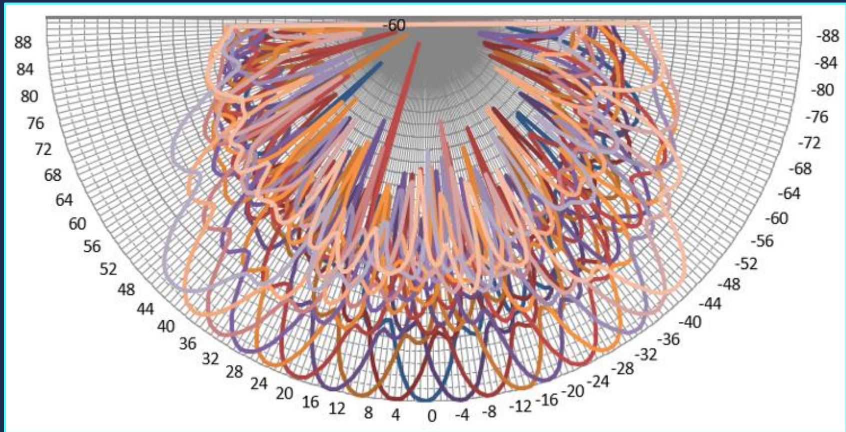
# Antenna Array Diagnostic Tool

## EMAG's Vertically Integrated Scalable X-Band AESA





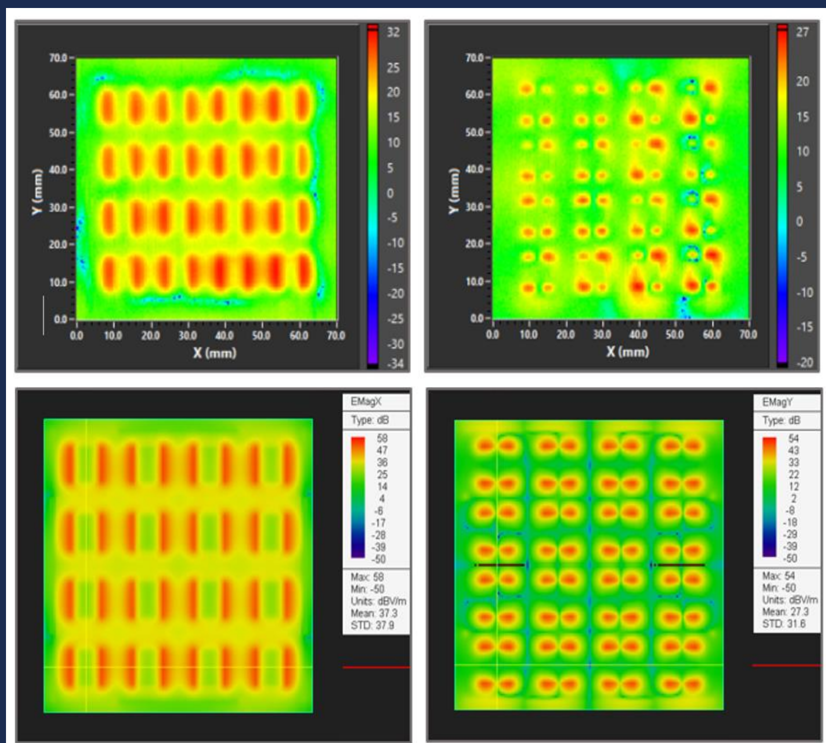




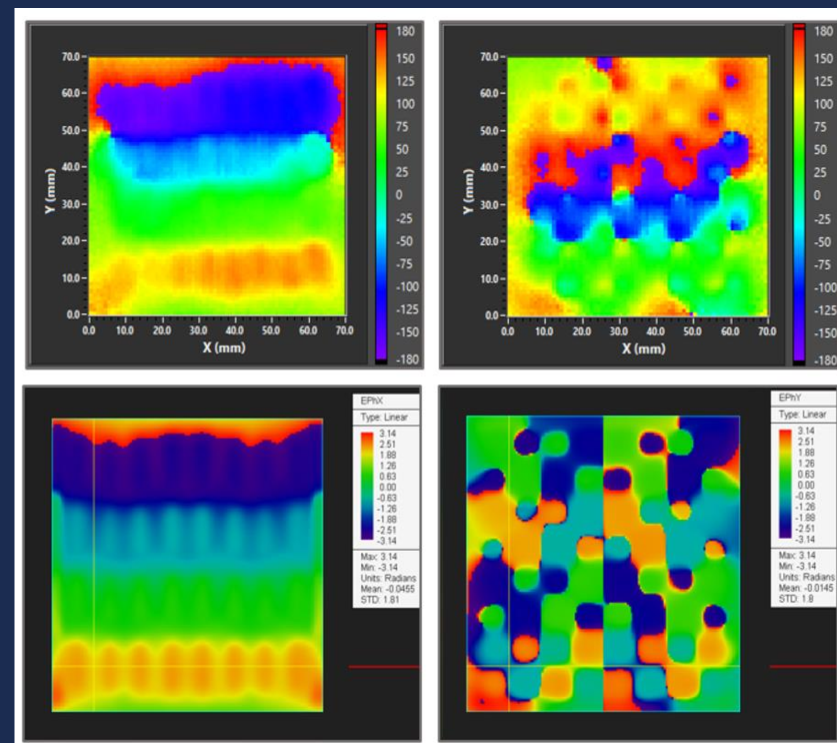
# Antenna Array Diagnostic Tool

## AESA Tile Near-field Scanning Results at 9.5GHz

A comparison of measured (Top) and simulated (Bottom) near-field maps of the AESA tile at a height of 0.6mm above the aperture: (Left) amplitude of $E_x$ component, and (Right) amplitude of $E_y$ component.




A comparison of measured (Top) and simulated (Bottom) near-field phase maps of the AESA tile with beam steering angles $\theta_s$ = 30° and $\phi_s$ = 90° at a height of 1.5mm above the aperture: (Left) phase of $E_x$ component, and (Right) phase of $E_y$ component.



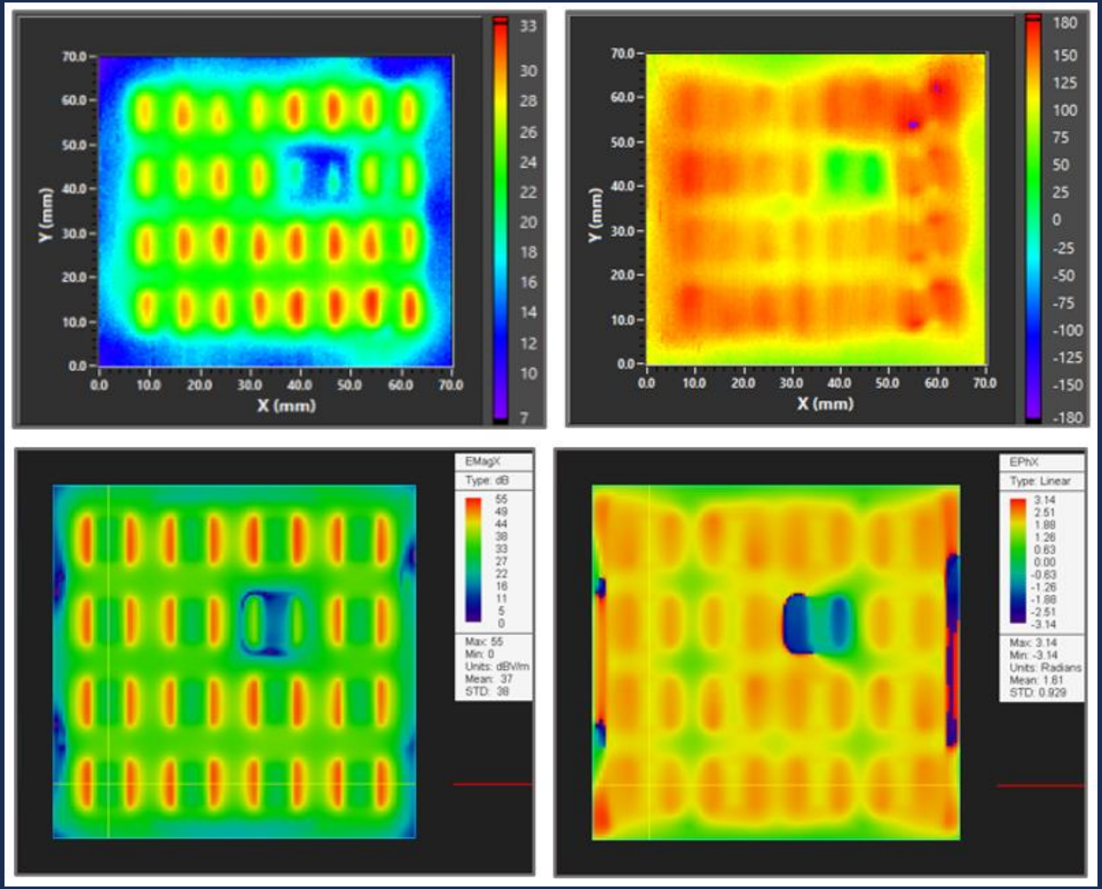

**Simulation Results Obtained Using EM.Cube's FDTD Module**

# Antenna Array Diagnostic Tool

## NeoScan EO Field probe System is the perfect diagnostic tool for fault detection in active phased array system.

A comparison of measured (Top) and simulated (Bottom) near-field maps of the AESA tile with a missing connector bullet: (Left) amplitude of Ex component, and (Right) phase of Ex component.

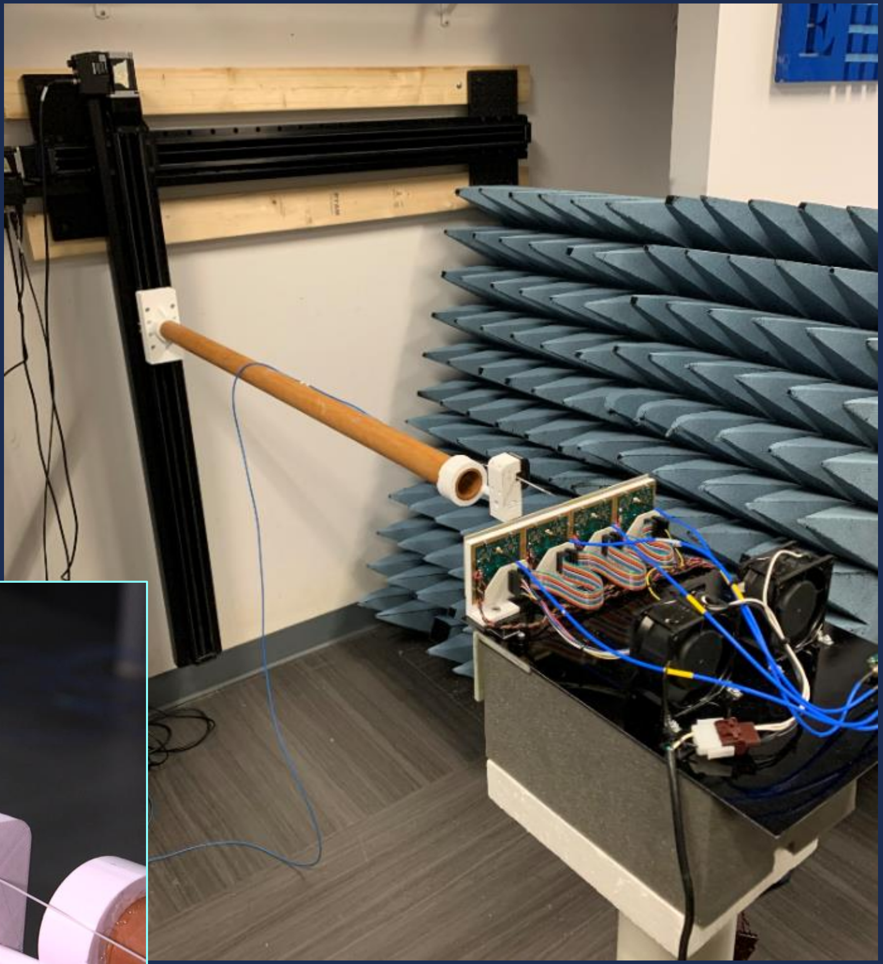
**The near-field maps were measured with a spatial resolution of 500μm at a height of 600μm above the aperture surface.**

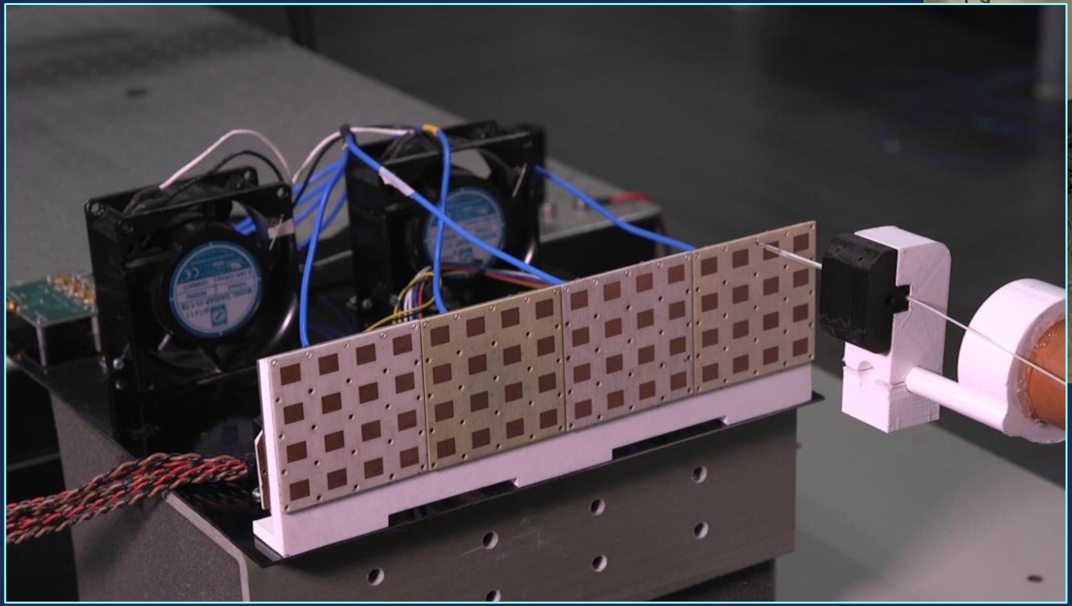



Simulation Results Obtained Using EM.Cube's FDTD Module

# Antenna Array Diagnostic Tool

**EMAG's Gen-2 Vertically Integrated Scalable X-Band AESA using Anokiwave integrated Tx-Rx RFIC chips**

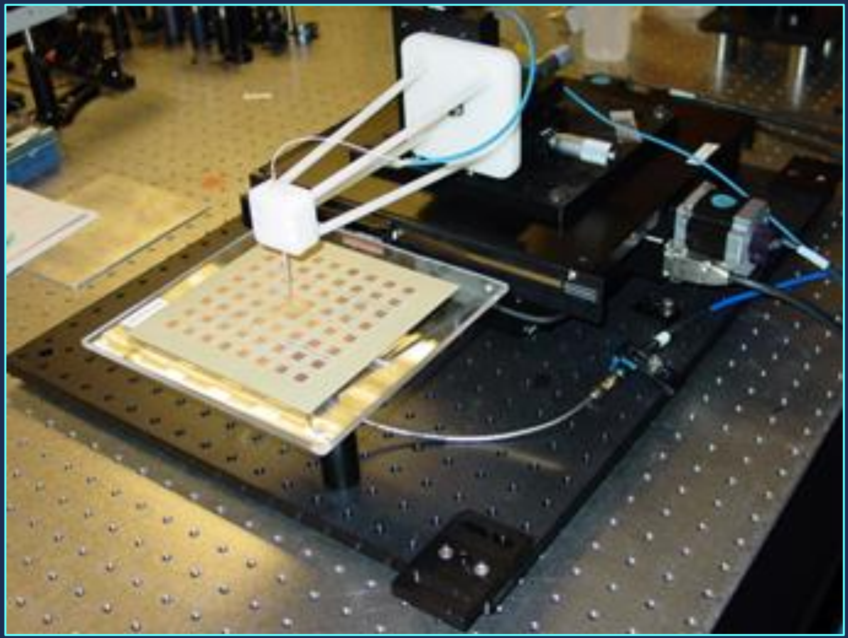


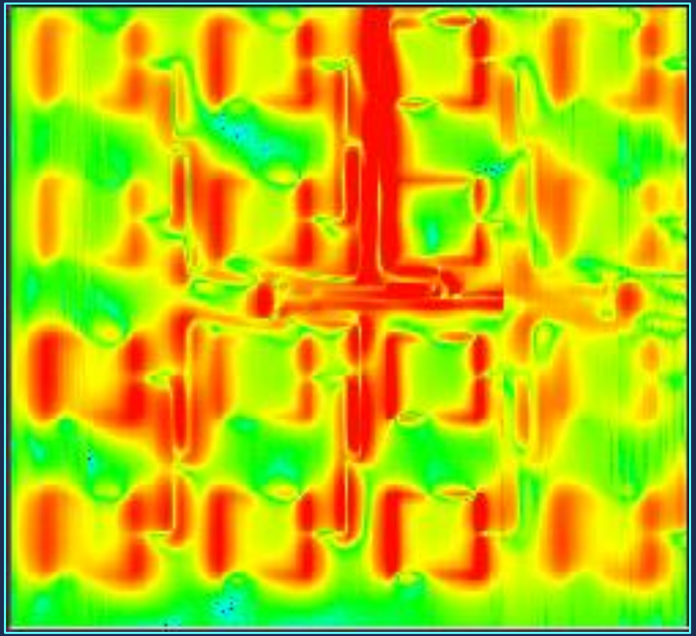


# Antenna Array Diagnostic Tool

NeoScan lets you quantify and visualize the true near-fields of antenna arrays right at the aperture surface. This helps you better evaluate adverse inter-element coupling effects.

High-resolution near-field map of a 64-element X-band patch antenna array with a corporate feed network measured at 10.65GHz



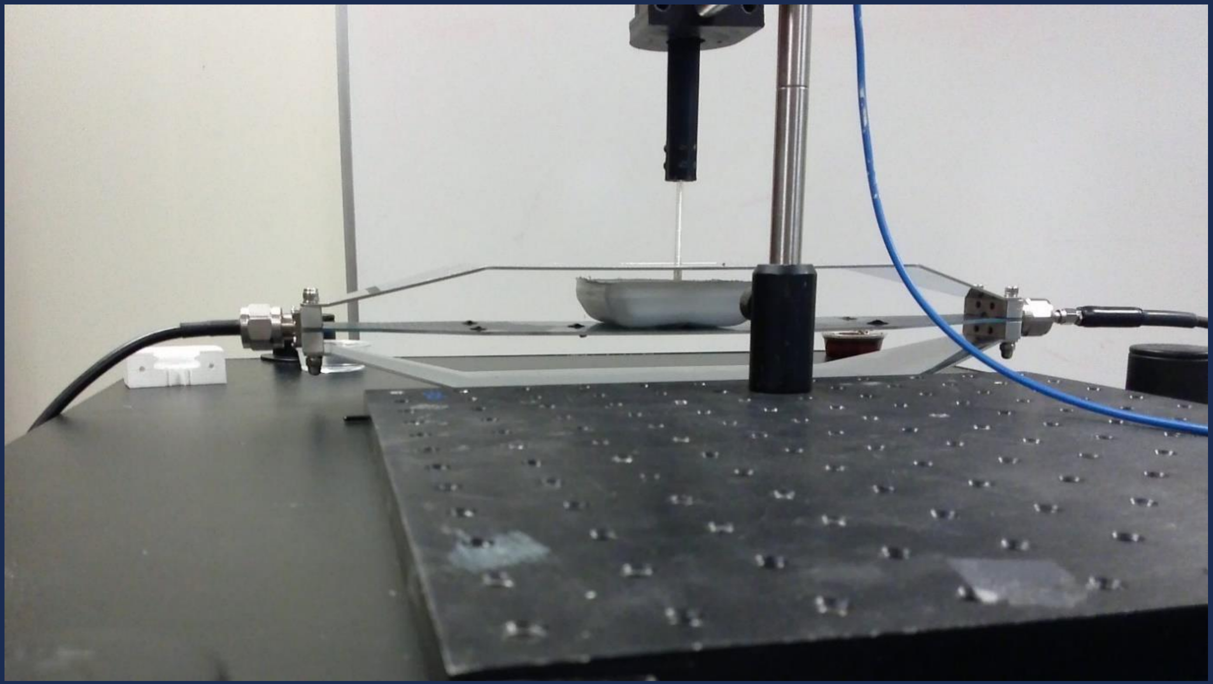


# Near-Field Measurement for Biomedical Applications

## Collaboration with New York University's Neuroscience Institute on Measuring Electrical Field Inside Rat Brain

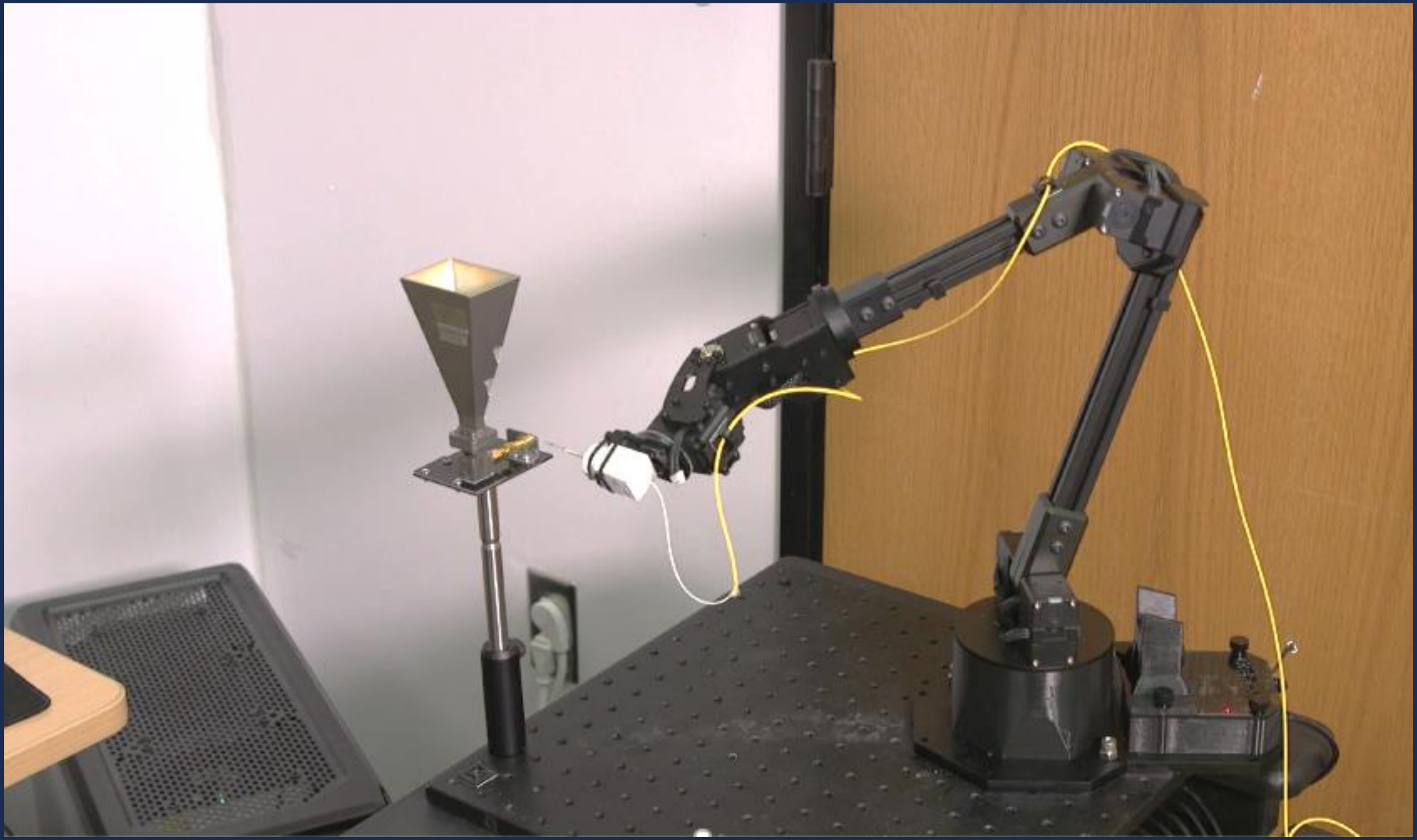
Low-frequency system measuring fields inside saline environments covering 1 kHz to 2 GHz

EO Probe with protective glass tube

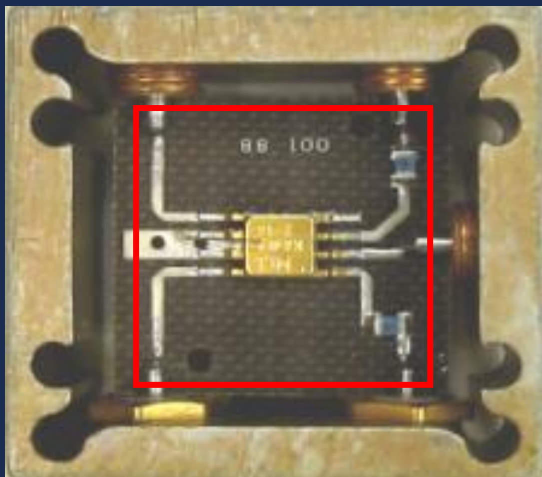


# Using Robotic Arms for 3D Point Cloud Measurements

## Useful for EMC Radiation and Susceptibility Test Measurements



# Diagnostic Near-Field Measurement : RF Switch



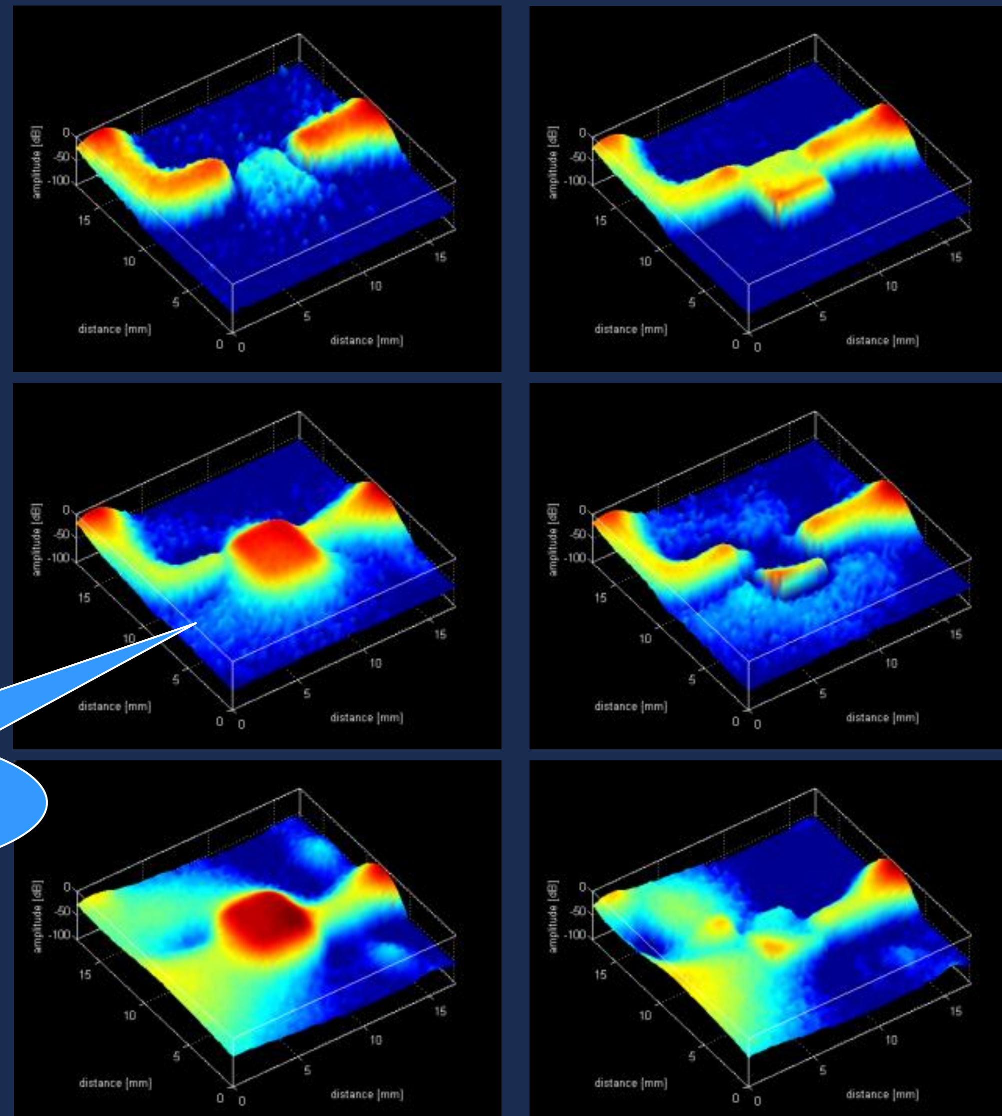
RF switch ZFSWA-2-46
(f = 4.563 GHz)

Faulty Switch Design | Improved Switch Design

803 MHz

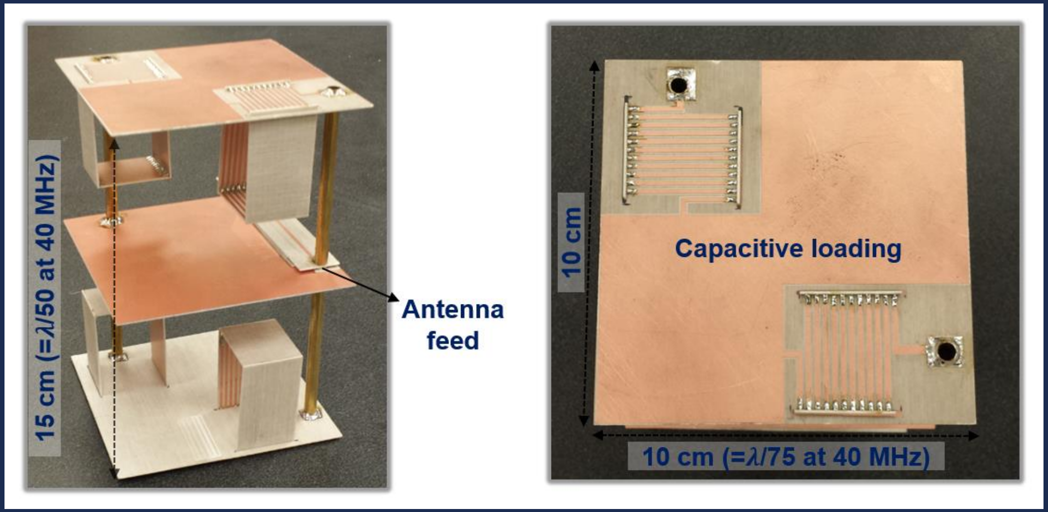
4.563 GHz

6.003 GHz




Emissions / Leakage from the Package

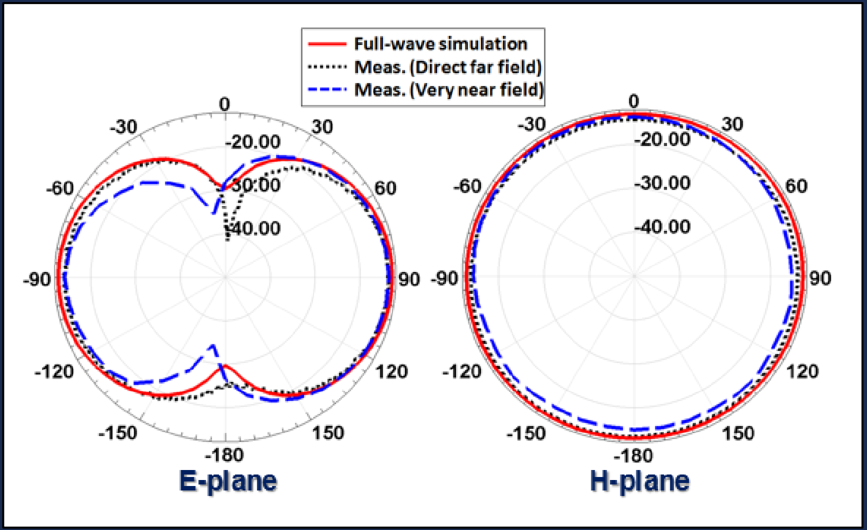
# SCANNING COMPLEX 3D ANTENNAS




Miniaturized HF Folded Dipole Antenna Designed and Fabricated by the University of Michigan

< Antenna gain comparison >

| Process | Simulation | Direct-far-field | Very-near-field |
|---|---|---|---|
| Center freq. | 40.01 MHz | 40.00 MHz | 40.06 MHz |
| Peak gain | -12.8 dBi | -13.3 dBi | -13.6 dBi |

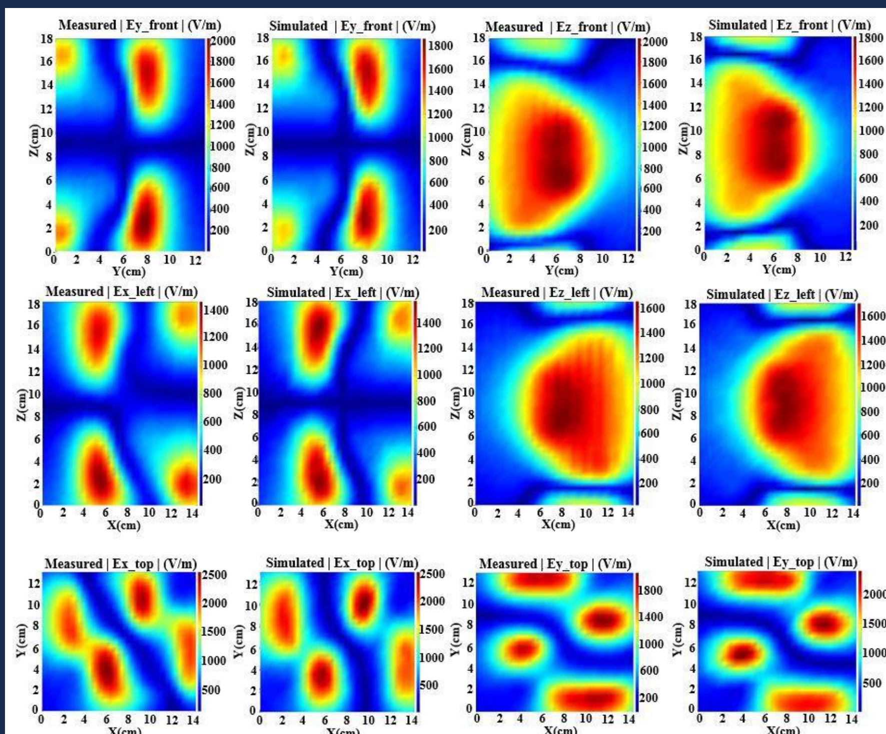


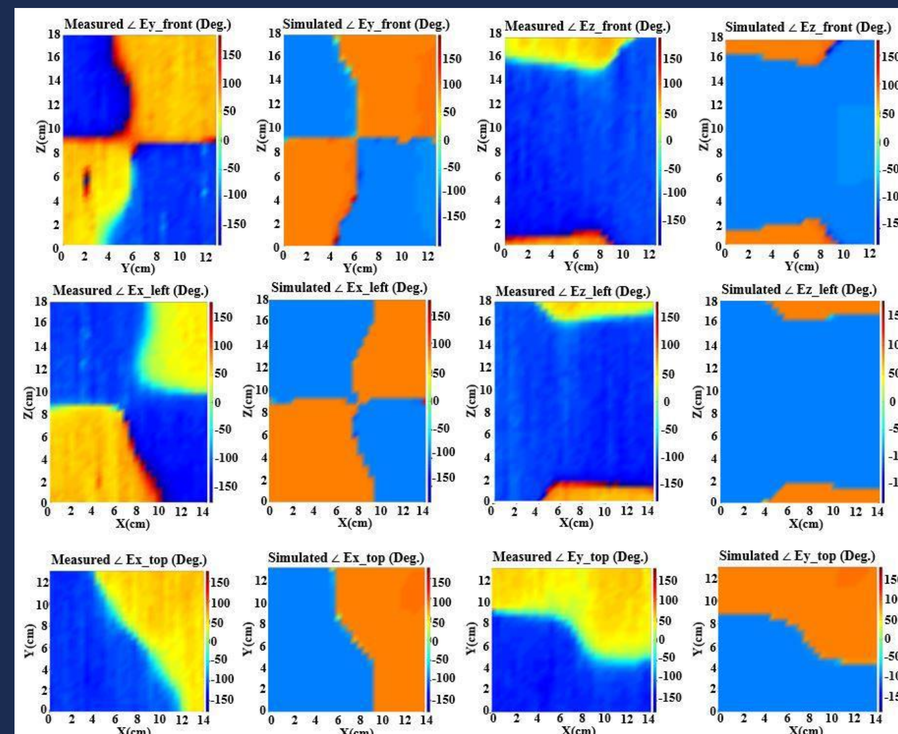
# SCANNING COMPLEX 3D ANTENNAS

Comparison of measured and simulated field amplitudes and phases on six faces of a Huygens box enclosing the Miniaturized HF Folded Dipole Antenna

**Simulation: ANSYS HFSS**

**Measurement: NeoScan**

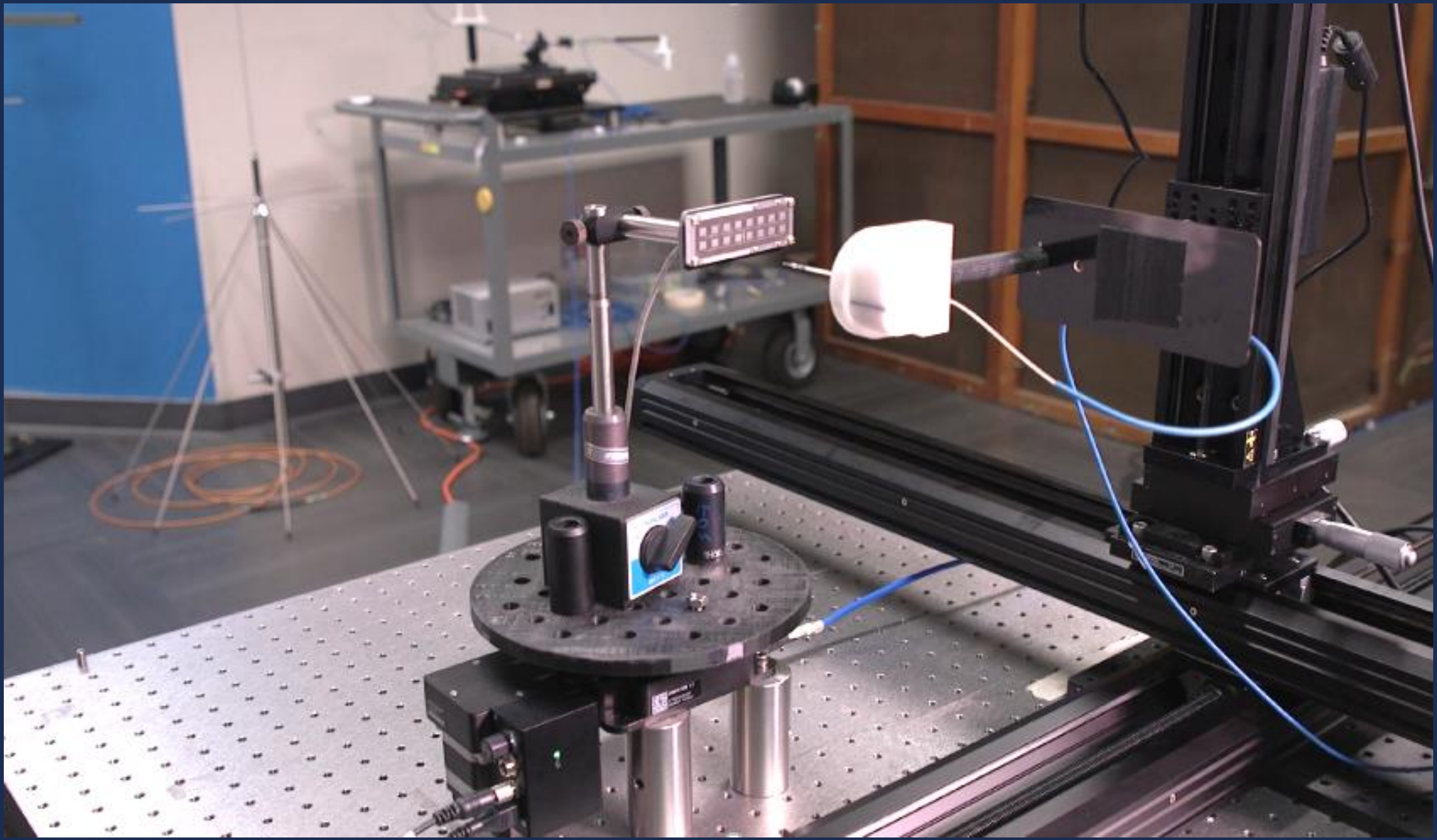


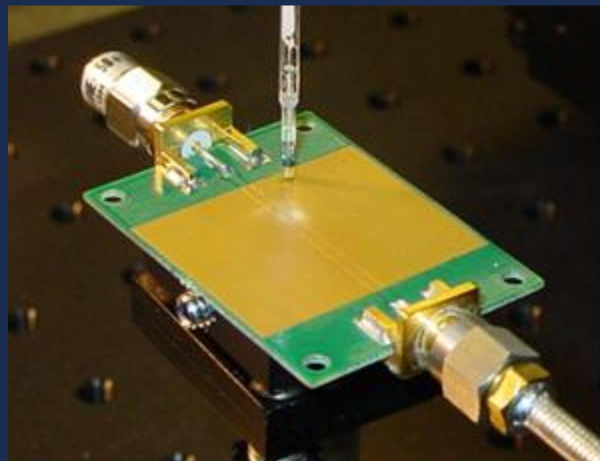

Sarabandi, J. Choi, A. Sabet and K. Sabet, "Pattern and gain characterization using nonintrusive very-near-field electro-optical measurements over arbitrary closed surfaces," IEEE Trans. Antennas & Propagat., vol. 65, no. 2, pp. 489-497, Feb. 2017.

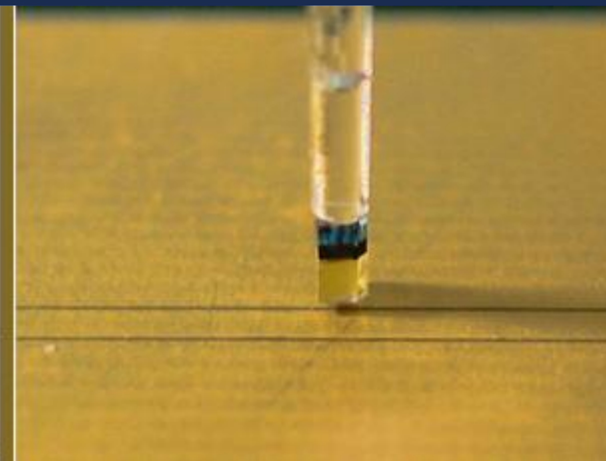
# CYLINDRICAL NEAR-FIELD SCANNING

EO field mapping using vertical linear and rotary stages for lateral surface and 2D XY stage for top and bottom surfaces



# Non-Invasive Extreme Near-Field Measurement



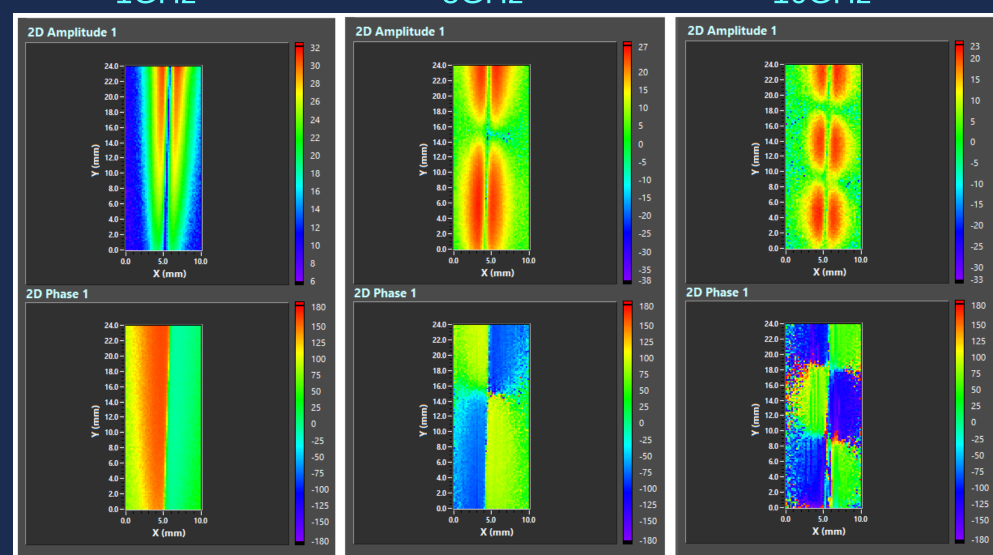


**Can your field probe get this close to the surface of a CPW?**

NeoScan accurately measures not only propagating mode fields at a distance from the DUT but also evanescent mode fields very close to the surface of the DUT.

NeoScan's small, non-contact, field probe uses a narrow laser beam to sample the DUT's surface fields at a very high spatial resolution without perturbing them.

1GHz 5GHz 10GHz

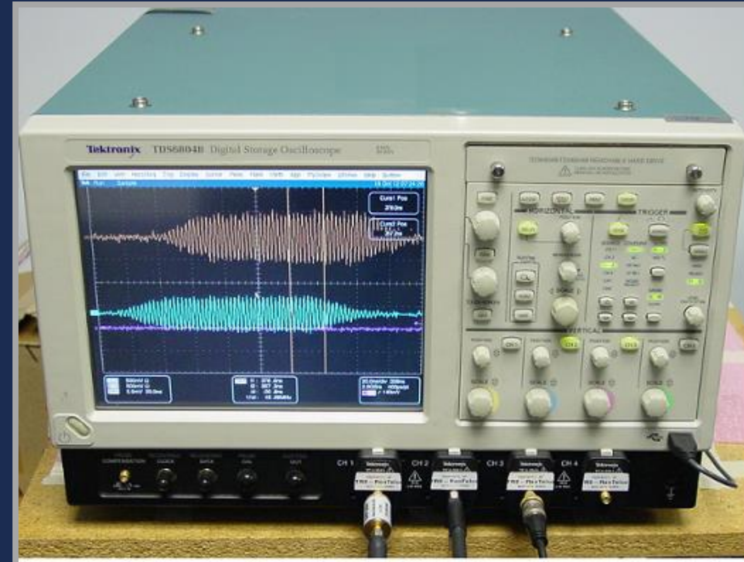


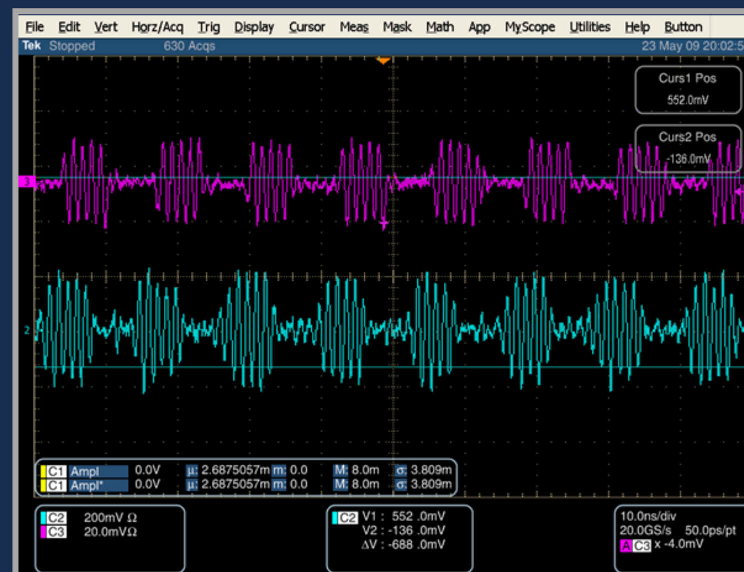
# Real-Time Waveform Measurement

NeoScan can be used as a multi-channel system for simultaneous, coherent, real-time field measurement at multiple locations.

The electro-optic modulation effect provides a unique means of sensing and detecting wideband RF and microwave signals in real time. Since the carrier signal is at optical frequencies, the modulating RF field can have a substantial instantaneous bandwidth. The non-contact EO probe effectively serves as an extremely high impedance probe.

NeoScan's RF output can be sampled by a high-speed digital storage oscilloscope to track and display the waveforms detected by the EO probe.



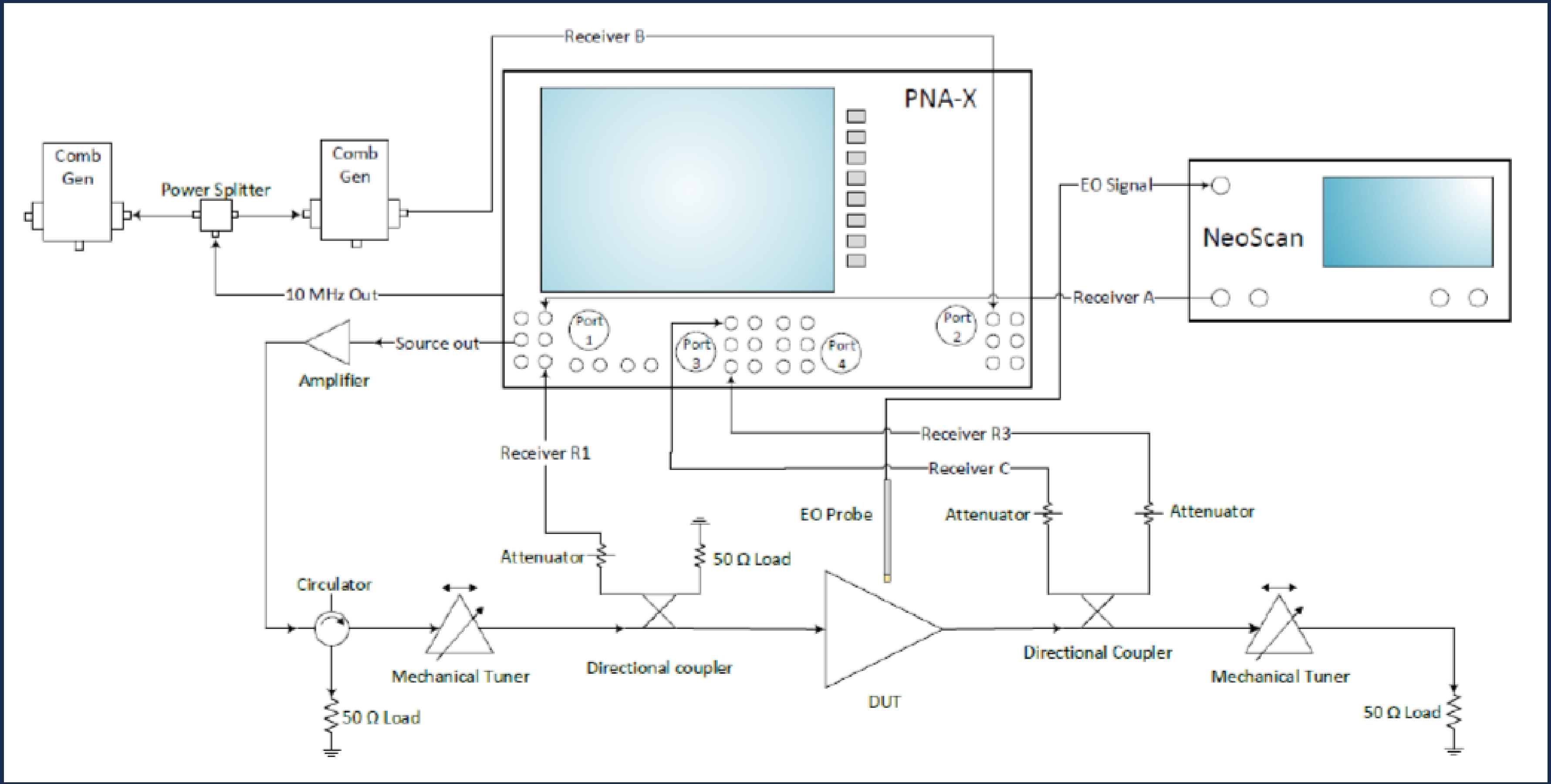


# Nonlinear Active Device Characterization

- For the characterization of microwave power amplifiers like LDMOS and GaN, large-signal data is needed to capture the nonlinear device behavior.
- To reconstruct the large-signal time-domain waveforms at the device terminals, cross-frequency phase coherence is needed. This can be accomplished using a combination of a nonlinear vector network analyzer (NVNA) and a load-pull (LP) measurement system.
- The combination of NeoScan and a pulsed NVNA-LP measurement system enables distributed time-domain vector E-field measurements under continuous wave (CW) or pulsed operation.
- A practical setup can be realized using NeoScan in conjunction with Keysight's PNA-X microwave vector network analyzer, two comb generators and wideband mechanical impedance tuners for source-pull and load-pull.
- NeoScan EO field probes can accurately map the E-field on the surface of the active device with a spatial resolution as high as 10 microns.

# Nonlinear Active Device Characterization

## Integrated NeoScan and Pulsed NVNA Load-Pull Measurement System for Non-Invasive Multi-Harmonic Vector E-Field measurements




J. Urbonas, K. Kim, F. Vanaverbeke, and Peter H. Aaen, "An Electro-Optic Pulsed NVNA Load–Pull System for Distributed *E*-Field Measurements," IEEE Trans. Microwave Theory Tech., Vol. 66, No. 6, June 2018.

# Nonlinear Active Device Characterization

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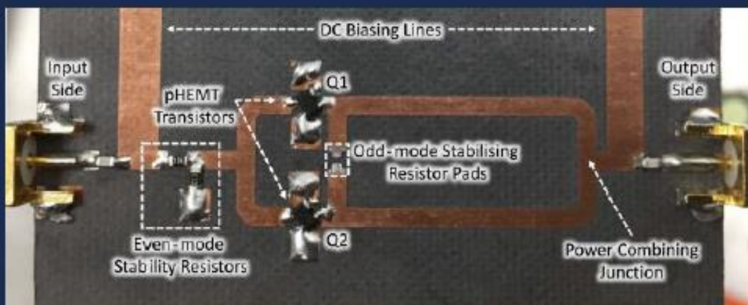
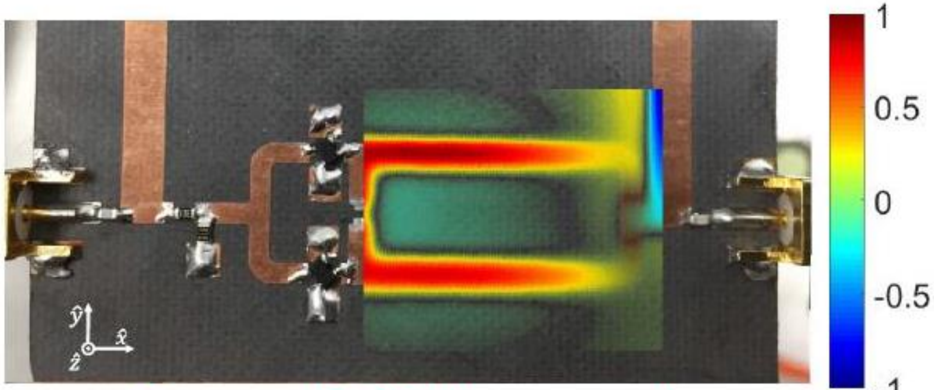
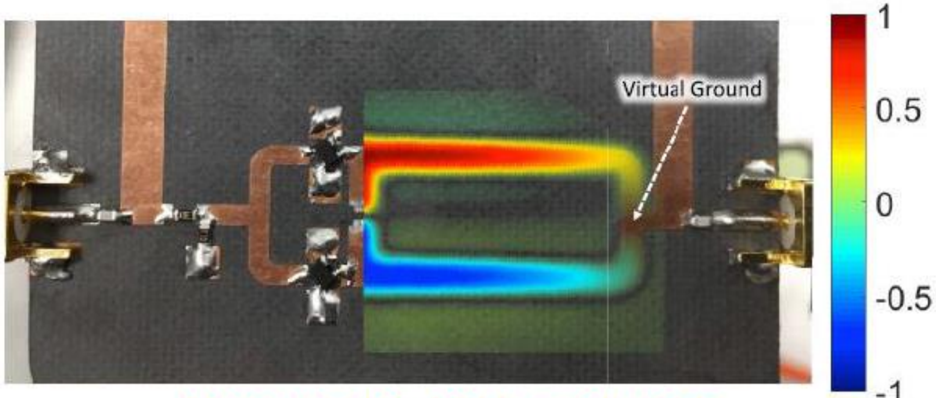



Low-power power amplifier (PA) highlighting the key components and the power combining junction where a virtual ground is formed during an odd-mode oscillation

J. Urbonas, K. Kim and Peter H. Aaen, "Direct *E*-Field Measurement and Imaging of Oscillations within Power Amplifiers," IEEE Trans. Instrumentation Measurement, 2018.



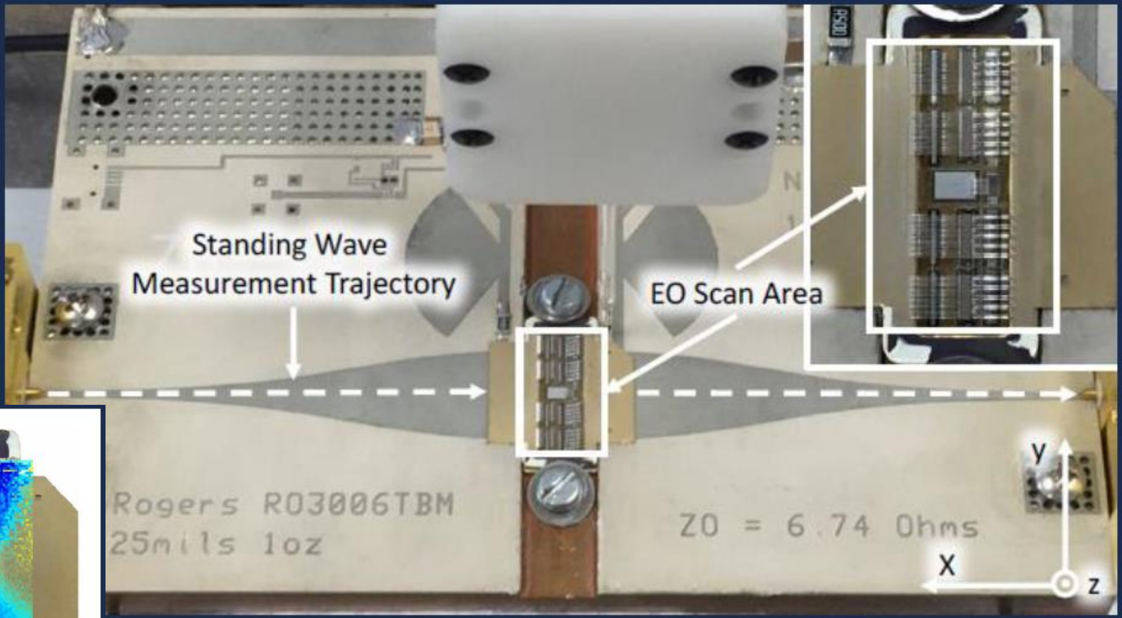

Measured 2.8GHz even mode



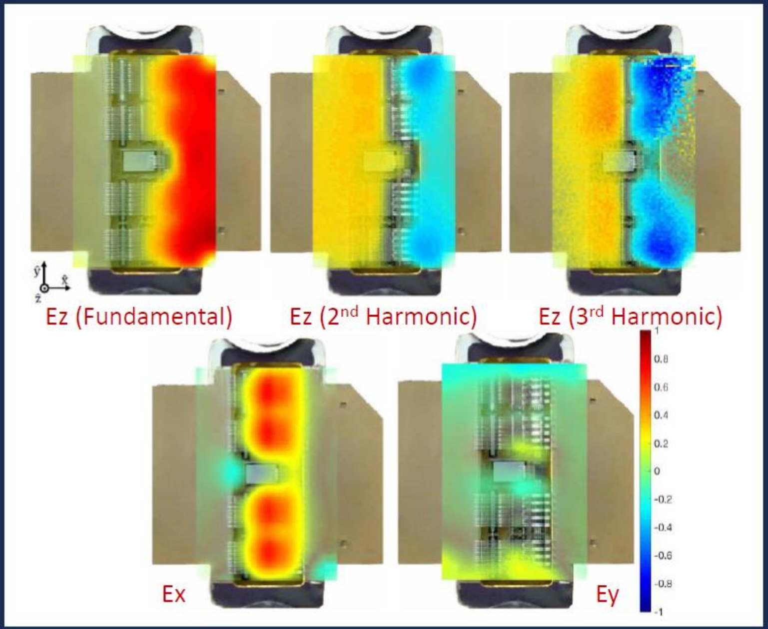

Measured 1.4GHz odd mode

# Nonlinear Active Device Characterization

## Integrated NeoScan and Pulsed NVNA Load-Pull Measurement System for Non-Invasive Multi-Harmonic Vector E-Field measurements



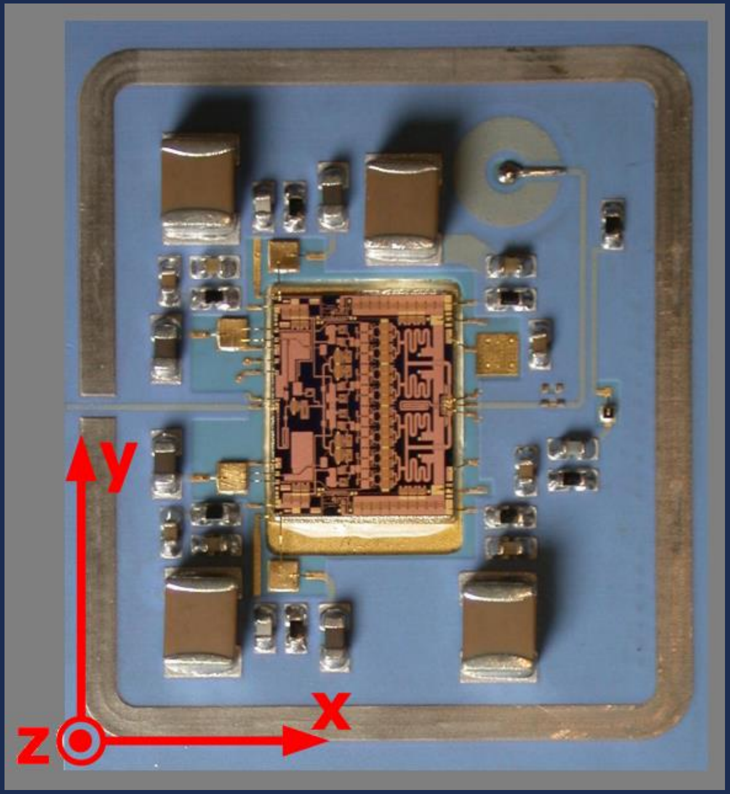

f = 2.2GHz



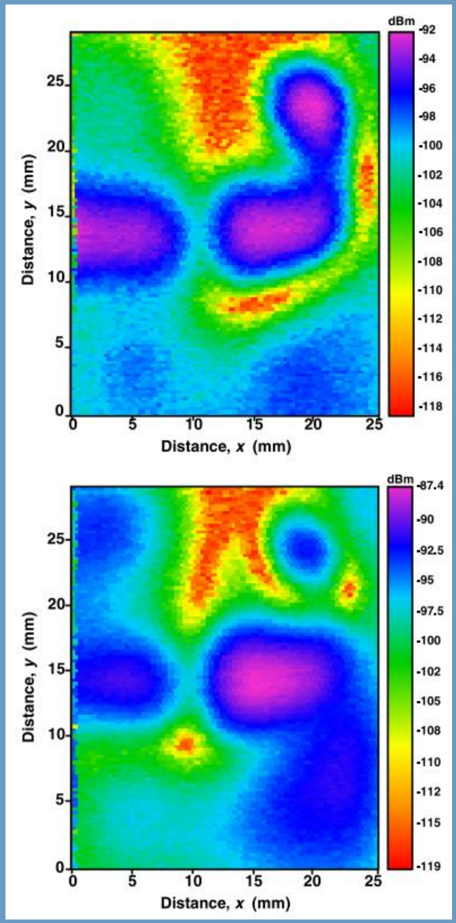

Transistor fixture image showing the E-field scan axes, EO scan area (12 mm x 18 mm) on the LDMOS transistor, and the scan trajectory used for standing wave measurements along the impedance transformer

# Testing RF Multi-Chip Modules (MCM)

Sandia National Labs' S-band Single-chip Pulsed Power Amplifier Incorporated into an LTCC Module



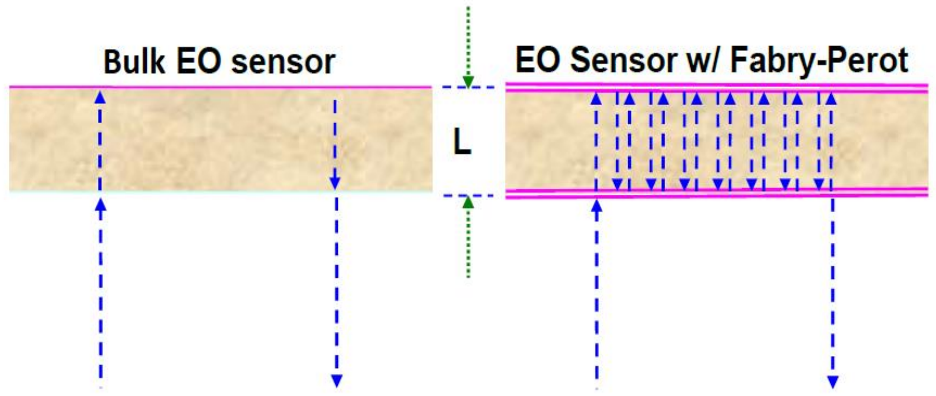

C. Rodenbeck, et al., "Electrooptic inspection of vector leakage in radiofrequency multichip modules," IEEE Transactions on Electromagnetic Compatibility, VOL. 55, No. 6, December 2013.




Non-radiating normal field distribution above LTCC package (top) without and (bottom) with an epoxy encapsulant.

# Fabry-Perot EO Field Probe System

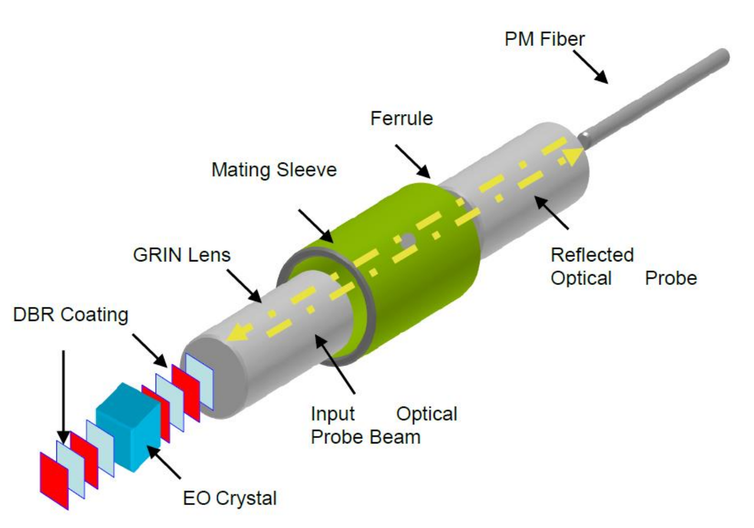
- Uses a Fabry-Perot resonator with a thin-film EO crystal
- Requires a tunable laser
- Utilizes amplitude modulation
- Can achieve the sensitivity of a bulk probe at 1/10 thickness



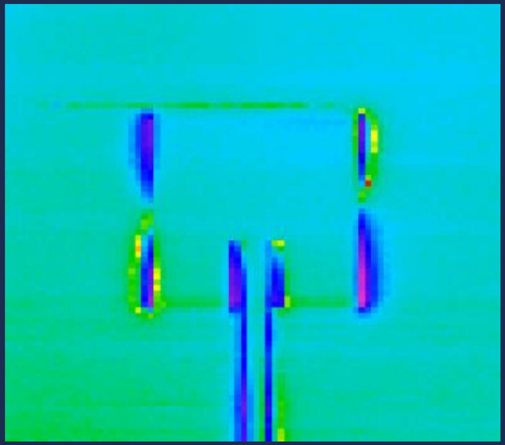

Airy transmission function:

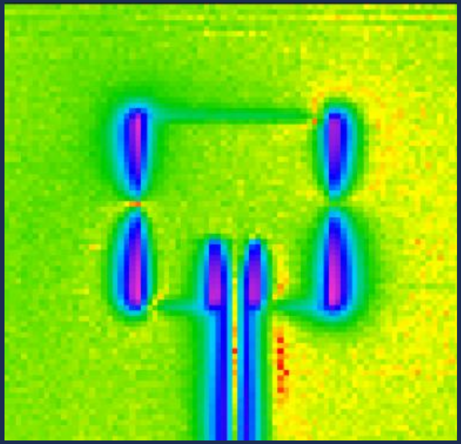
$$T(E) = \frac{1}{1 + \left(\frac{2F}{\pi}\right)^2 \sin^2\left(\frac{2\pi}{\lambda} L n_{eff}(E)\right)}$$

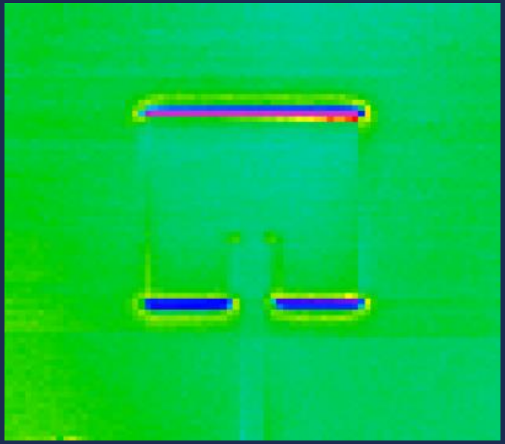
$$F = \pi\sqrt{R}/(1-R)$$

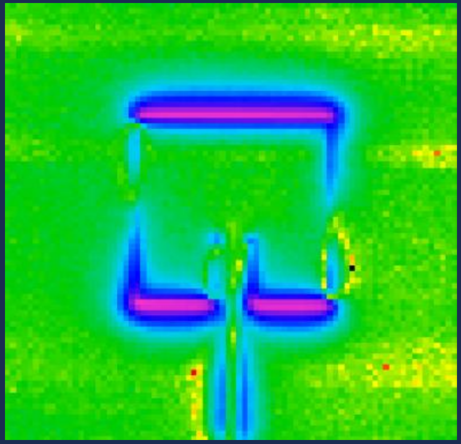


# Fabry-Perot EO Field Probe System





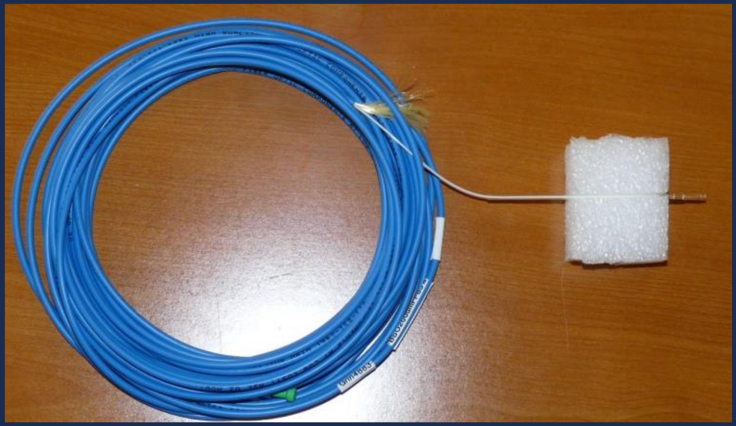




Fabry-Perot Probe

Bulk Crystal Probe

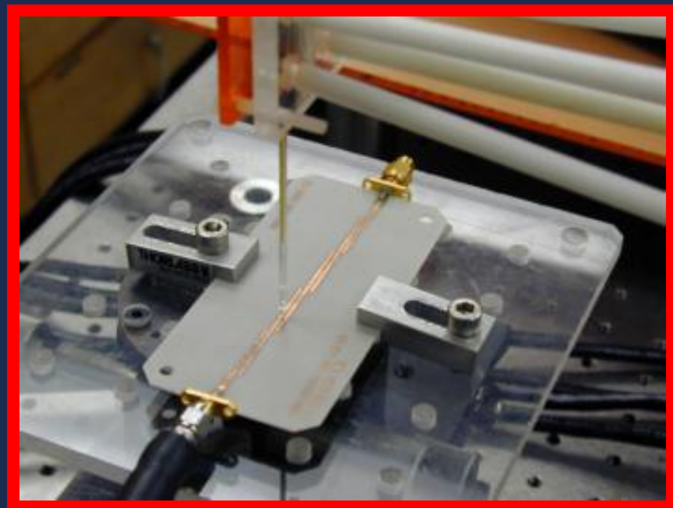
Probe tip thickness: 100 $\mu$m

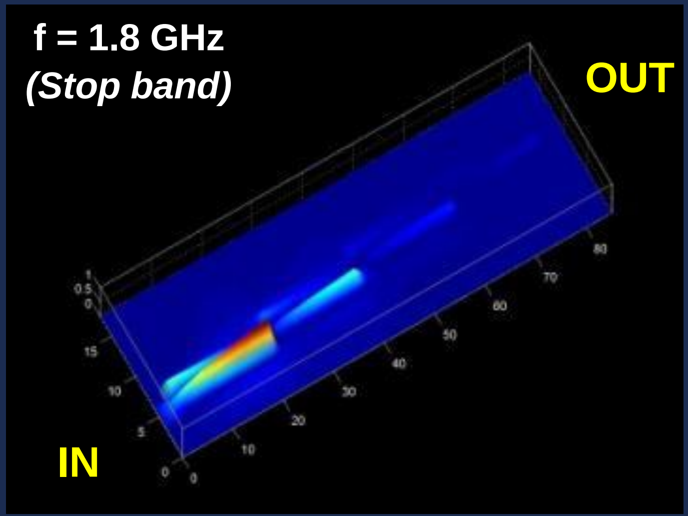


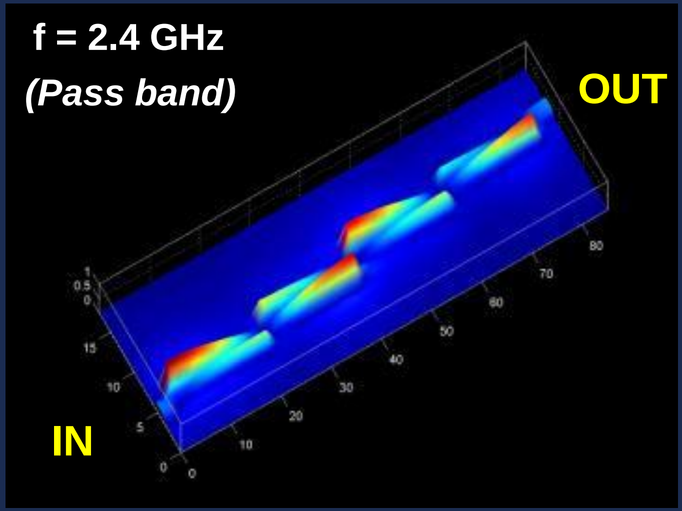
**TRUE SURFACE PROBE**

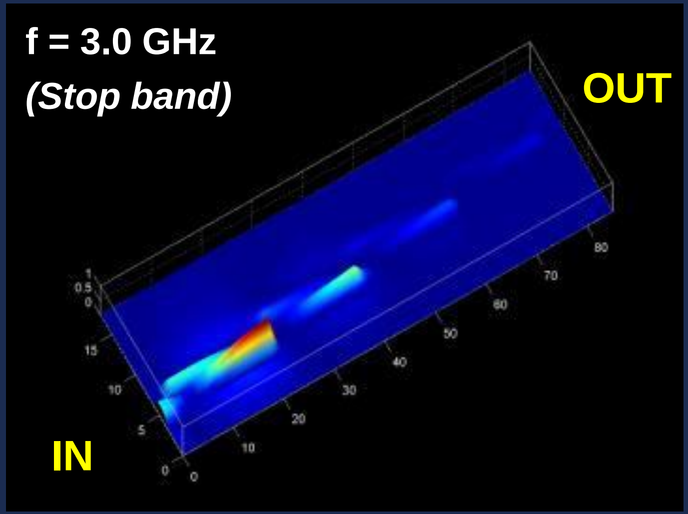
# An Effective Educational & Research Tool

## Demonstrating the Frequency Response of a Planar Microstrip Filter

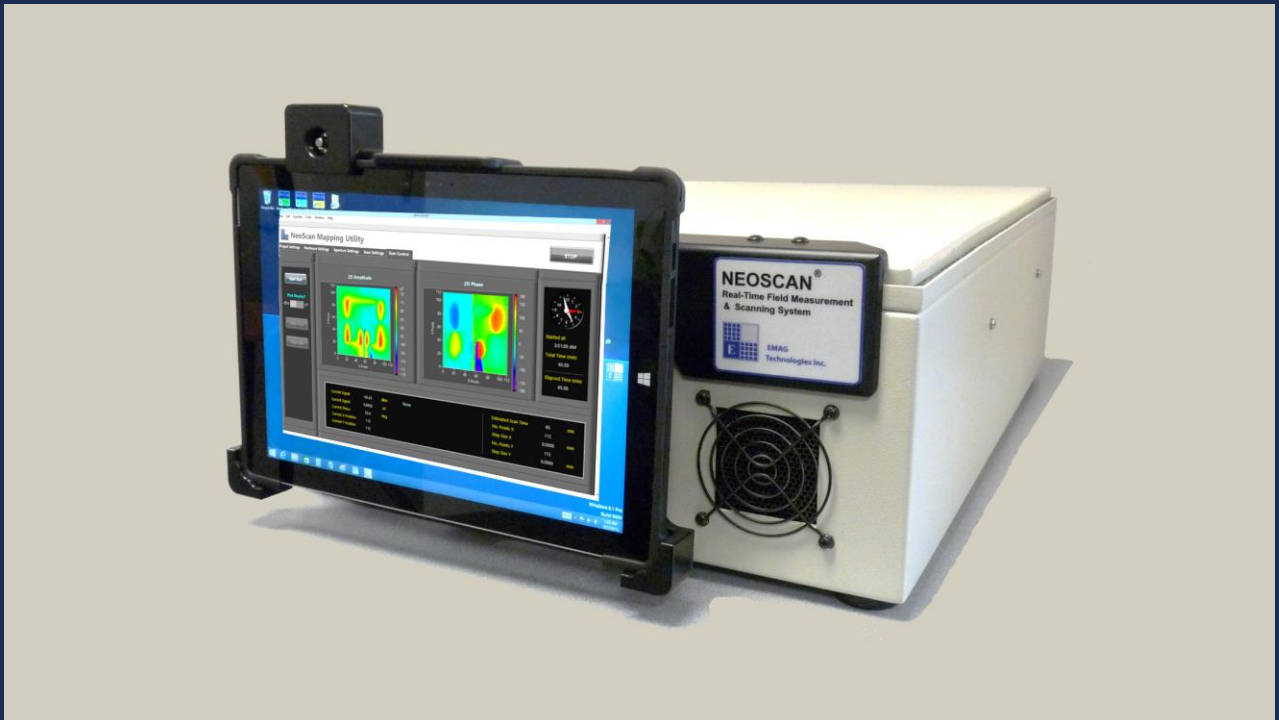




*Capture the Invisible™*




# NEOSCAN®

## Turnkey Field Measurement System