NI is now part of Emerson.

# The evolution of Wireless Communication is shaking up Test And Measurement!

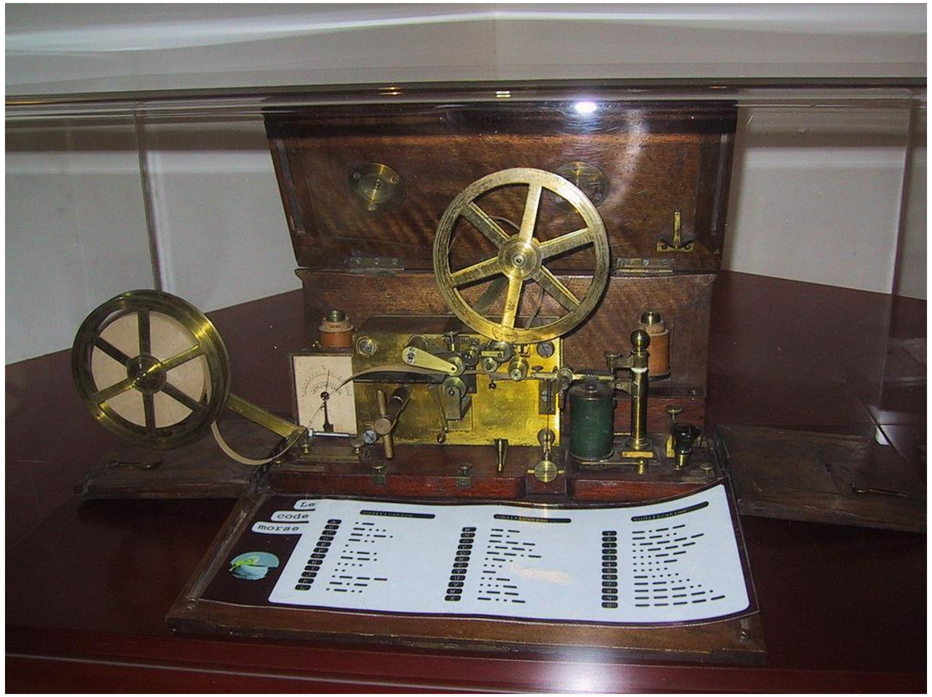
Marc Vanden Bossche

Contact: Marc.Vanden.Bossche@ni.com

# Evolution of Telecommunication

## The first wired, electrical commercial communications

5 Needle telegraph (1837)
Cooke and Wheatstone (British) (*)

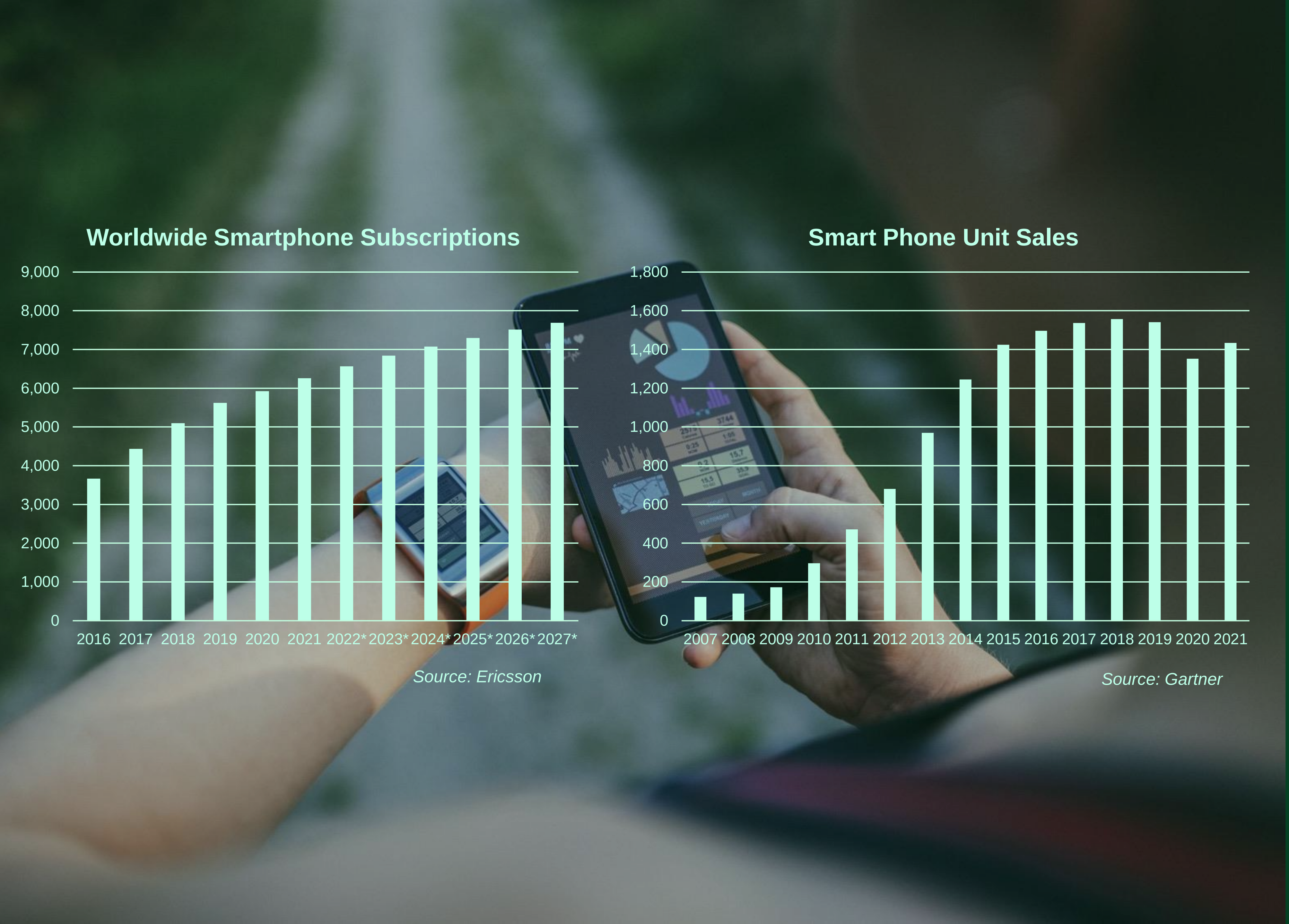


Morse telegraph (1837)
Samuel Morse (American) (**)

# Evolution of Telecommunication


Source: Ericsson




**27%**

2016 Smartphone Penetration Rate

**78%**

2020 Smartphone Penetration Rate

**87%**

2025 Smartphone Penetration Rate

# Wireless Adoption Will Continue to Grow



## 6%

FORECASTED WIRELESS IC REVENUE CAGR
FROM $23B (2022) TO $32B (2027)

## 4X

PROJECTED INCREASE OF MOBILE
TRAFFIC DATA BY 2027

## 51%

OF ALL CELLULAR CONNECTIONS
BY 2027 WILL BE MASSIVE IoT

# Shift to IoT Applications

**Human**-Centric Wireless Systems

- **Inputs & outputs** are human-centric (audio, video, tactile)
- Traditional **CPU-based software** (augmented with ML)
- **Latency** requirements are human-centric (100’s of ms)
- Systems mimic their **centricity** – designed for 1-1 connections

**Machine**-Centric Wireless Systems

- **Inputs & outputs** are machine-centric (radar, lidar, cameras, motors)
- **ML-based neural nets** play a much larger role
- **Latency** requirements are machine-centric ($\mu$s or better)
- Systems mimic their **centricity** – designed for machines to collaboratively perform a task

"A decade ago, we had about 24 months from engineering sample to delivery of our first customer sample. Ramp to a million units would take another seven or eight months. By contrast, today, the time from engineering sample to shipping a million units happens in less than six months."

—LEADING RF CHIPMAKER

RF FRONT-END COMPLEXITY

500,000X

Increase

TIME-TO-MARKET DEMANDS

32 → 6

Months Months

# Compounding and conflicting issues pressure the product development lifecycle

**Product Lifecycle**

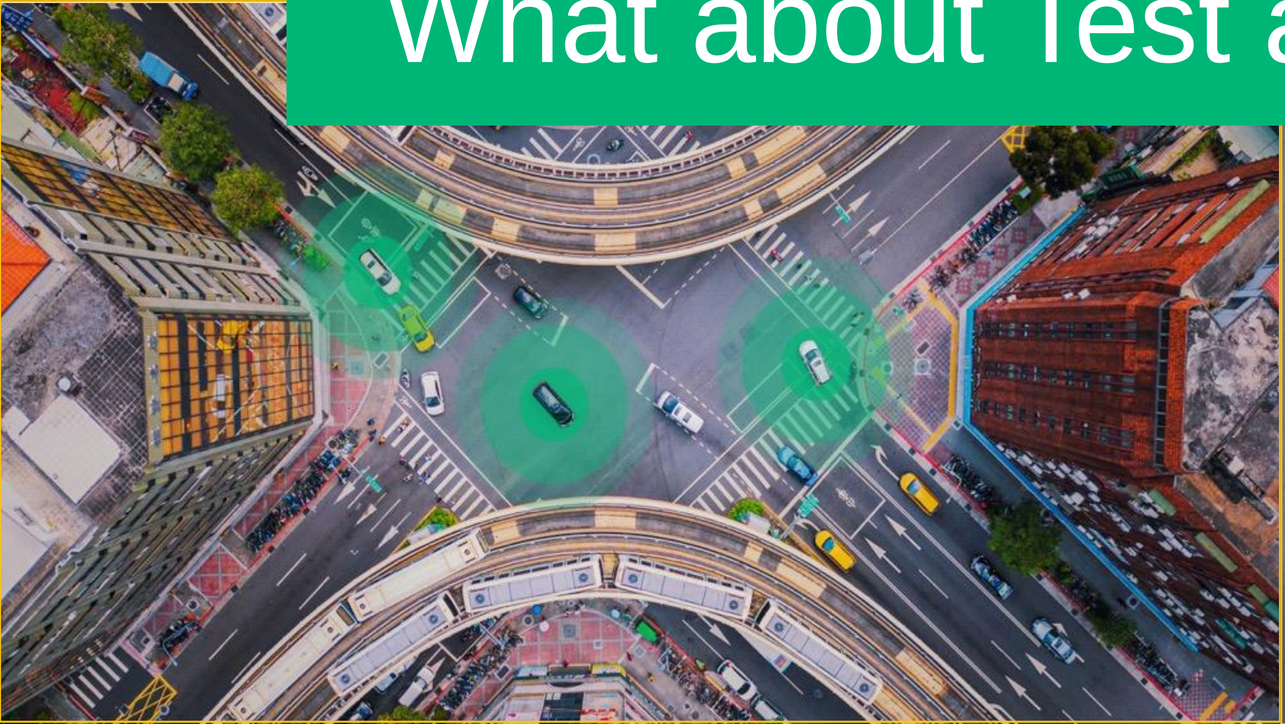
| | |
|---|---|
| Product Complexity & Customer Demands | More tests. |
| Competition & Shrinking Time-To-Market | Less time. |
| Responding with Technology | New tools. |

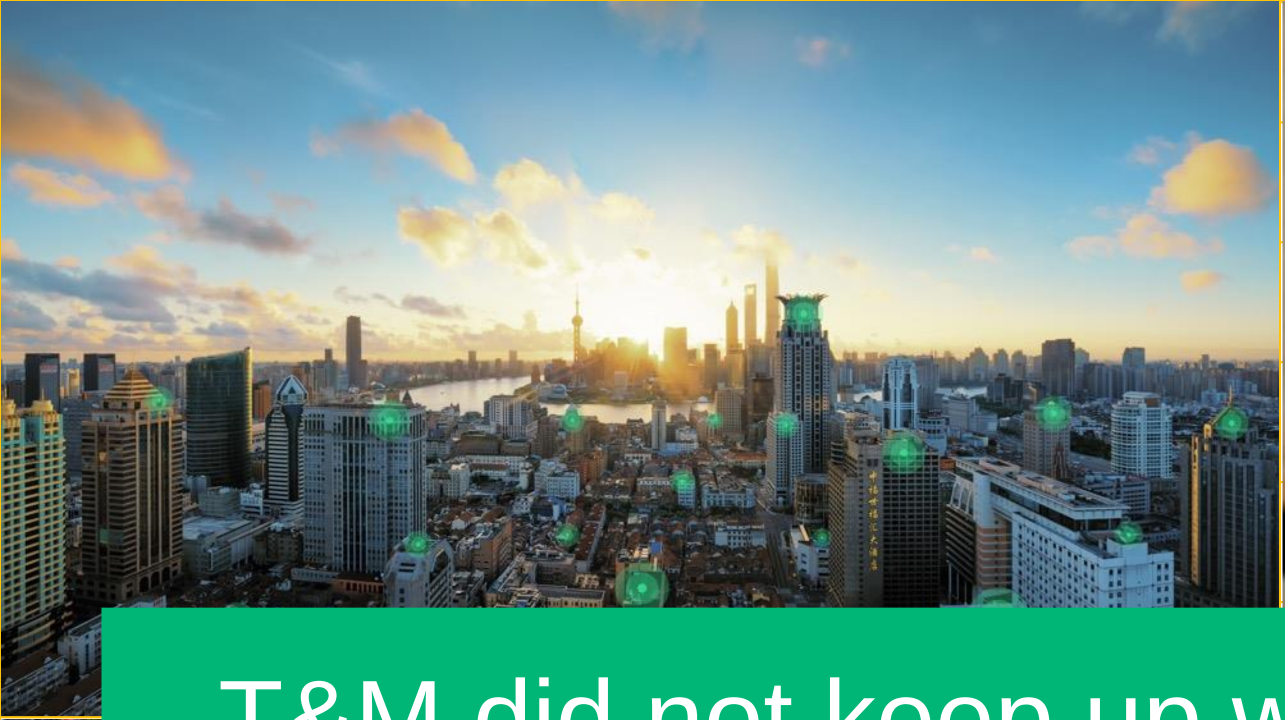
DESIGN → VALIDATION → MANUFACTURING

**57%** of respondents fear their production processes are outdated and cannot keep up with new business and technology trends

**46%** say they will lose market share within 2 years unless they make significant changes to product lifecycle processes

# What about Test and Measurement?





# T&M did not keep up with the Rate of Change

# An Example of Rate of Change: History of the Camera




**1930s** | **1970s** | **1990s** | **2000s** | **2020+**

**First CMOS imaging sensor (1985)**

***Camera meets Cell Phone (1997)***

- Capturing Memories
- Home security
- Car backup cameras
- Wireless picture exchange
- Video conferencing
- Video doorbells
- Augmented reality

# History of Analogue Electronics Measurement Equipment

**Box Instruments**

Signal Sources

Power Meters

Spectrum Analyzers

Oscilloscopes

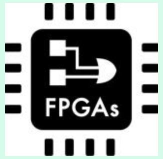
Noise Figure Meter

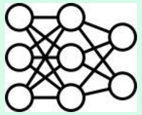
Phase Noise Analyzers

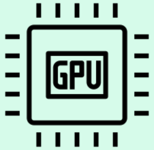
Vector Signal Generators

Vector Signal Analyzers

Vector Network Analyzers



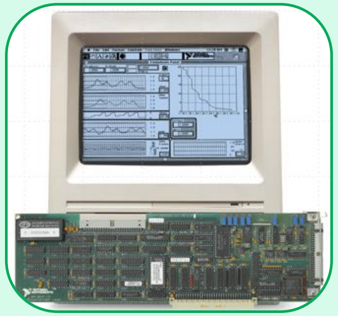






AI/ML

?

**Modular Instruments**

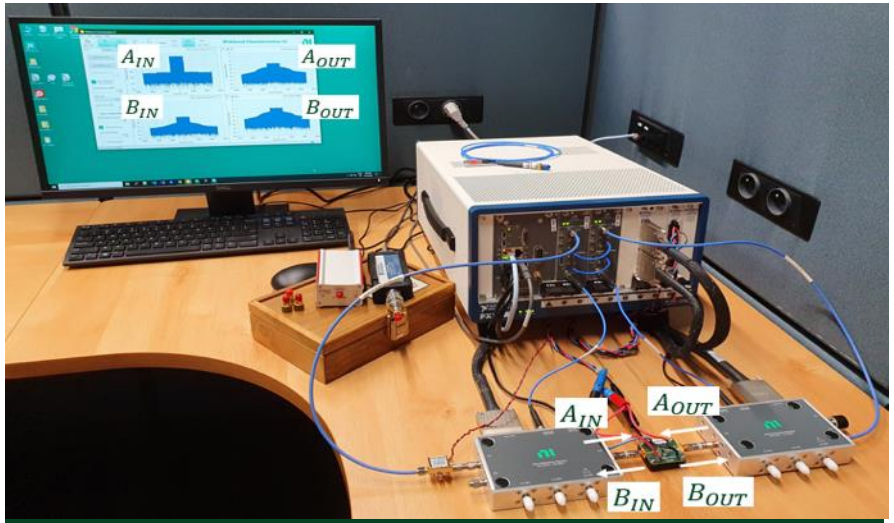


**1930s** **1970s** **1990s** **2000s** **2020+**

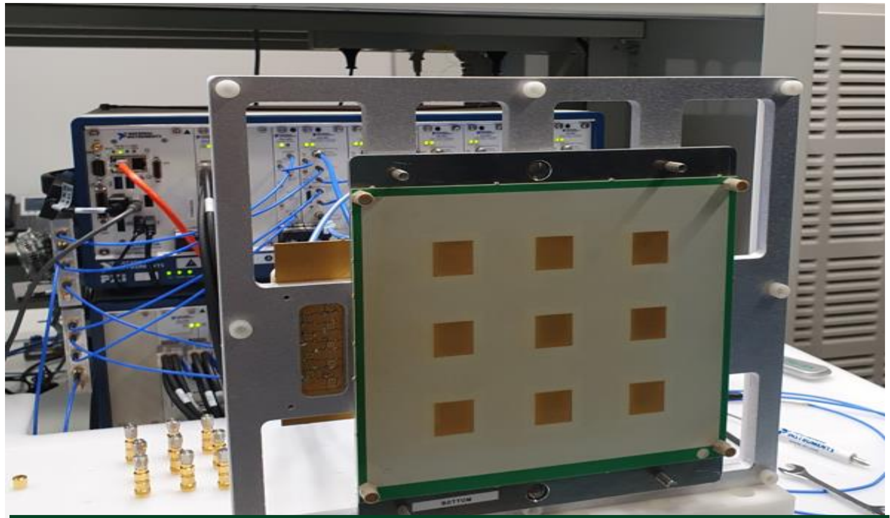
**Nyquist Theorem (1924)**

**First CMOS Flash ADC (1979)**

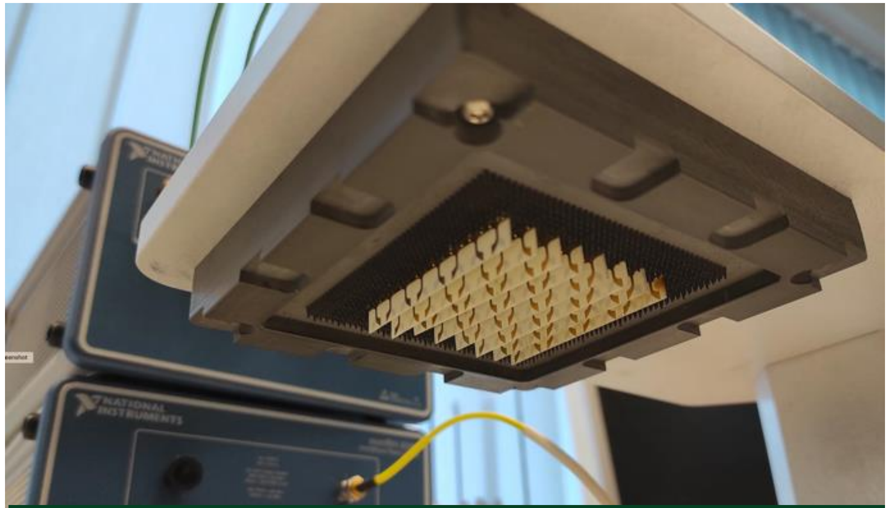
# Measurement Hardware Will Evolve




Improved measurement accuracy



Channel / Port Count



Over the Air Characterization

Massive-scale system emulation

Higher Frequency and Larger Bandwidths (closer to the DUT)

Scalability in Channels (smaller and lower cost)

Higher Performance Measurements

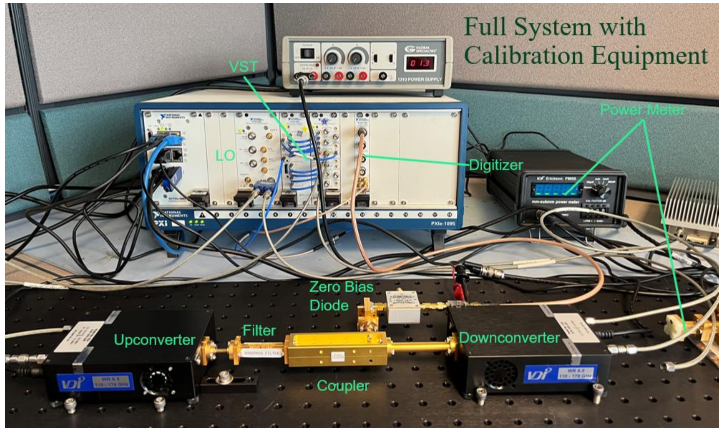
Real-time processing (HIL)

System Level Measurements

Efficiency of Cloud and Edge Processing

Blend of Virtual & Physical Testing

# Improved Measurement Accuracy under Realistic Conditions




- Spectrum Analyzer
- Oscilloscopes
- Vector Signal Analyzers

**Signal Analysis**

In many cases
Nonlinear behavior

Higher frequencies
Larger instantaneous bandwidth

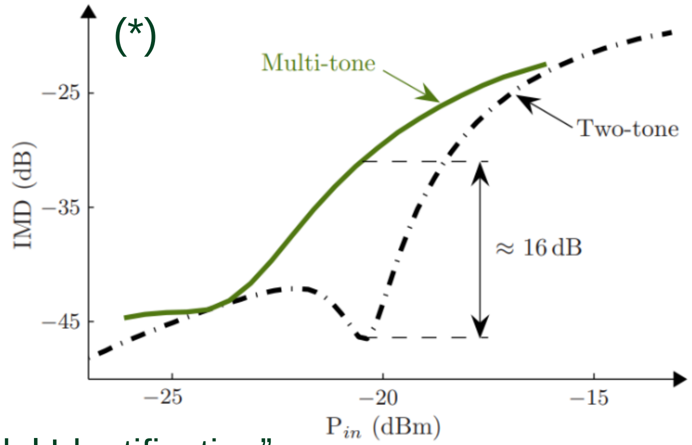
- Vector Network Analyzers

**DUT Analysis**

BUT
Limited to Linear Devices
[S-parameters]

- Path distortion
- Impedance mismatch
- Realistic signals

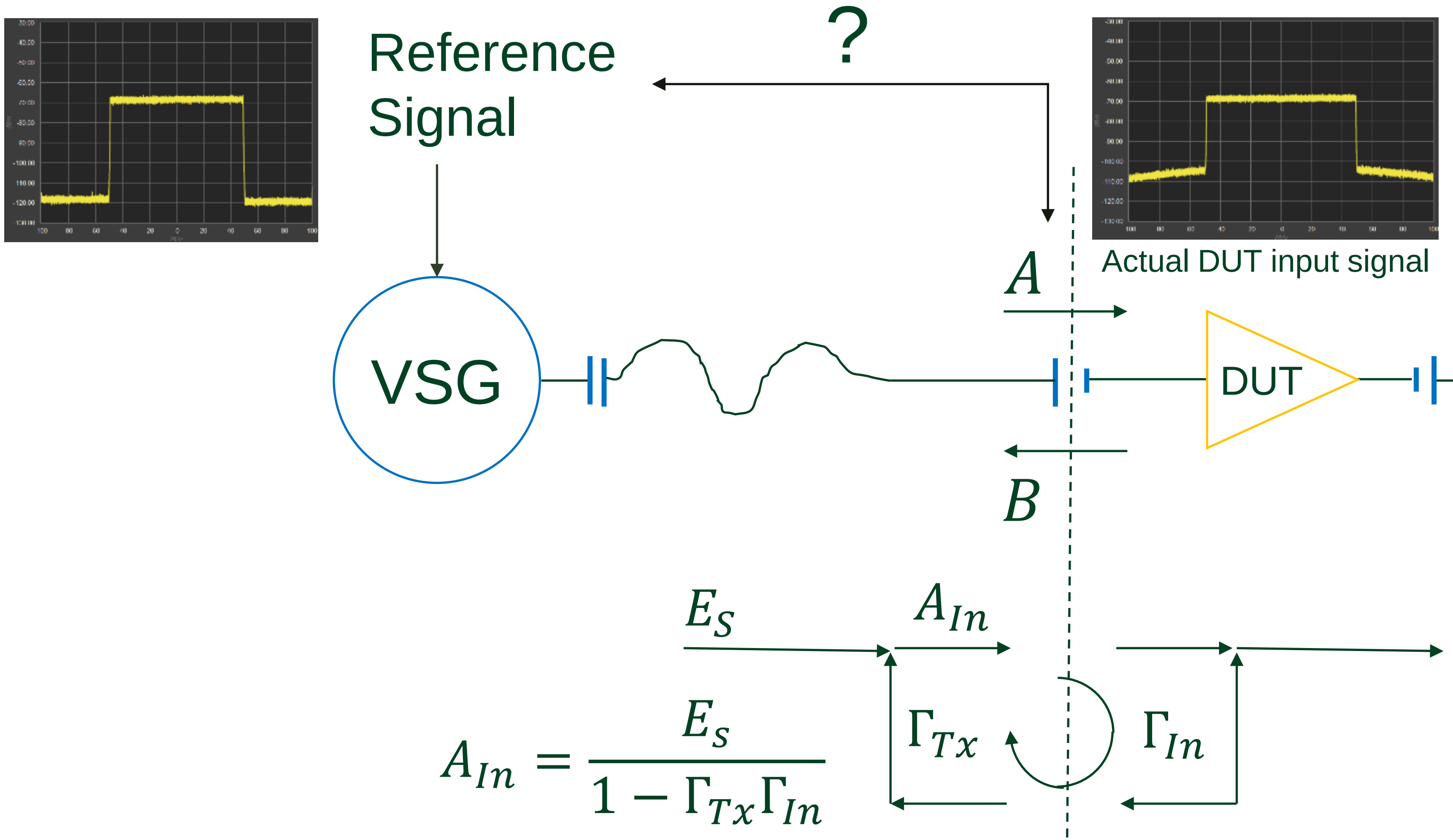
(*)






(*): J.C. Pedro, N.B. Carvalho," Designing Band-Pass Multisine Excitations for Microwave Behavioral Model Identification"

# Improved Measurement Accuracy – VSG and VSA Setup




$$A_{In} = \frac{E_s}{1 - \Gamma_{Tx}\Gamma_{In}}$$

Linear and Nonlinear

- Path distortion
- Mismatch distortion

# Improved Measurement Accuracy – Ampl / Phase Uncertainty $A_1$

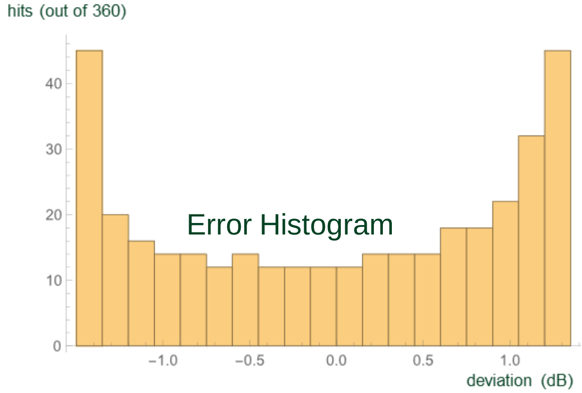
## Amplitude

**Lower limit**

| $\Gamma_S$ \ $\Gamma_L$ | -25 | -20 | -15 | -12 | -10 | -8 | -6 |
|---|---|---|---|---|---|---|---|
| -25 | -0.0275 | -0.0490 | -0.0873 | -0.124 | -0.156 | -0.197 | -0.248 |
| -20 | -0.0490 | -0.0873 | -0.156 | -0.221 | -0.279 | -0.353 | -0.447 |
| -15 | -0.0873 | -0.156 | -0.279 | -0.397 | -0.503 | -0.638 | -0.811 |
| -12 | -0.124 | -0.221 | -0.397 | -0.566 | -0.719 | -0.915 | -1.17 |
| -10 | -0.156 | -0.279 | -0.503 | -0.719 | -0.915 | -1.17 | -1.50 |
| -8 | -0.197 | -0.353 | -0.638 | -0.915 | -1.17 | -1.50 | -1.93 |
| -6 | -0.248 | -0.447 | -0.811 | -1.17 | -1.50 | -1.93 | -2.51 |

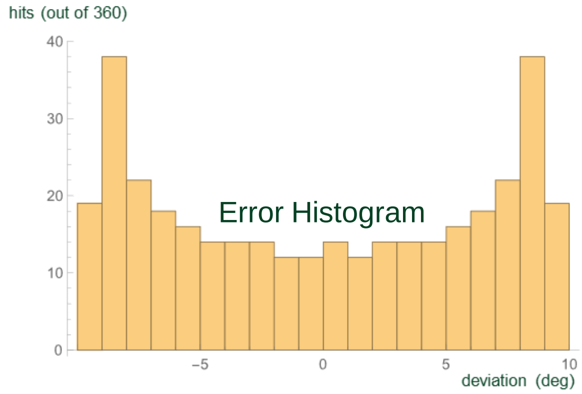
**Upper limit**

| $\Gamma_S$ \ $\Gamma_L$ | -25 | -20 | -15 | -12 | -10 | -8 | -6 |
|---|---|---|---|---|---|---|---|
| -25 | 0.0274 | 0.0487 | 0.0864 | 0.122 | 0.153 | 0.192 | 0.241 |
| -20 | 0.0487 | 0.0864 | 0.153 | 0.215 | 0.270 | 0.339 | 0.425 |
| -15 | 0.0864 | 0.153 | 0.270 | 0.380 | 0.475 | 0.594 | 0.742 |
| -12 | 0.122 | 0.215 | 0.380 | 0.531 | 0.664 | 0.828 | 1.03 |
| -10 | 0.153 | 0.270 | 0.475 | 0.664 | 0.828 | 1.03 | 1.28 |
| -8 | 0.192 | 0.339 | 0.594 | 0.828 | 1.03 | 1.28 | 1.58 |
| -6 | 0.241 | 0.425 | 0.742 | 1.03 | 1.28 | 1.58 | 1.95 |



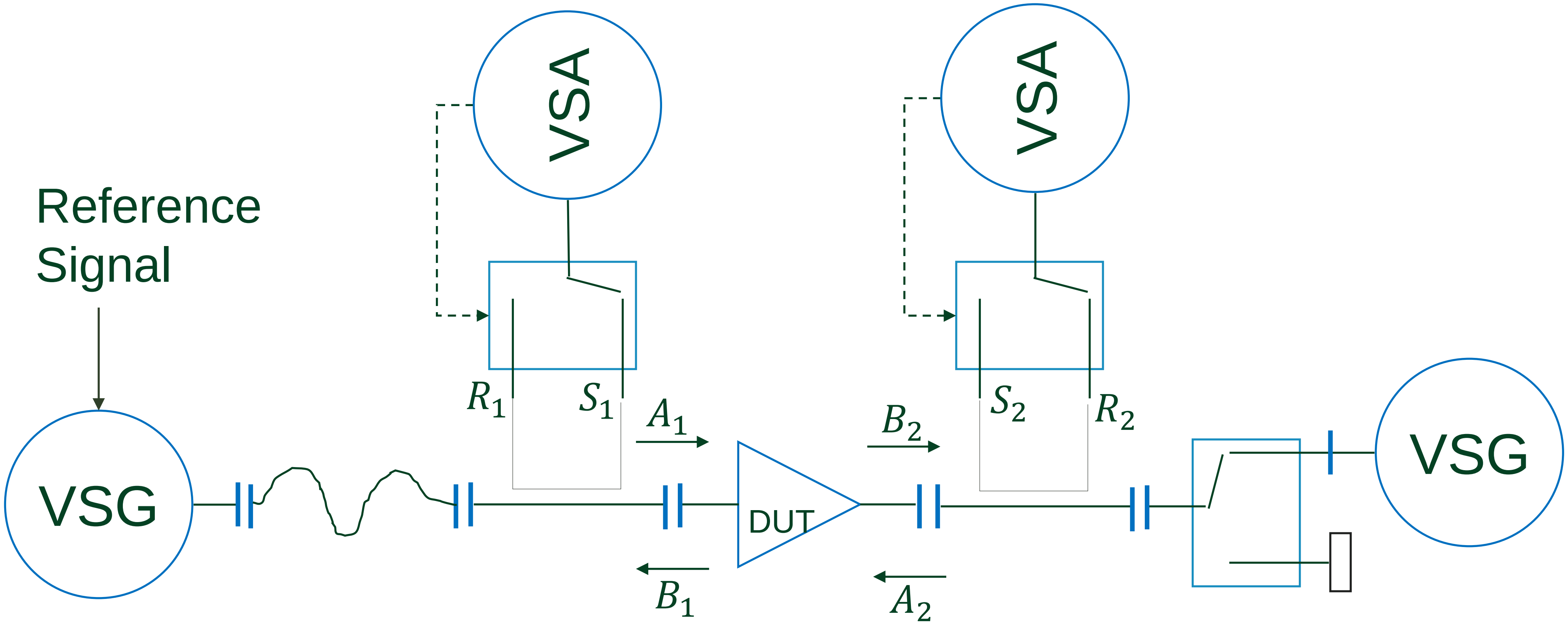

## Phase

| $\Gamma_S$ \ $\Gamma_L$ | -25 | -20 | -15 | -12 | -10 | -8 | -6 |
|---|---|---|---|---|---|---|---|
| -25 | 0.181 | 0.322 | 0.573 | 0.809 | 1.02 | 1.28 | 1.61 |
| -20 | 0.322 | 0.573 | 1.02 | 1.44 | 1.81 | 2.28 | 2.87 |
| -15 | 0.573 | 1.02 | 1.81 | 2.56 | 3.22 | 4.06 | 5.11 |
| -12 | 0.809 | 1.44 | 2.56 | 3.62 | 4.56 | 5.74 | 7.23 |
| -10 | 1.02 | 1.81 | 3.22 | 4.56 | 5.74 | 7.23 | 9.12 |
| -8 | 1.28 | 2.28 | 4.06 | 5.74 | 7.23 | 9.12 | 11.5 |
| -6 | 1.61 | 2.87 | 5.11 | 7.23 | 9.12 | 11.5 | 14.5 |




For -10/-6 dB mismatch combination
- -1.5 .. +1.3 dB
- -9.1 .. +9.1 deg

# Convergence of Instrumentation for Improved Measurement Accuracy (I)



# Convergence of Instrumentation for Improved Measurement Accuracy (II)

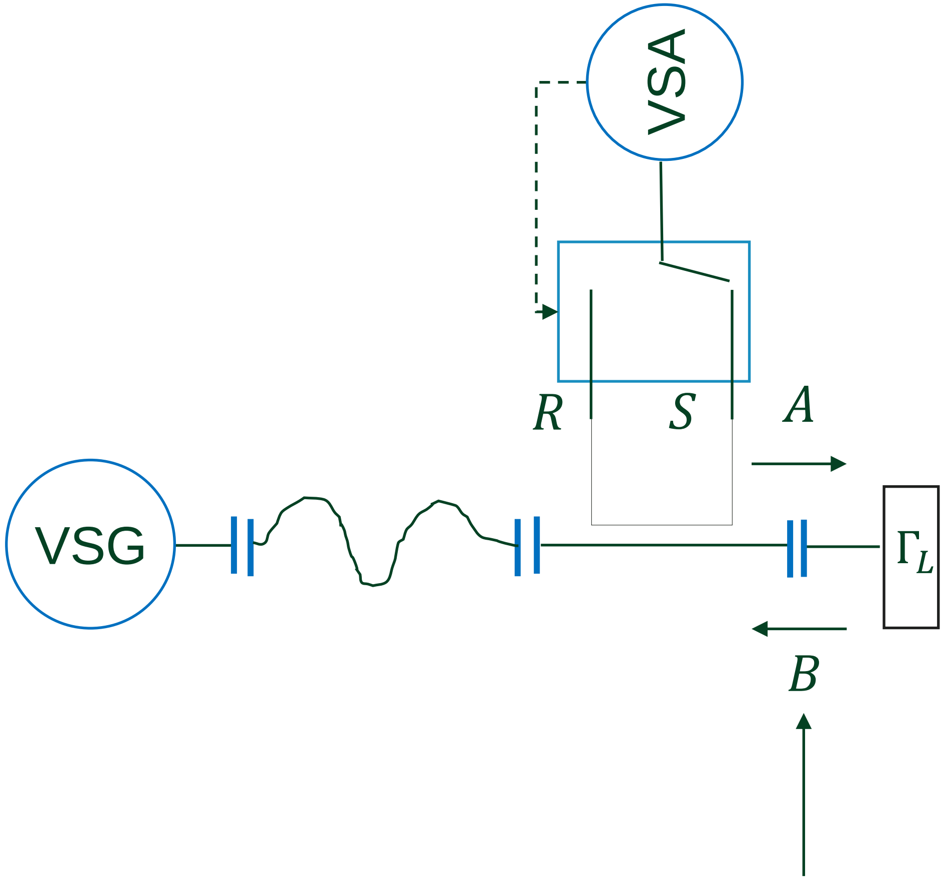
Measured Quantities: *R*, *S*

Quantities at DUT Input Plane: *A*, *B*

Vector error correction model in wave formalism:

$$\begin{pmatrix} A \\ B \end{pmatrix} = K \begin{bmatrix} 1 & \beta \\ \gamma & \delta \end{bmatrix} \cdot \begin{pmatrix} R \\ S \end{pmatrix} = K\mathbf{M} \cdot \begin{pmatrix} R \\ S \end{pmatrix}$$

Signal Analysis (→ $K$)    DUT Analysis (→ $\mathbf{M}$)




Reference Plane

Calibration Plane

$\mathbf{M}$ … relative error coefficients


$|K|$ … absolute power scaling

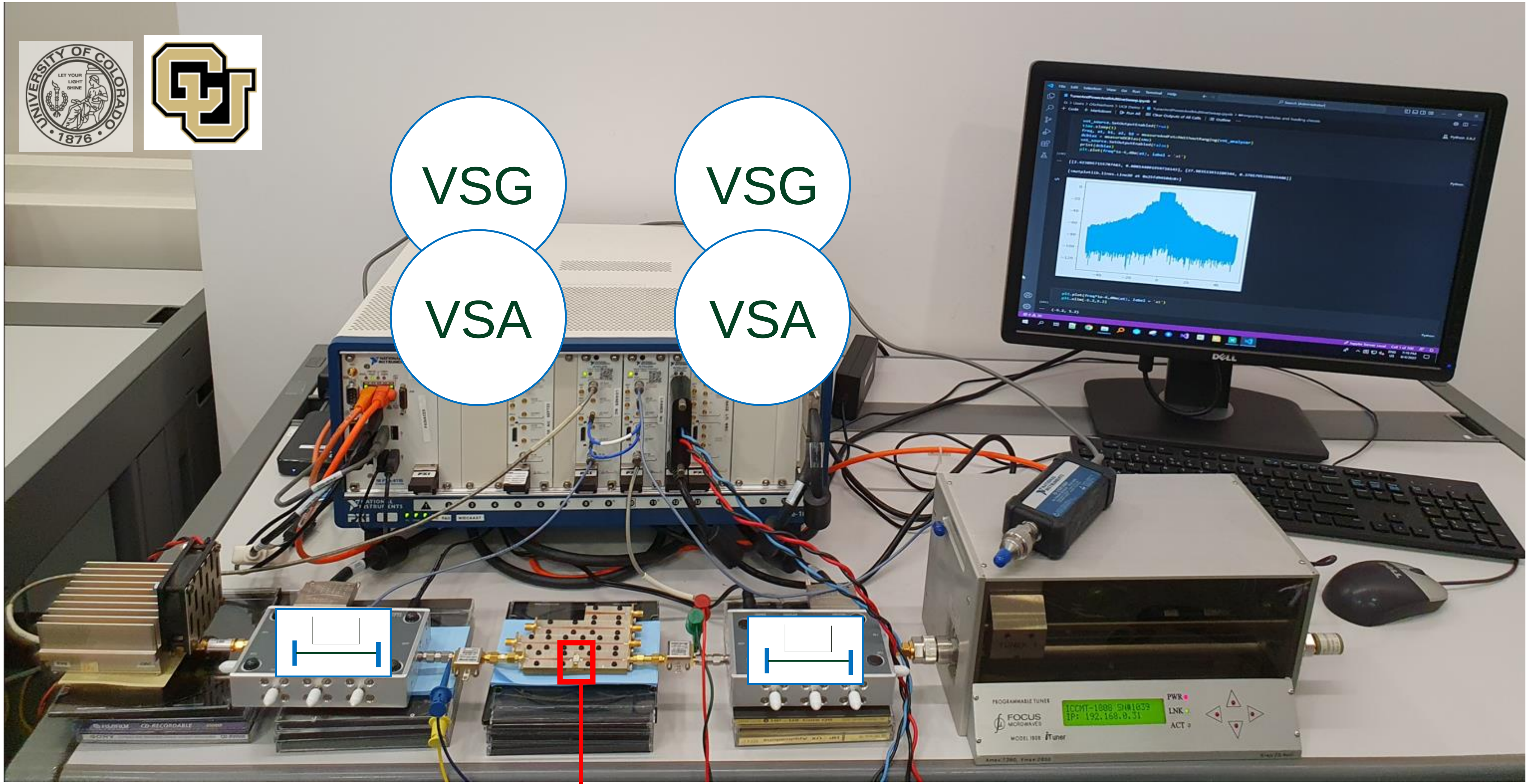
Power Sensor

$\arg(K)$ … absolute phase

Comb generator

<u>Remark:</u> Measurement of $\Gamma_L$ does not need a K factor.

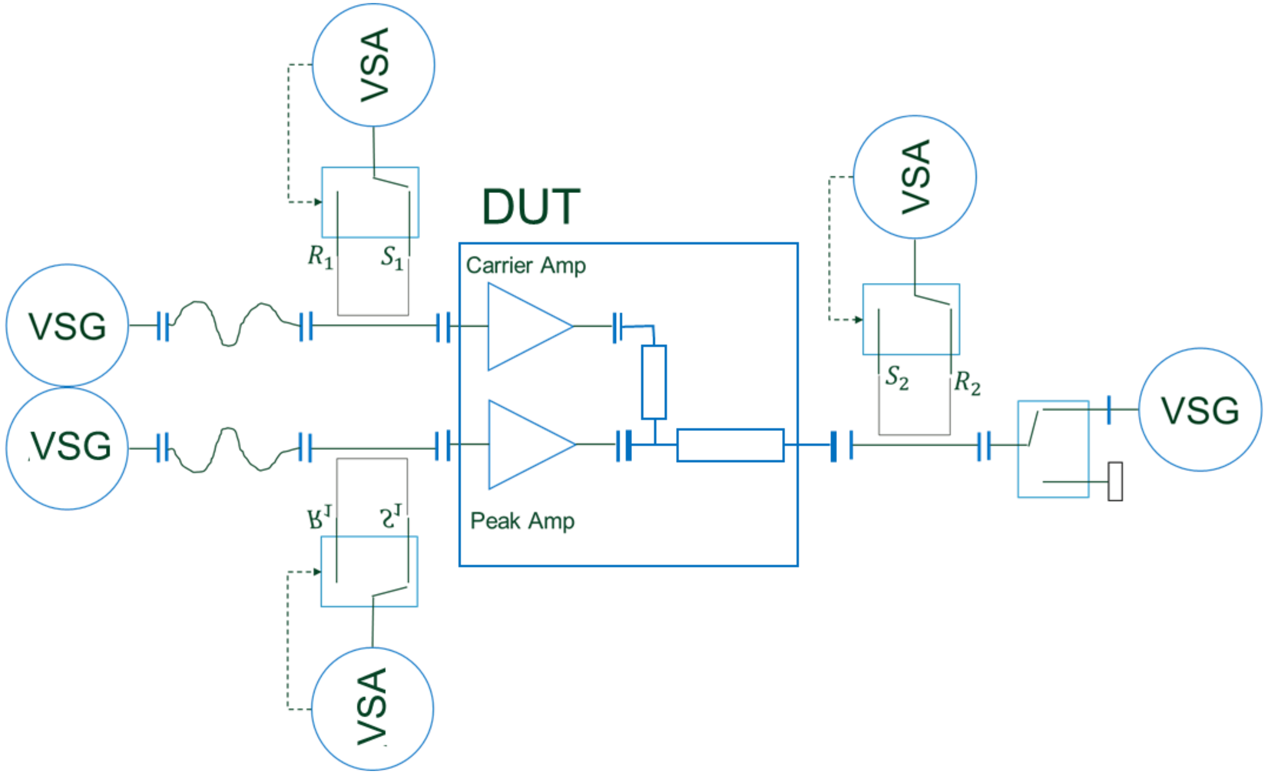
# Improved Measurement Accuracy for a Two-Port Setup – In Fixture




CGH40006P 6 W, RF Power GaN HEMT

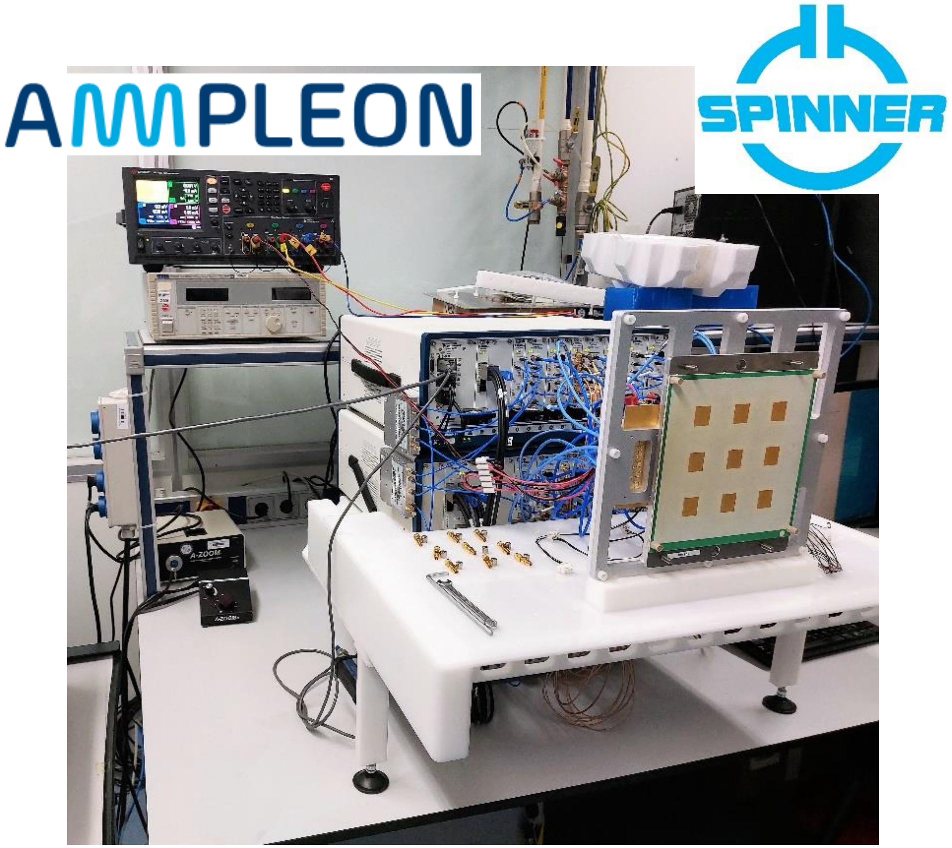
# Channel / Port Scalability

## 3-port




Doherty Amplifier

## 9-port




Amplifier Characterization under Beamforming

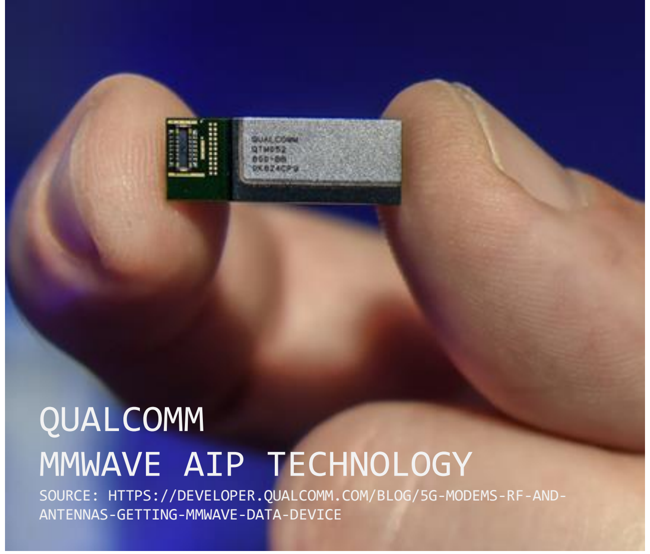
# From Conductive to Over the Air Characterization

mmWave active antenna arrays are being deployed already for 5G

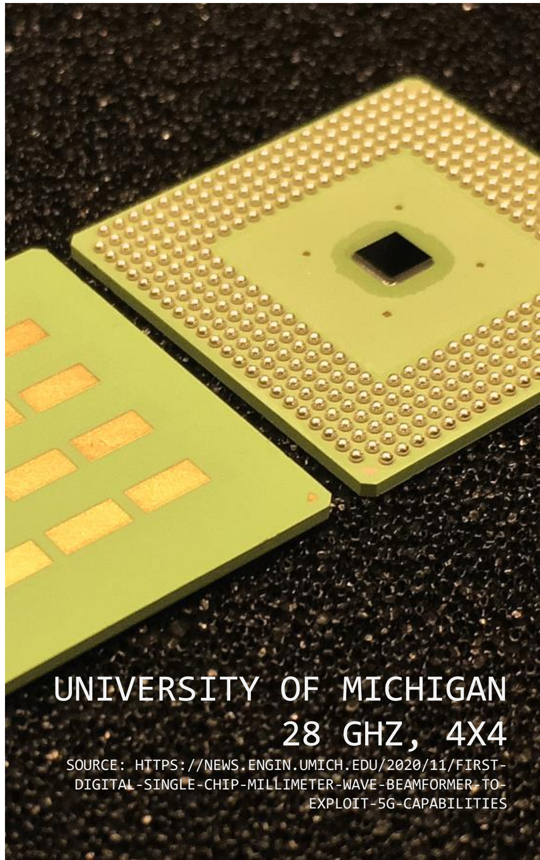
Combined use of analog and digital beamforming

Trend towards highly integrated designs

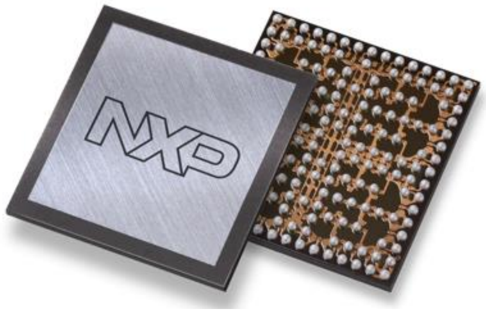
- Antenna in package (AiP)
- Antenna on chip (AoC)



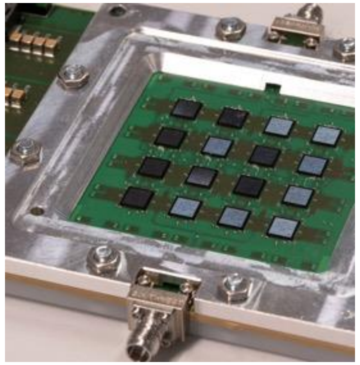


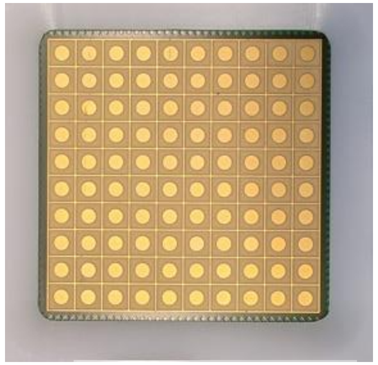
# Over the Air Characterization



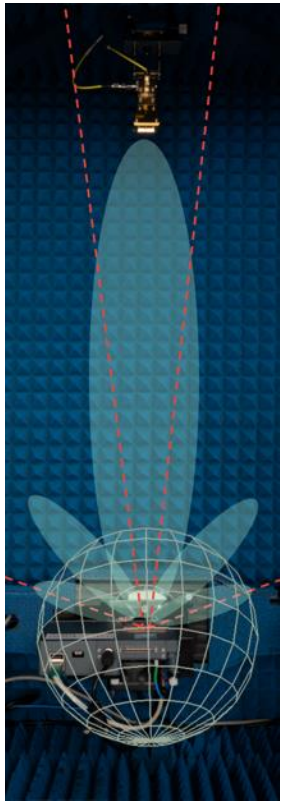
NXP MMW9014K beamformer

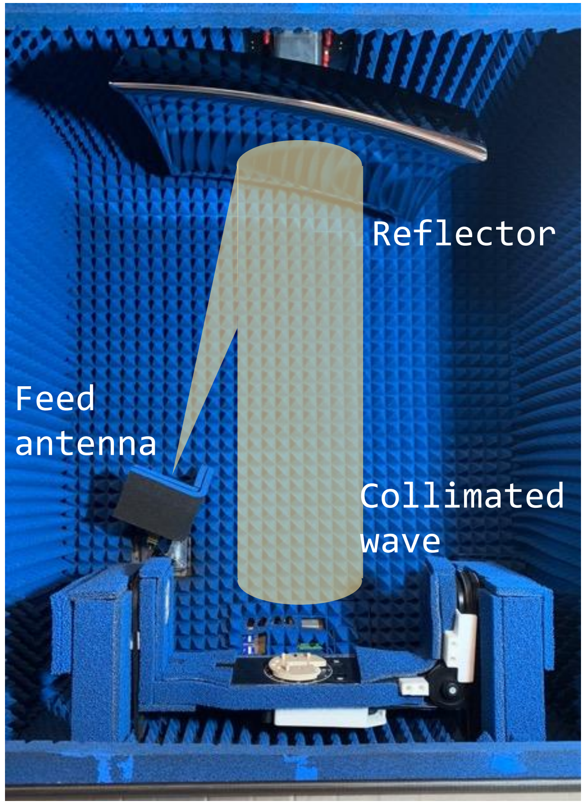


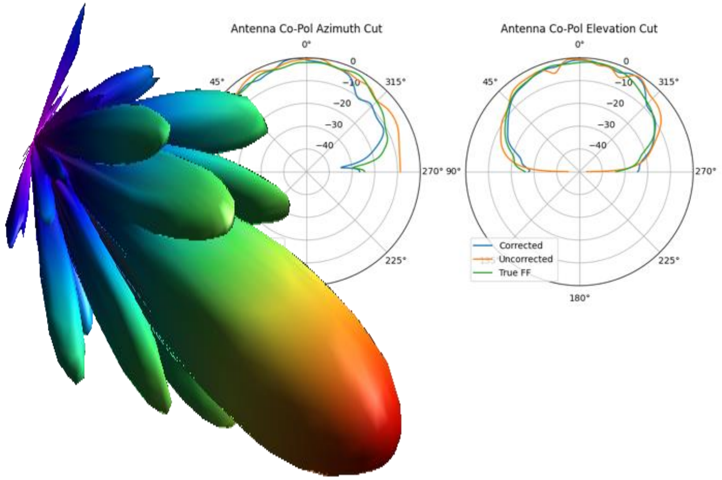
NXP 8x8 dual-pol antenna panel



Antenna side





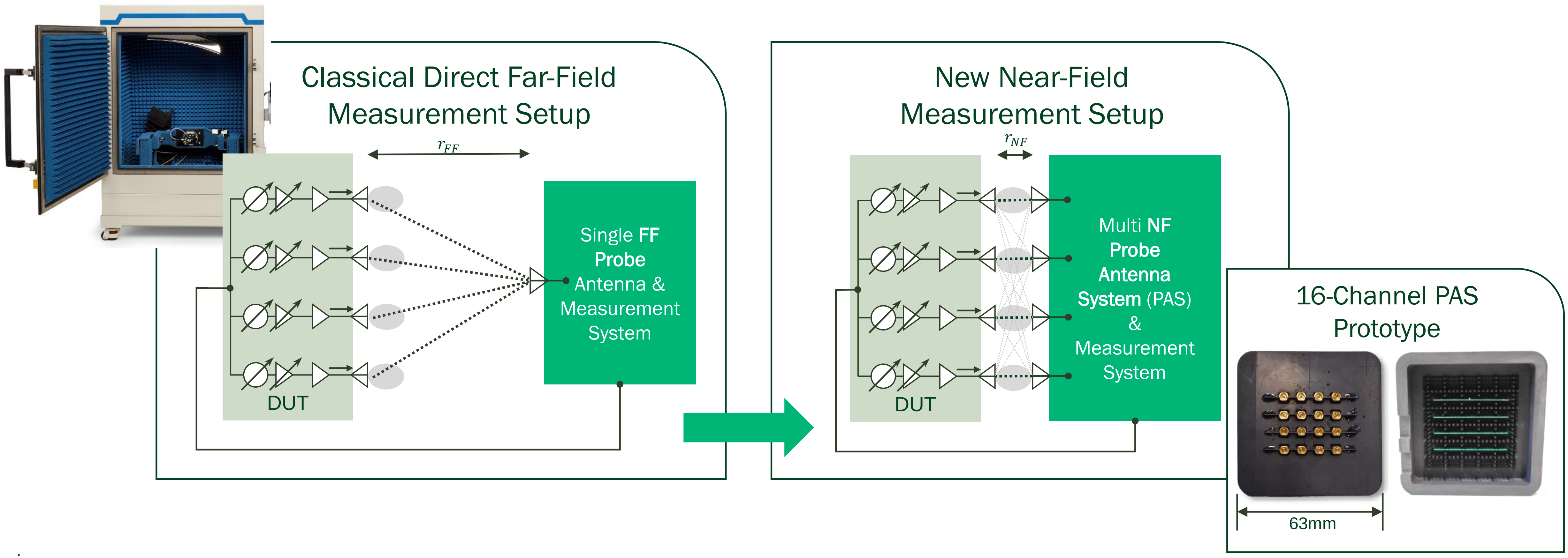

- HF Electrical Measurements
- and Accurate Mechanical Positioning
- What does one need to measure ?
- New calibration techniques

# Evolve Instruments to reduce Cost of Production Test

## Example

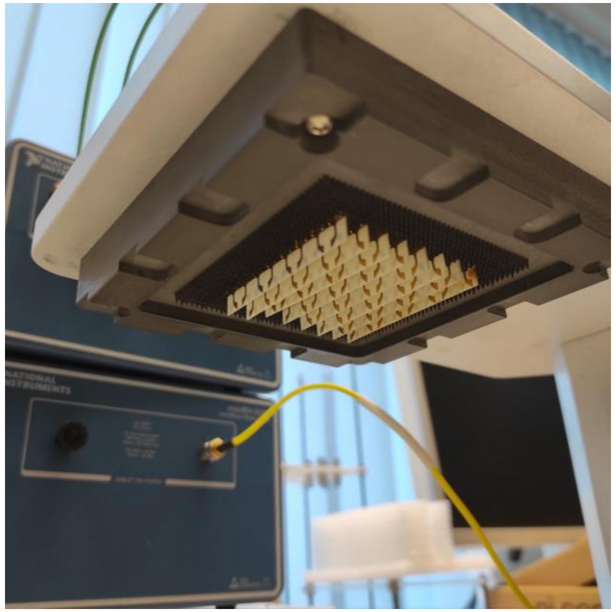
### Near-Field Probe Antenna System (PAS)

TECHNISCHE UNIVERSITÄT DRESDEN



# The Near-Field Probe Antenna System

PAS



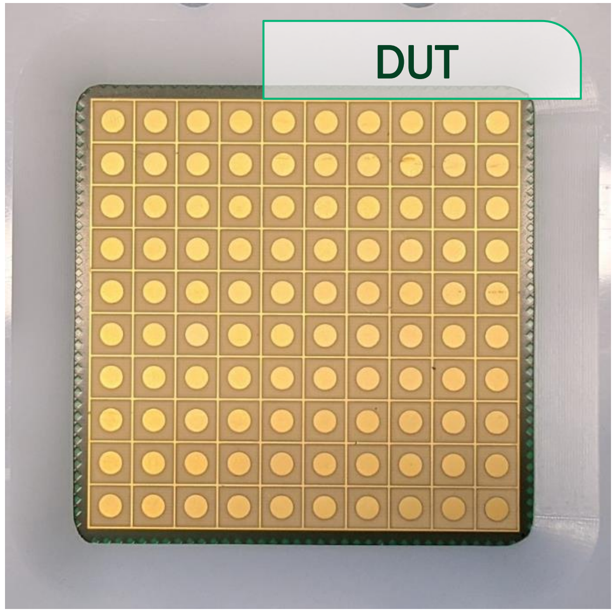
PAS

~3mm

DUT

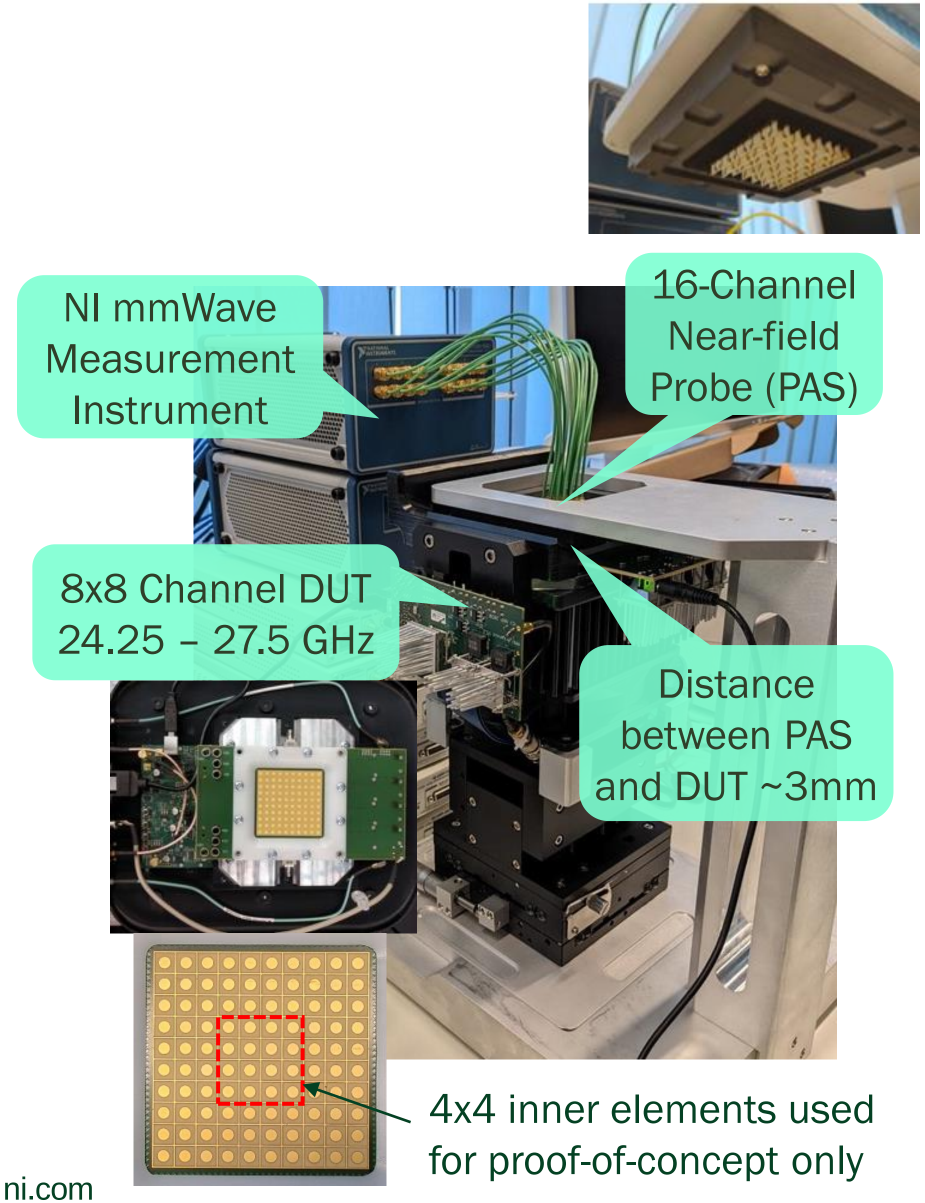
Static fixturing

Single N-parallel measurement




Reconstruction of the DUT far-field behavior with a static appliance

# The Near-Field Probe Antenna System




4x4 inner elements used for proof-of-concept only


Beam #1

Beam #2

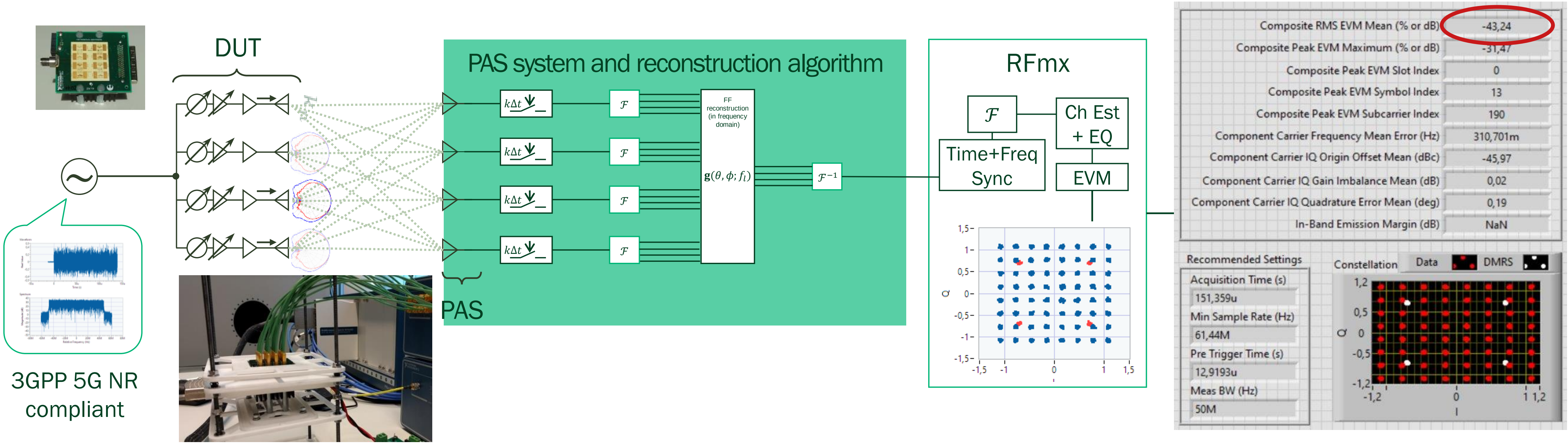
Reconstructed from near-field measurements
Reference far-field measurement

Measurements at 26 GHz

# The Near-Field Probe Antenna System

## Extension to broadband operation enables modulated measurements

- Multi-tone calibration and frequency-sliced reconstruction yield far field under modulation conditions
- **NF PAS has better measurement sensitivity** compared to an OTA chamber-based approach because we minimize pathloss that occurs in chamber



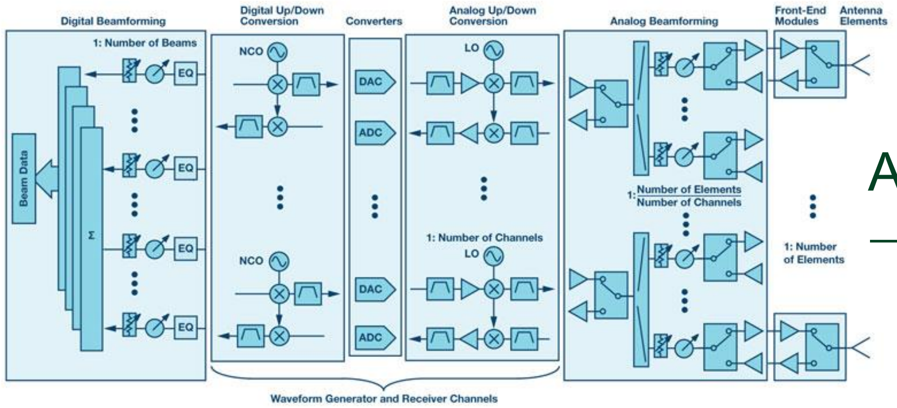

Many Disciplines meet each other !!!

# T&M and AI/ML

Temperature

Reflections

Many different hardware states




Antenna's
→ beamforming

Sensors
Actuators
[Digital]

Sensors
Actuators
[Analogue]

- Very deterministic
- Complex / Many tests
- Physical insight
- Model
- E.g. Adaptative sampling

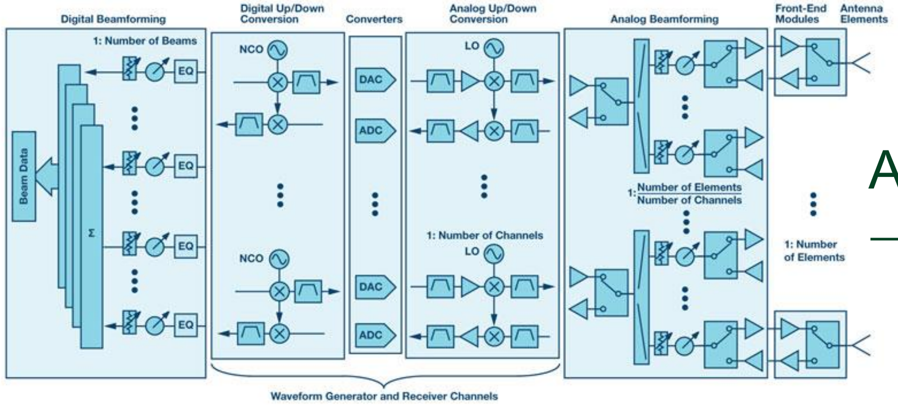
= more efficient than AI / ML


(*) https://electronicsmaker.com/digital-beamforming

# T&M and AI/ML

Real Environment (many combinations of temperature and reflections)

Many different hardware states




"Intelligence"

Learning as "it" evolves

Sensors
Actuators
[Digital]

Antenna's
→ beamforming

Sensors
Actuators
[Analogue]

- Very dynamic
- Complex

↓

- Lack of Physical insight
- Scenario testing
- No guarantees anymore
- "DUT needs to pass exam"
- "To create / adapt the exam, use AI/ML in T&M"



(*) https://electronicsmaker.com/digital-beamforming

NI is now part of Emerson.

# Questions …

The evolution of Wireless Communication is shaking up Test And Measurement!

Contact: Marc.Vanden.Bossche@ni.com