Progress and Testing Challenges of Large-aperture Digital Phased Array

Speaker:

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Chairman & C.E.O, Tron Future Tech Inc.

Tron Future Tech Inc.

Our Mission:

- We help our customers collect, analyze and utilize valuable data through fundamental sensor and communication inventions.

Area of Focus:

- Ultrathin all-digital/hybrid phased array based radar/communication turnkey systems.
- Value-added data processing infrastructure.

Major Capabilities:

- **IC design**: III/V RFFE, CMOS RFSoC, ASIC
- **Module design**: Power, FPGA, GPU modules
- **Hardware system design**: SatCom, AESA Radar
- **Software system design**: cloud service

About Us:

>20% employee with Ph.D. degrees from Caltech/USC/MIT/UCLA/NTU/NCTU/NTHU etc.

Address:

7F-A, No.1, Sec. 3, Gongdao 5th Rd.,
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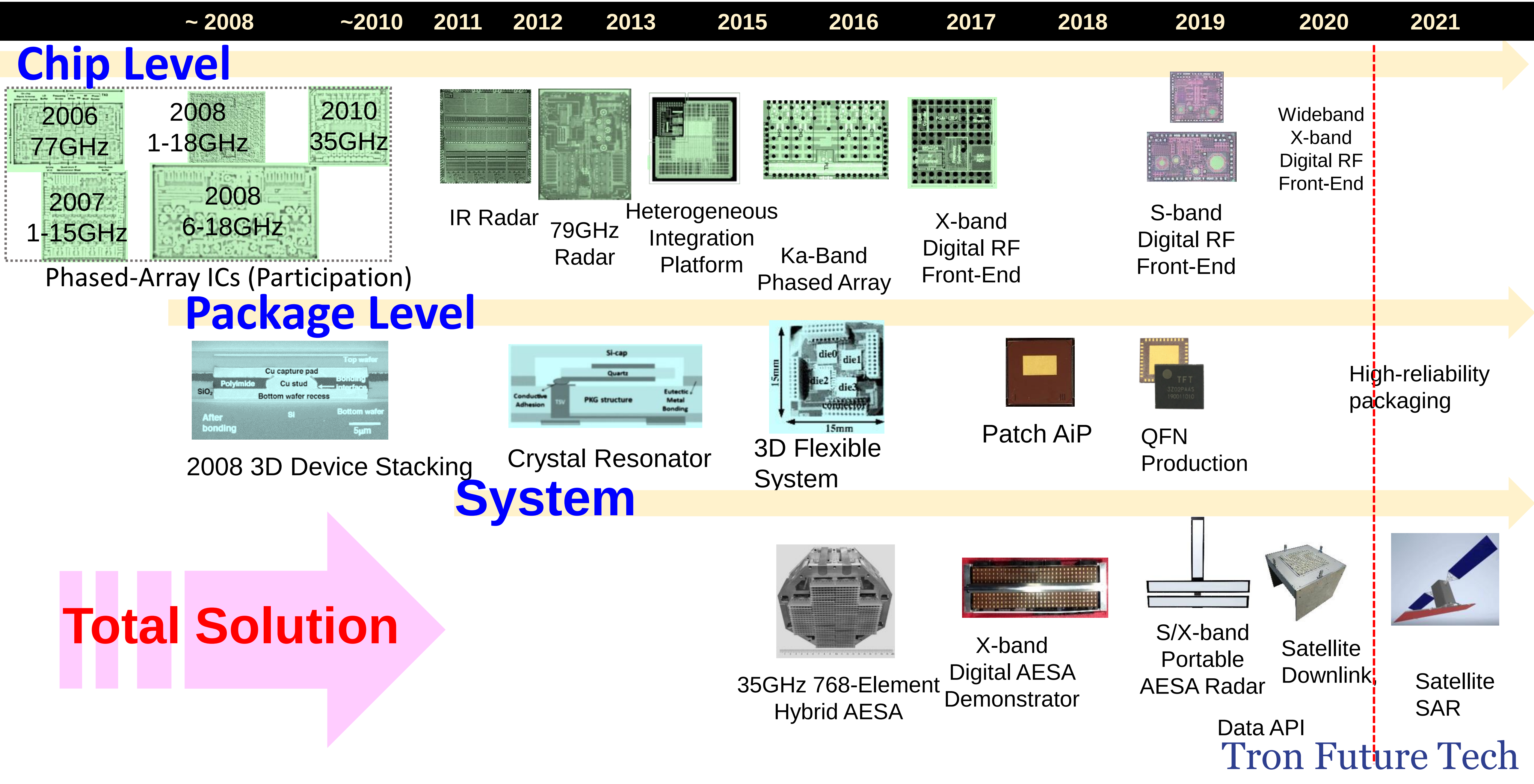
Our History and Experiences

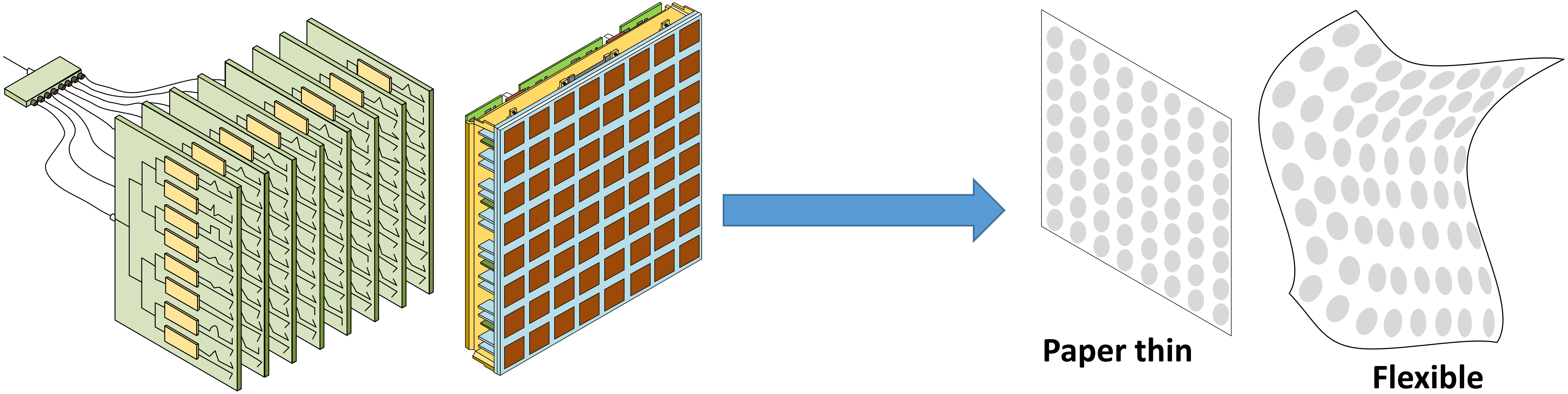


Agenda

- Technology Progress Overview.
- Market Segmentation.
- Testing Challenges.

Let's Imagine Future AESA

(and ignoring technological feasibility for 30 seconds….)



1. Paper thin, and probably flexible.
2. Include all Radar/COM/EW functions and very easy to use.

Two fundamental problems need to be addressed:

1. To what extent can this ideal concept be fundamentally possible?
2. How feasible are the underlying technologies today?

Ref: Our 2019 IEEE Radar Talk: An X-band Scalable 4x4 Digital Phased Array Module using RF SoC and Antenna-in-Package

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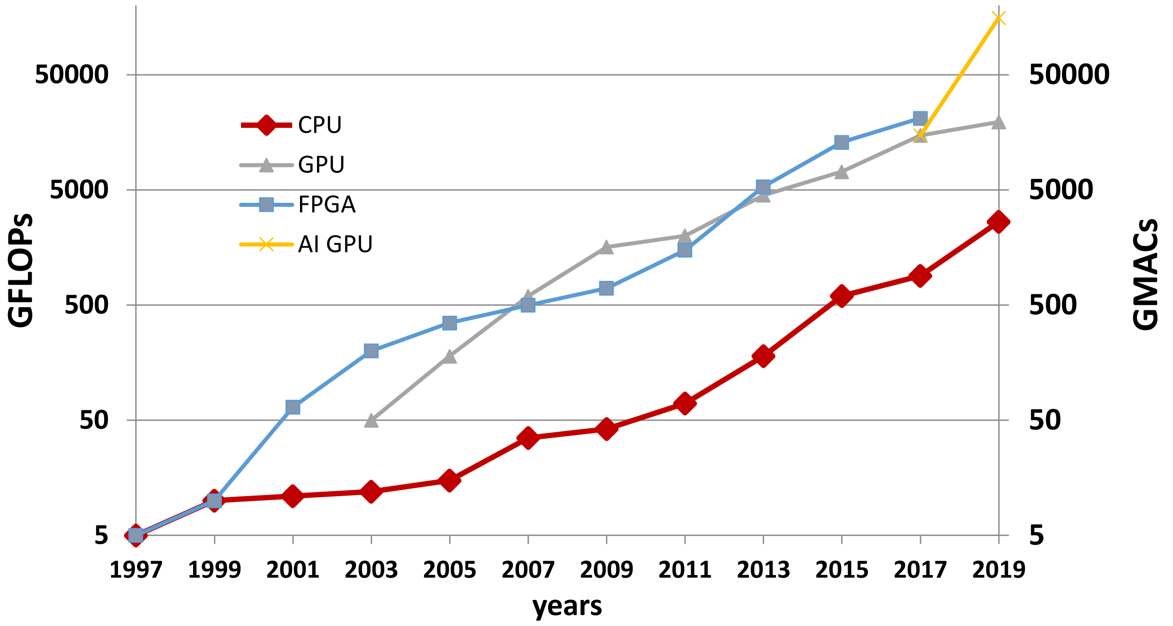
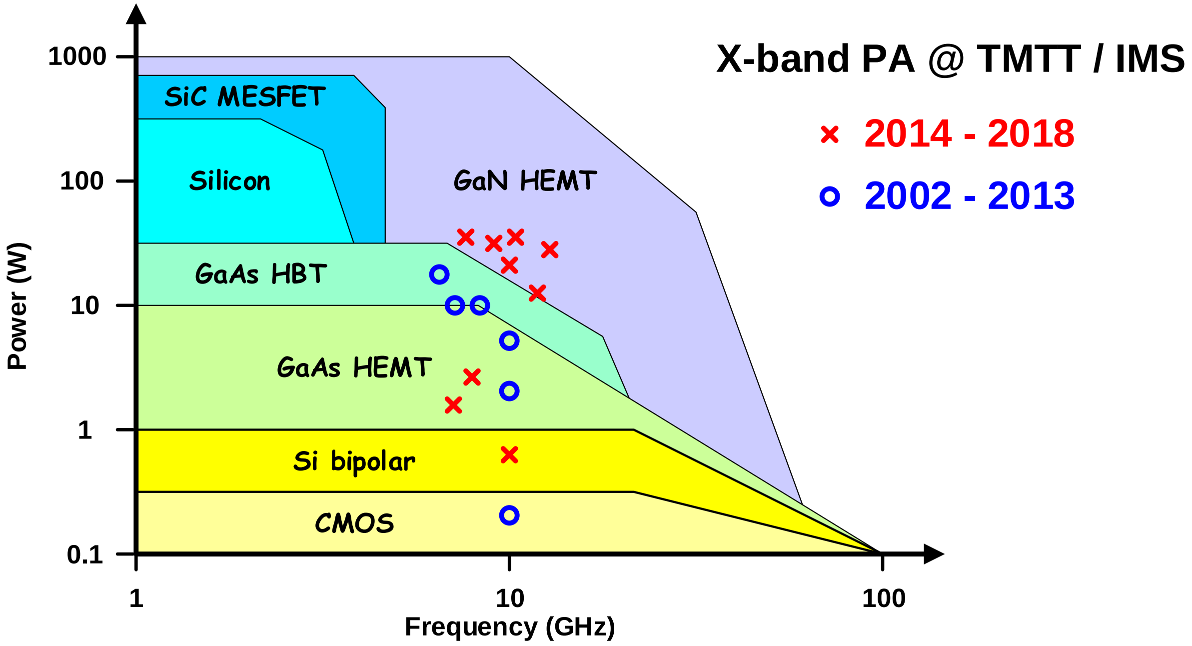
Underlining Technology Progress





- **What breakthroughs have been made in technology?**
  1. **Arithmetic and Logic Circuit →** 80x size & performance improvement in last 12 years.
  2. **Analog-to-Digital Converter →** 5x size & power improvement in 10 years.
  3. **RF Power Amplifier →** GaN PA generates 10x more power with >50% efficiency.
  4. **Transceiver Modules →** discrete to integrated TR module, >100 times size reduction.
  5. **Packaging and Assembling →** 3D-IC-stacking ball grid array (BGA) with flip-chip process.

Ref: Our EW Europe 2018 Talk:" Flexibility and Thinness – How Semiconductor Technologies Shape Future Radar and Electronic Warfare?"

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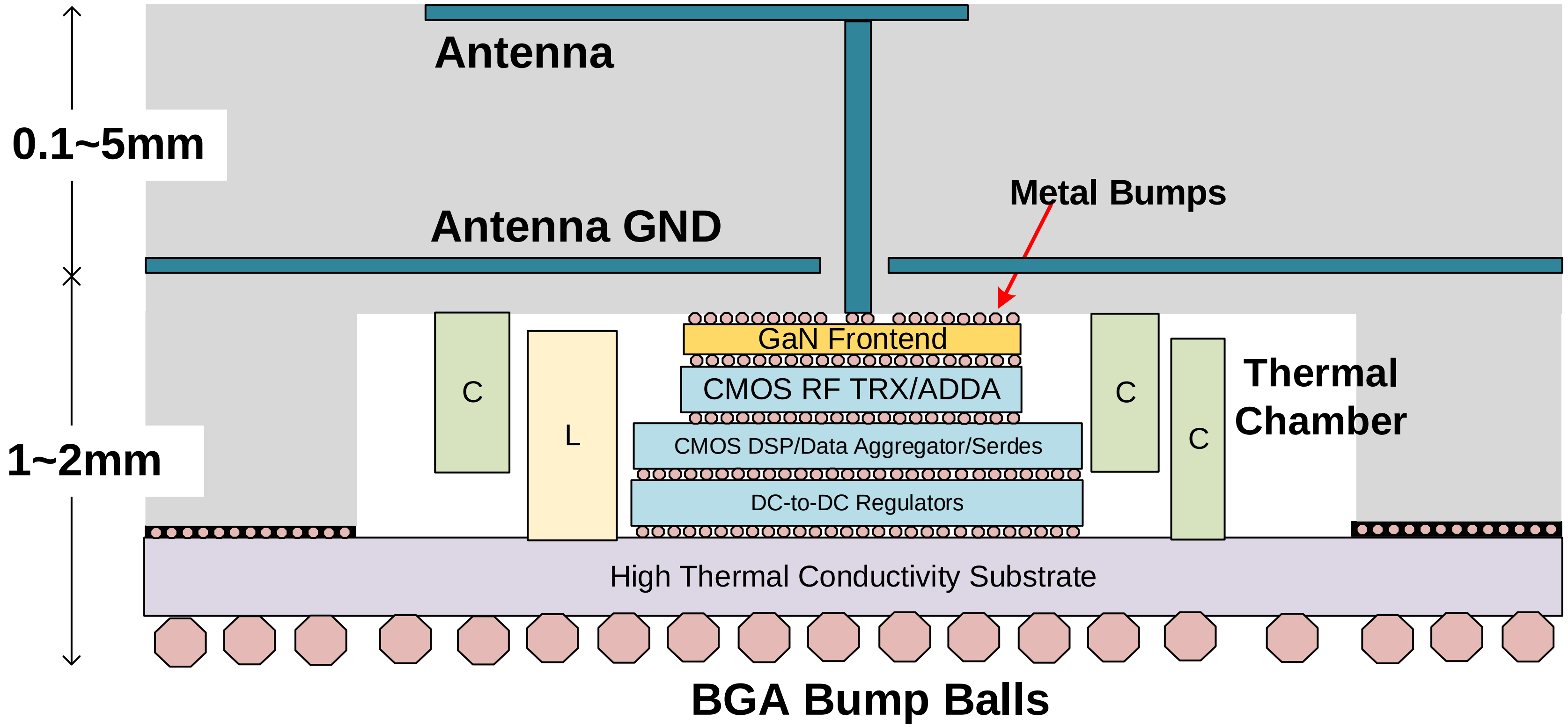
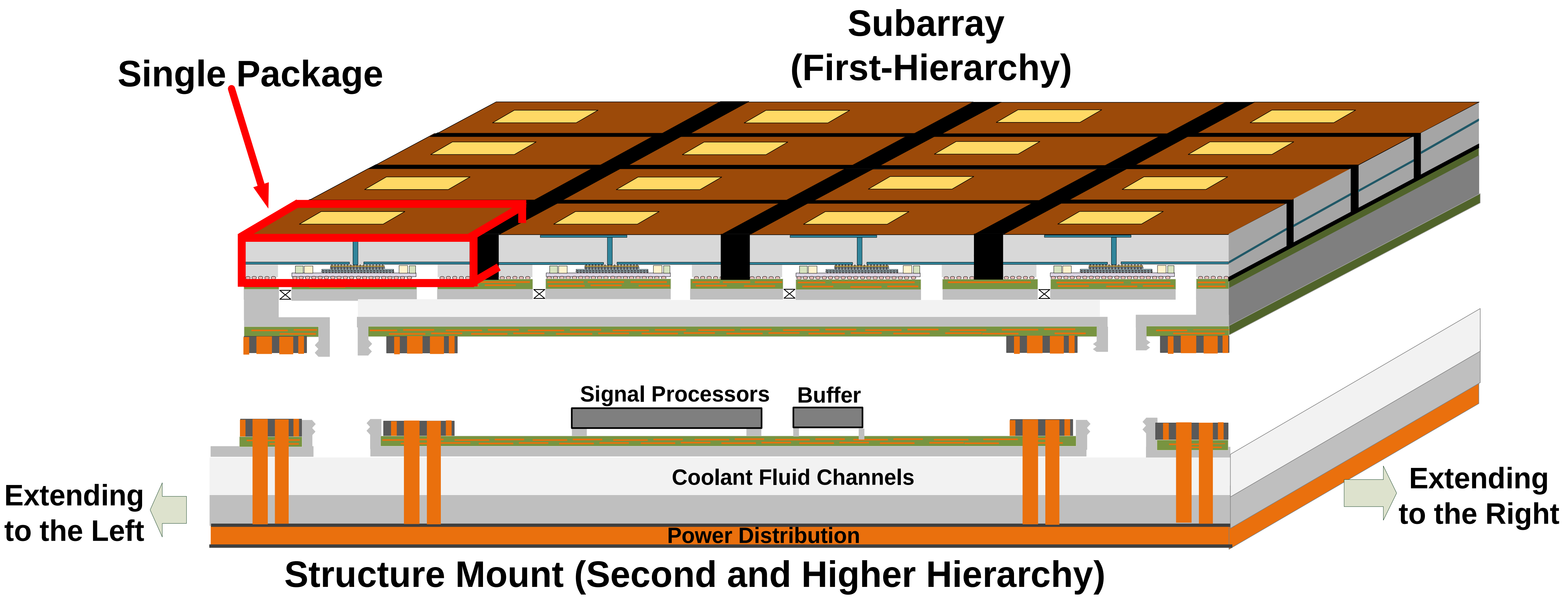
A Possible Future X-band Array Element



- Antenna is fundamentally limited by (signal wavelength) times (fractional bandwidth) $\sim \left(\lambda_0 \cdot \frac{\Delta f}{f_C}\right)$.
- Electronics will be limited by capacitors, inductors and filters (➔ switching speed & material properties).
- Element-level functions will be 3D heterogeneously integrated/packaged. Several challenges:
  - Mechanical stress, and heat exchange.
- The package has to be mounted on a substrate (AlN or graphene on Si/SiC) with a thickness of 300-500 μm to provide mechanical strength.

Large Array System Scenario



- The thickness is mainly limited by how heat and DC power are transferred.
- For 10GHz system, 3-15 mm subarray thickness and 2-15 mm global mounting structure (secondary or higher hierarchy) can be achieved.
- This make it possible to achieve ~3mm lower-power hundred-element array at X-band, <30mm thickness for THAAD-grade radar within a decade.

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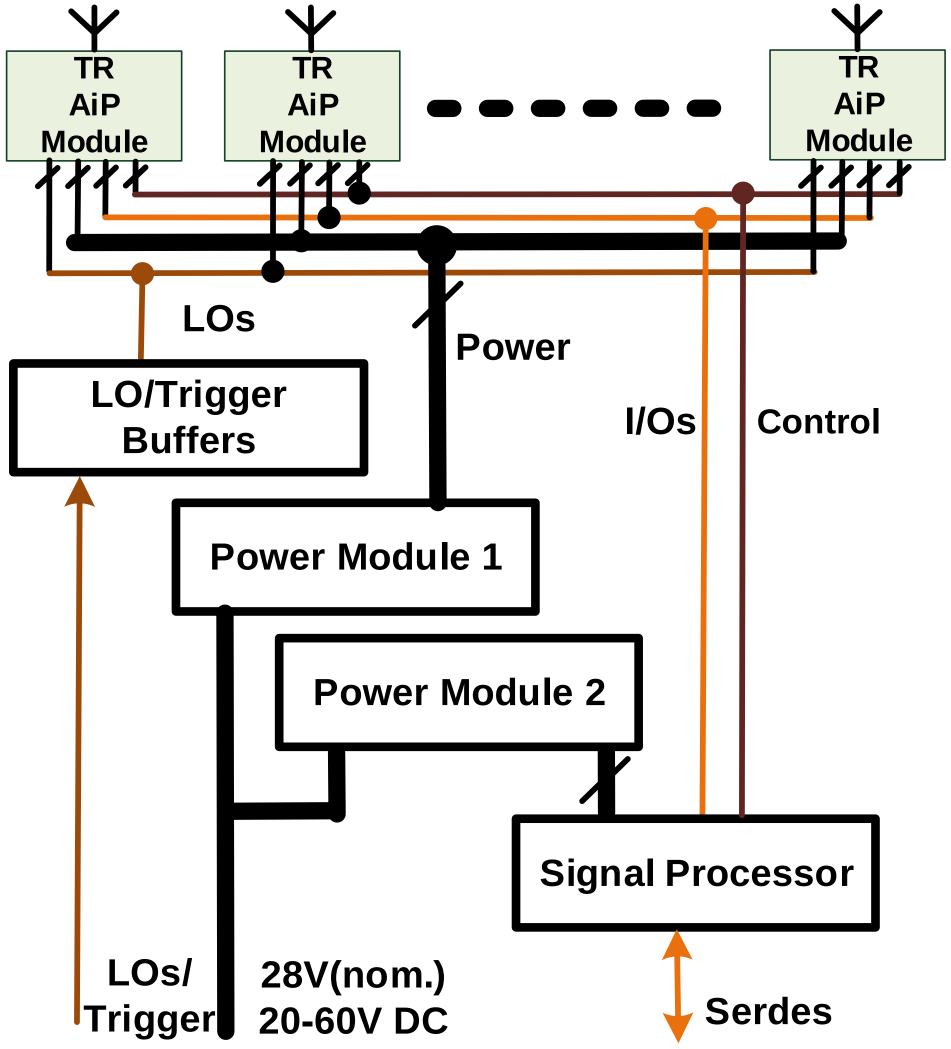
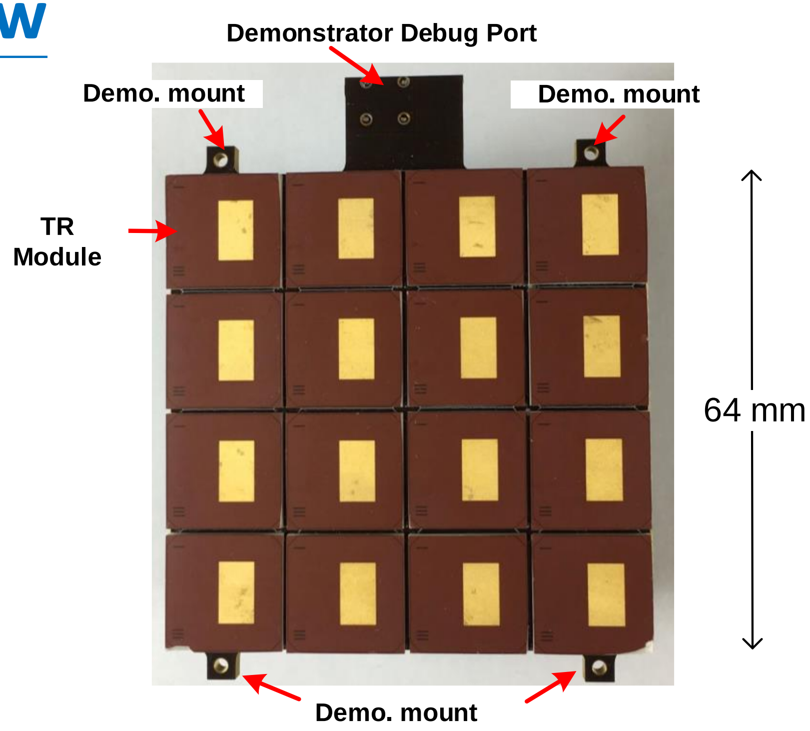
Scalable Subarray 2018 Prototype (4x4)

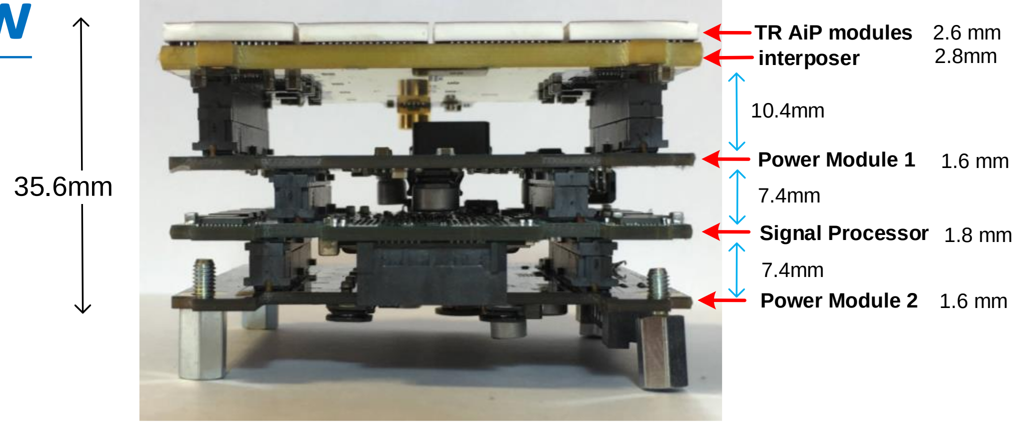
Subarray Architecture



Top View



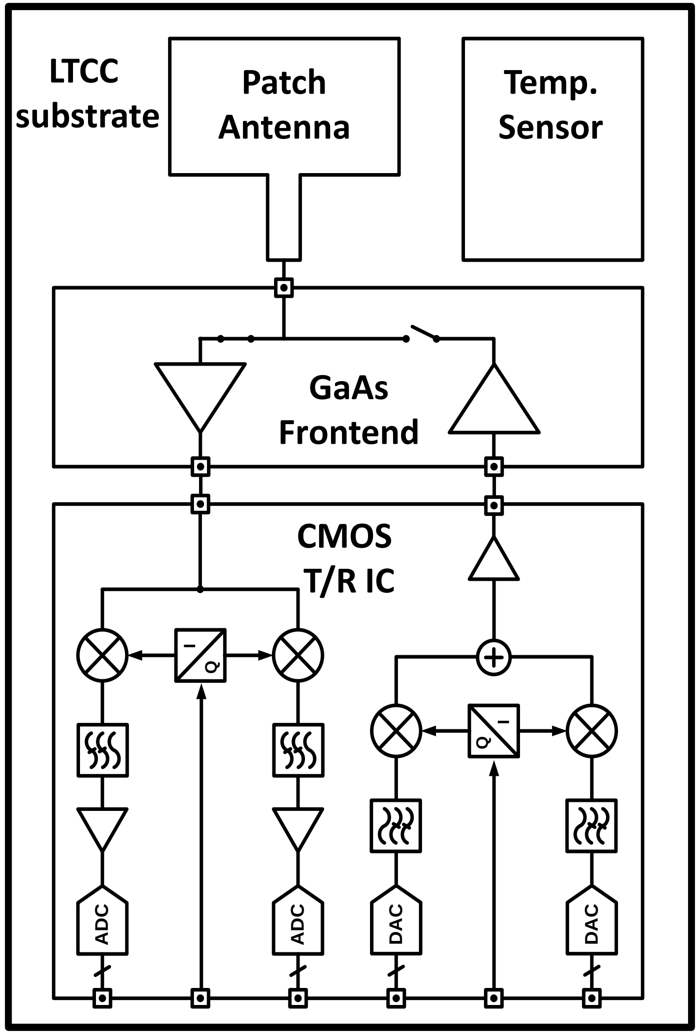
Side View



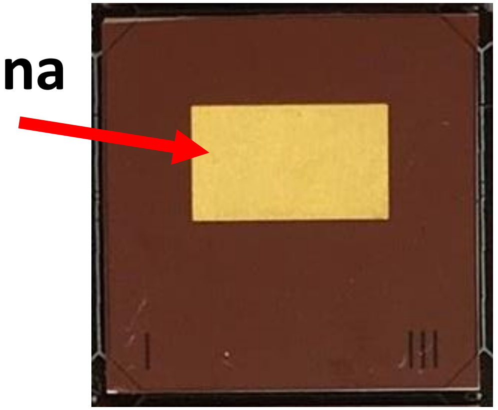
2018 prototype

- **Element-level digital AESA with cm-thickness.**

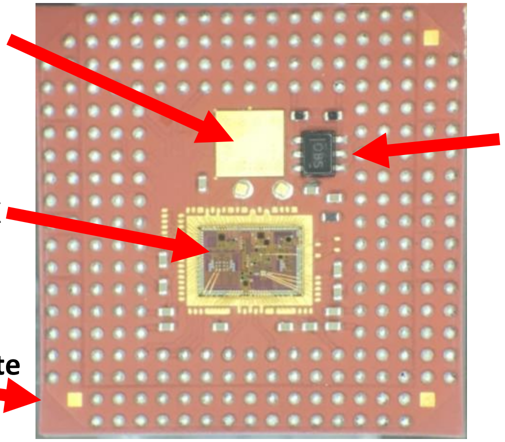
The LTCC Multichip TR Modules and AiP



Antenna



Top View



Bottom View

Operational Frequency
Band: 9-10 GHz
Channel BW: 40 MHz

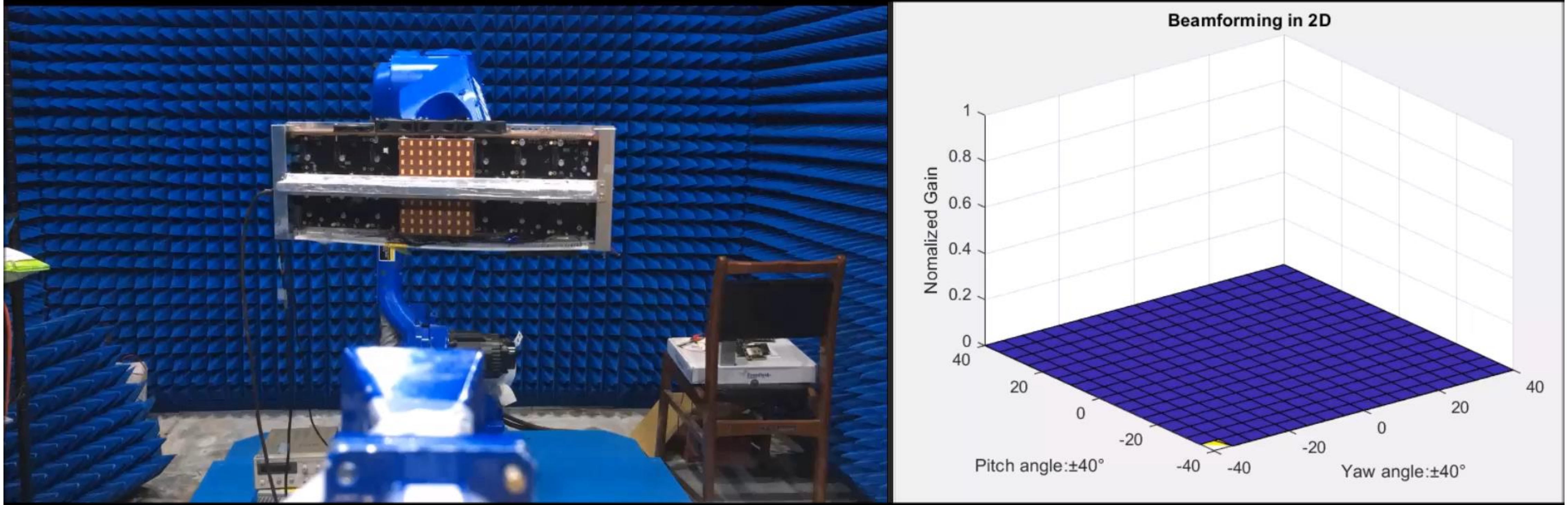
A Typical GaAs Frontend
PA Power: 27 dBm
LNA Gain: 16 dB
LNA NF: 2.5 dB
Switch Time : 1ns

CMOS RF SoC	
Transmitter	Receiver
Digital Input RF Output	RF Input Digital Output
Synchronized CLK Distribution	

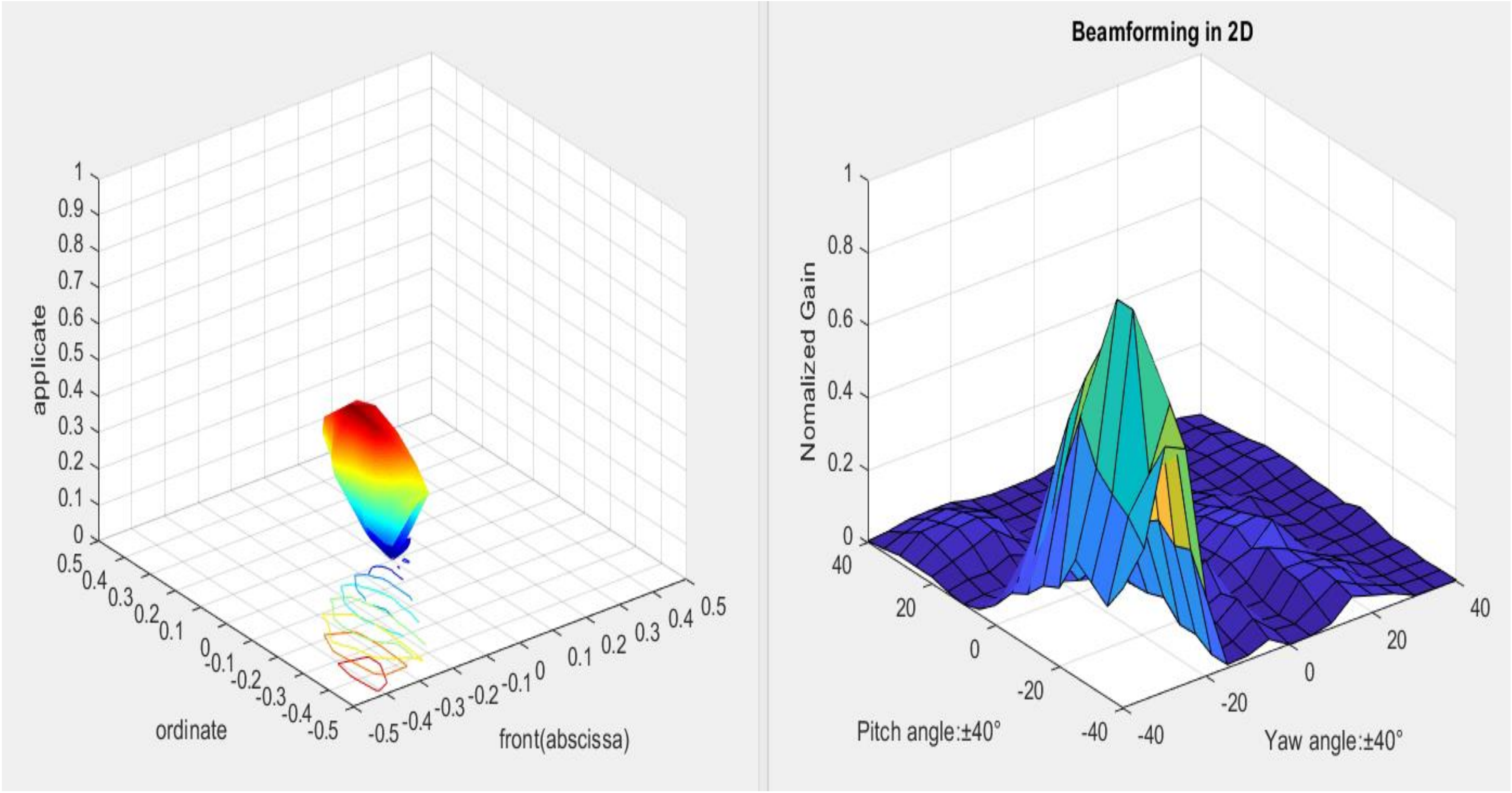
Package Size
15.3mm x 15.3 mm x 3mm 2.6mm (assembled thickness)

- The RF SoC can work with several GaAs and GaN frontends (LNA/PA).
- **This is 2018 RD prototype, not a product.**

Early 4x8 Array Pattern Measurement



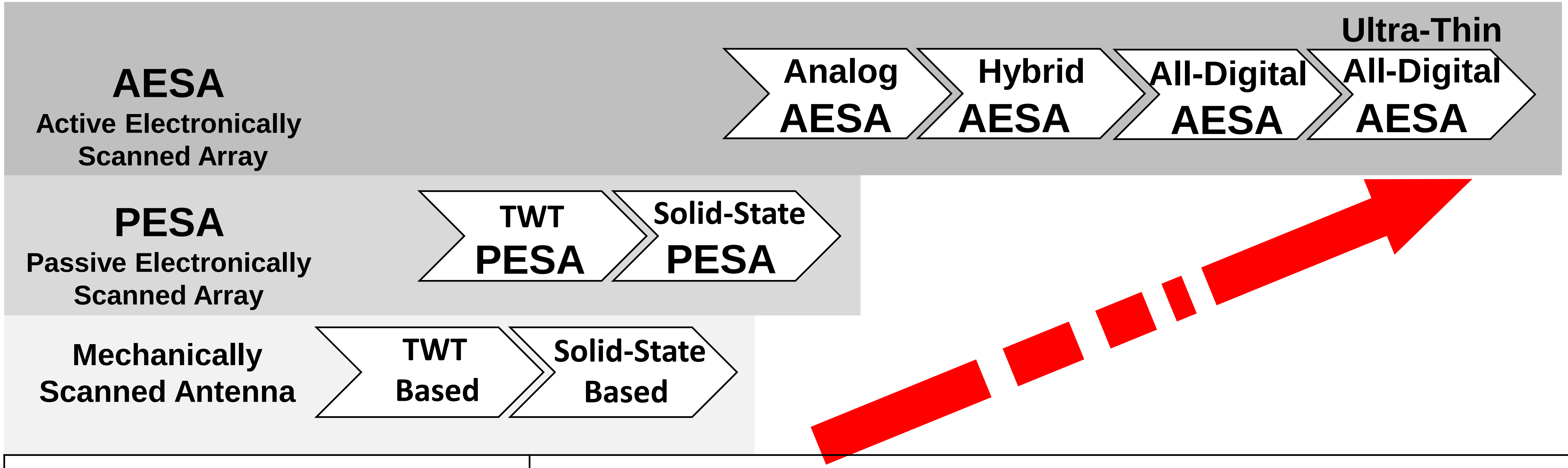
Early 4x8 Sequential Scanning Pattern



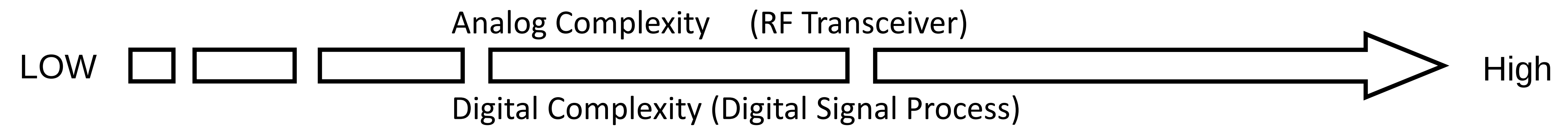
- **Measured peak EIRP ~ 48 dBm with 32 CMOS only TXs.**

Technical Details published in IEEE Radar Conference 2019.

Wireless Scanning Technology Development



Mechanically Scanned Antenna	Electronically Scanned Array	
	PESA	AESA
Single RF Transceiver		Multiple RF Transceiver



Ref: EW Asia 2019:"Ultrathin All-Digital Software-defined Active Phased Array Technology"

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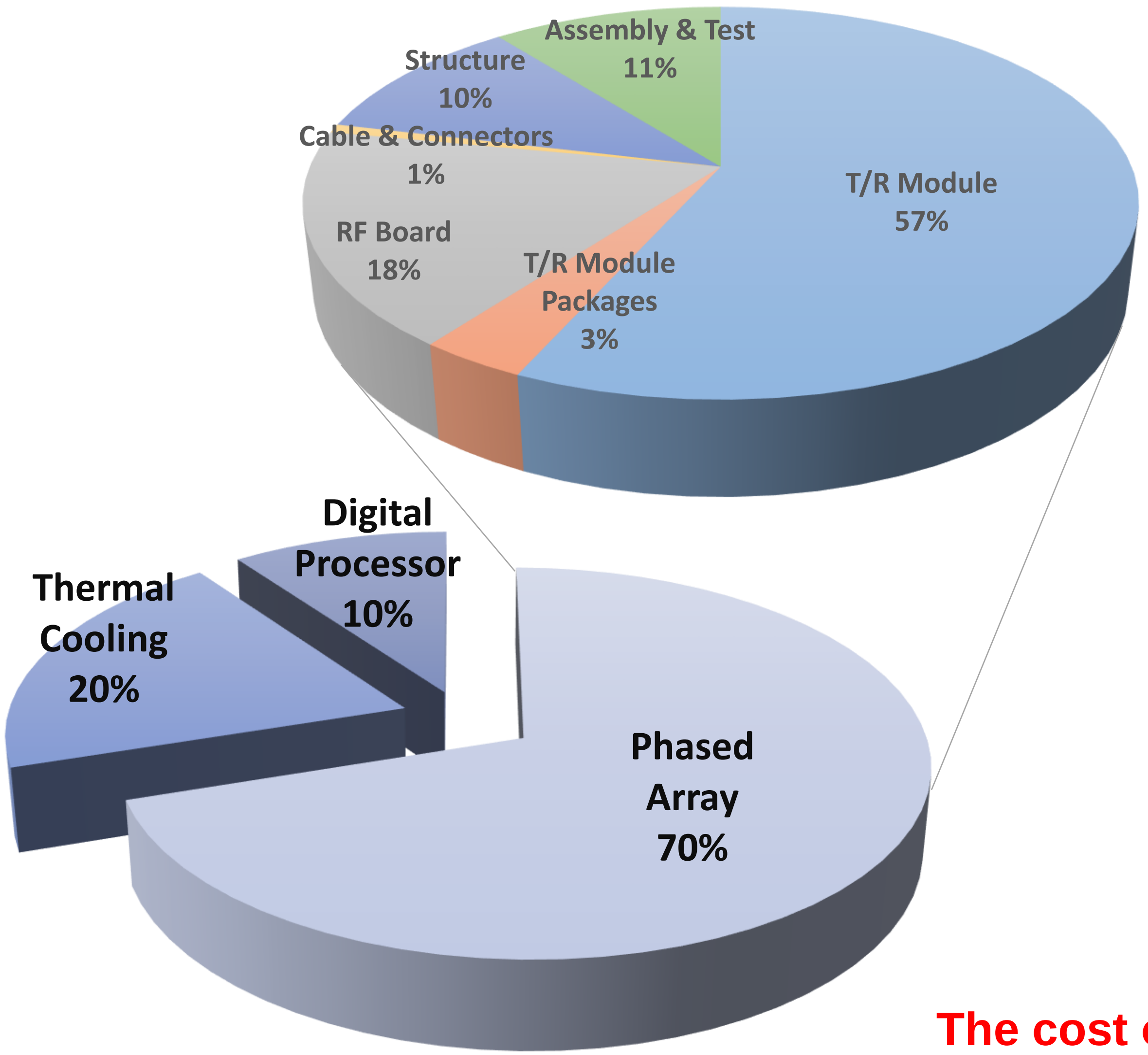
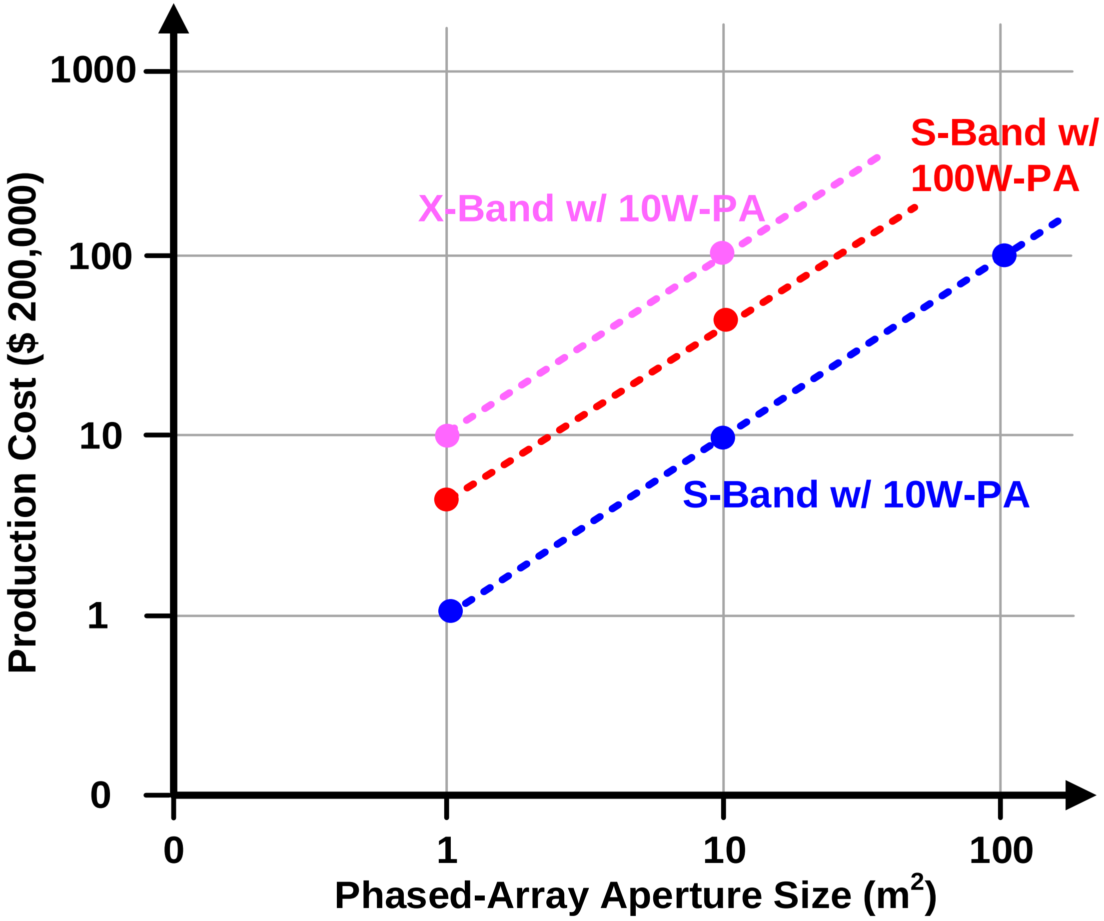
AESA Cost Issues



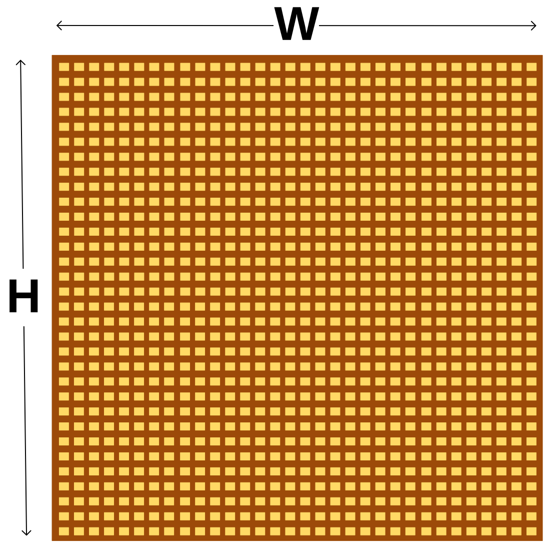


The cost of phased array is proportional to the total no. of array elements and PA power.

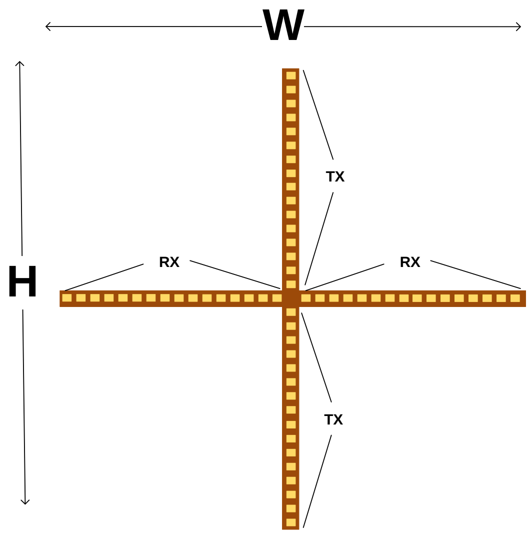
[Ref] Herd J.S., Conway M.D. The Evolution to Modern Phased Array Architectures. *Proceedings of the IEEE*, 2016, Vol. 104, No. 3, pp. 519-529.

3D AESA Cost Reduction

- Fully Populated Planar AESA.
- Orthogonal Linear Digital AESA.



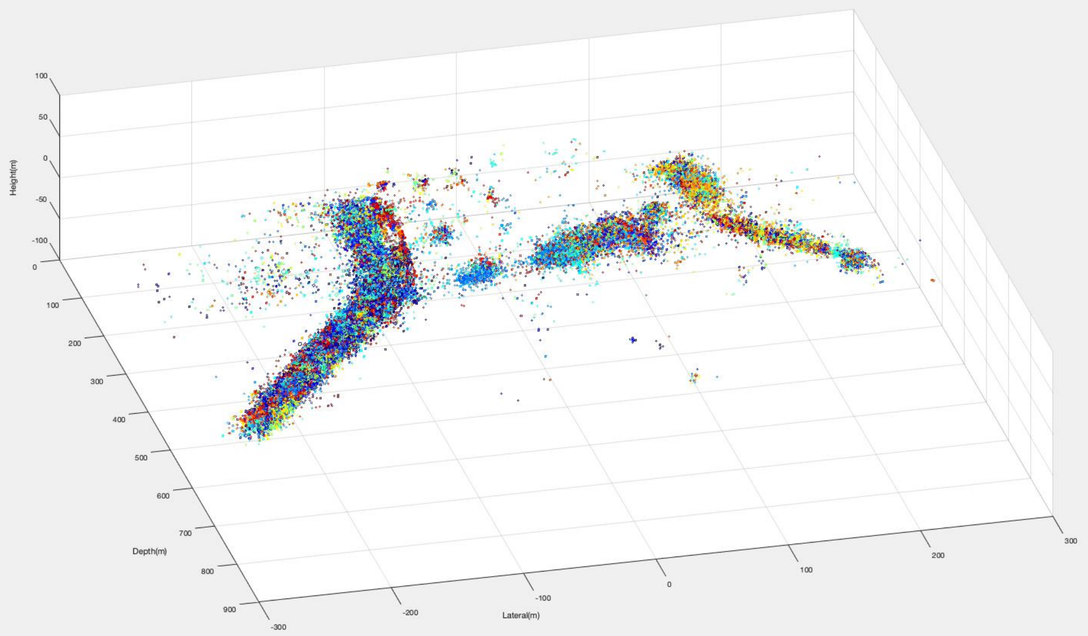
Comparable side-lobe suppression, mainlobe.

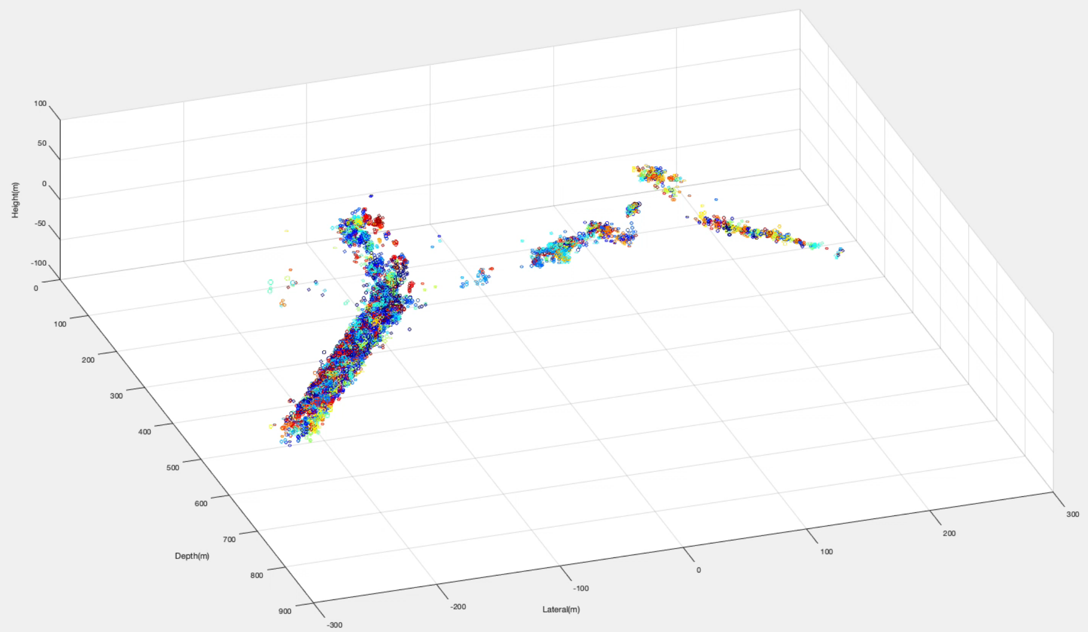


No. of Elements	W*H	H (TX), W (RX)	1024 ➔ 32 (3% cost)
Peak Power	$P_0 * W * H$	$\sim P_0 * (H)$	3% original power
Antenna Gain	$\propto W * H$	$\propto W$ (RX), $\propto H$ (TX)	3% gain for RX & TX
Max. Dwell Time	T_0	T_0* H	32 times with RX multibeam
SNR	SNR_0	$SNR_0 \cdot H/H^3$	1/1024 ➔ (18% detection range)
Cost per Area	C_0	C_0	Similar cost per coverage area.

An Urban Surveillance Scenario

3D Detection with 16TX, 24RX





- “3D” position of an RCS target can be extracted.
  - Curvature of high-way can be precisely measured from a remote site.
- Ground surface estimation and target pattern recognition is used to identify drone from clutters(cars).
  - Target height from estimated earth surface.
  - Speed range and track properties
  - RCS Size.

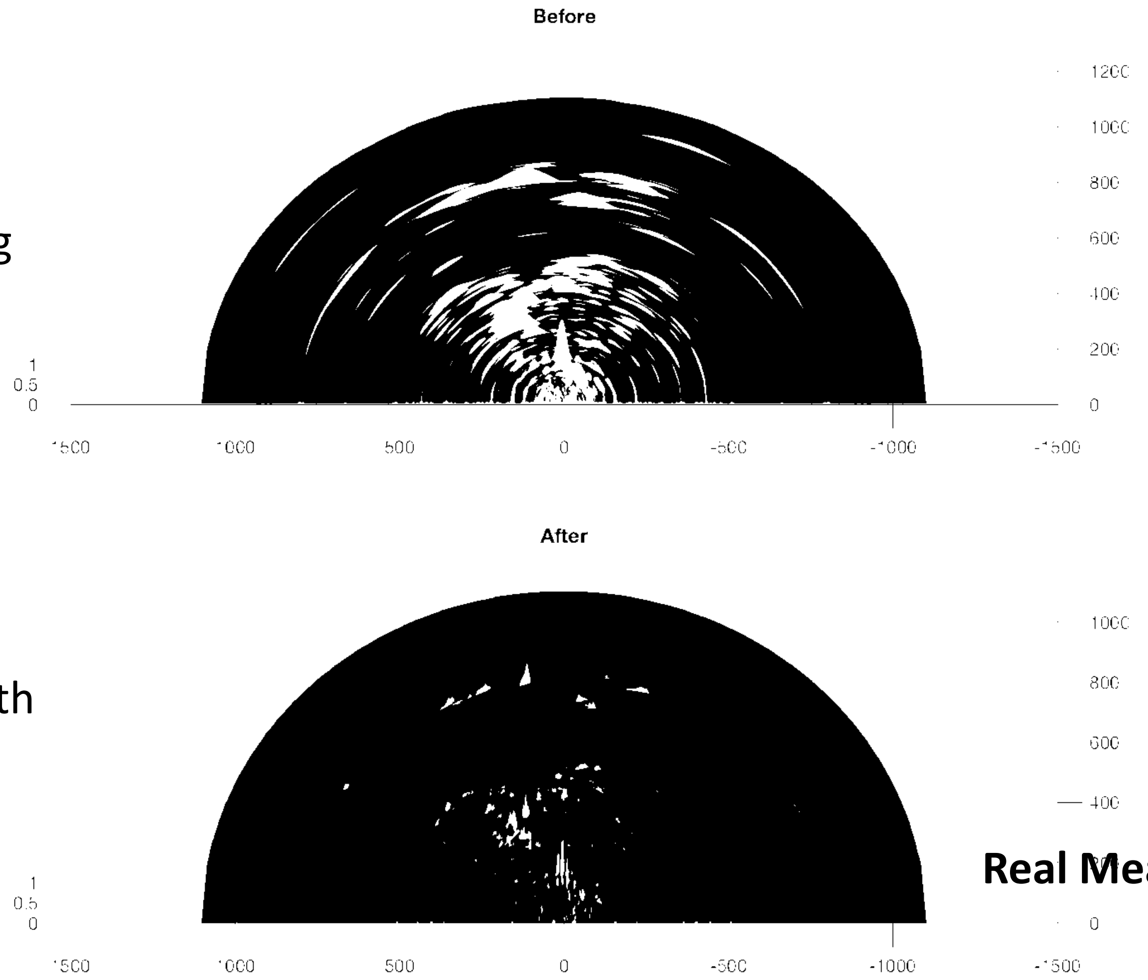
10 frames, 1 Hz update Rate, 10 Sec. continuous. Each point represents a moving object.

Digital AESA + massive computations

- In previous slides, digital AESA tries to mimic analog AESA. Today's CPU is 10,000 times better than CPU in 2000.
- Compressive sensing requires 10^5 times computations compared to beamforming for 1000 RTX.

Traditional Beamforming with 8 RXs

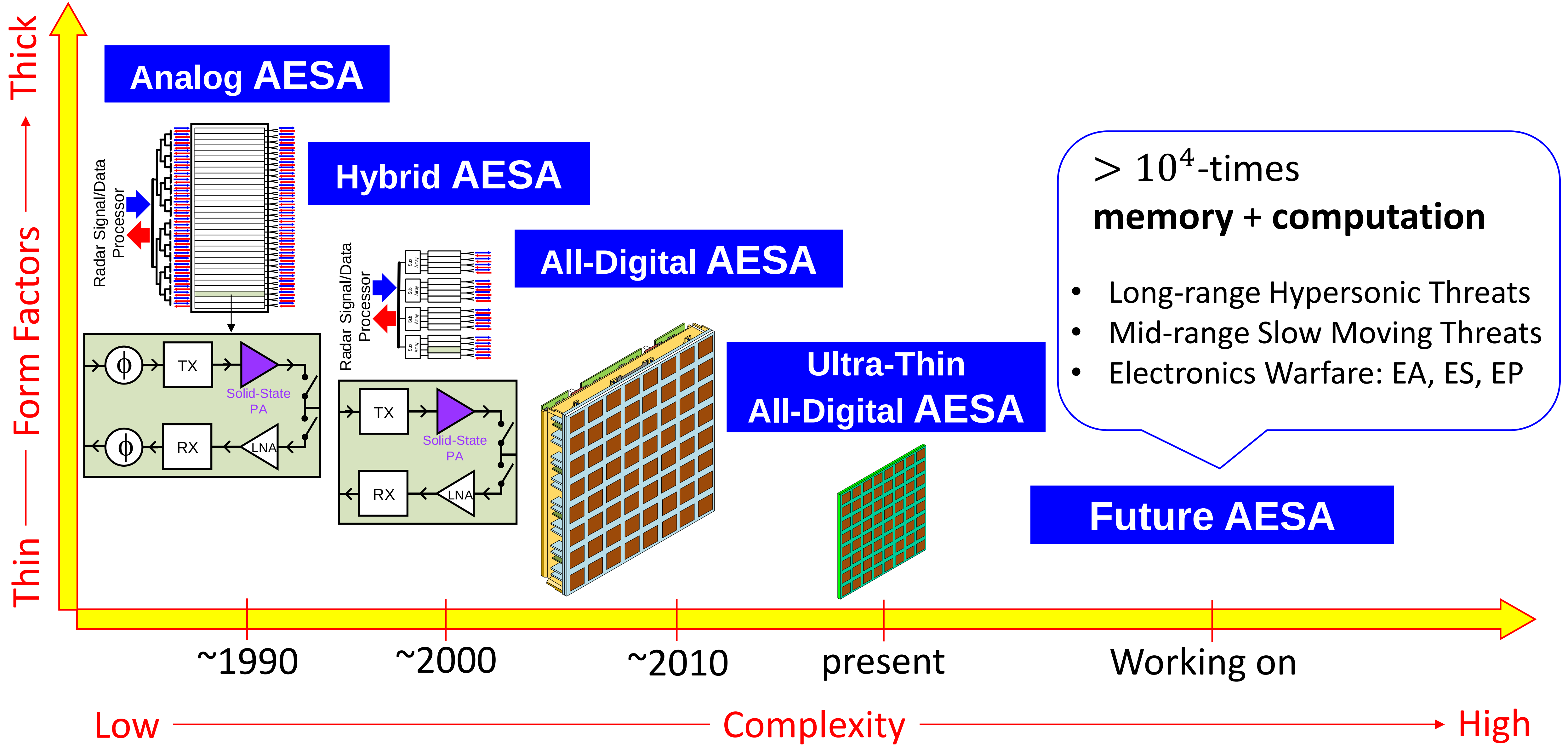
Compressive Sensing with only 8 RXs



Real Measurements with 8 RXs.

- **<u>Ultra-fine spatial/velocity- resolution in the same aperture.</u>**

AESA Radar Future Trends



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Agenda

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- Testing Challenges.

This section will be updated during presentation.

Summary

- Technology progress enables large-aperture phased array in ultra-thin formfactor, and enhancing many existing and new applications.

- Future phased array market will be segmented into three major sectors:
  - **Digital full array:** computation intensive high performance market.
  - **Digital sparse array:** computation intensive low cost market
  - **Hybrid array:** power efficient satellite market.

- Ultrathin array testing will not only rely on Keysight's high-performance equipment's (e.g. PNA-X), array products will have extensive built-in-self-test, system-level adaptive algorithm, software-intensive system-level environment testing simulation framework, and innovative production testing mechanics to drive normalized array cost by a factor of four in the next decade.