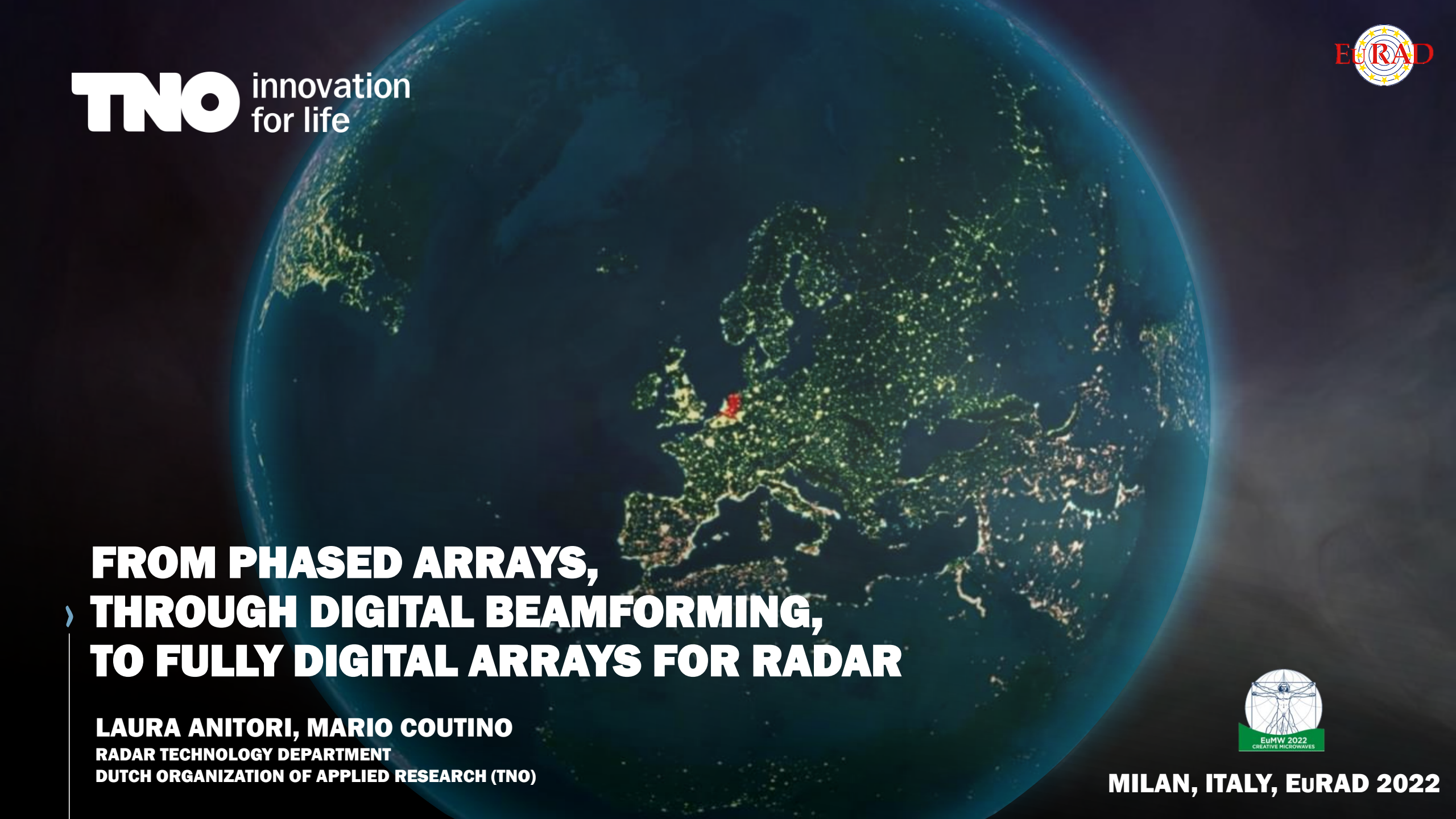

TNO innovation for life

EuRAD

# FROM PHASED ARRAYS, THROUGH DIGITAL BEAMFORMING, TO FULLY DIGITAL ARRAYS FOR RADAR

**LAURA ANITORI, MARIO COUTINO**
RADAR TECHNOLOGY DEPARTMENT
DUTCH ORGANIZATION OF APPLIED RESEARCH (TNO)

EuMW 2022 CREATIVE MICROWAVES

MILAN, ITALY, EuRAD 2022

# OUTLINE

## In today's talk

- The Radar Technology Department at TNO
- History – Recap
  - Timeline
  - Development Path
- The road to fully digital array systems in radar – A TNO's view
  - Digital array processing on receive
  - MIMO Arrays
  - Fully Digital Arrays
  - Distributed Arrays

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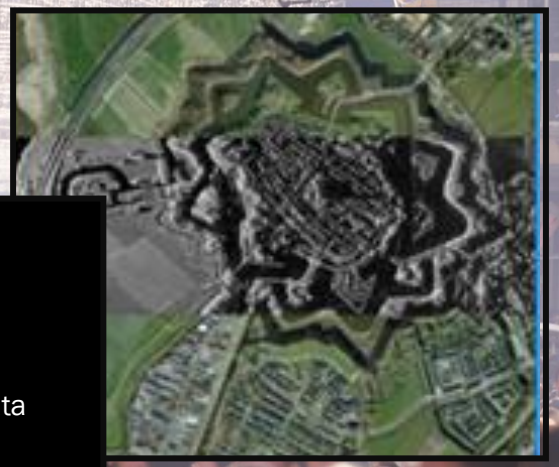
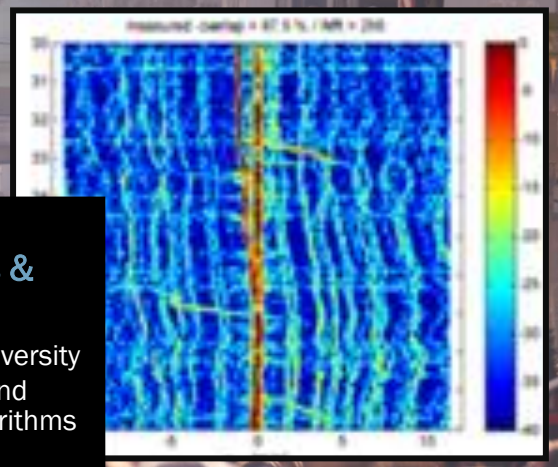
## Systems and Concepts

- AESA
- Airborne Ground Surveillance
- FMCW



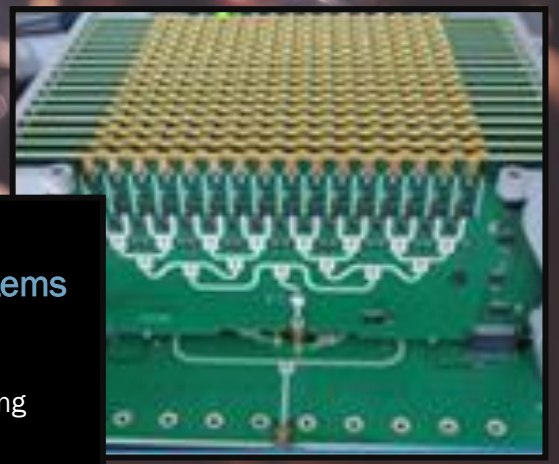
## Signal Processing

- Information extraction
- Real-time data processing



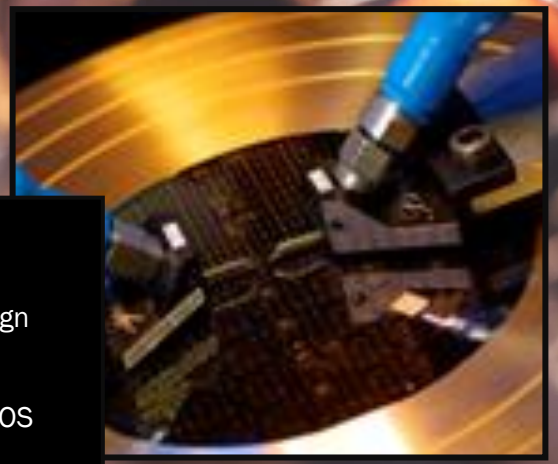
## Waveforms & Algorithms

- Waveform diversity
- Non-linear and iterative algorithms



## RF Subsystems

- Design
- Prototyping
- Manufacturing



## MMICs

- Fabless design center
- GaAs, GaN
- SiGe, RF CMOS

# THE RADAR TECHNOLOGY DEPARTMENT

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# RADAR EVOLUTION

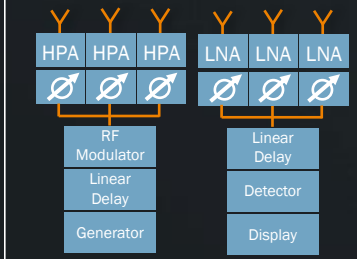
Analogue Domain

Digital Domain

Present

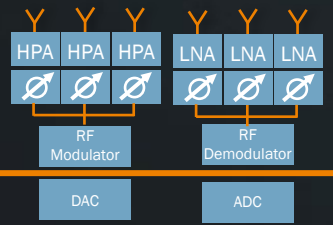
Few Years

## Analogue Phased Array



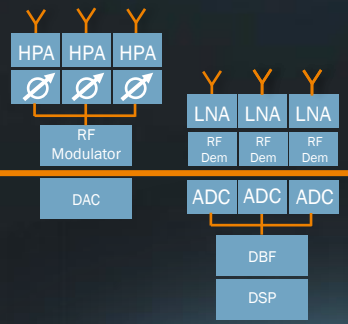

(Extremely) Narrow band

## Digital Signal Generation & Digital Processing



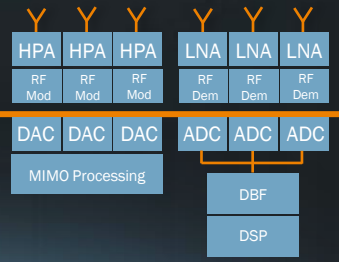

Improved Detectors

## Digital Beam Forming on Receive



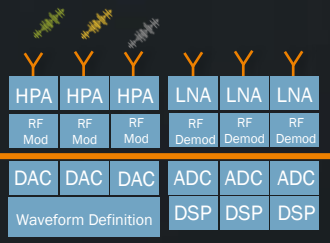

Simultaneous Beams @ Receive

## Spatial Waveform Diversity on Transmit



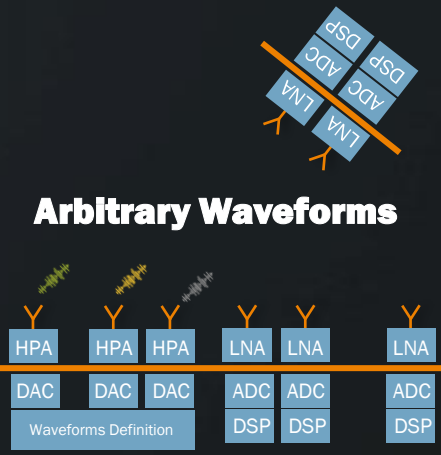

Resolution Improvements

## Digital Transmitter




Exploits all DoFs

## Arbitrary Waveforms




- Networked Operations
- Enhancement on LPI

# FROM THEN TO NOW

## 1940s

**Würzburg-Riese**

Single Tx
Single Rx

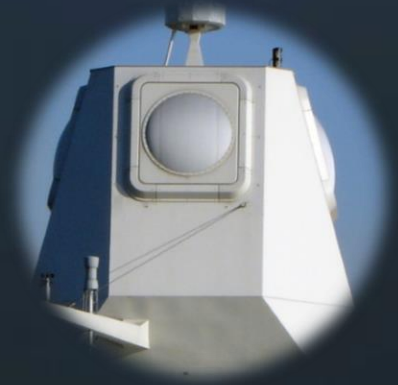
Mechanical Steering

## 1970s

**CAISSA**

Single Tx
Single Rx

Antenna Array



## 2000s

**APAR**

Distributed Tx Power
Central Rx

Antenna Array

## 2010s

**NS-Family**

Distributed Tx Power
Digital, distributed Rx Power

Antenna Array

## Next Generation

## ——

**[???]**

Digital, distributed Tx Power
Digital, distributed Rx Power

Antenna Array

# DIGITAL ON RECEIVE

**Benefits of AESA:**

Longer range

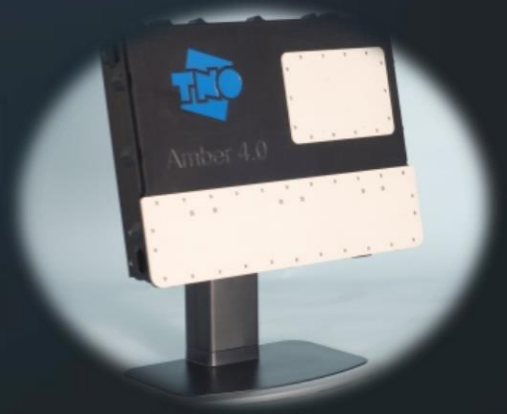
Ability to detect smaller targets

Better resistance to jamming

Less likely to experience system failure

*Limited field of view*

**Active Phased Array Radar (APAR)**




**Benefits of Digital on Receive:**

Improved dynamic range

Controlling of multiple beams

Improved adaptivity

Improvement on accuracy/resolution

*Digitalization costs*

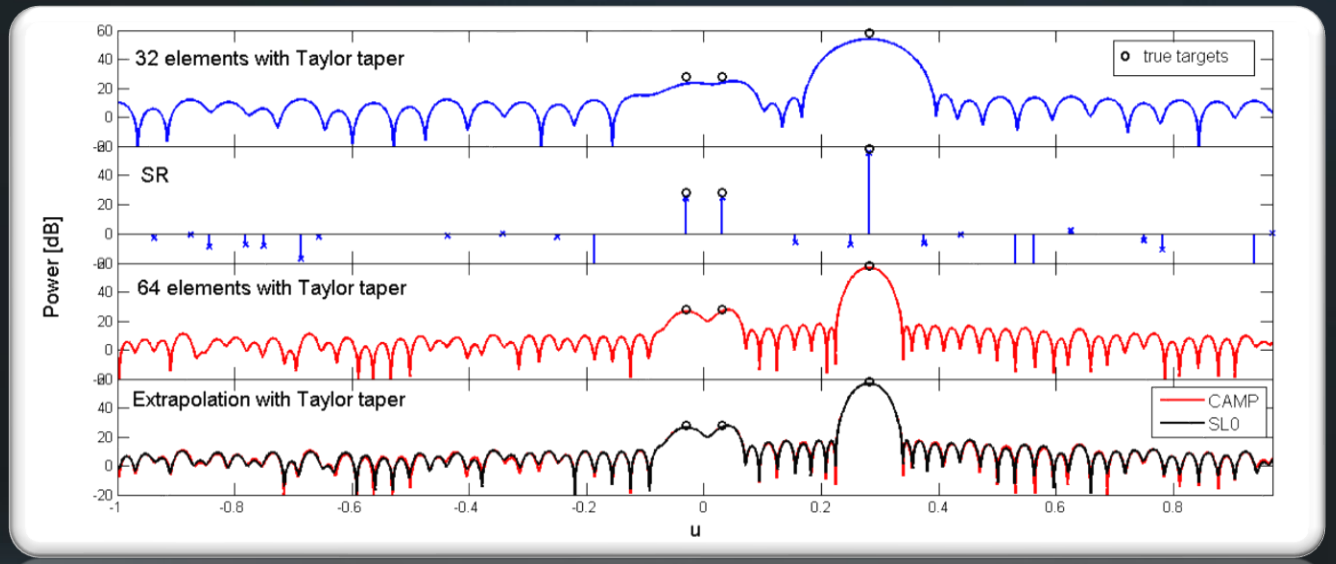
**Affordable Multiple Beam Radar (AMBER)**

## TOWARDS FULLY DIGITAL ARRAY SYSTEMS

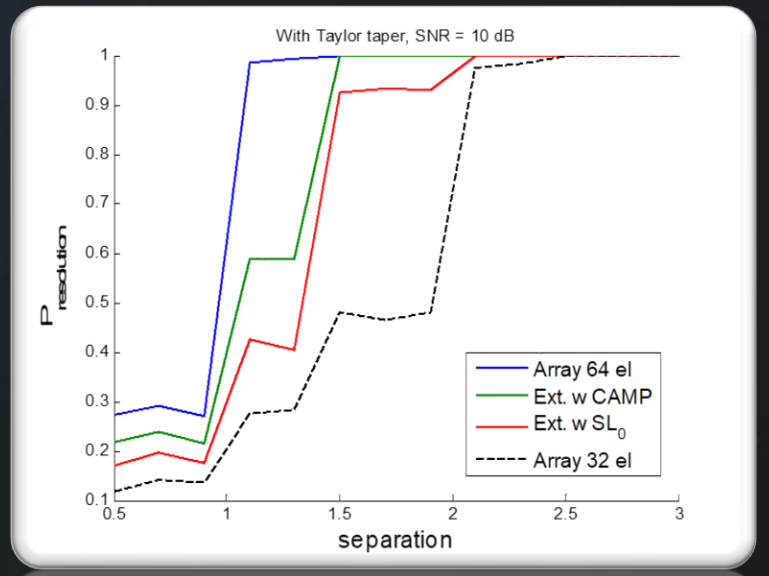
### A TNO'S VIEW

# DIGITAL ON RECEIVE

## Array Aperture Extrapolation using Sparse Reconstruction




Aperture Extrapolation




Resolution Comparison

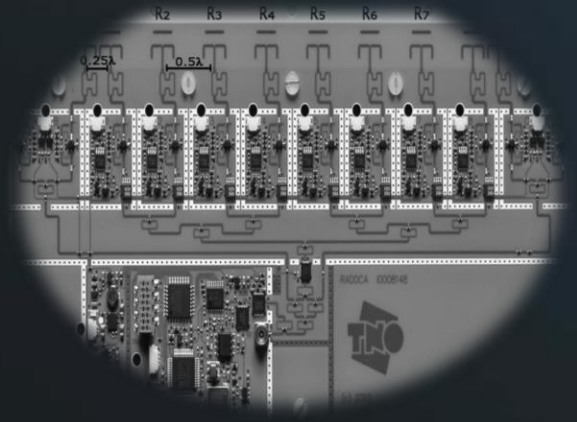
# TOWARDS FULLY DIGITAL ARRAY SYSTEMS

## A TNO'S VIEW



Anitori, Laura, Wim van Rossum, and Albert Huizing. "Array aperture extrapolation using sparse reconstruction." *2015 IEEE Radar Conference (RadarCon)*. IEEE, 2015.

# MIMO

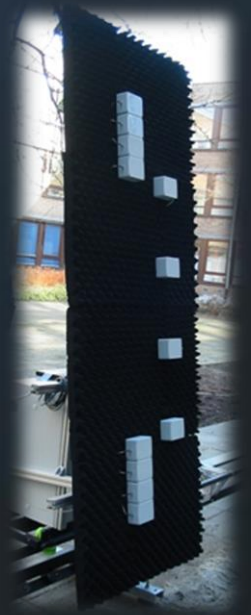



**What is MIMO?**

Stands for Multiple-input multiple-output

Concept based on transmitting “orthogonal” waveforms

Tx and Rx arrays may have holes (sparse arrays)



**Benefits of MIMO:**

Improvement on angular resolution

Increase on number of detectable targets

Flexibility on spatial energy distribution

*Loss of coherent processing gain*

**RADAR DOME CAMERA (RADOCA)**

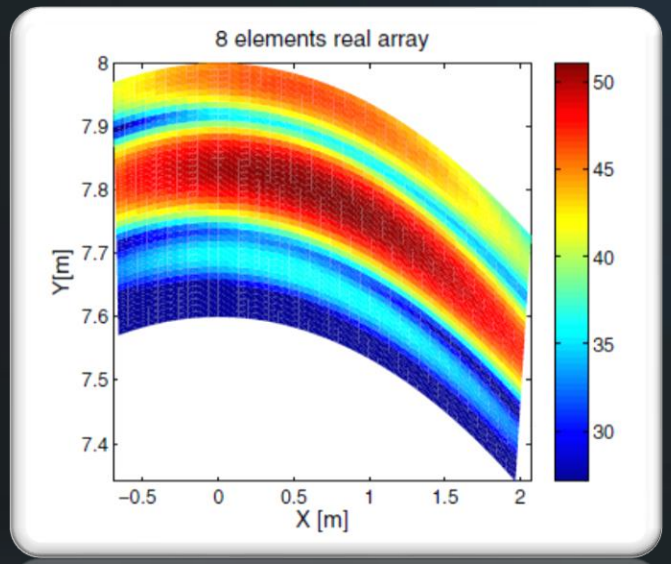
**Synthetic Aperture Polarimetric Phased Array Interferometer Radar Equipment (SAPPHIRE)**

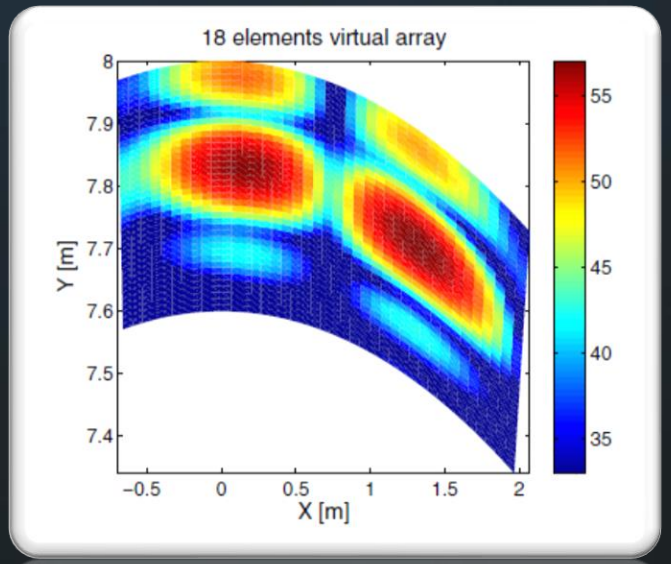
# TOWARDS FULLY DIGITAL ARRAY SYSTEMS

## A TNO’S VIEW

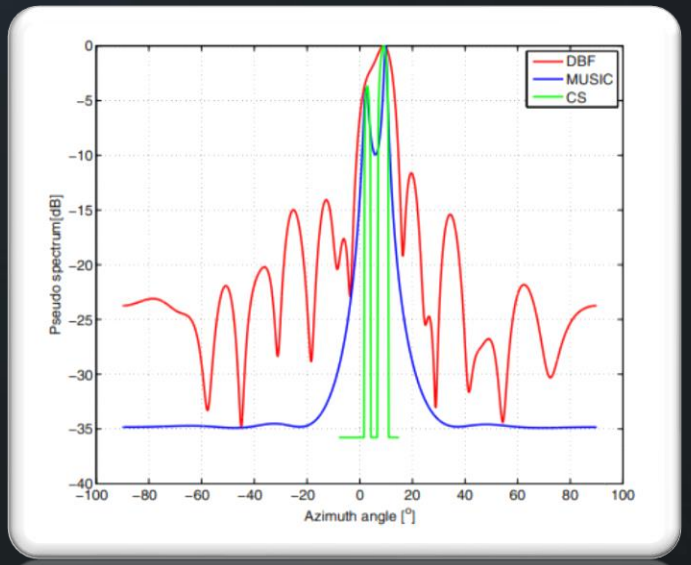
# MIMO

## Digital-Beamforming- and Compressing-Sensing-based DOA Estimation in MIMO Arrays




Comparison of MF output using (left) “real” Rx array and (right) MIMO array



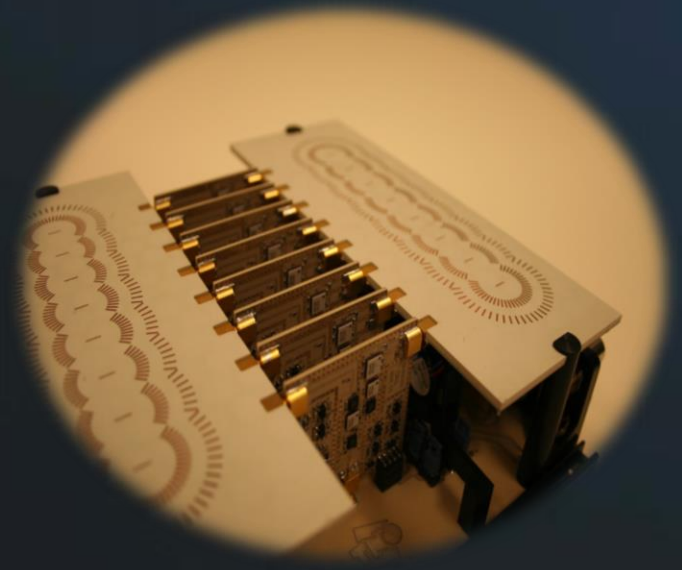

Classical and CS Techniques on MIMO Array

# TOWARDS FULLY DIGITAL ARRAY SYSTEMS
## A TNO’S VIEW



Belfiori, Francesco, et al. "Digital beam forming and compressive sensing based DOA estimation in MIMO arrays." 2011 8th European Radar Conference. IEEE, 2011.

# FULLY DIGITAL



**Benefits of Digitalization**

Possibility of using all degrees of freedom

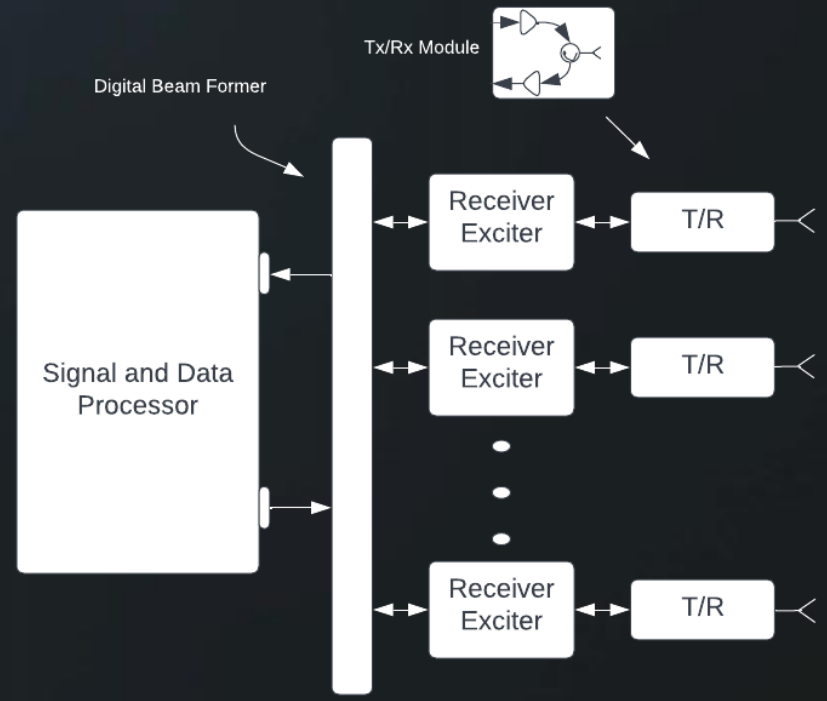
- Improved control on Tx and Rx beampatterns

- Waveform diversity / adaptivity

-- Software-defined on-the-fly capabilities, e.g., MIMO

*Digitalization costs*

*Technological challenges*



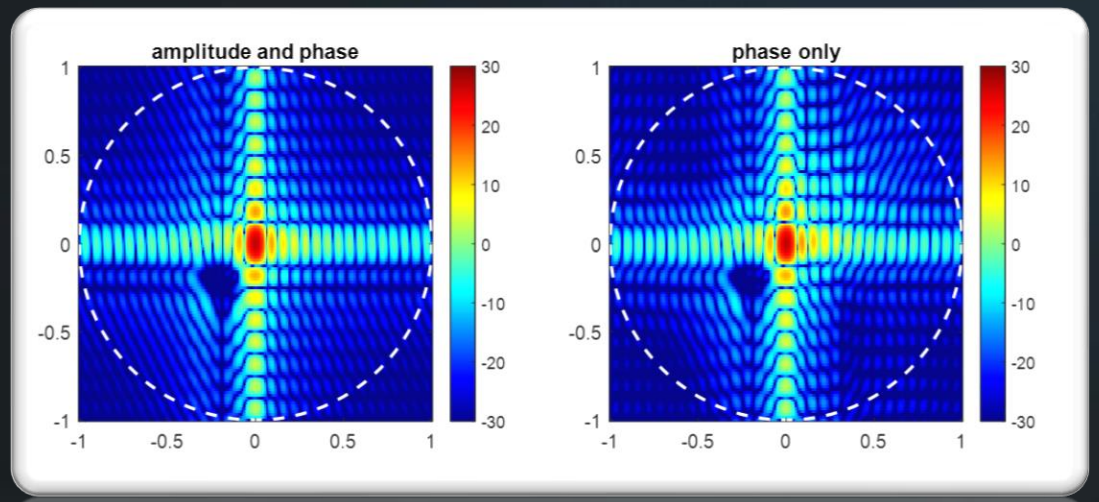

**Electronically Scanned Multiple Function Radio Frequency Array for Light-Weight Payloads (EMERALD)**

# TOWARDS FULLY DIGITAL ARRAY SYSTEMS

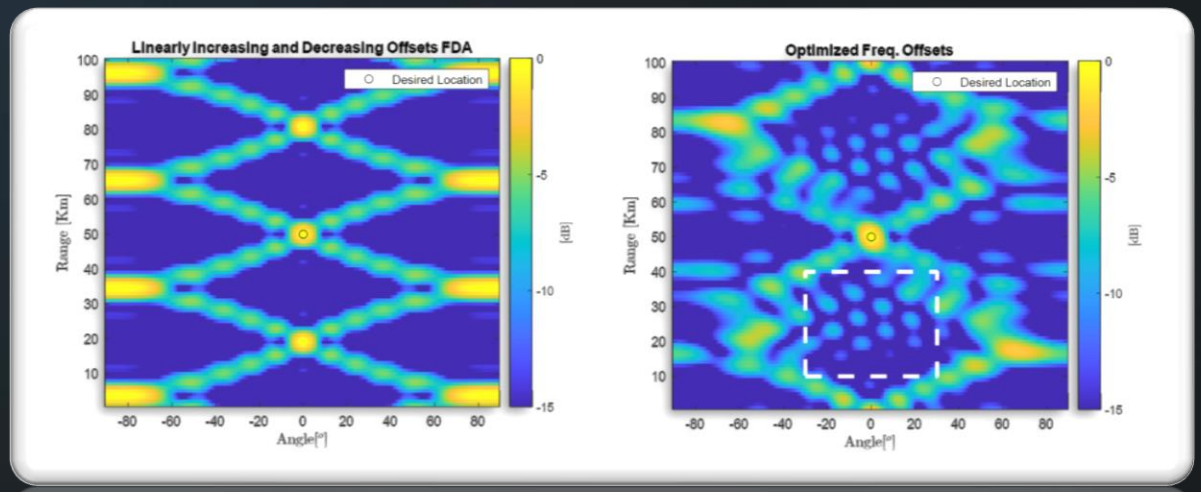
## A TNO'S VIEW

# FULLY DIGITAL

## Optimization of Transmit Waveforms Per Element




Comparison of adaptive Tx beam pattern using (left) amplitude modulation (right) phase only




Angle-Range response of Frequency Diverse Array (FDA) using (left) up-down offsets (right) optimized offsets

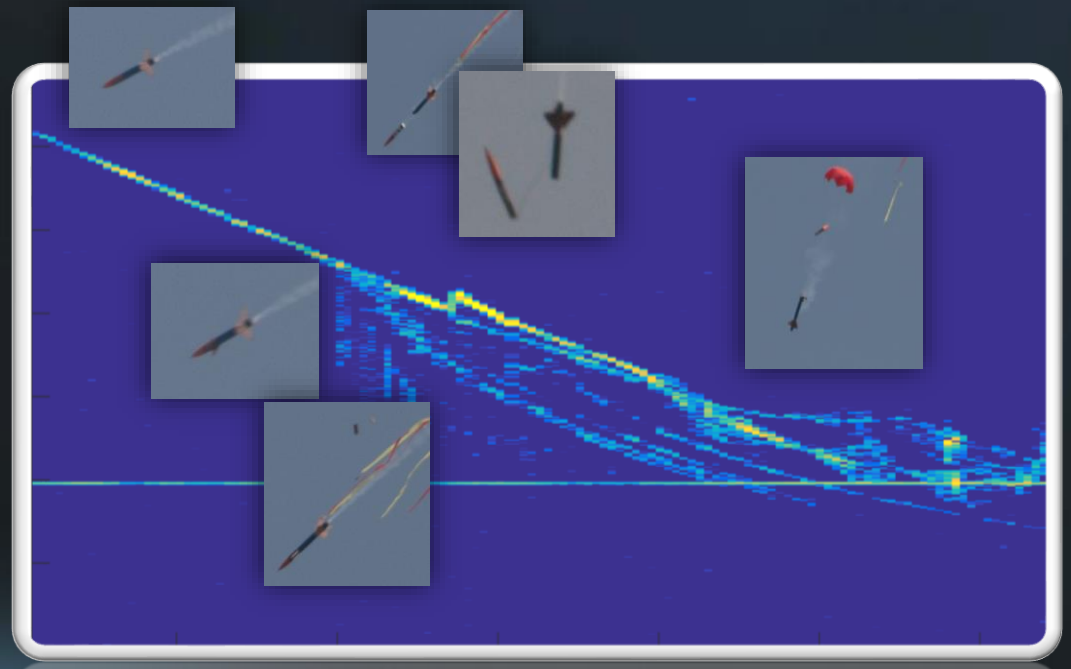
# TOWARDS FULLY DIGITAL ARRAY SYSTEMS
## A TNO'S VIEW



M.A. Coutiño, R.E. Struiksma, D.J. Bekers, J.J. Boschma, M. Mouri, R. v. Dijk, L. Anitori, "Amplitude Coded Waveforms and Amplitude Coded Beamforming (ARPA)", TNO, 2021

# FULLY DIGITAL

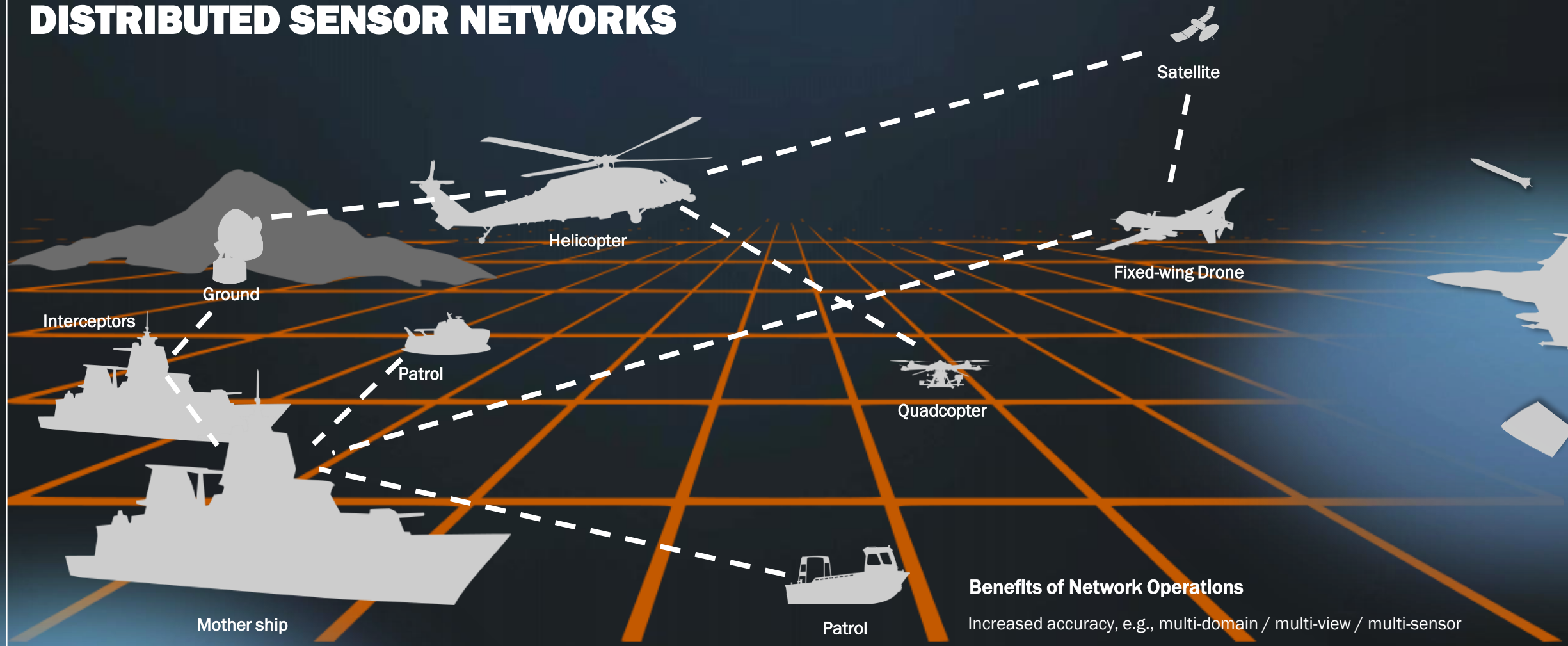
## Measurements with Arbitrary Waveform Generator Testbed



# TOWARDS FULLY DIGITAL ARRAY SYSTEMS

## A TNO'S VIEW

# DISTRIBUTED SENSOR NETWORKS




## TOWARDS FULLY DIGITAL ARRAY SYSTEMS

### A TNO'S VIEW

**Benefits of Network Operations**

Increased accuracy, e.g., multi-domain / multi-view / multi-sensor

Increased coverage

Reduced individual requirements

Reduced vulnerability and improved robustness

*Interoperability –across vendors/nations*

*Several new concepts/possibilities yet to explore*

# THANKS
# FOR YOUR ATTENTION


**Radar Technology Department**

Laura Anitori
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Lennaert Bronts
Miguel Caro
Aodhan Coffey
Pepijn Cox
Michel Deconinck
Duije Deurloo
Sercan Deve
Raymond van Dijk
Philip van Dorp
Joyke Elbers
Jaap Essing
Alessandro Garufo
Victoria Gomez-Guillamon
Marcel vd. Graaf
Nadia Haider
Marc v. Heijningen
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Peter de Hek
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Keith Klein
Rob Knight
Martijn de Kok
Costas Kokke
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Noud Mass
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Henk Medenblik
Stefania Monni
Millad Mouri
Evert Nieuwkoop
Matern Otten
Giuseppe Papari
Diana van Putten
Diogo Ribeiro
Marien Rodenburg
Wim van Rossum
Remko Struiksma
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Arne Theil
Christian Trampuz
Danilo Tromp
Faruk Uysal
Frank van Vliet
Wouter Vlothuizen
Jelle Vonk
Maurice van Wanum
Jacco de Wit

and from everyone that contributed to all this...


TNO innovation for life


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