Awareness and Localization of Explosives-Related Threats (ALERT)
A Department of Homeland Security Center of Excellence

Millimeter-Wave Sensing and Imaging

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ALERT
AWARENESS AND LOCALIZATION OF EXPLOSIVES-RELATED THREATS

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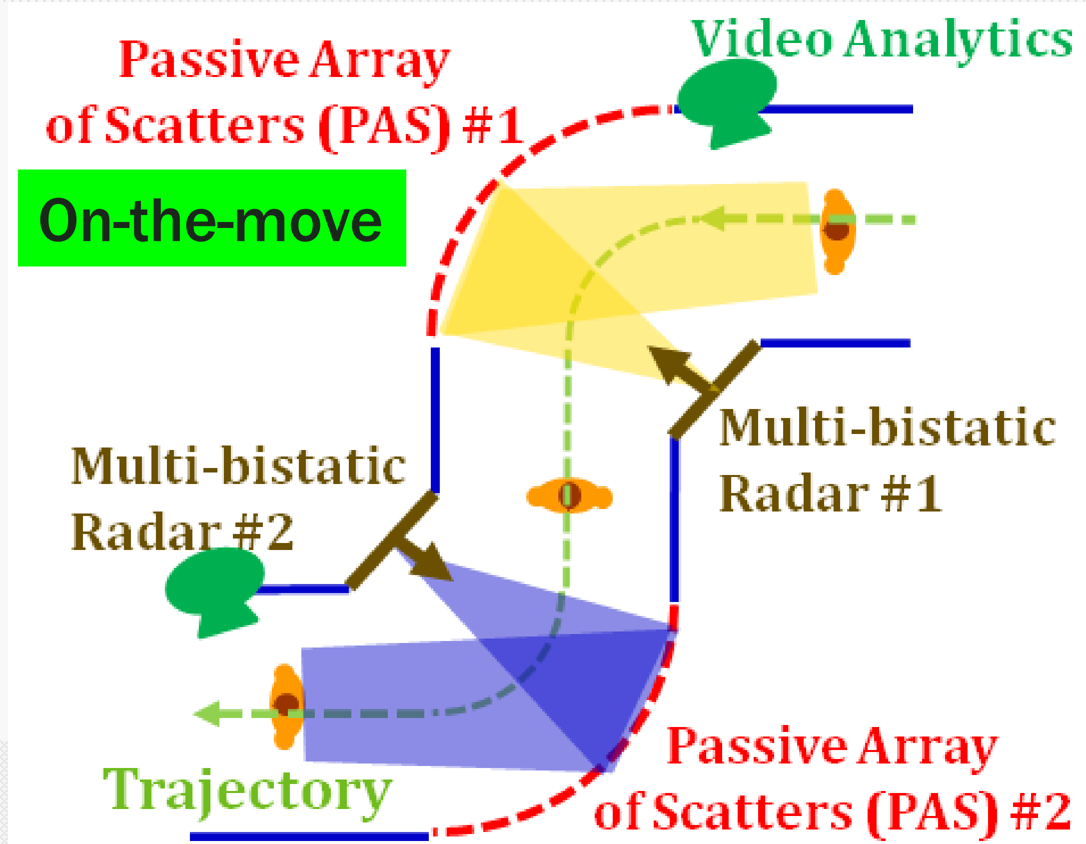
"Stand-off" and "On-the-Move" Detection of Security Threats

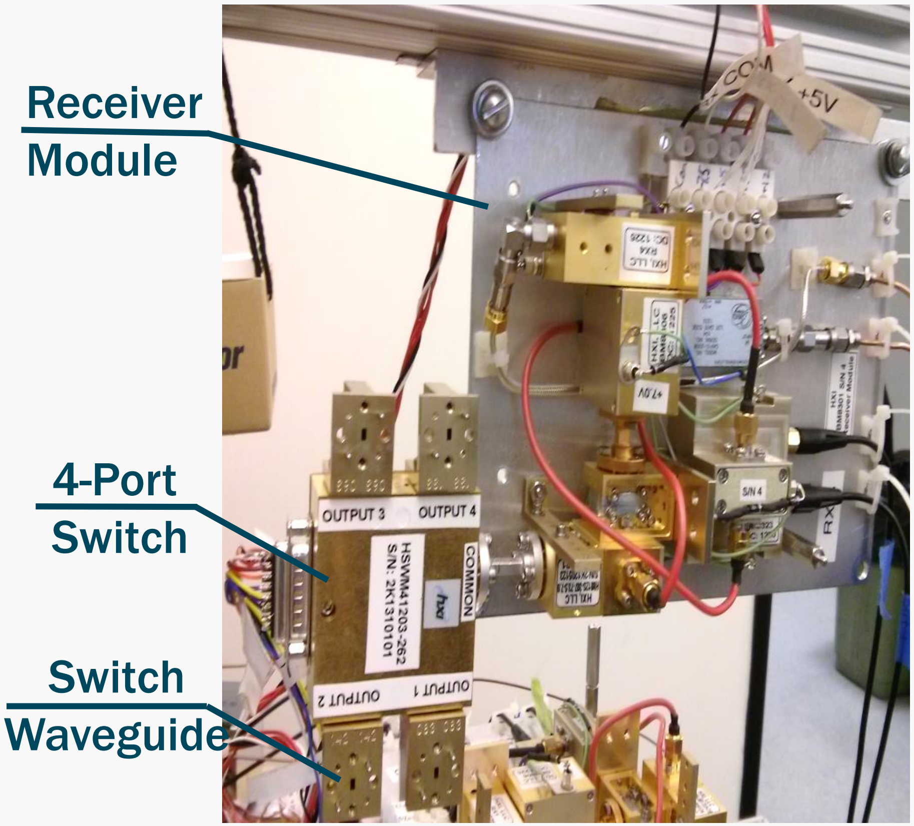
- Needs:
  - New low-cost mm-wave imaging for "Standoff" (10-50 m range) and "On-The-Move" (1-3 m walk through) concealed body-worn threat detection

- So what?
  - Imaging for high throughput, non-invasive, minimal disruption scanning
  - Full body coverage for imaging without interrupting forward steady pedestrian movement
  - Affordable, with minimum number of non-uniform sparse array of Tx/Rx radar modules
  - Dielectric characterization



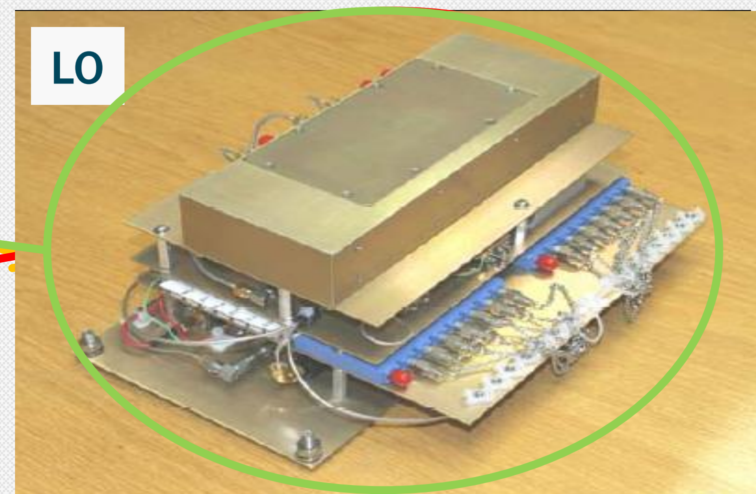
- Who cares?
  - Industrial transition partners: HXI, Inc ; Rapiscan, L3 Communication; Smiths Detection
  - Target government customers: TSA, DOJ, CBP, Dept. of State

Hardware Overview



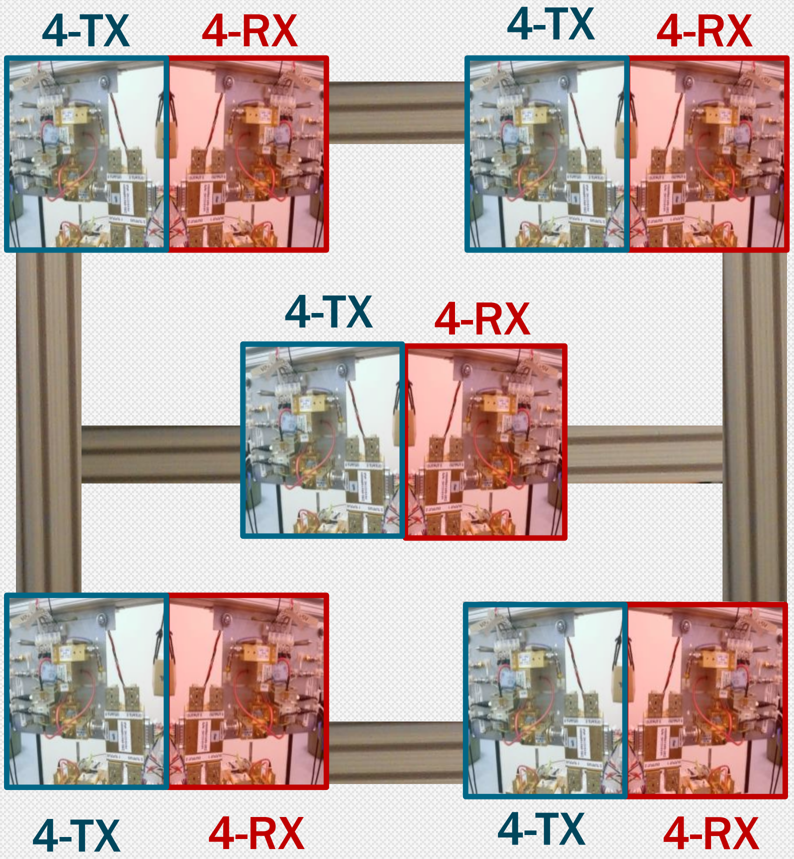
Innovative Elements

- Array of Tx/Rx
  - Rx. – static array
  - Tx. – mechanically scanned
  - Fully coherent multistatic radar
  - Separated Tx & Rx
  - Mm-wave switches



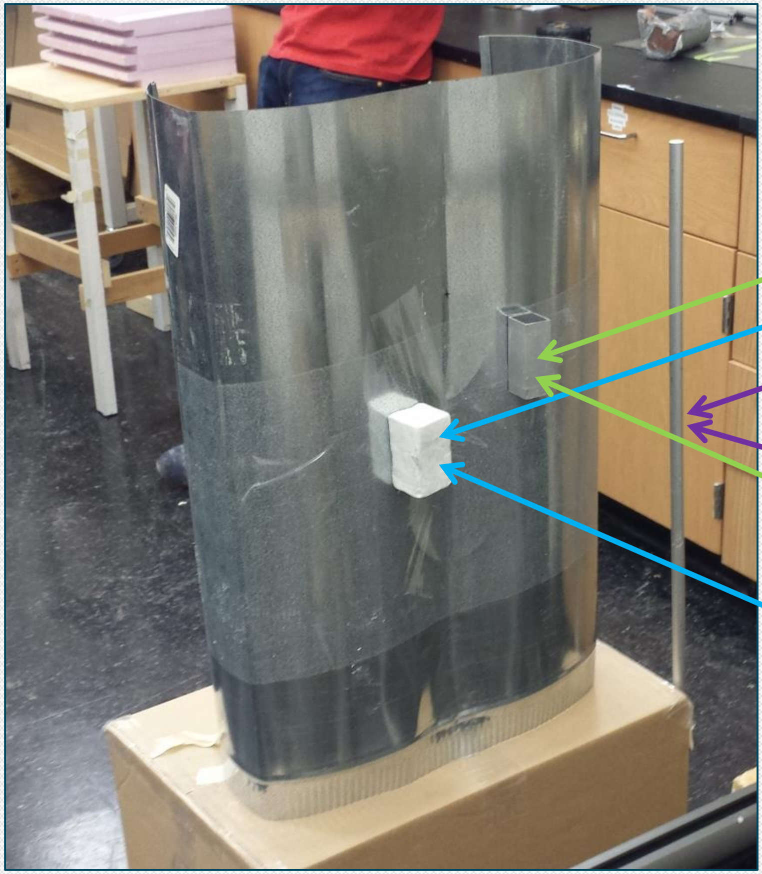
2015/2016 Hardware Development

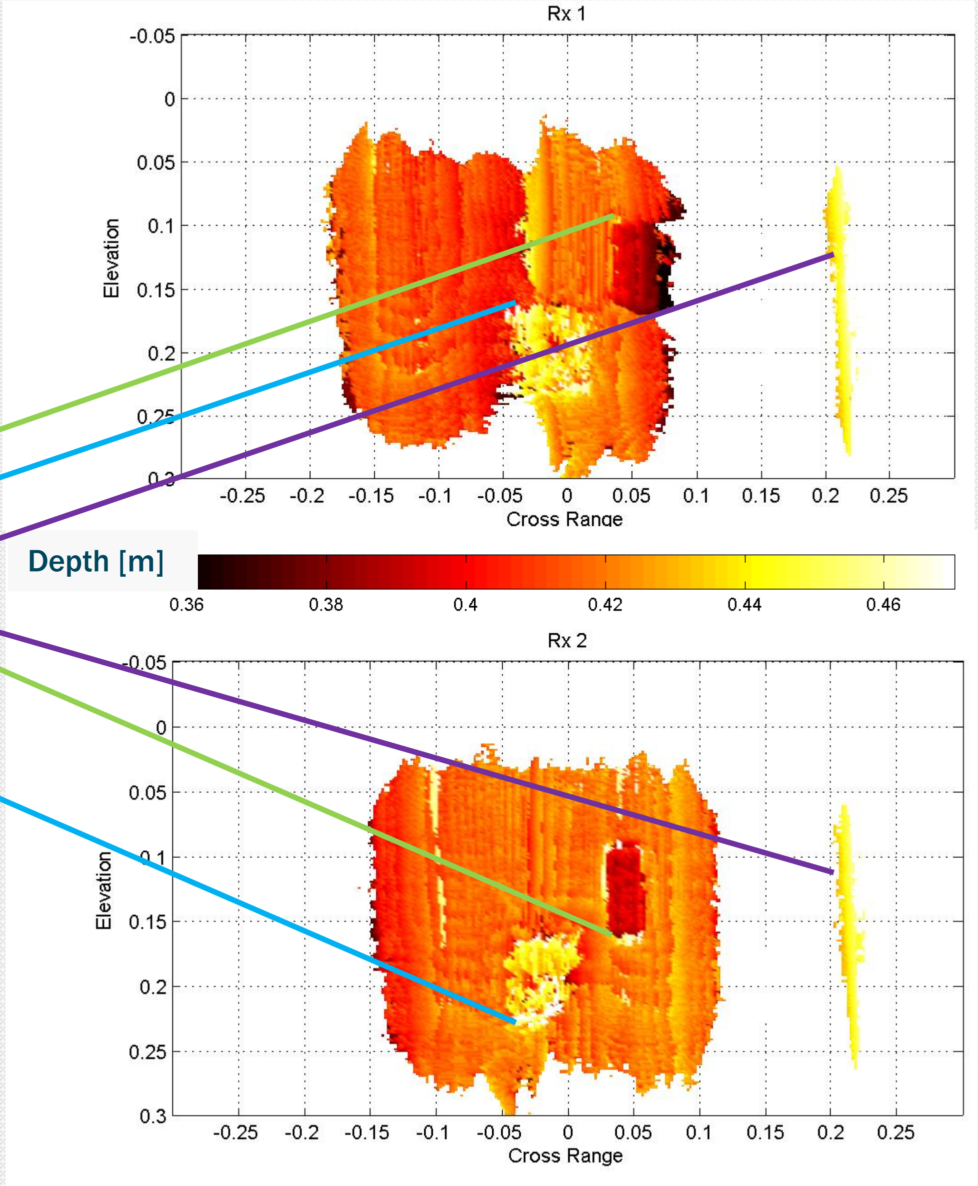
- 3D Imaging fully electronic: (5*4) * (5*4) = 400 Channels



Experimental result #1: 3D Imaging explosive threats (metallic & dielectric) (FFT-multi-static)

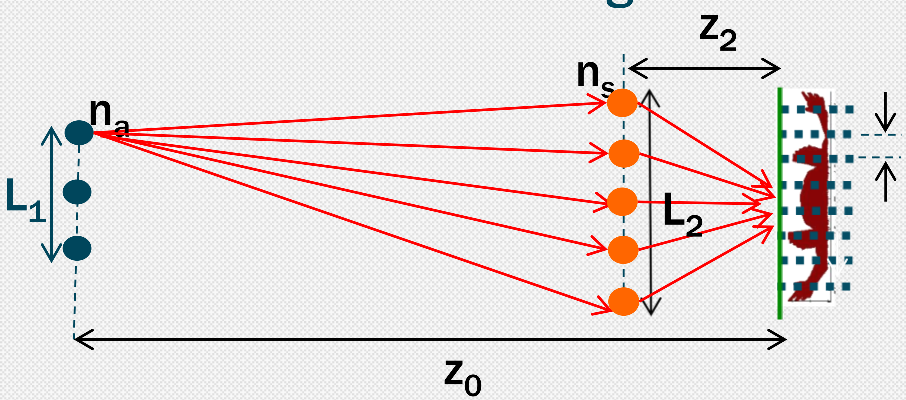
- Metallic pipe
- Dielectric (TNT)

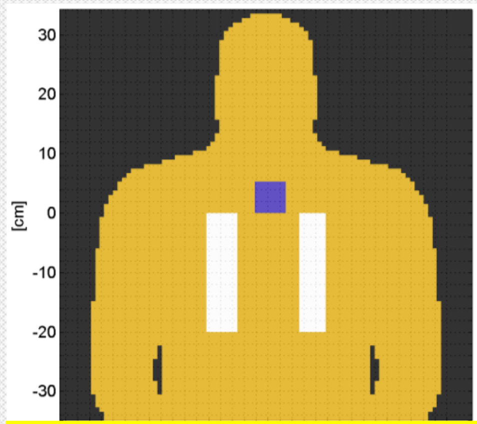




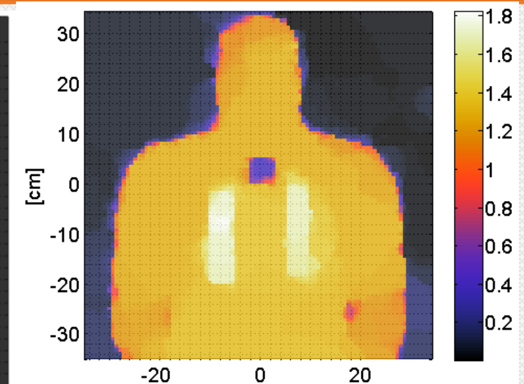
Algorithm #1: Standoff detection using PAS and MRS and 3D Compressive Sensing (CS)

- 2D reconstruction using PAS



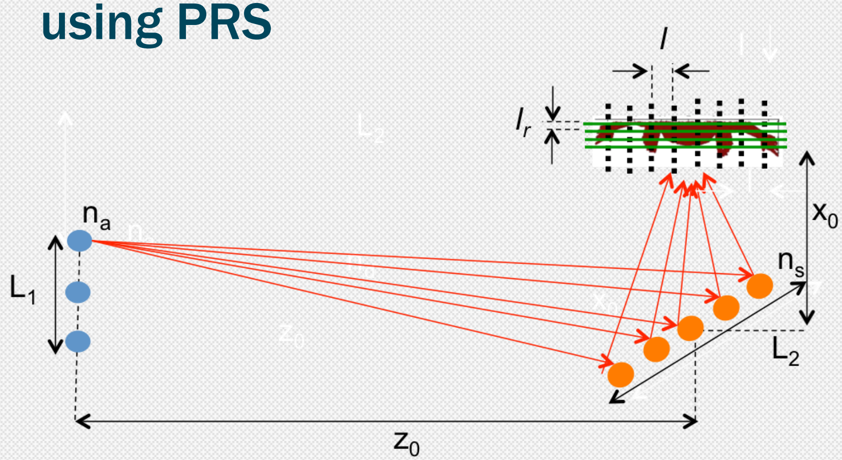


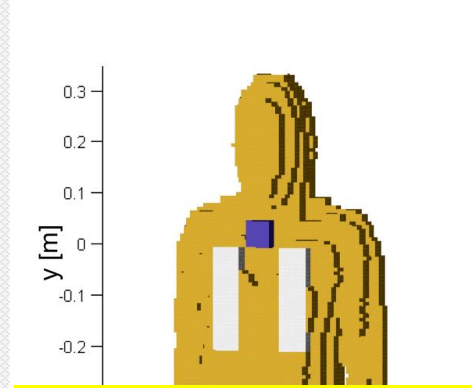
Ground truth



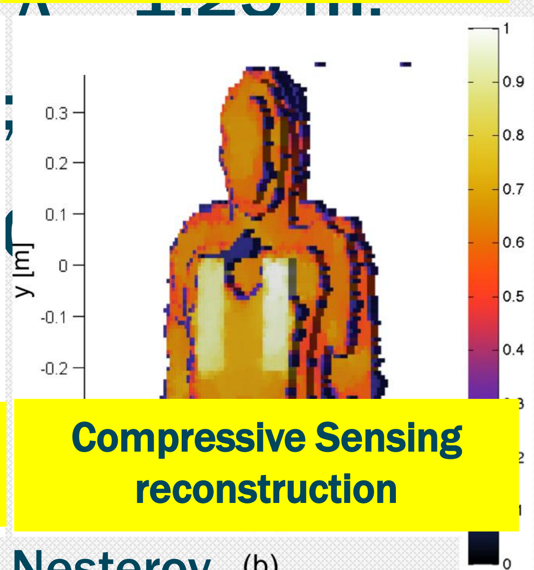
Compressive Sensing reconstruction

- First approach to 3D reconstruction using PRS





Ground truth

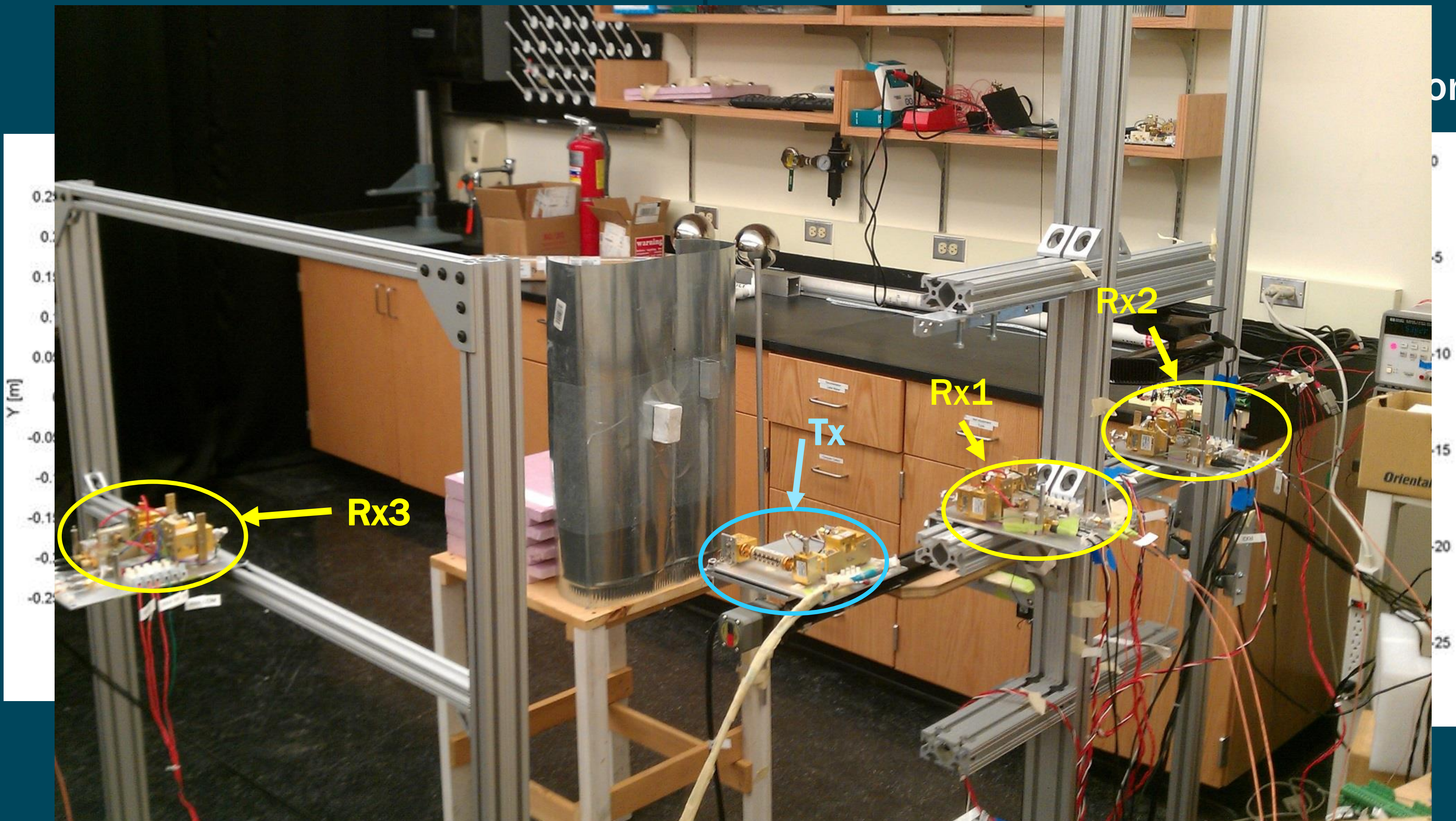


Compressive Sensing reconstruction

(a) (b)

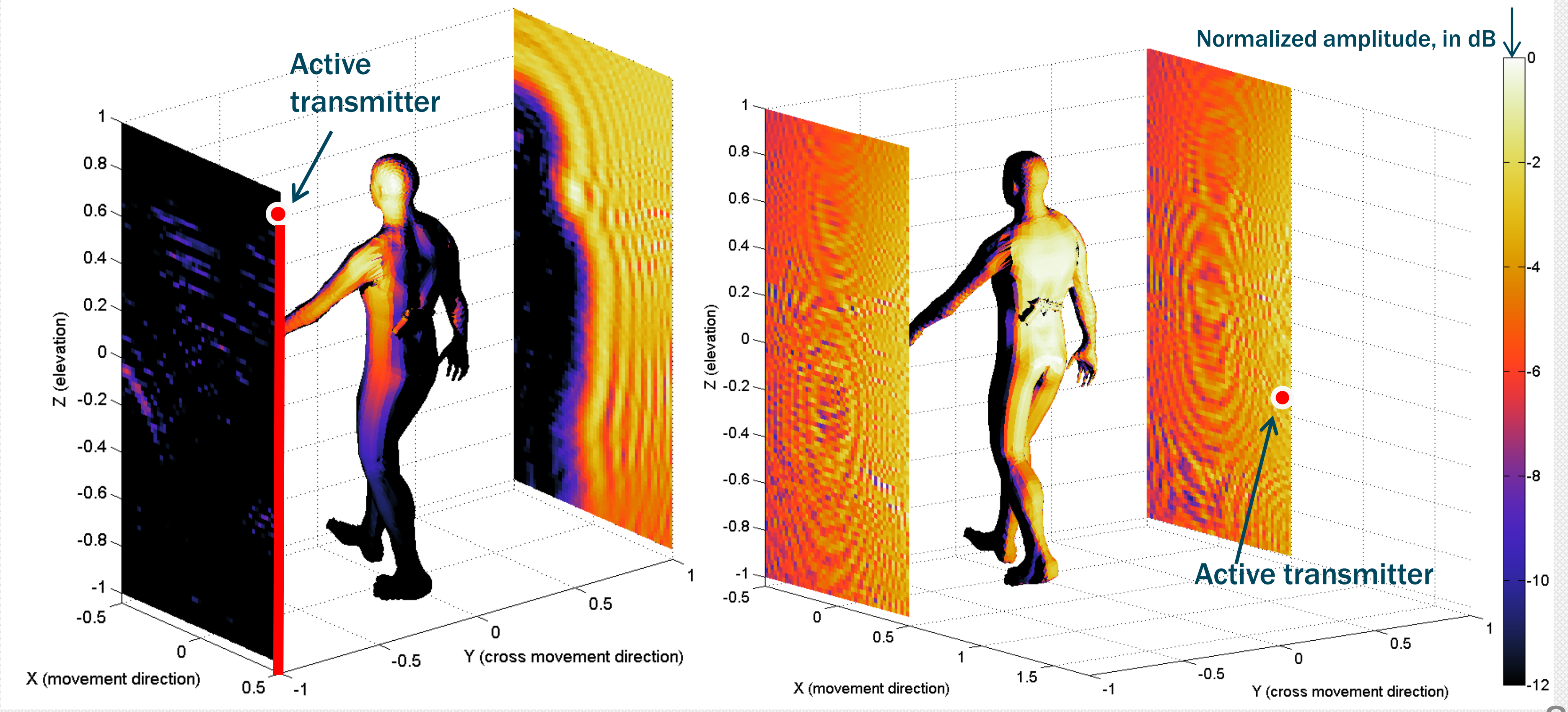
- Next step is used Fourier-based imaging combined with Nesterov inversion (CS) to improve the speed of the inversion.

Why is important LO? On-the-move concept



3D forward modeling of a novel "On-the-move" configuration using MECA

- Forward method (MECA) for the simulation of realistic human bodies: Metallic; Dielectrics – Lossy & Dispersive (including Meta-materials)
  - Equivalent currents based method for fast simulation of scattered fields for Rx/Tx



3D imaging of a novel "On-the-move" configuration using CS + FFT (forward+inverse)

- 3D Fourier-based reconstruction for different positions

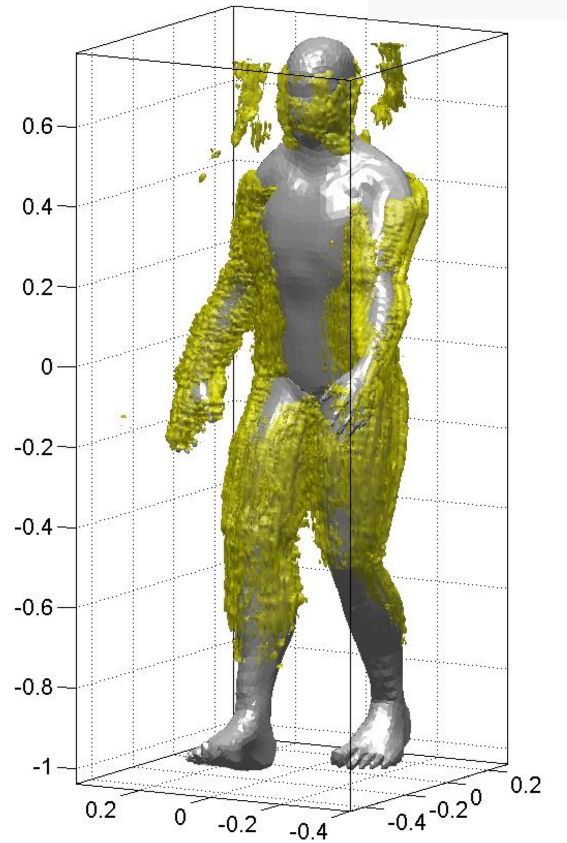
15 to 30 GHz BW

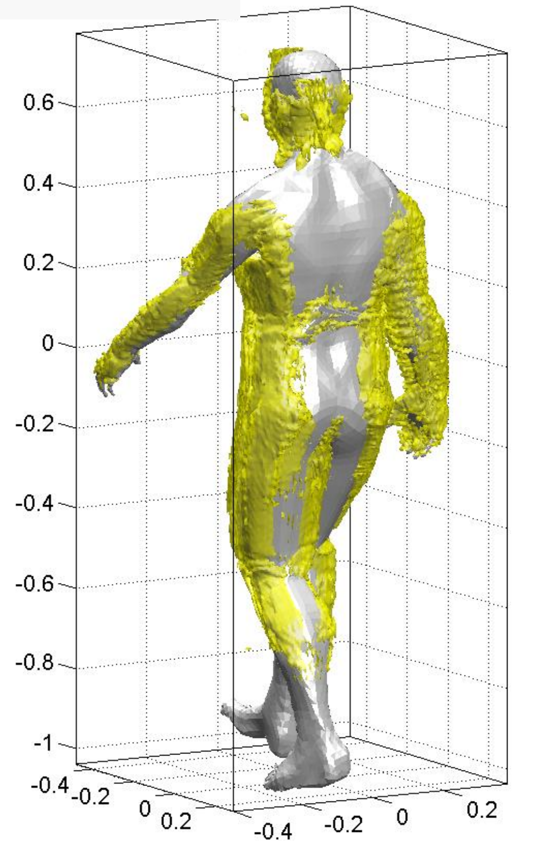
50 transmitters

201 x 401 receiving

SAR → 1400 s
FFT → 10 s

Recovered reflectivity.
-15 dB isosurface

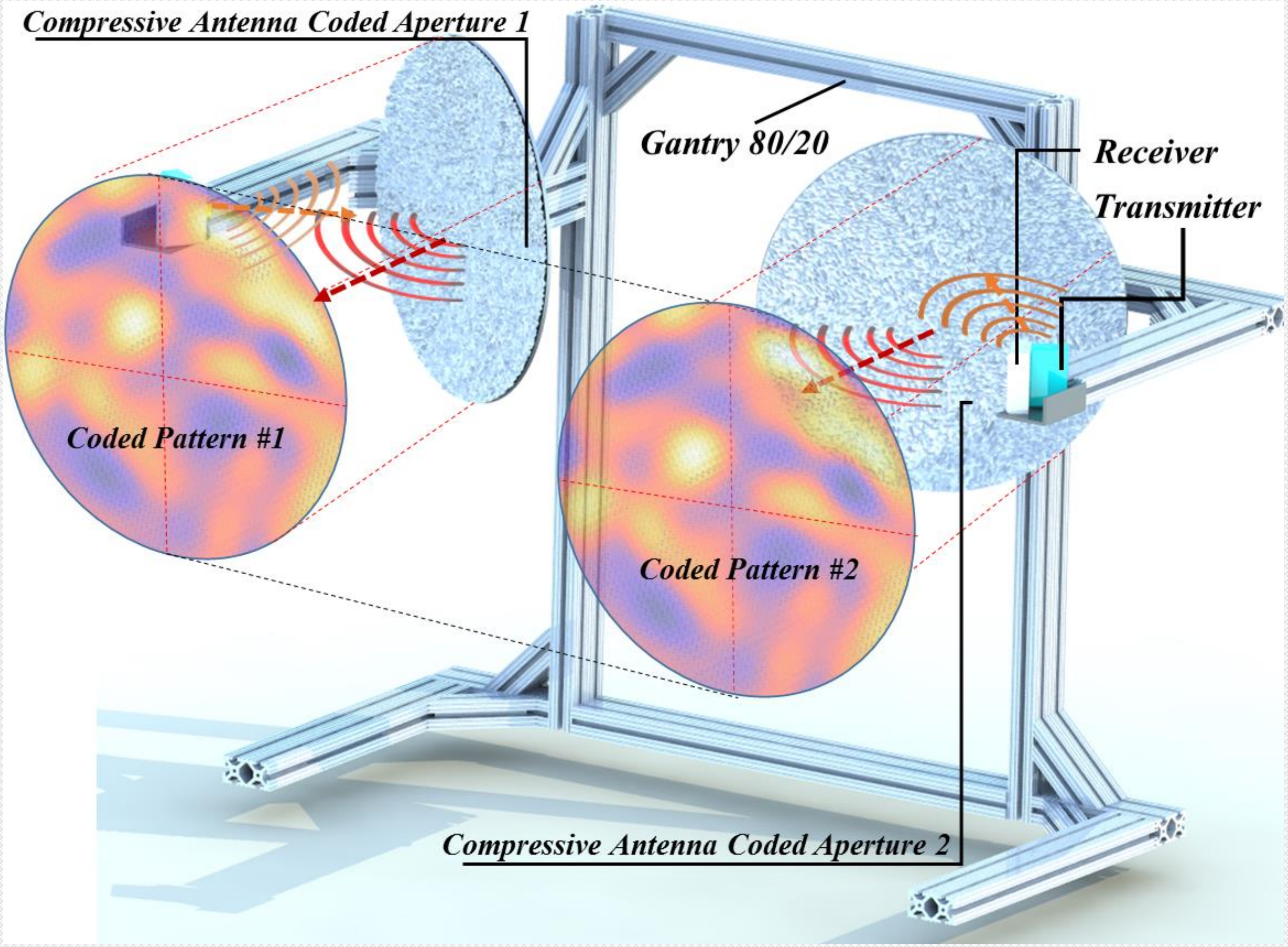




Yolanda Rodriguez Vaqueiro, Yuri Ivarez, Borja Gonzalez-Valdes, Fernando Las-Heras and J. A. Martinez-Lorenzo. Fast Multistatic Fourier-based Forward and Inverse Operators for Compressive Sensing Imaging. accepted for publication AP-S 2015 — IEEE AP-S International Symposium, Vancouver, Canada, Jul. 2015.

CCA/CCMA testbed

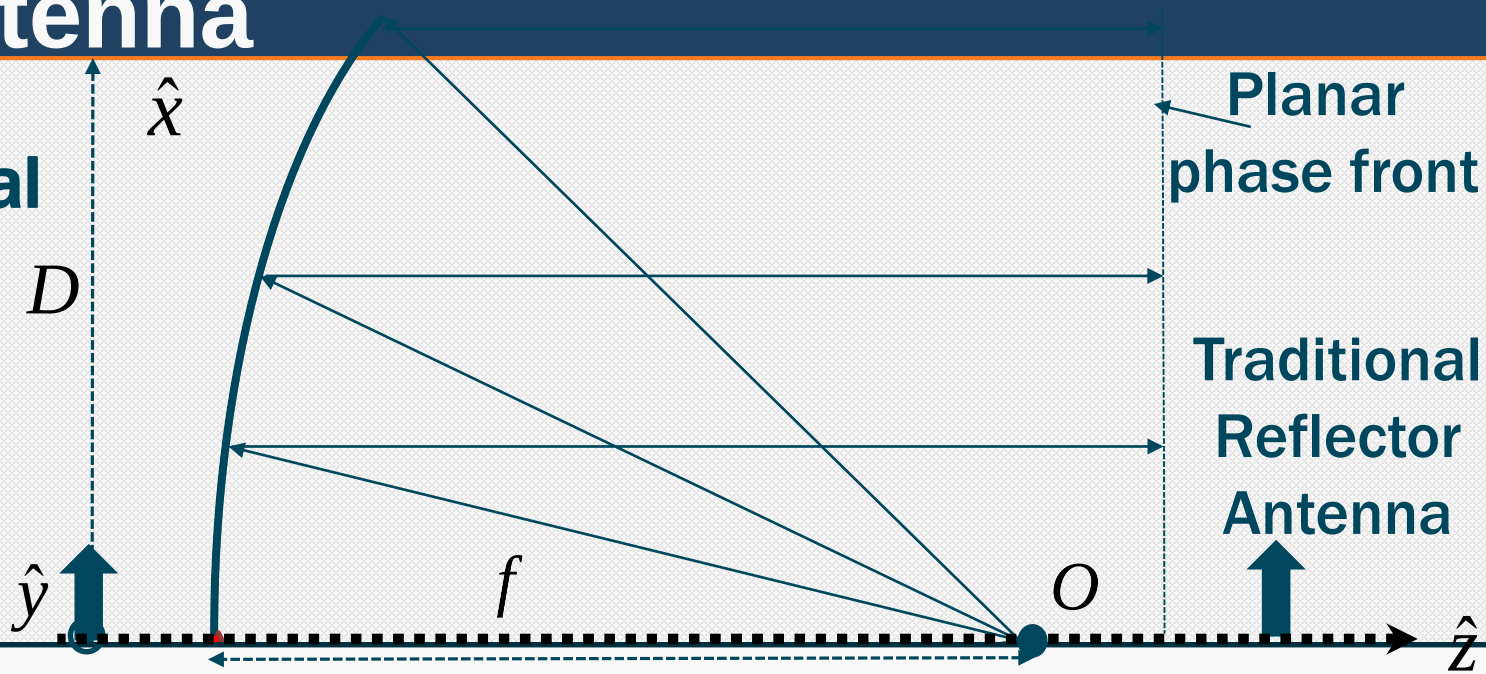
- Configuration



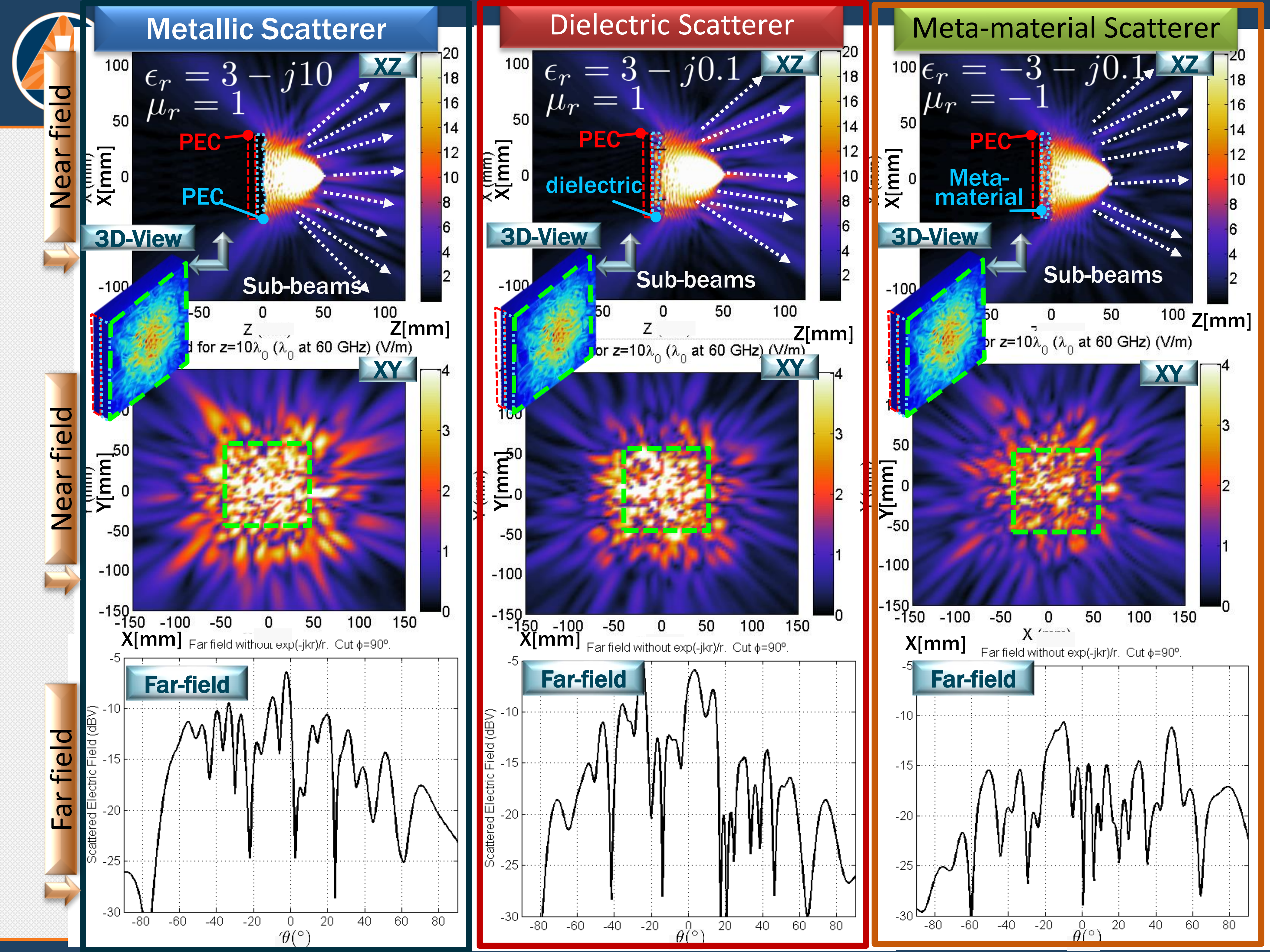
CCA: Compressive Reflector Antenna

Traditional Reflector Antenna

$x > 0$



Each scatterer Ω_i is defined by Electromagnetic parameters and 3D size



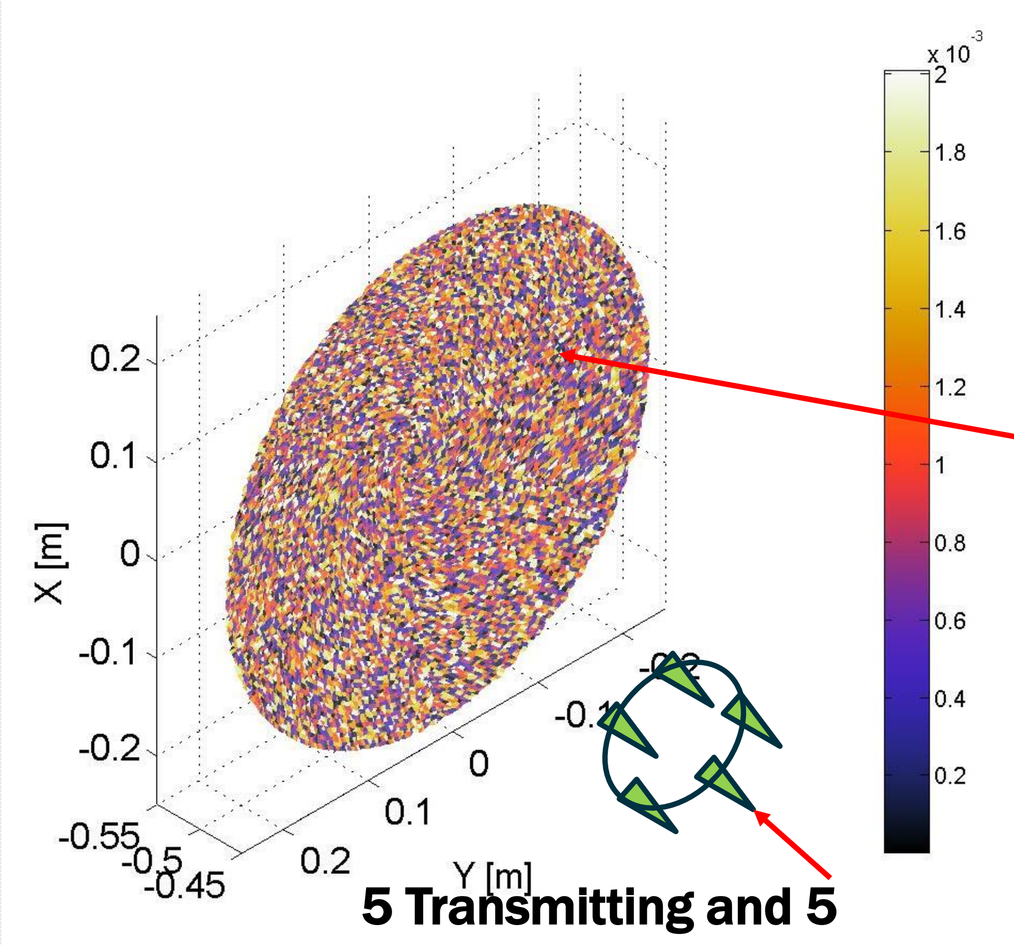
Metallic Scatterer
Dielectric Scatterer
Meta-material Scatterer
Near field
Near field
Far field
$\epsilon_r = 3 - j10$
$\mu_r = 1$
$\epsilon_r = 3 - j0.1$
$\mu_r = 1$
$\epsilon_r = -3 - j0.1$
$\mu_r = -1$
XZ
XY
PEC
PEC
dielectric
Meta-material
3D-View
Sub-beams
X[mm]
Z[mm]
Y[mm]
Far field without exp(-jkr)/r. Cut ϕ=90º.
Far-field
Scattered Electric Field (dBV)
θ(°)

Example #1- "Fully-Electronic": Geometry

a) Reflector antenna with pseudo-random codification mask

PARAM.	CONFIG.
λ_c	$5 \cdot 10^{-3} m$
D	$200\lambda_c$
$\langle D^x \rangle = \langle D^y \rangle$	$1.5\lambda_c$
D_i^z	$U(\pm 0.54\lambda_c)$
f	$200\lambda_c$
h_0	$0\lambda_c$
N_t	93
N_θ	31

PARAM.	CONFIG.
N_f	3
N_p	25000
z_0^T	$195\lambda_c$
Δx_0^T	$36\lambda_c$
Δy_0^T	$36\lambda_c$
Δz_0^T	$7.5\lambda_c$
l	$1.5\lambda_c$

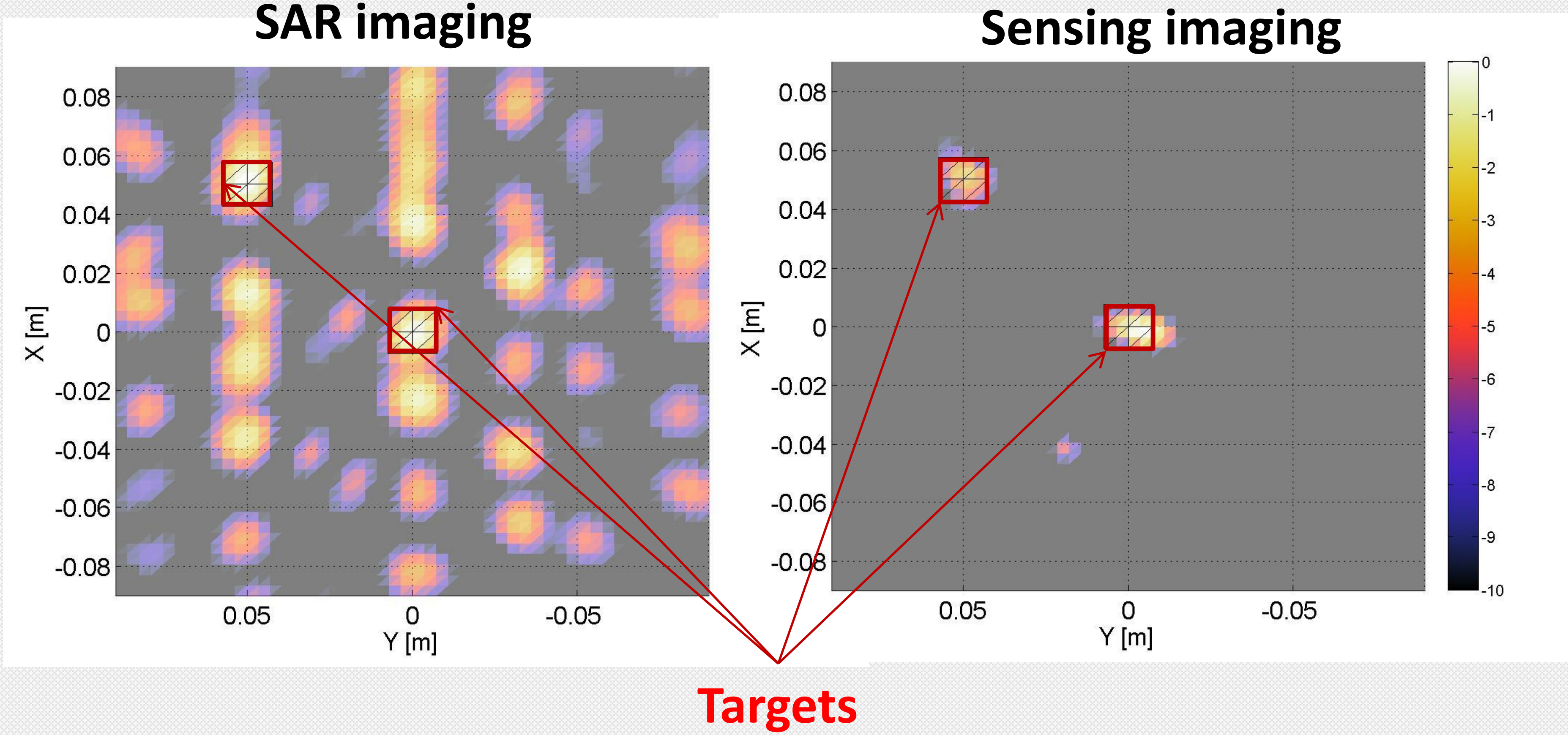


Distortions are relative to a perfect parabolic profile

5 Transmitting and 5 Receiving horns

Example #1-Preliminary imaging results

Traditional SAR imaging | **Compressive Sensing imaging**



METHODOLOGY	EXECUTION TIME
Pseudoinverse	10 ms
NESTA	203 s
ADMM	3 s

Conclusions

- **Hardware:** Coherent, multiple transceivers and switches
- **Algorithms: Compressive Sensing** techniques (consensus)
- **CCA/CCMA** is obtained adding **pseudo-random appliqué scatterers** on the surface of the TRA: dielectrics, metallic, meta-materials.
- **CCA/CCMA** enhances the **channel capacity**
- Potential configurations of **Compressive Reflector Antenna:**
  - Mechanical scanning (3D imaging):
    - Conf. #1: single frequency; single transceiver ($).
  - Electrical scanning (3D imaging):
    - Conf. #2: single freq.; multiple transceiver ($$).
    - Conf. #3: multiple freq.; multiple transceivers ($$$)
    - Conf. #4: multiple freq.; multiple transceivers; dielectric/meta-materials ($$$$)