Ultra-Wideband Radar Imaging

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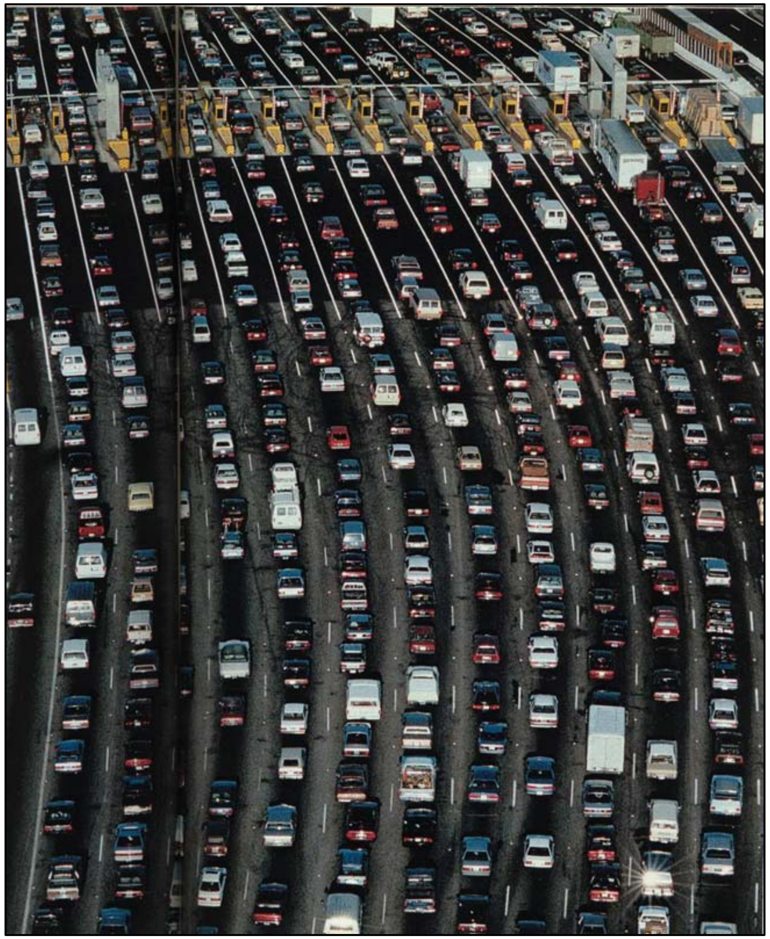
The growing world population gets prone to

a wide spectrum of security and safety concerns as



In Europe each year about 1.3 million traffic accidents cause:

- More than 35.000 fatalities
- Economical damage of more than 200 billion € per year

Human error is involved in over 90% of accidents

http://ec.europa.eu/information_society/activities/policy_link/brochures/documents/intelligent_car.pdf

The growing world population gets prone to

a wide spectrum of security and safety concerns as

Natural and anthropogenic catastrophes resulting in search for survivors

The growing world population gets prone to

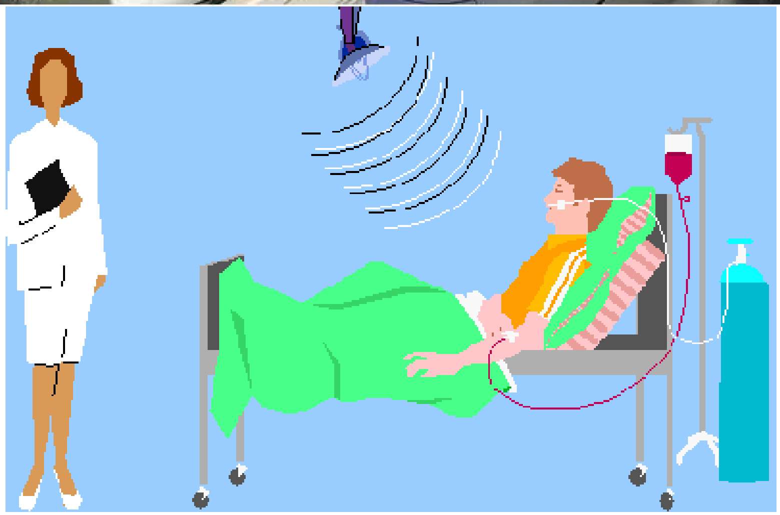
a wide spectrum of security and safety concerns as

Kidnapping and terrorist attacks

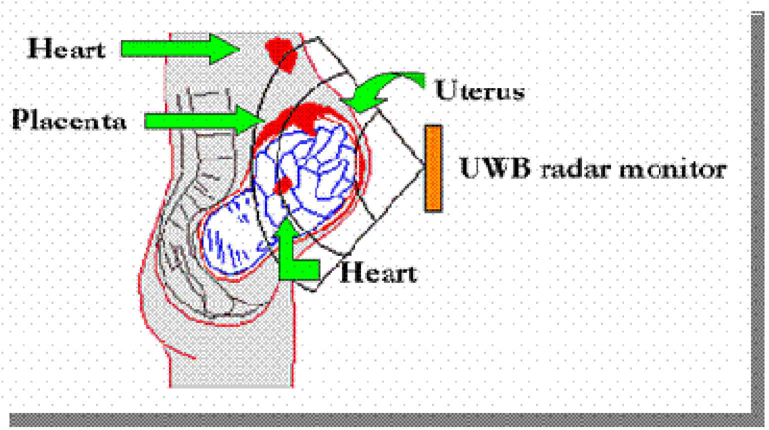
Source: P. Withington, H. Fluhler, and S. Nag, “Enhancing homeland security with advanced UWB sensors,” *Microwave Magazine, IEEE,* vol. 4, no. 3, pp. 51-58, 2003.

The growing world population gets prone to

a wide spectrum of health concerns which require



- Remote health monitoring
- Body imaging



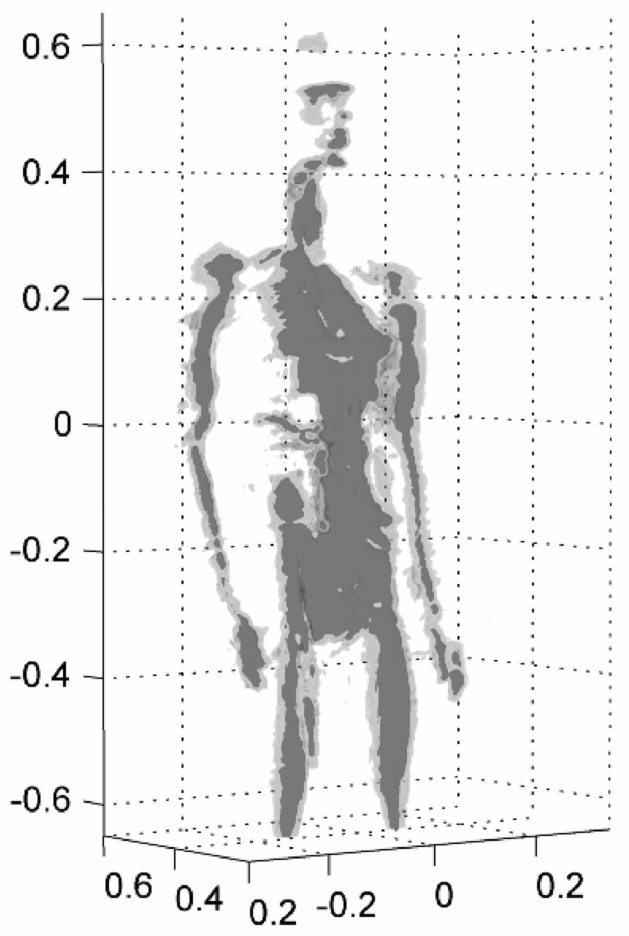
Growing need for microwave imaging sensors

High-resolution radar belongs to those sources of data which can provide crucial information in a number of scenarios such as shown above.

Subsurface imaging is an essential requirement to these sensors.

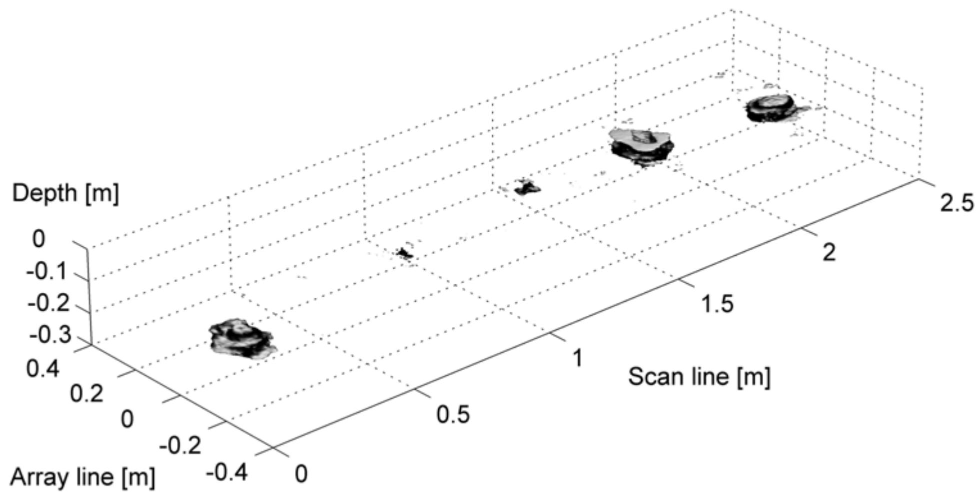
Microwave frequencies (300MHz-30GHz) allow for a combination of through-the-interface penetration and high resolution.

3D microwave imaging



Concealed weapon detection

What is needed to create such images in real-time?

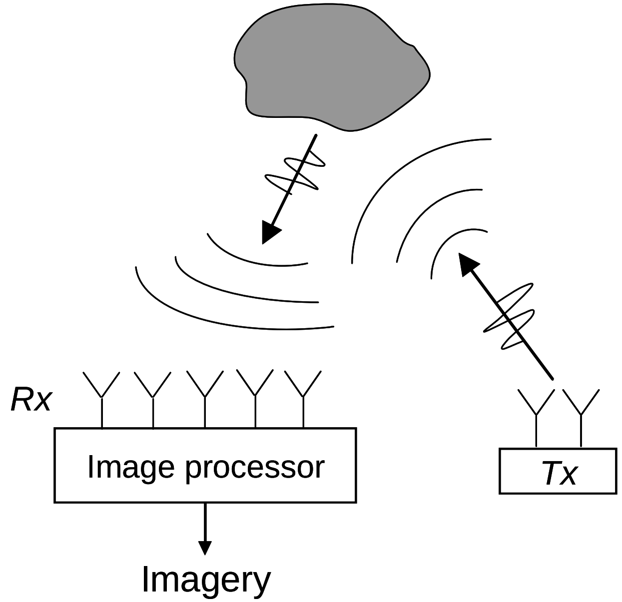


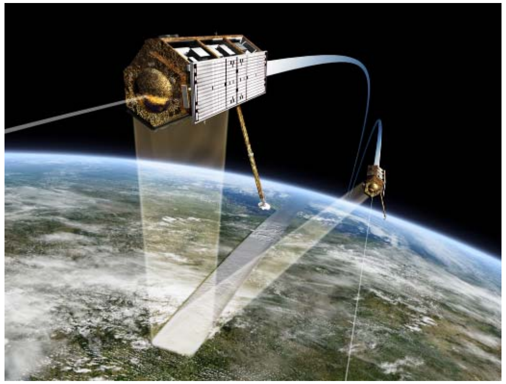
Buried antipersonnel mine imaging

Principles of microwave imaging

Methodology

- Microwave transmitter illuminates the scene with EM waves
- Target reflects parts of energy
- Receive antenna intercepts the reflected or scattered energy
- The receive system processes the echoes and reconstruct the imagery





SAR

Real aperture array

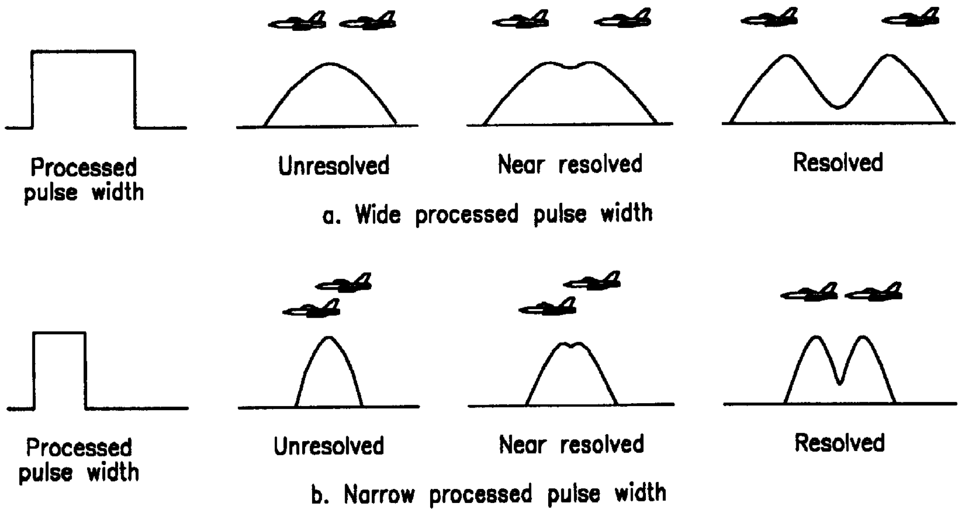
Established methods

- Dielectric lens or a focusing reflector with focal plane array
- Synthetic aperture radar
- Real aperture imaging

Challenges – 1/3

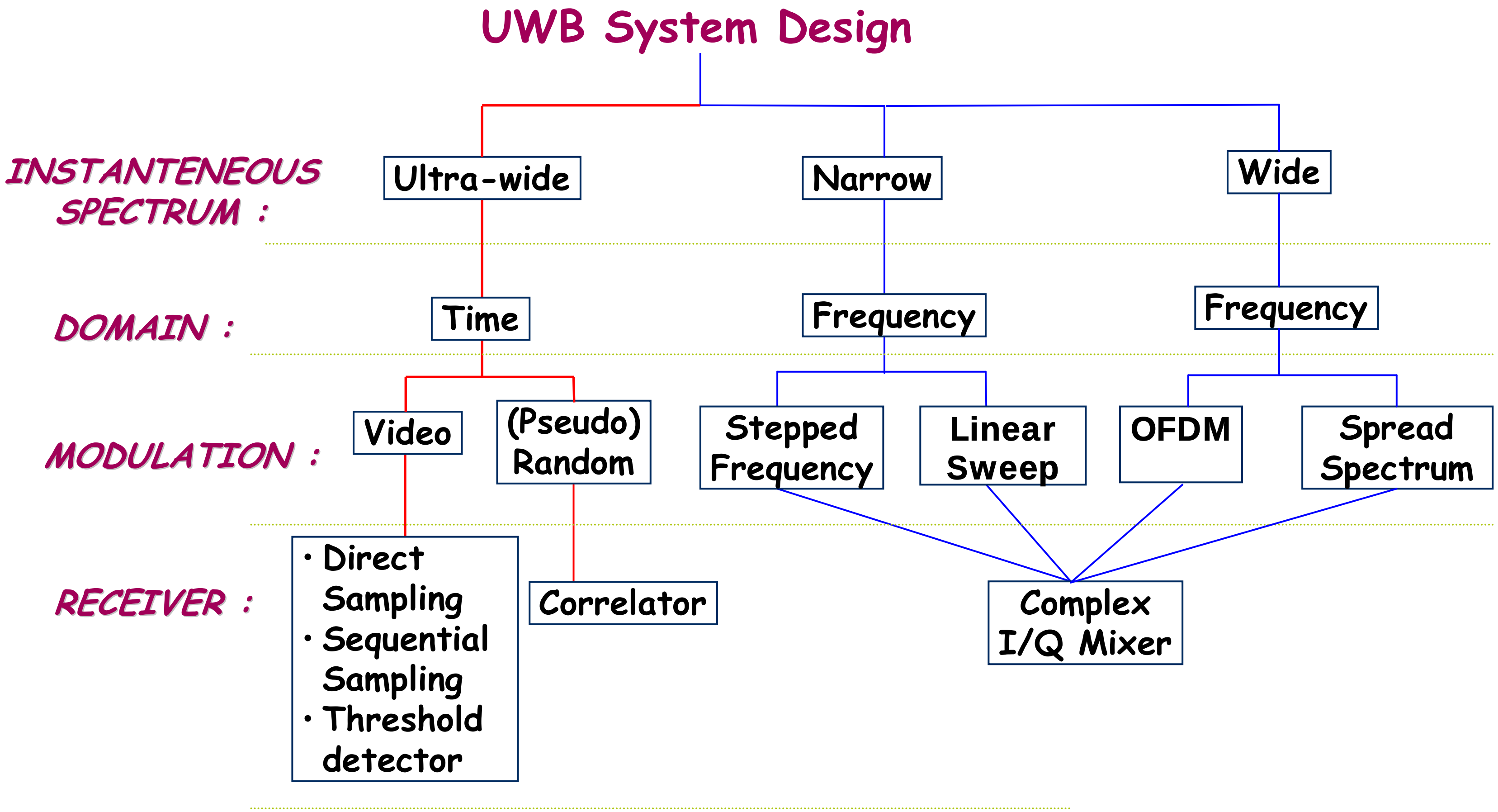
Fine down-range resolution can be achieved by selecting sufficiently large operational bandwidth

Resolution: $\Delta R = \dfrac{c}{2B}$



Large bandwidth can be also used for target classification via waveform analysis

UWB system types



[Adapted from D.J.Daniels, "Surface-penetrating radar", IEE]

Optimal UWB technology selection

depends on a particular application.

For a short range through-the-wall imaging …

Transmission scheme	Data acquisition time	Other limitations
Video impulse	868usec	Linear dynamic range
SFCW	1.6msec	No
FMCW	80usec	No
M-sequence	330nsec	Linear dynamic range

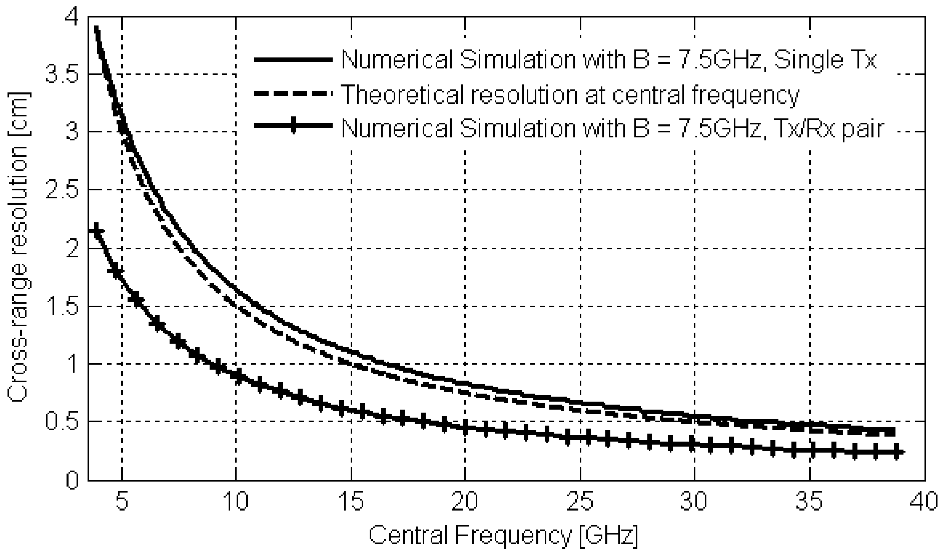
For this set of parameters, FMCW technology looks the most attractive one

Performance comparison for a single Tx/Rx pair

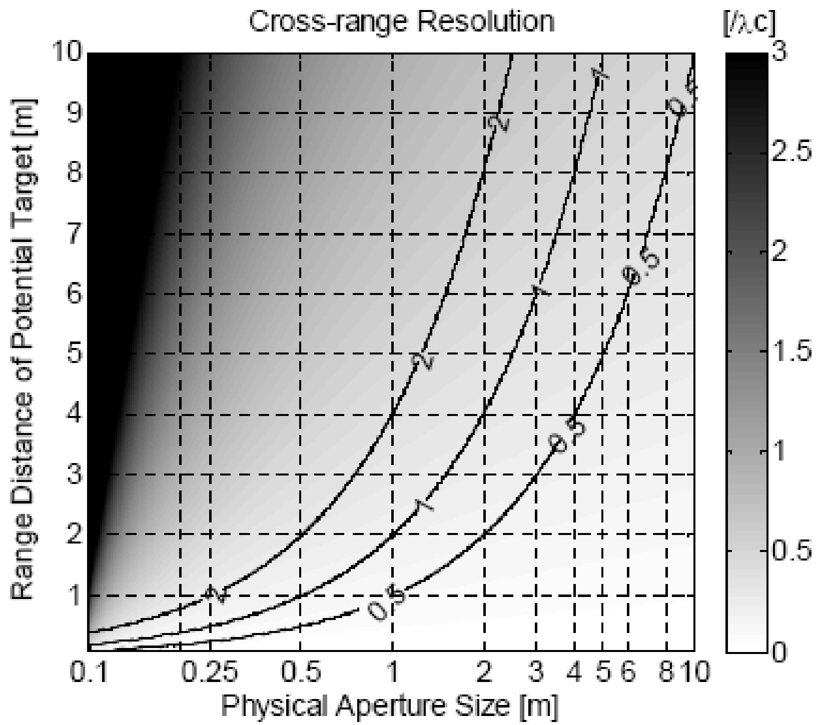
Challenges – 2/3

Resolution in the cross-range:

- Inversely proportional to the operational frequency
- Array aperture size should be similar to the potential target range.



Dependence of resolution on frequency

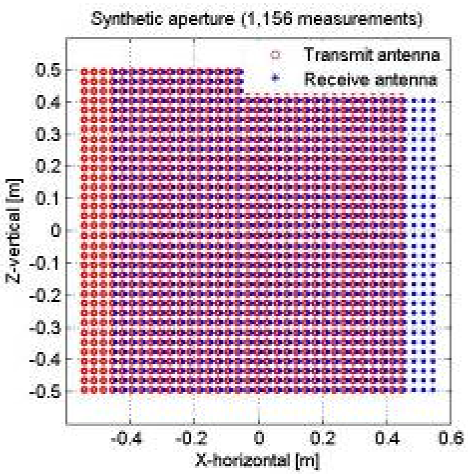


Resolution vs. aperture size and target range

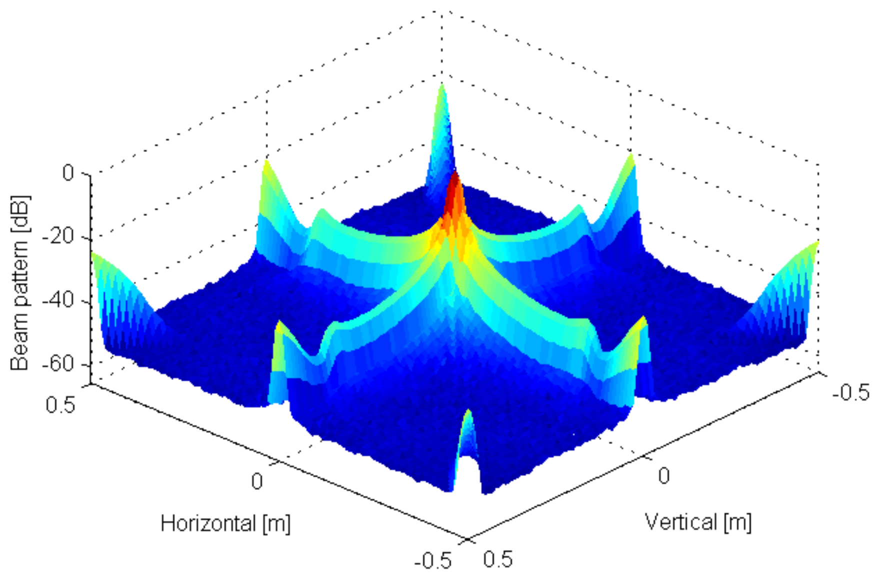
Challenges - 3/3

System complexity: too large number of antenna elements within the array aperture is required

- Element spacing must obey the half-wavelength rule to avoid unwanted grating lobes, which severely reduces contrast and dynamic range available for imaging
- A planar 2D array requires prohibitive number of elements to achieve both high-resolution and focusing capabilities



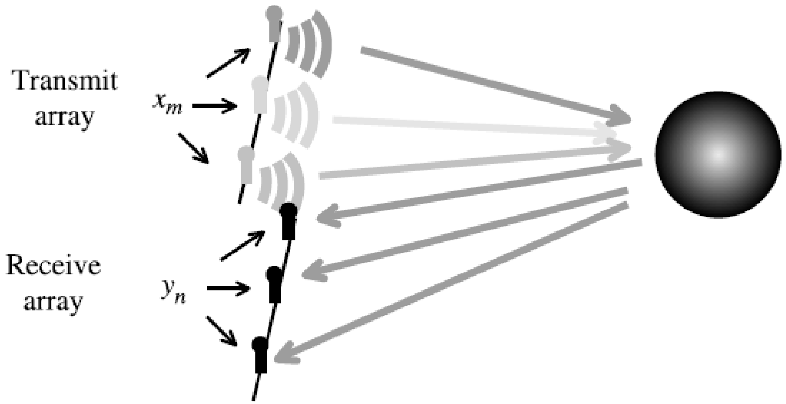
1,200 element aperture at 7 GHz center frequency still exhibits -20 dB grating lobe level



Multiple-Input Multiple-Output

Multi-static radar with distributed transmitters and receivers

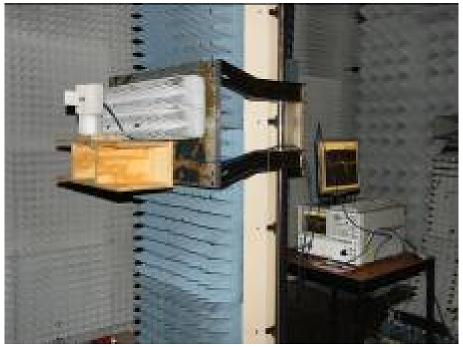
- Compliments mono-static diversity as in SAR with multi-static diversity
- Possesses the following advantages: possibility to reduce number of channels and speed-up data acquisition
- Has the following consequences:
  - Research on optimal topology is needed to avoid high sidelobes
  - Multi-static imaging instead of SAR-like approach (signals over all transmit/receive pairs are processed together to form the image)

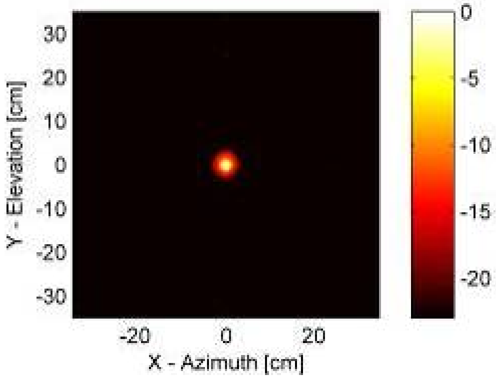


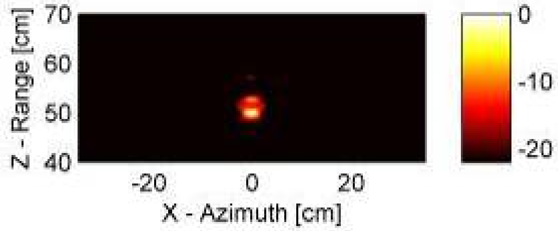
Real aperture MIMO array vs SAR

1D real aperture array combined with synthetic aperture in 1D shows the same imaging performance as 2D synthetic aperture for a point-like target

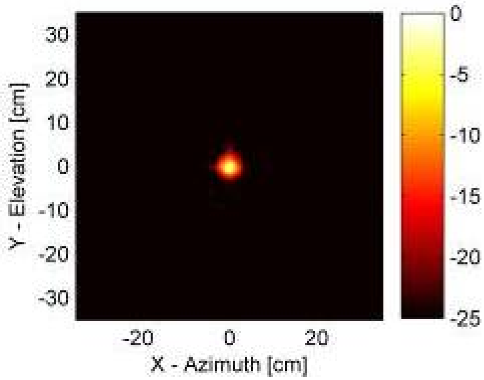
SAR

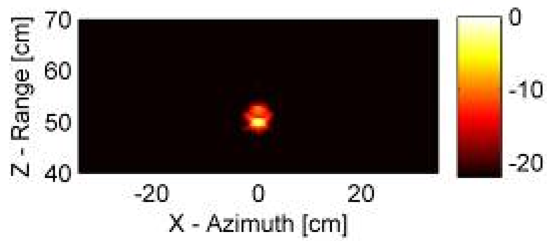






Array +SAR





Measurement setup

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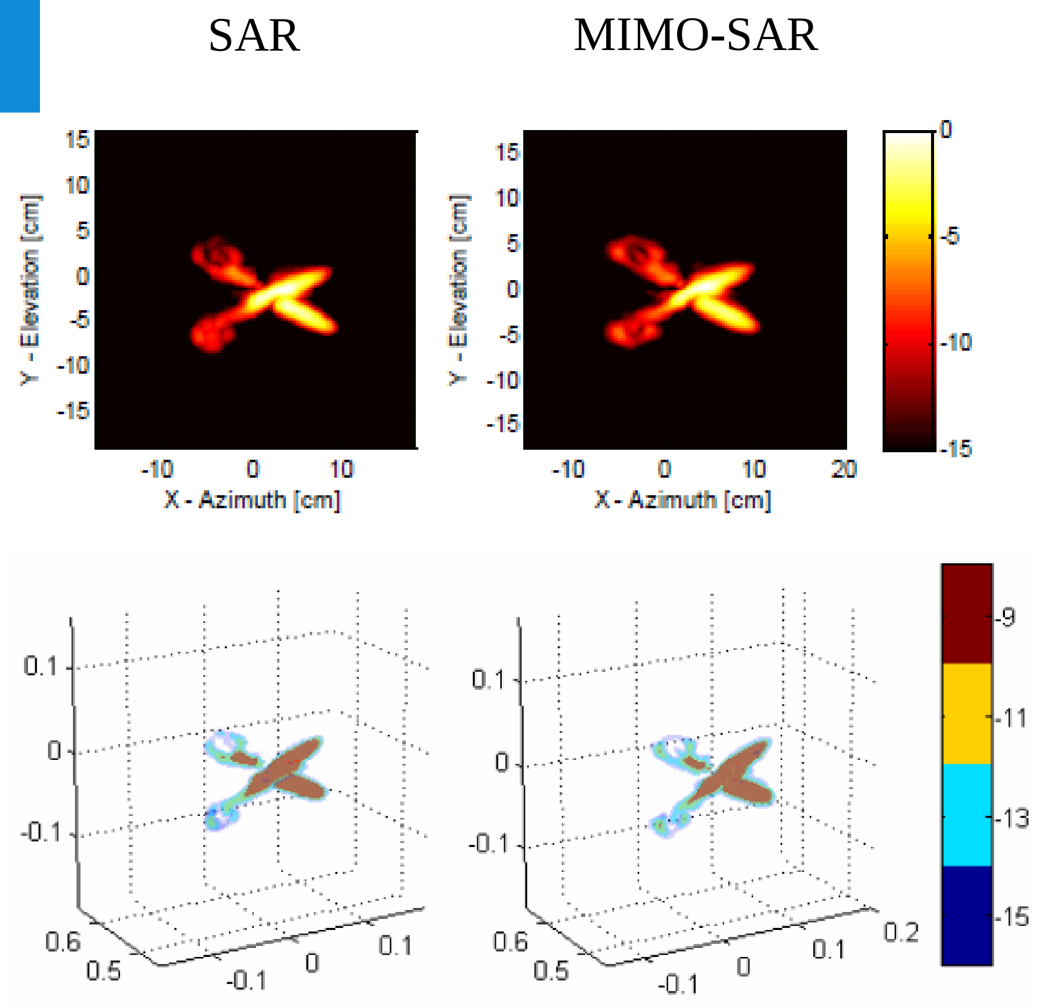
Distributed target imaging



Imaging of metallic scissor placed at 0.5 m range

- Both MIMO-SAR and SAR are able to reconstruct the profile of the target with details
- No artifacts are visible until -25 dB
- The MIMO array with 12 antennas gives better object reconstruction than SAR with 40 positions

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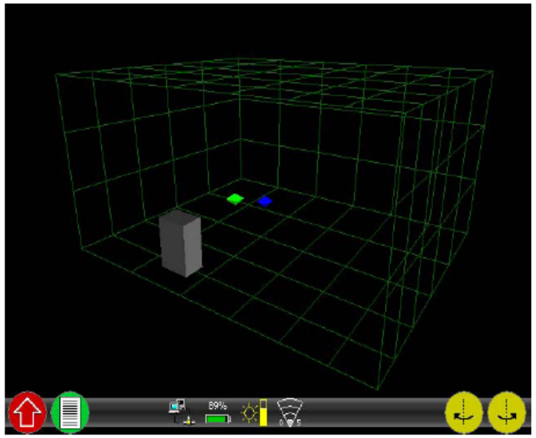
UWB Multiple-Input Multiple-Output radar applications

- Through-the-wall radars
- Concealed weapon detection
- Health care

Through-the-wall radar

RaderVision2i screen displaying 2 targets

Radar Vision 2, Handheld through-wall radar, Time Domain Corp. Courtesy Time Domain Corp.

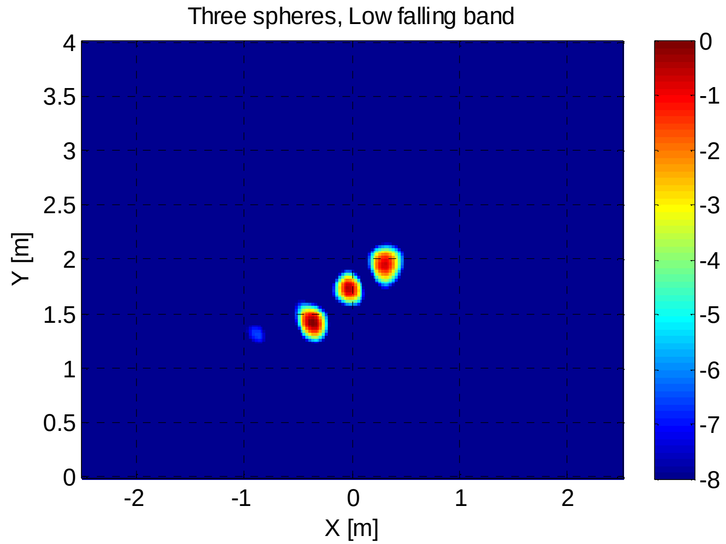


Prism 200, Handheld through-wall radar, Cambridge consultants. Courtesy Cambridge consultants

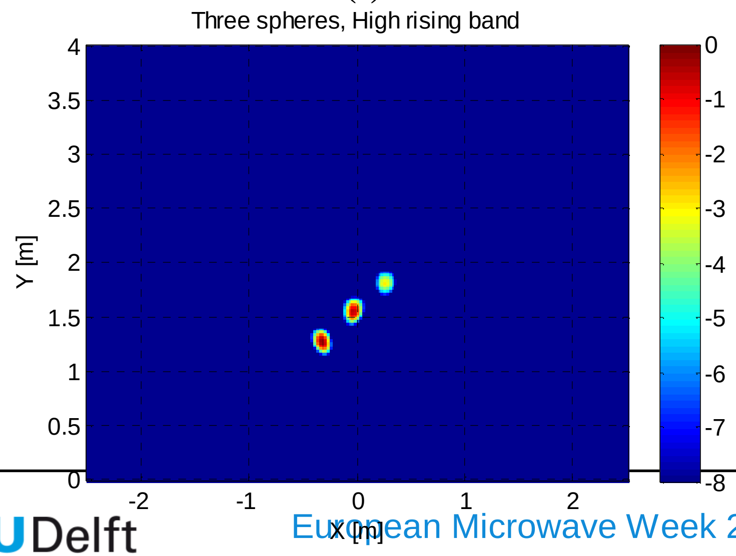
Probant: MIMO dual-band FMCW radar

- Continuous illumination for micro-Doppler
- 2.5GHz bandwidth
- Imaging volume – 5m * 5m * 20m
- 12 imaging frames per second

Probant: MIMO dual-band FMCW radar



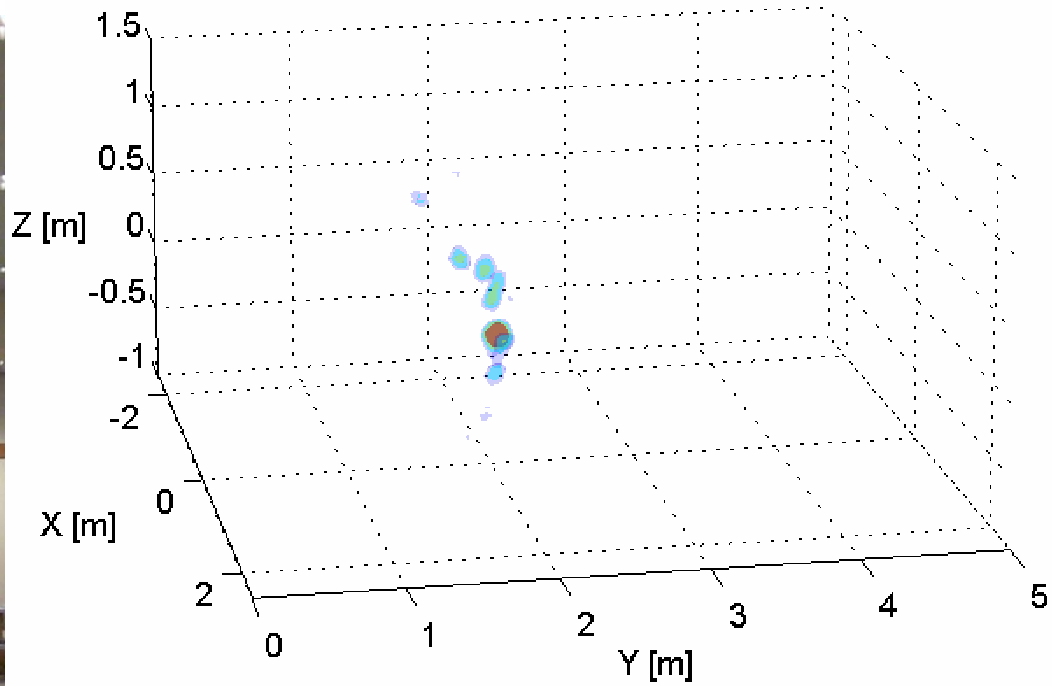
(a)



(b)

Radar resolution in down- and cross-range at different frequency bands is of about 30cm

Through-the-wall imaging



Simple 3D human body shape reconstruction is possible even through 30cm-thick reinforced concrete wall.

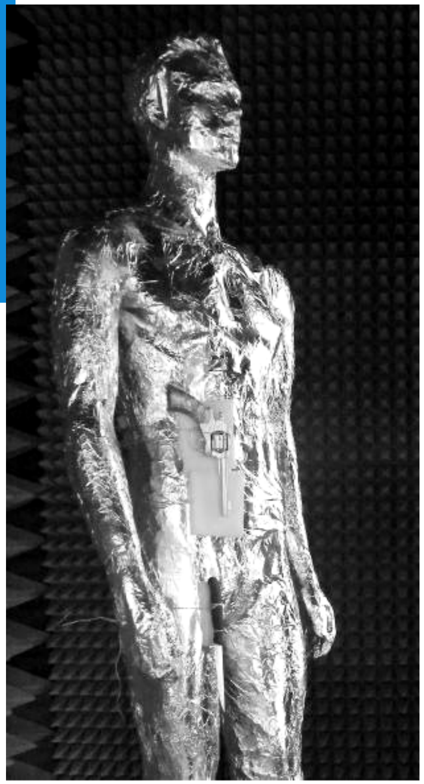
Passenger screening

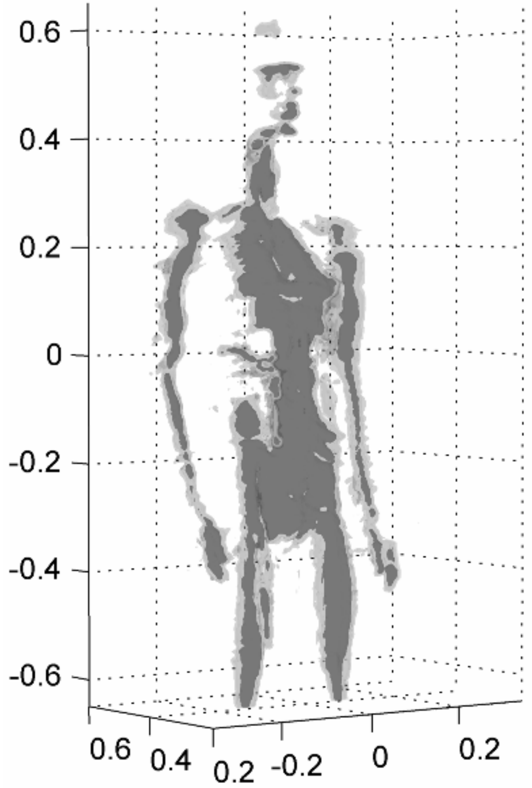
Provision Body Scan, Schiphol airport

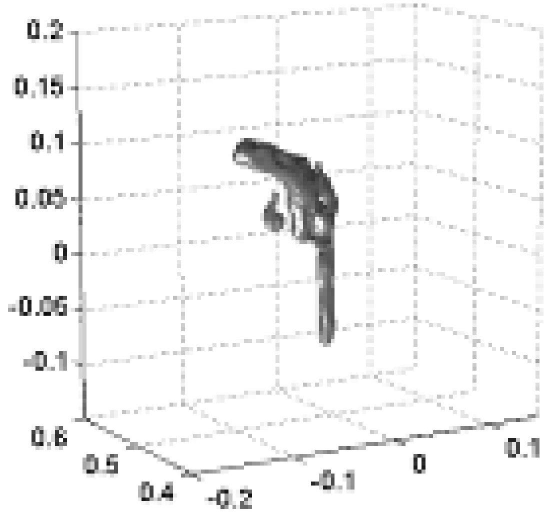
Courtesy L3 Communications

MM-wave image. Courtesy DPA

ATOM: Imaging of full-size mannequin





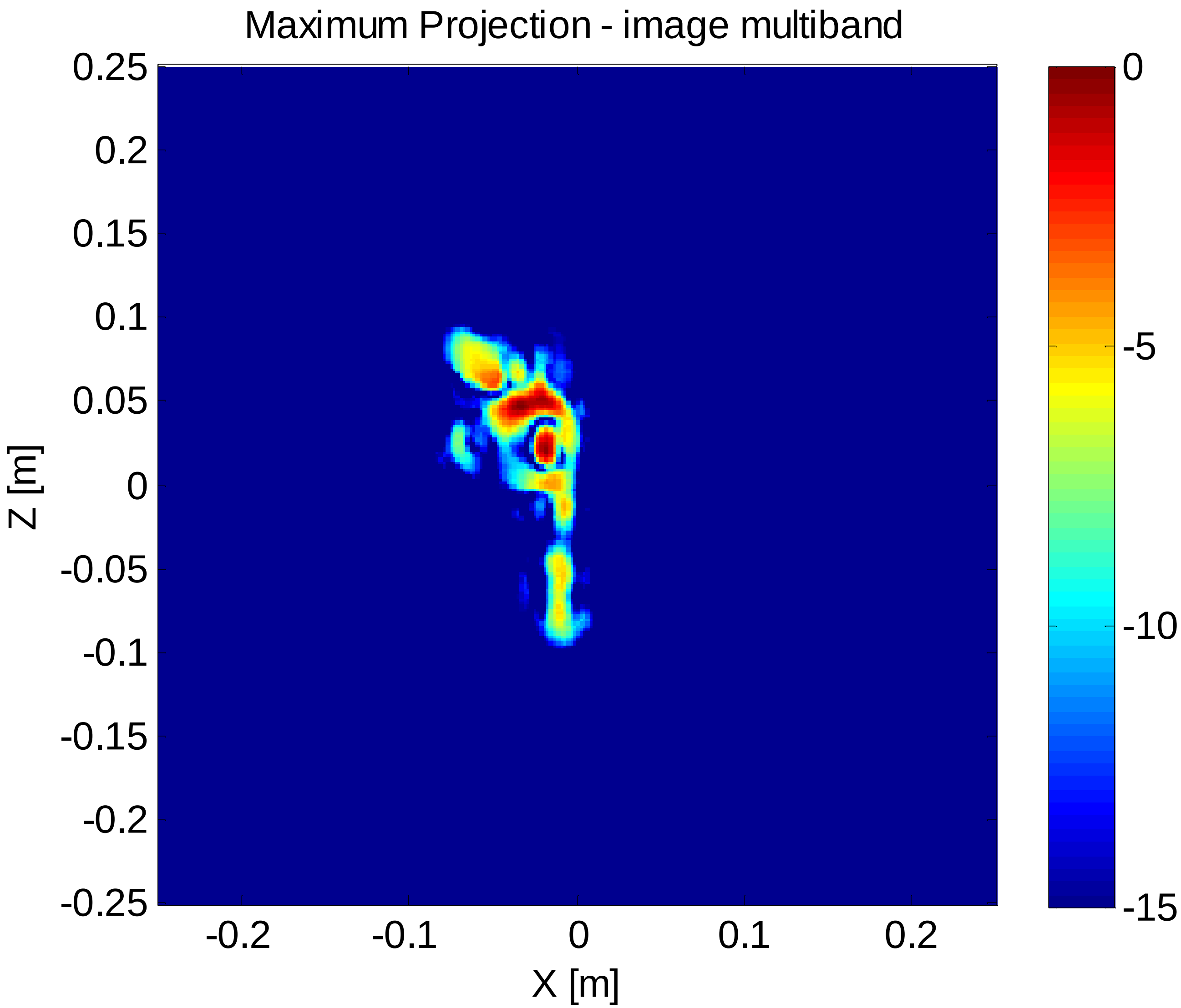


Aluminum foil-covered mannequin

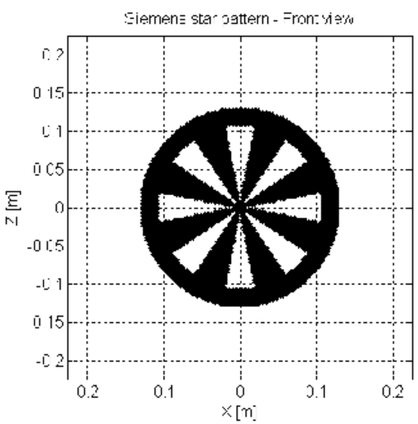
Image is thresholded at -15dB level

X.Zhuge and A. Yarovoy, "A Sparse Aperture MIMO-SAR-Based UWB Imaging System for Concealed Weapon Detection," IEEE TGRS 2011

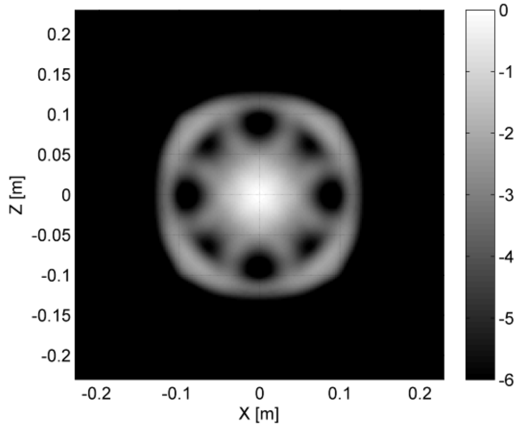
ATOM: Imaging with MIMO UWB array



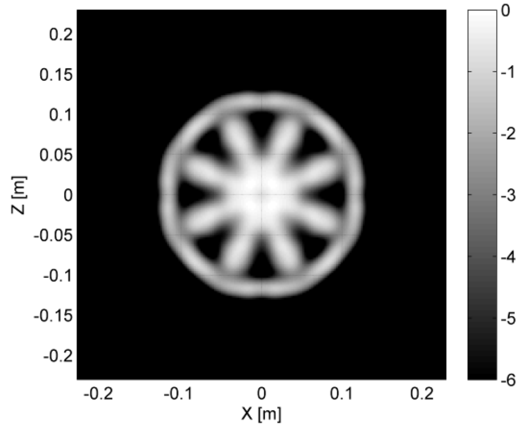
ATOM: Fast imaging algorithms for MIMO UWB array



Test target



Conventional algorithm



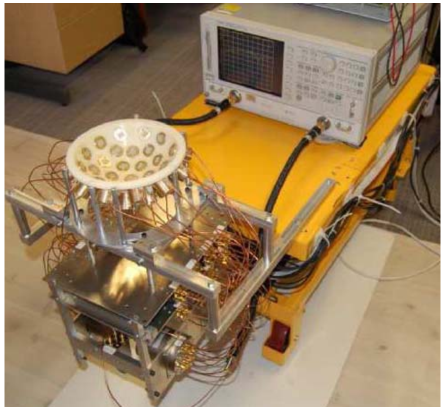
Proposed algorithm

$$f(\mathbf{r}') = v^2 \iiint \frac{k_z}{\omega} \cdot u(k_x, k_y, k_z) e^{-j(k_x \cdot x + k_y \cdot y + k_z \cdot z)} dk_x dk_y dk_z \quad k_z = \sqrt{(2\omega / v)^2 - k_x{}^2 - k_y{}^2}$$

X.Zhuge, A. Yarovoy, "3-D Near-Field MIMO Array Imaging Using Range Migration Techniques," accepted at IEEE TIP

Health care

Microwave imaging equipment is less physically intrusive on patients and apply safe level of radiation. These techniques could assist traditional X-rays which have high doses of ionizing radiation, thus having limited usage.



Microwave breast cancer detection system

Courtesy Ian Craddock, Bristol univ.

Assist and improve

Existing screening systems

Conclusions

- Microwave imaging is an attractive alternative to mm-wave and THz-imaging
- 3D imaging with cm-resolution can be achieved using microwaves below 30GHz
- Real-time imaging can be achieved using reasonably simple and cheap systems
- Especially attractive for sub-surface applications
- Despite of availability of the first commercial products microwave imaging is a hot research area