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MIMO and MULTISTATIC RADAR

for through wall applications ?

David J Daniels
Dr Mike Philippakis

Synopsis

- Background
- Targets and their environment
- Current radar systems
- Research areas
- Human characteristics
- RCS of basic targets
- Multi static radar
- MIMO radar
- Questions

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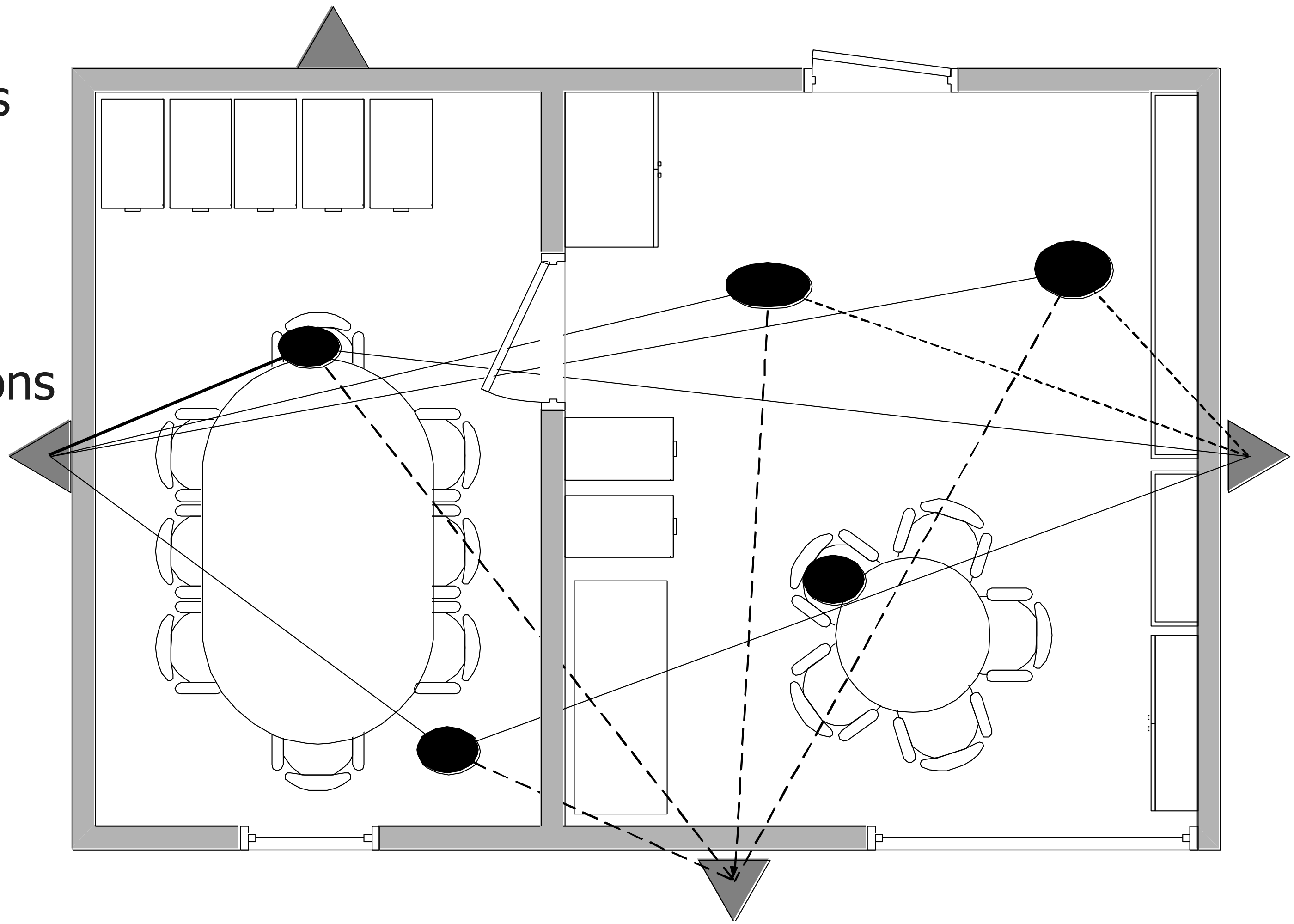
Background

- The safety of victims, hostages or security forces placed at risk often depends on the ability to assess situations quickly and accurately.
- Hostage and terrorism situations require knowledge of building interiors and the location and identification of individuals.
- This assessment must be carried out remotely so as to avoid endangering more people. Many dangerous situations also require that assessment be done discreetly so as not to alert criminals or the enemy to the intentions of security force personnel.
- This information must then be presented to the operator in a clear and simple way.
- The system must be easily deployable and ultimately be capable of producing a simple representation of both moving and fixed targets within the room.
- Through wall radar systems capable of monitoring the location of people in a room, by looking through the walls, floor and/or ceiling of the room have been developed by a number of organisations.

Targets and their environment

Targets and their environment

- Corner reflectors
- Planar reflectors
- Multiple reflections
- Multipath
- High clutter
- Wall loss



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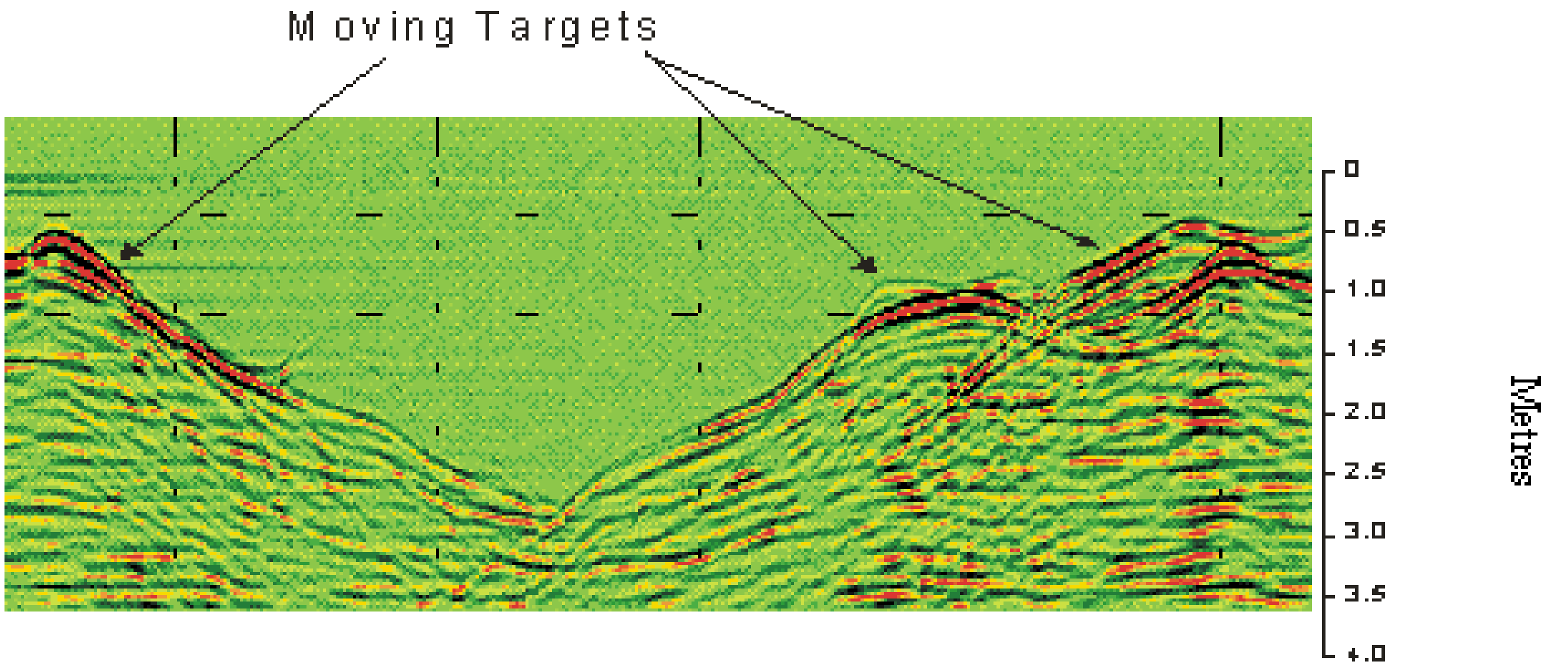
Current radar systems

- UWB monostatic TWR Ricker wavelet 2ns duration



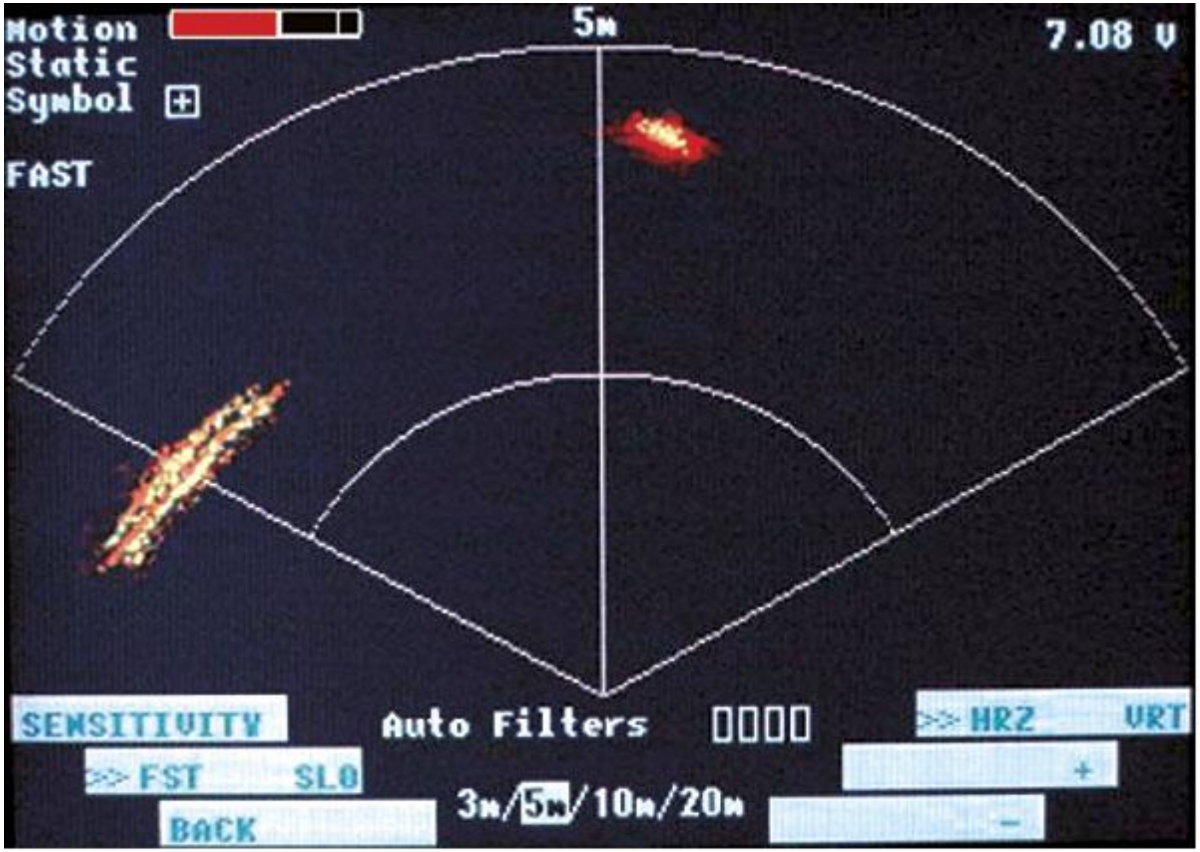
Current radar systems

Xaver™ 800 through wall radar system ©2008 Camero

Prism TWR © Cambridge Consultants

Current radar systems

Soldier vision and display (with kind permission © Time Domain Systems)



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Array based imaging

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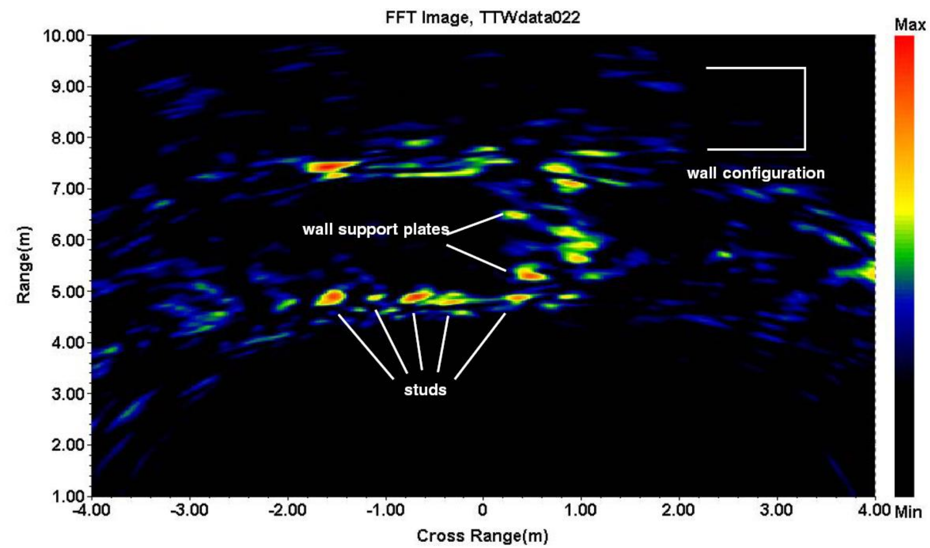
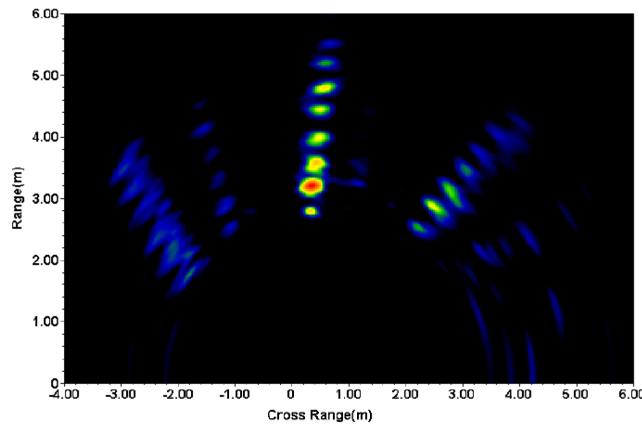
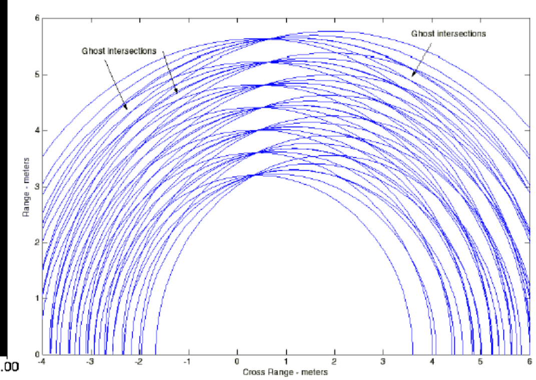
- Array imaging 4-element array
- Ghosts due to linear arrays
- and grating lobes





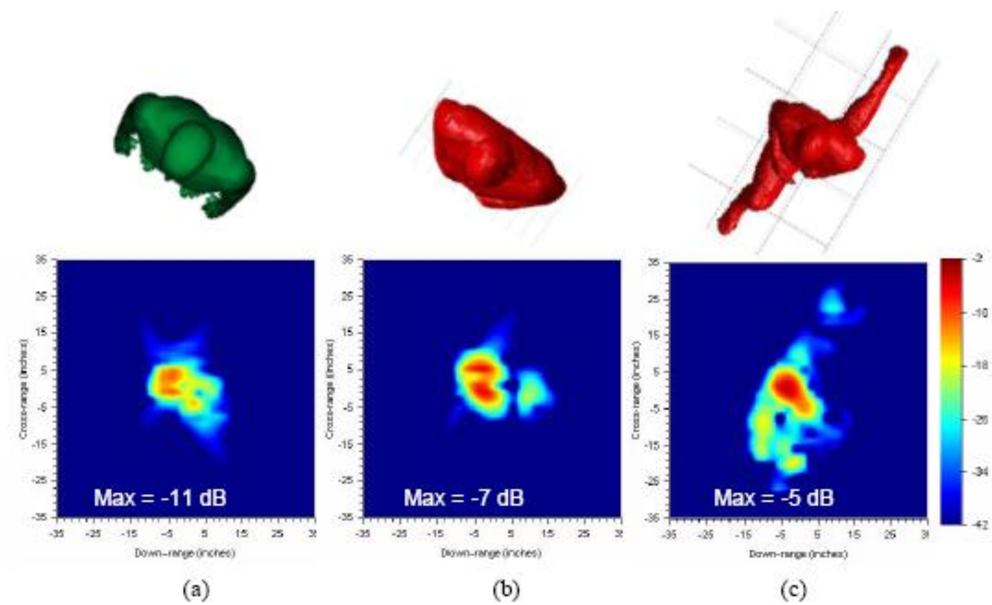


- Image formation through walls using a distributed radar sensor array, Hunt, A.R, Applied Imagery Pattern Recognition Workshop, 2003. 32nd Proceedings. 15-17 Oct. 2003, 232-237

SAR

- U.S. Army Research Laboratory (ARL) has been active in investigating the low-frequency ultra wideband (UWB) synthetic aperture radar (SAR) technology for through the wall sensing applications. Modelling work included computing and analyzing the human body signature in various configurations, as well as imaging complex rooms and buildings. Human body radar signature models using the Finite-Difference Time-Domain (FDTD) technique are shown .

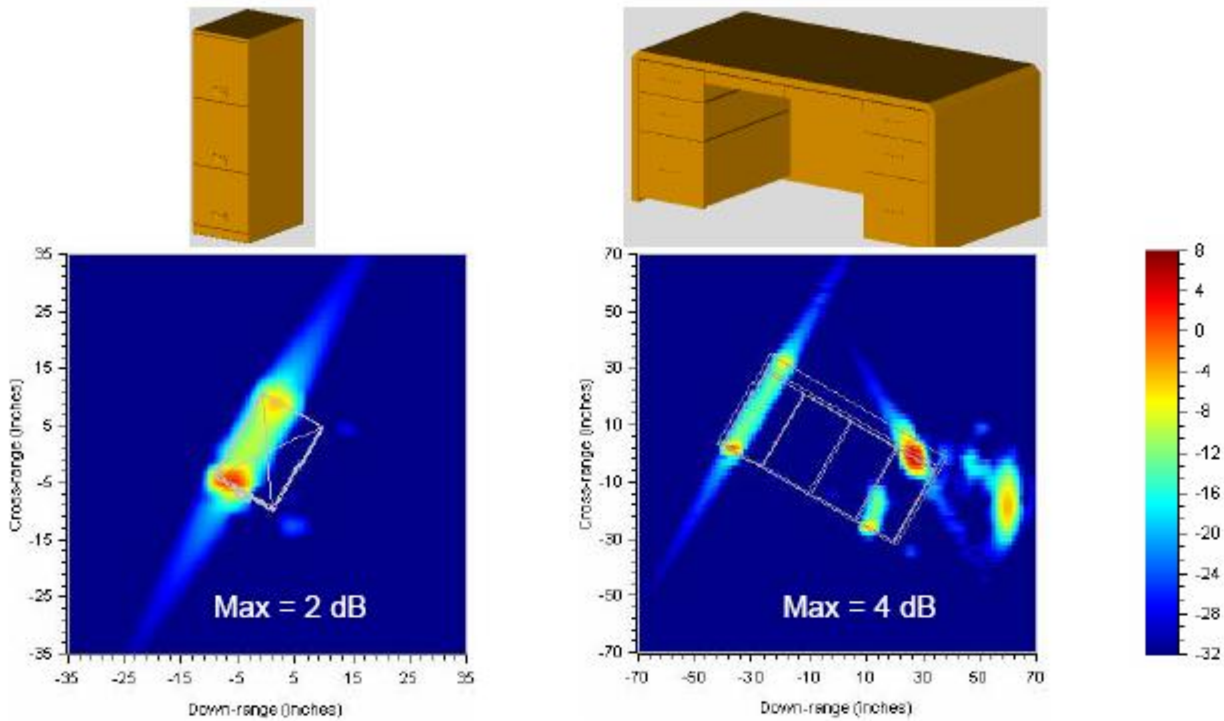
- The magnitude of the human body radar signature is not very sensitive to the aspect angle either, when the contributions over a large range of azimuth angles are integrated, such as in a SAR image.



- Recent investigations in sensing through the wall radar modelling, Dogaru, T. Calvin Le Antennas and Propagation Society International Symposium, 2008. AP-S 2008. IEEE 5-11 July 2008 pp1-4

SAR

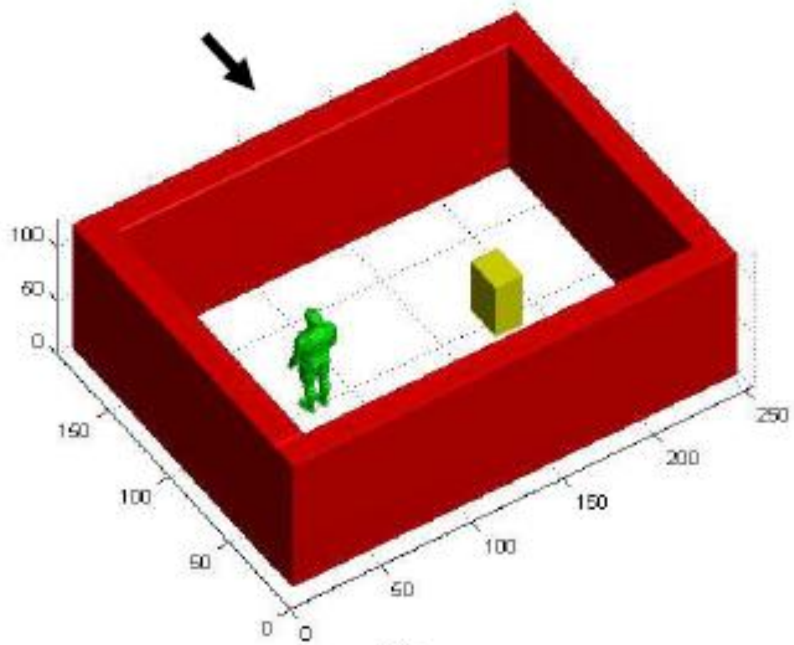
- Metallic furniture objects such as a filing cabinet or a desk display much brighter SAR images, which are also more aspect angle dependent.



(d) (e)

SAR

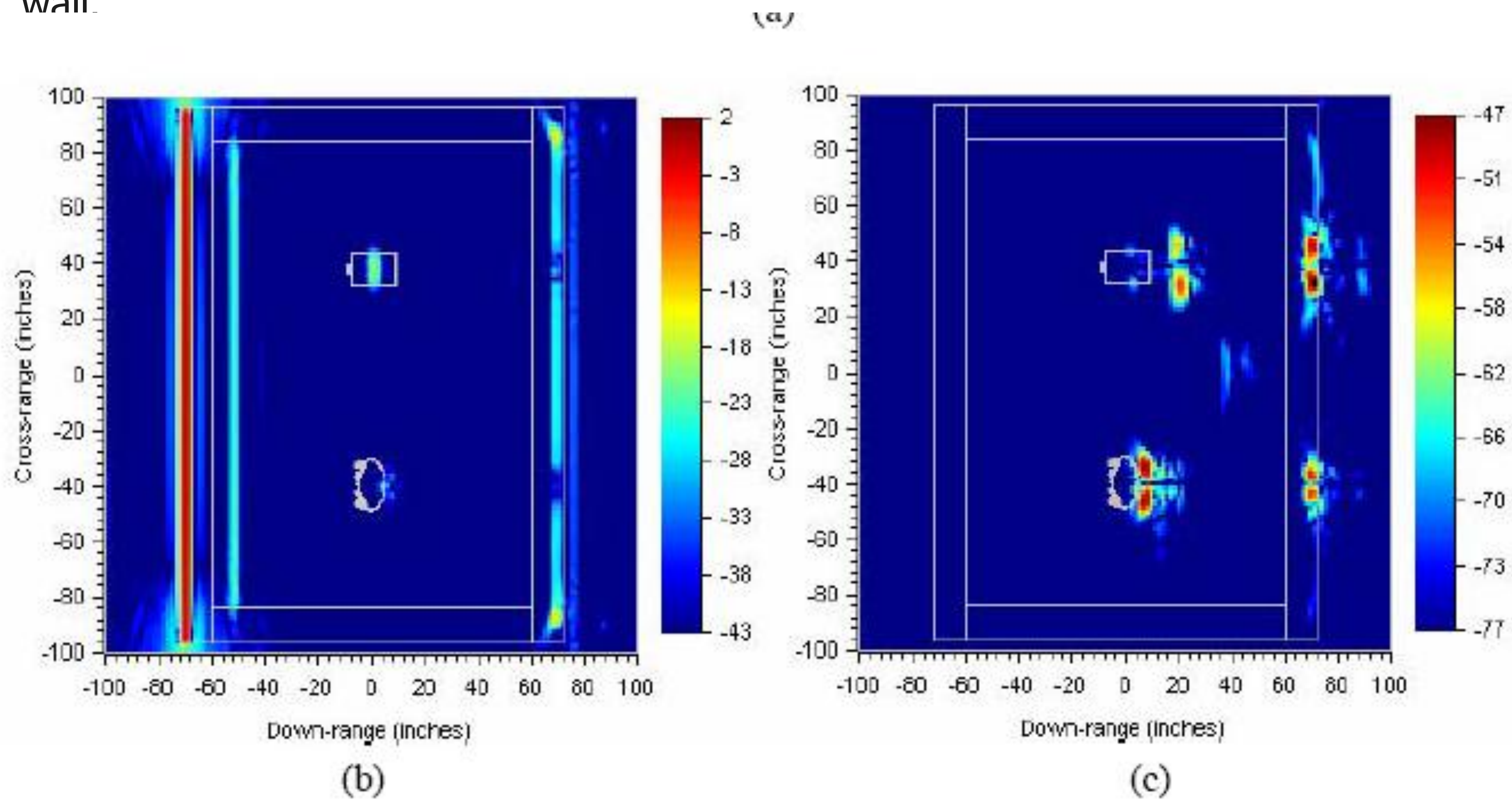
- The cross-polarisation return from the straight edges and corners of a room should theoretically be zero, unlike the off-broadside return from the human. Model simulation shown in following slides



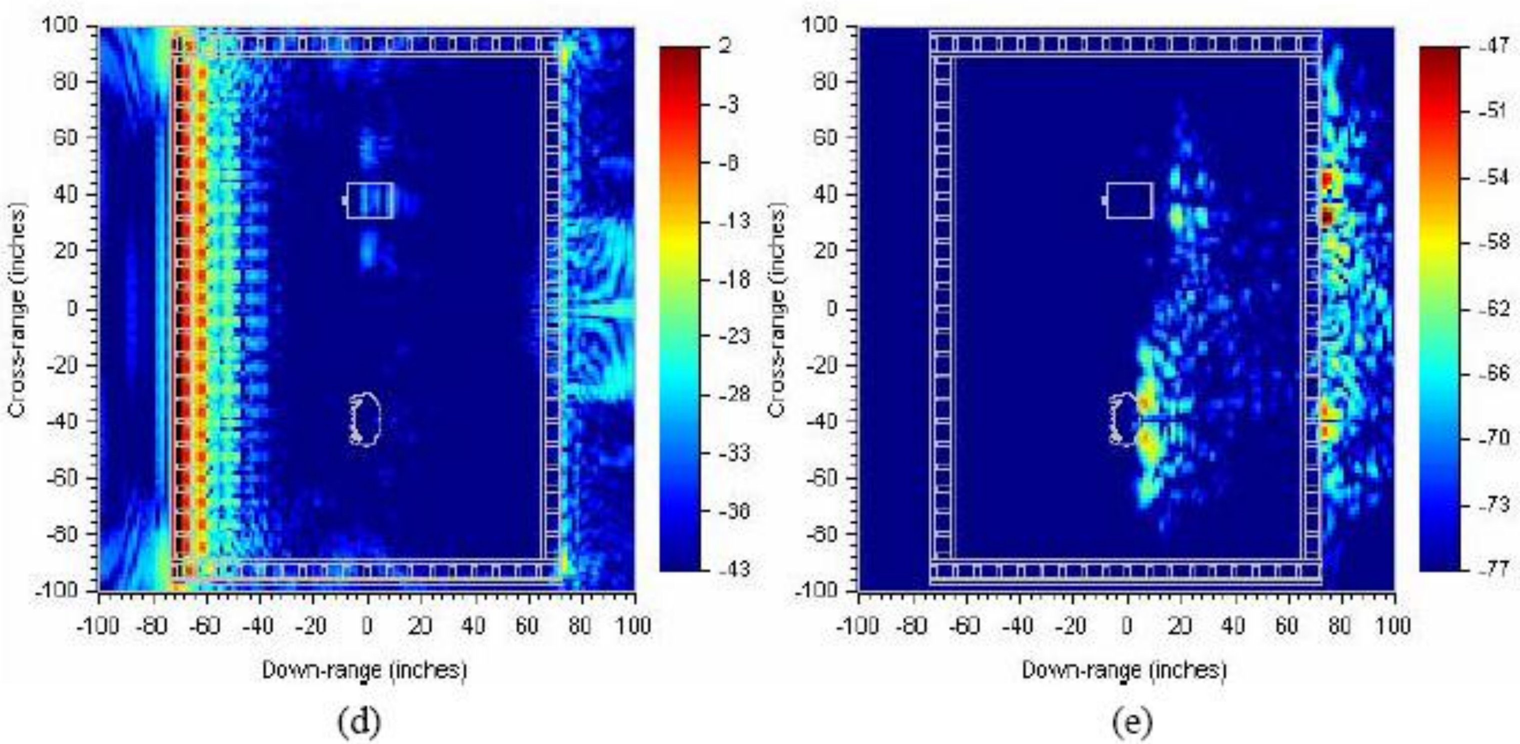
(a)

SAR

- Brick wall -- co polar VV and cross polar VH
- Multipath effects due to the bounces between the objects in the room and the back wall appear very prominently in cross-polarization as ghost images close to the back wall.

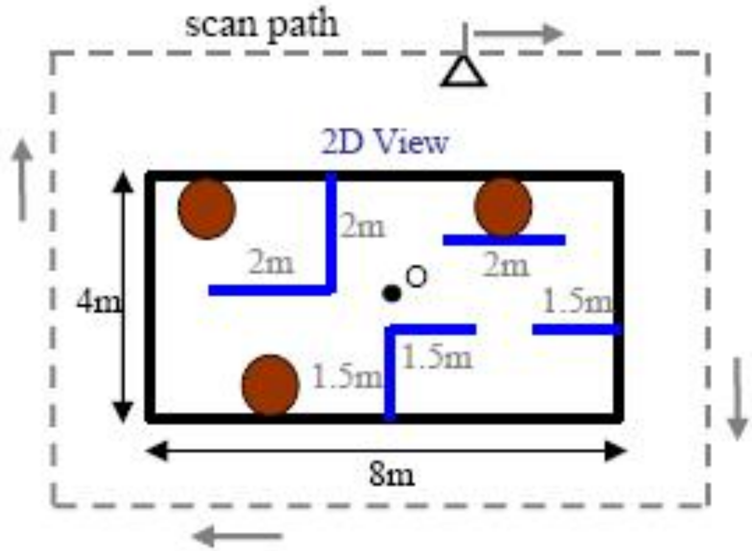


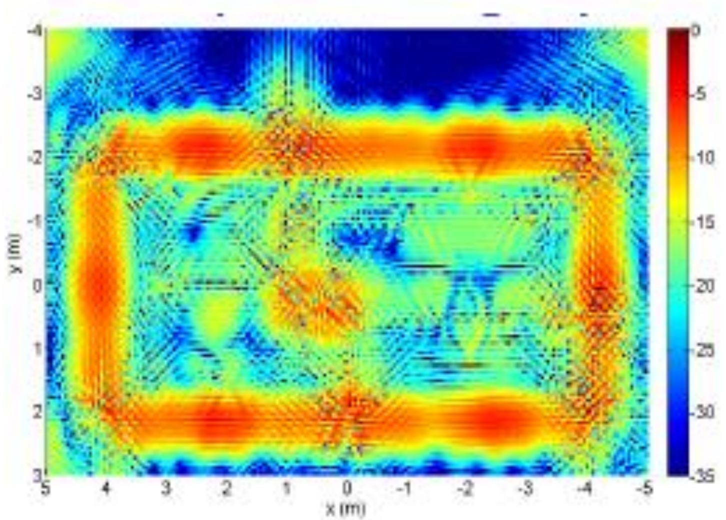
- Cinder block wall -- co polar VV and cross polar VH



Signature based

- Problem is the attenuation and distortion of signals propagating through one or more walls prior to interacting with objects of interest.

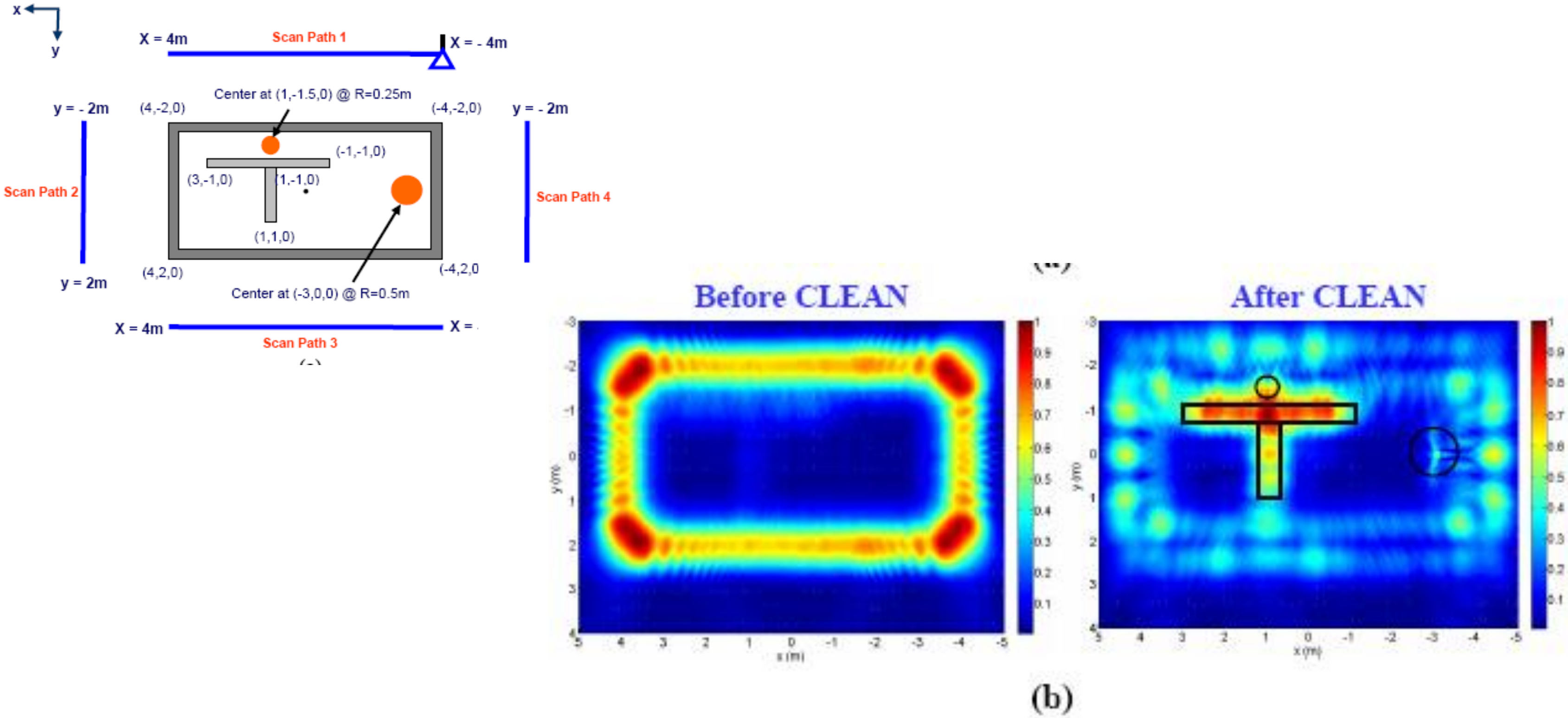




- Through-wall building image improvement via signature-based CLEAN, Chang, P.C. Burkholder, R.J. Volakis, J.L. Antennas and Propagation Society International Symposium, 2008. AP-S 2008. IEEE, 5-11 July 2008 pp1-4

Signature based

- The CLEAN algorithm searches for the brightest points from an image, assigns a point spread function to the brightest spot based on the associated intensity and subsequently removes its contribution from the image. Simulation shown below



Time reversal

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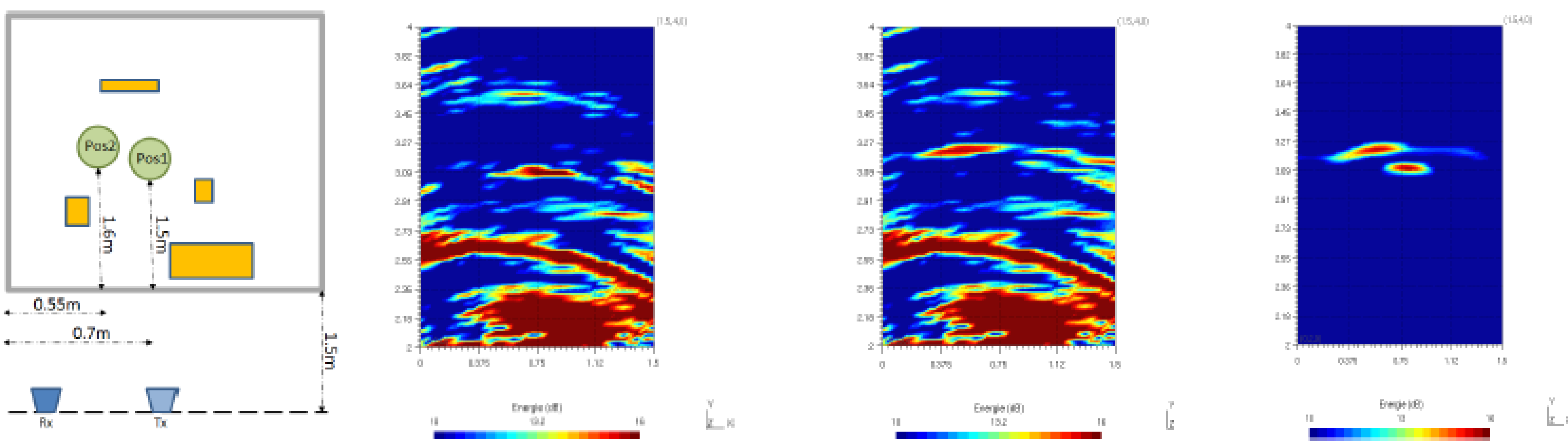
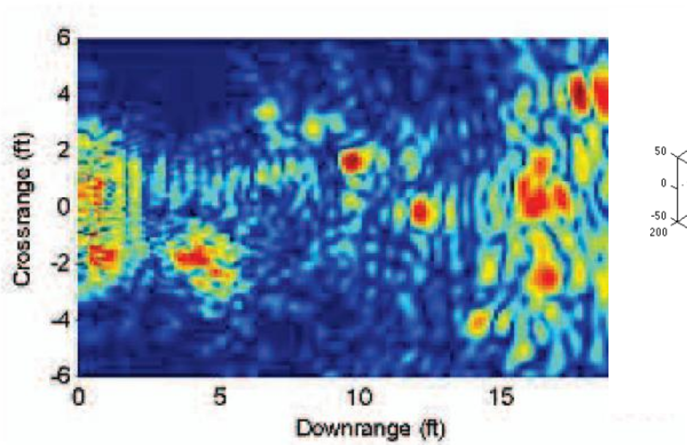
- Time reversal is based on the reciprocity of Maxwell's equations in a time-invariant medium.
- The radiated pulsed UWB signal is recorded by an array of receivers.
- Time reversing this data and radiating it from the same array, the source location is focussed
- The focusing precision is imposed by the size of the array of tranceivers and may even increase in presence of multipaths.

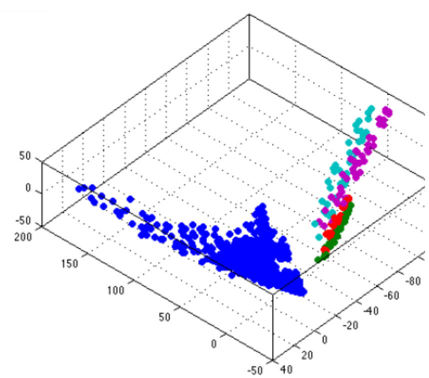


Experimental Through-The-Wall Detection in Cluttered Environment Using Time Reversal Processing N. Maaref*1, P. Millot1, X. Ferri`eres1, C.Pichot2, and O.Picon3

Classification

- The data are processed by a post data acquisition beam former to construct an occupancy image of objects behind the wall.
- Target features are captured in a multidimensional vector, whose dimensionality is equal to the number of slices cut through the scene. Although targets vary a great deal in their return strengths, we observed that by using the defined feature vector they are at sufficient statistical distances, in the Mahalanobis sense, from clutter as well as each other.
- Data, Projection of clutter and four object data on clutter space.



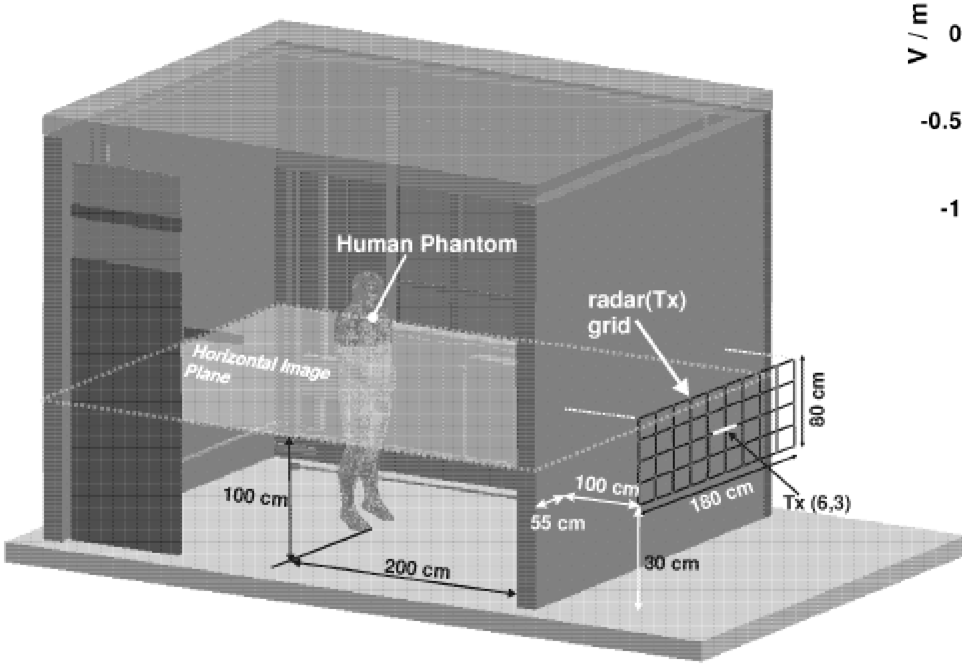


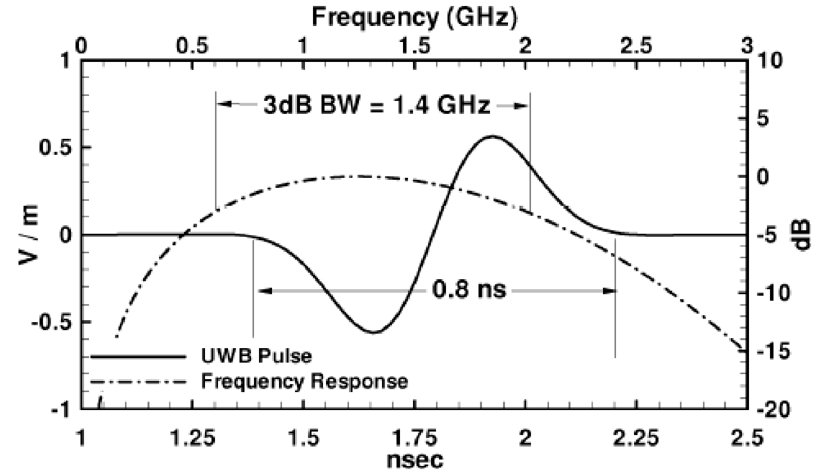
Model number	Object	Percent Accuracy
1	3" trihedral	91.4
2	3" trihedral	90.2
3	12" sphere	93.5
4	6" trihedral	98.0
5	5" dia. tophat	98.3
6	12" dihedral	93.5
7	12" dihedral	100.0
8	3" trihedral	87.5
9	12" dihedral	100.0

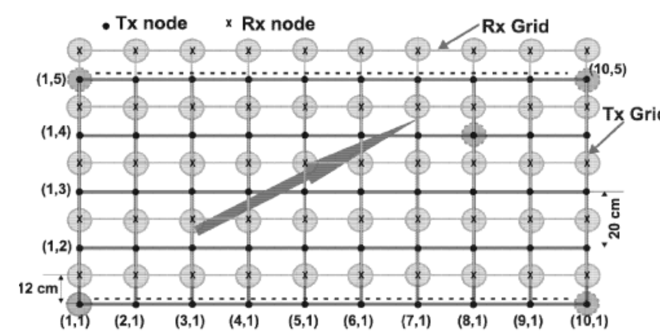
3D Classification of Through-the-Wall Radar Images Using Statistical Object Models Bijan G. Mobasseri and Zachary Rosenbaum Symposium on Image Analysis and Interpretation, SSIAI 2008. IEEE Southwest 24-26 March 2008, Pages: 149 - 152

Multistatic radar

- Modelled situation



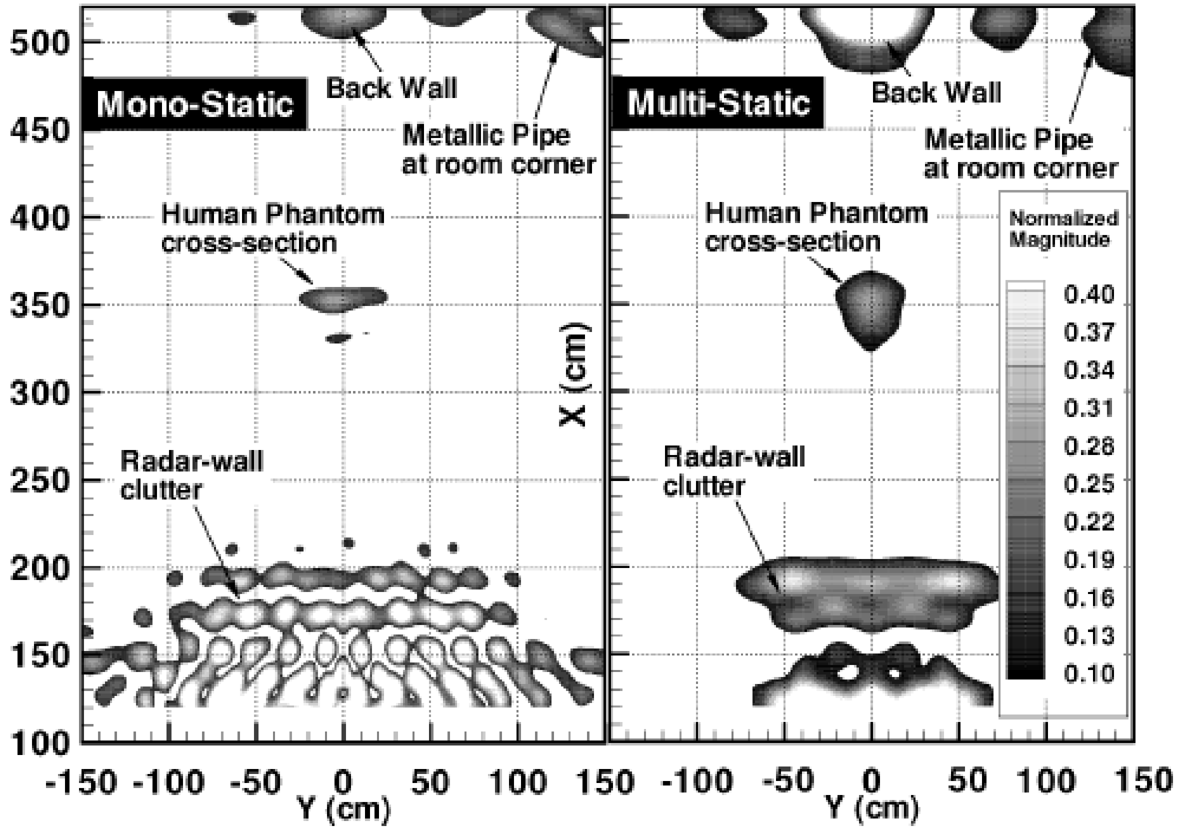




FDTD Modelling of a Realistic Room for Through-the-Wall Radar Applications, Walid A. Chamma, Workshop on Computational Electromagnetics in Time-Domain, 2007. CEM-TD 2007.15-17 Oct. 2007

Multistatic radar

- The post processing procedure used in this investigation is the time domain back-projection technique (Mensa) .



D. Mensa, High Resolution Radar cross-section Imaging, Boston, Artech House, 1991.

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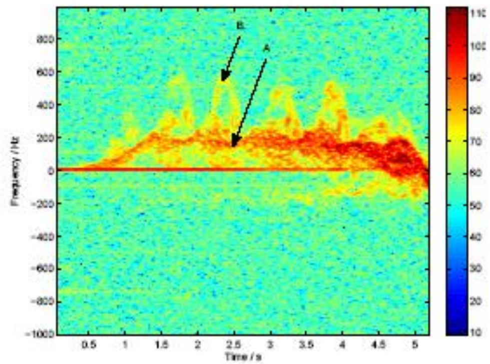
Human characteristics

- Detection of heartbeat, respiration and movement can be achieved by means of measurement of the micro-Doppler generated by the physical movement of either organs or limbs.
- A normal human at rest breathes at a rate of around 12 breaths per minute or 0.2 Hz with a velocity of 10^{-2} m.s^{-1} and up to 25 breaths per minute or 0.4 Hz when exercising.
- The typical heartbeat rate for a resting subject is 72 beats per minute rising to 140 beats per minute after exercise. Note that the maximum heart rate is 220-age.
- Assuming a rest rate of 72 b.m^{-1} gives a frequency of 1.2 Hz.
- Blood leaves the heart at a rate of 0.45m s^{-1}.

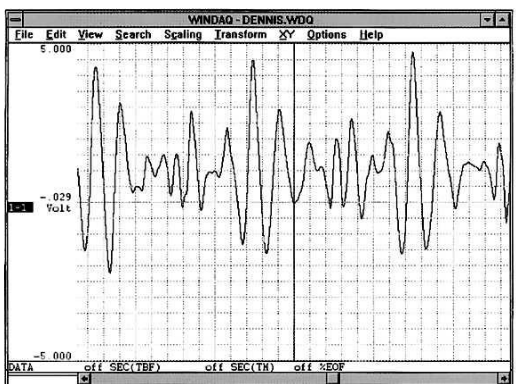
Human characteristics

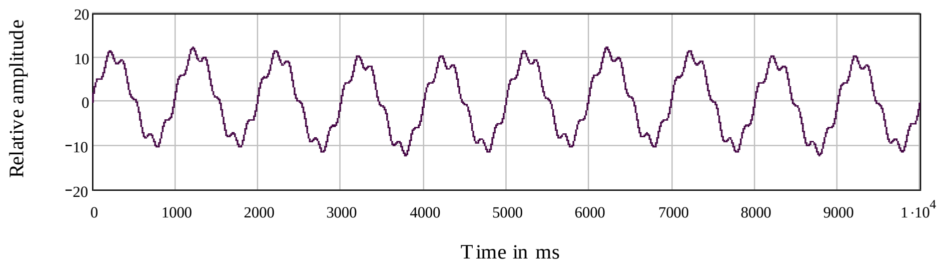
- Doppler frequencies at f_o = 1GHz and spectrogram of walker



Parameter	Velocity ms^{-1}	Doppler frequency in Hz
Hand movement	5	33
Rapid body movement	3	20
Walking	0.5	3.3
Heart movement	0.45	1-3
Breathing	0.01	0.1-0.5

- Measured and modelled Doppler signatures



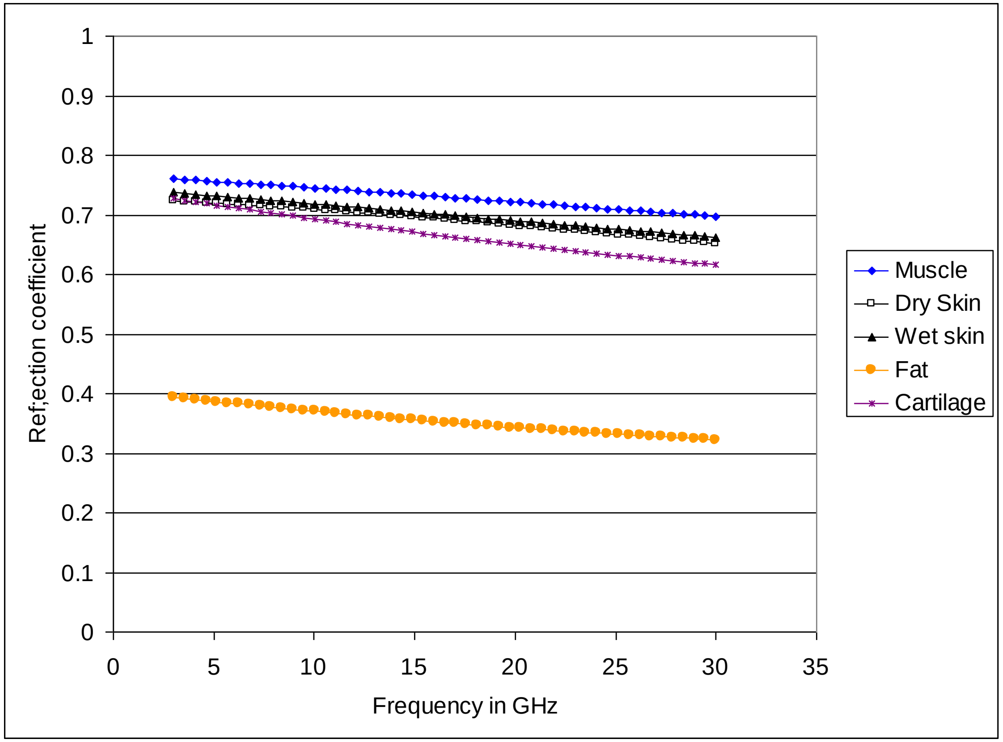


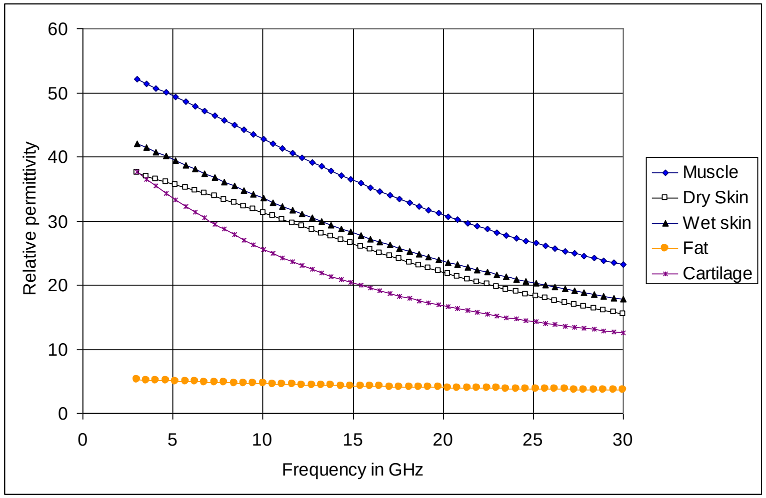
- Detection of Human Breathing and Heartbeat by Remote Radar, S.I. Ivashov, V.V. Razevig, A.P. Sheyko, I.A. Vasilyev, Progress in Electromagnetic Research Symposium 2004, Pisa, Italy,March 28 - 31
- Characterisation of human gait using a CW radar at 24GHz, Horsteiner and Detlefsen

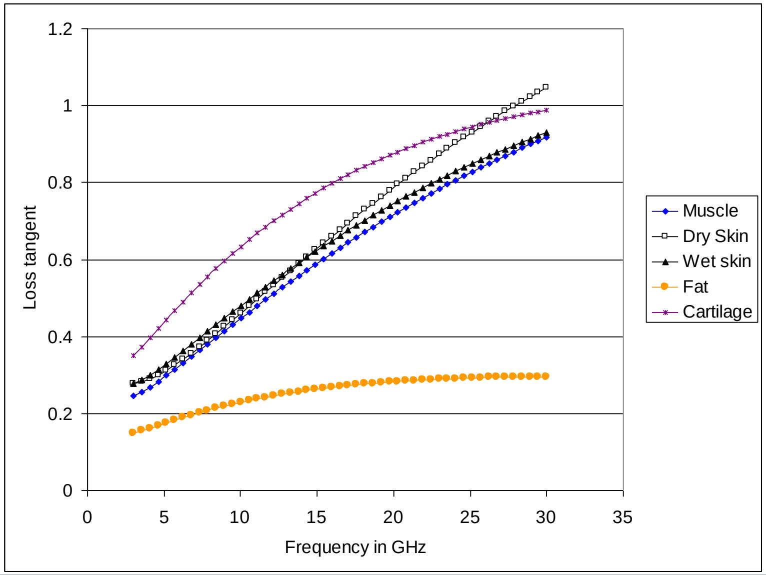
Human characteristics

- Human RF characteristics 1GHz to 35GHz

- Reflection coefficient
- Relative permittivity
- Loss tangent







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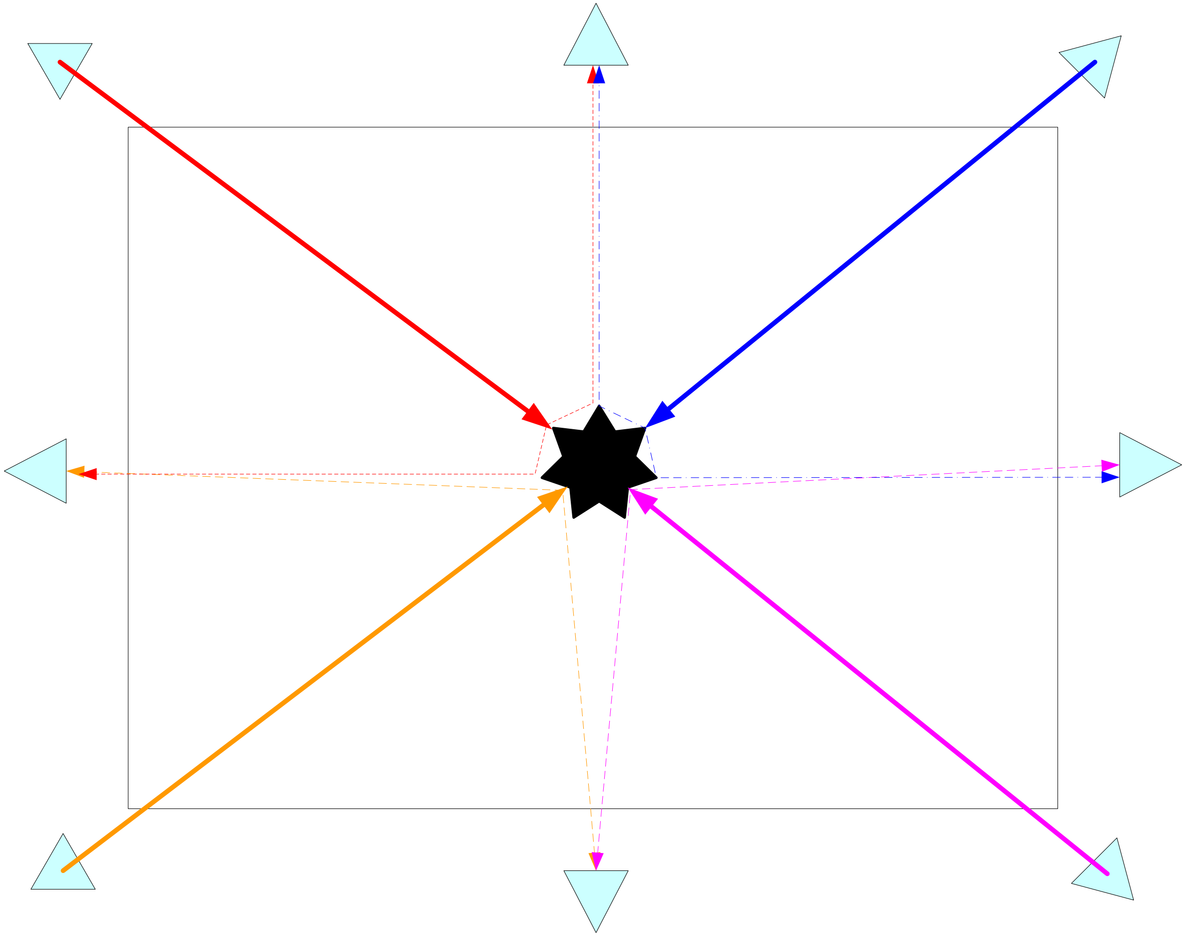
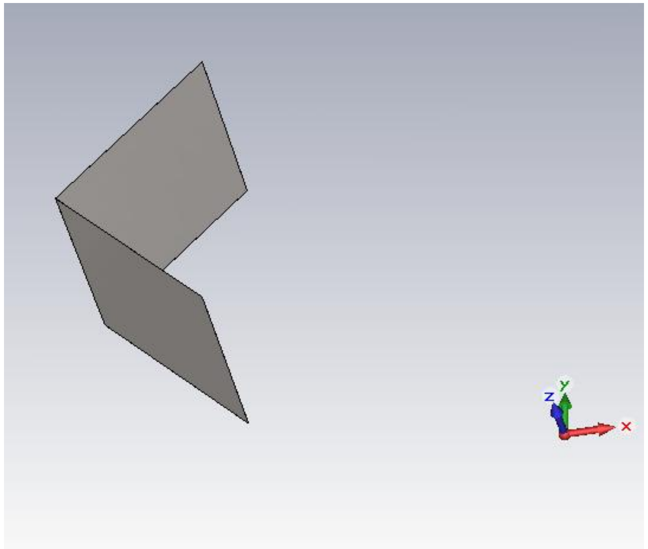
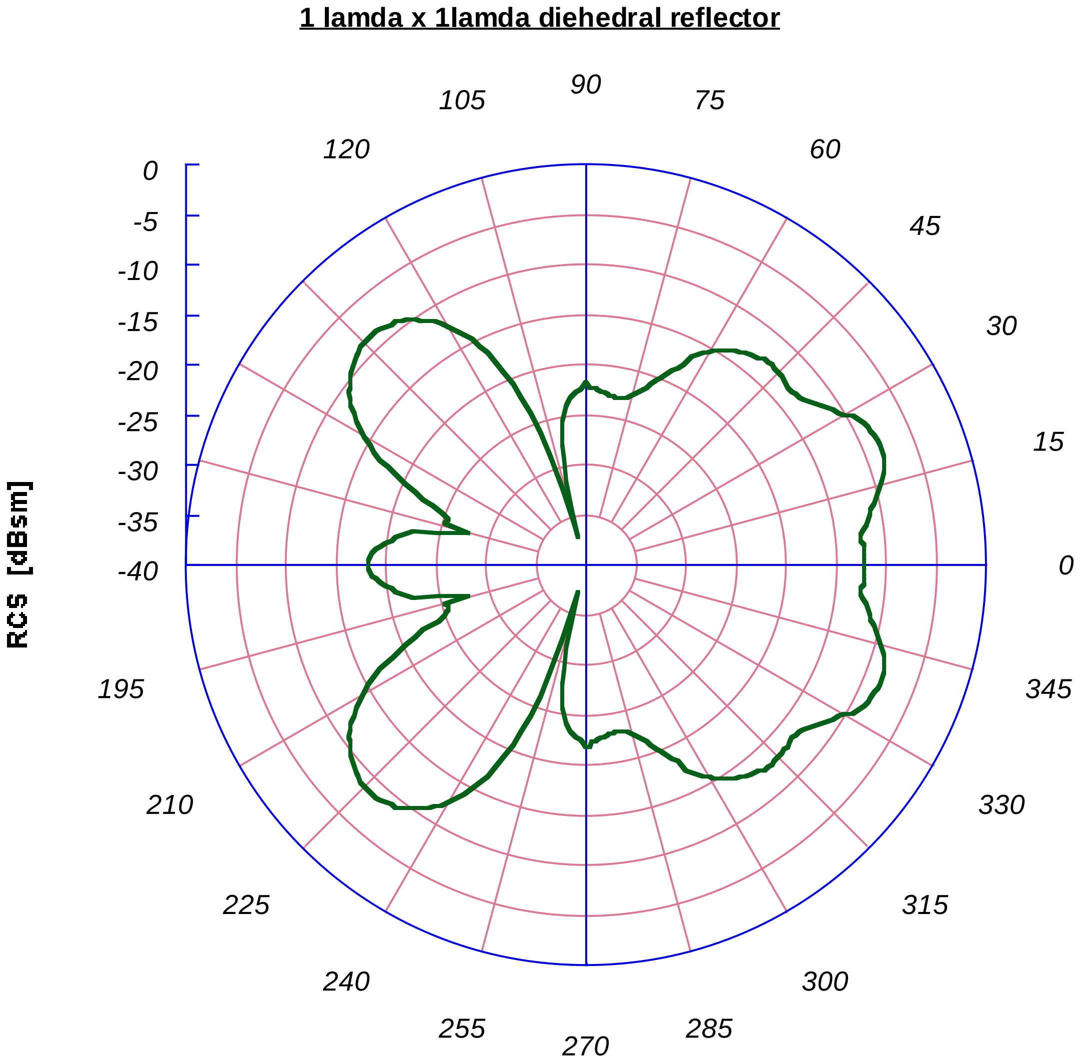
RCS considerations

- Multistatic or MIMO

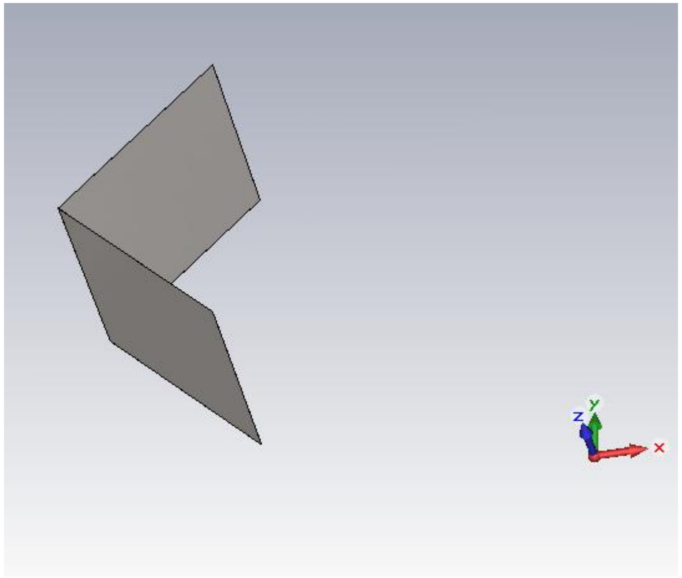


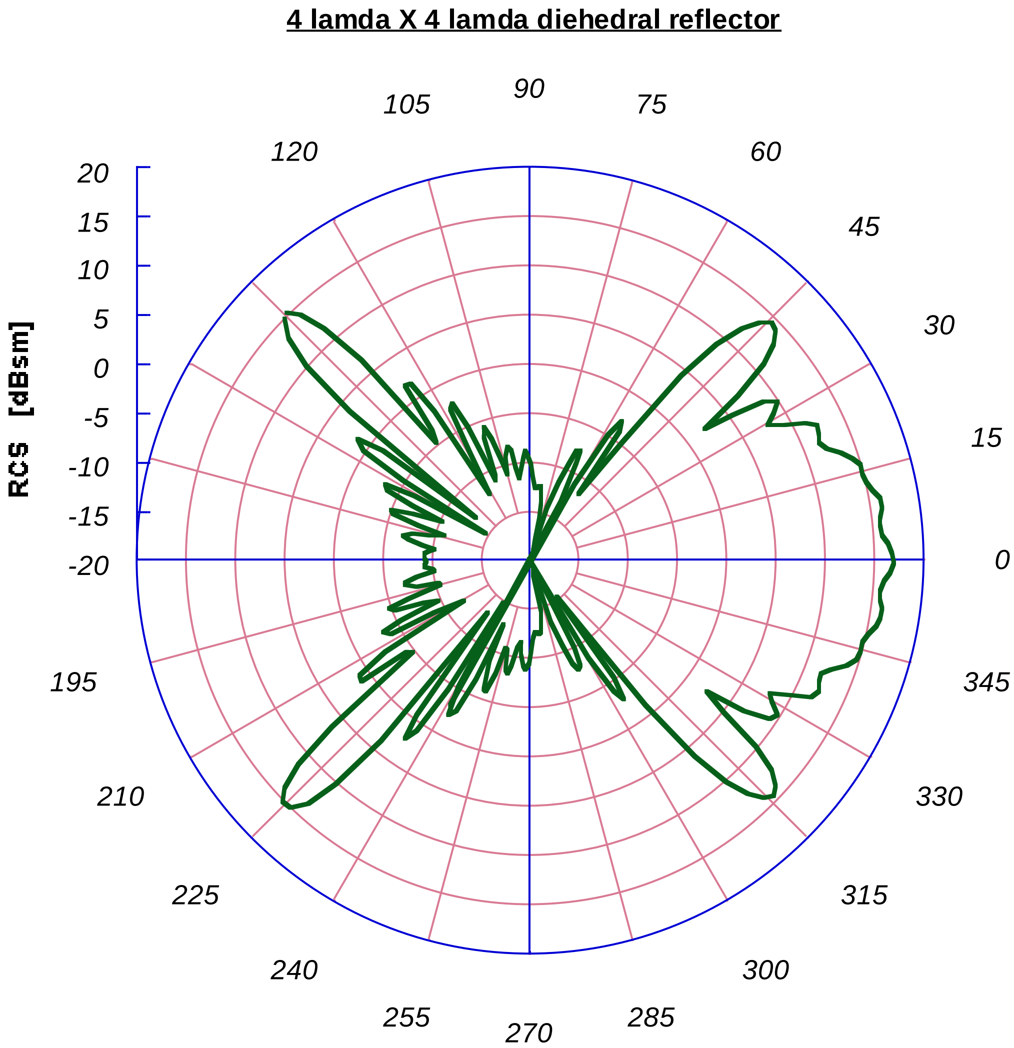
Dihedral – λ by λ monostatic 3GHz





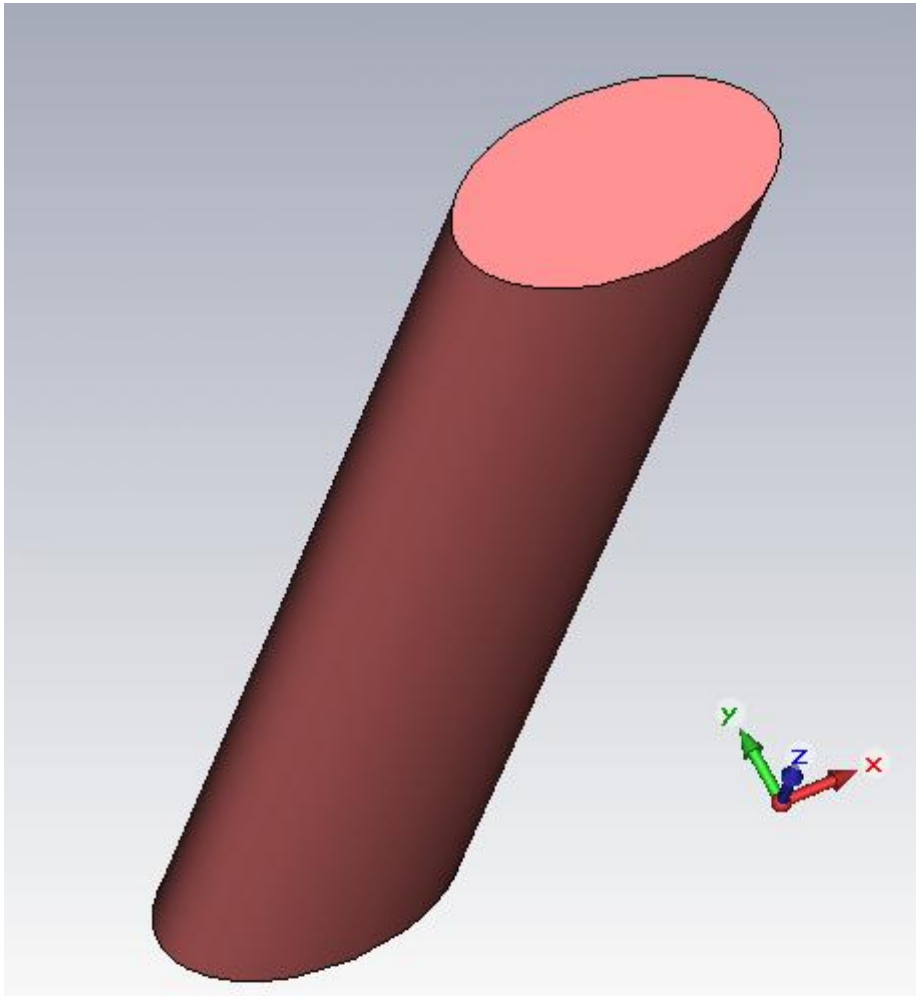
Dihedral – 4λ by 4λ monostatic 3GHz



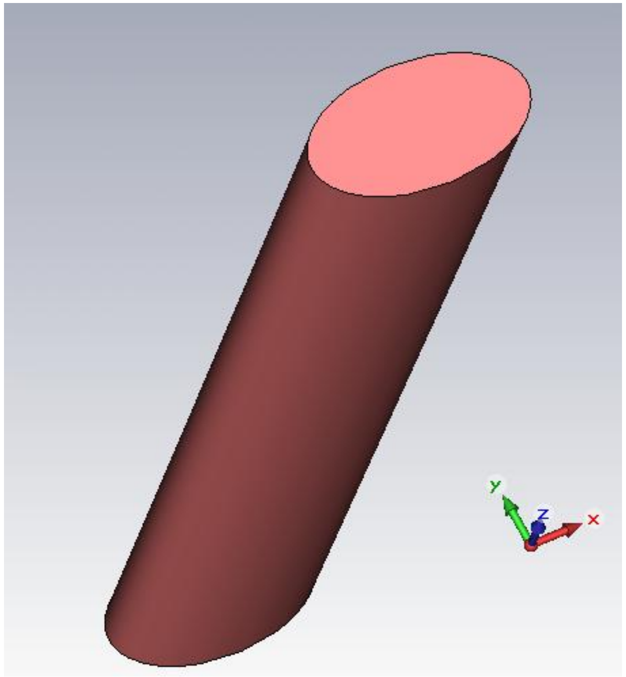


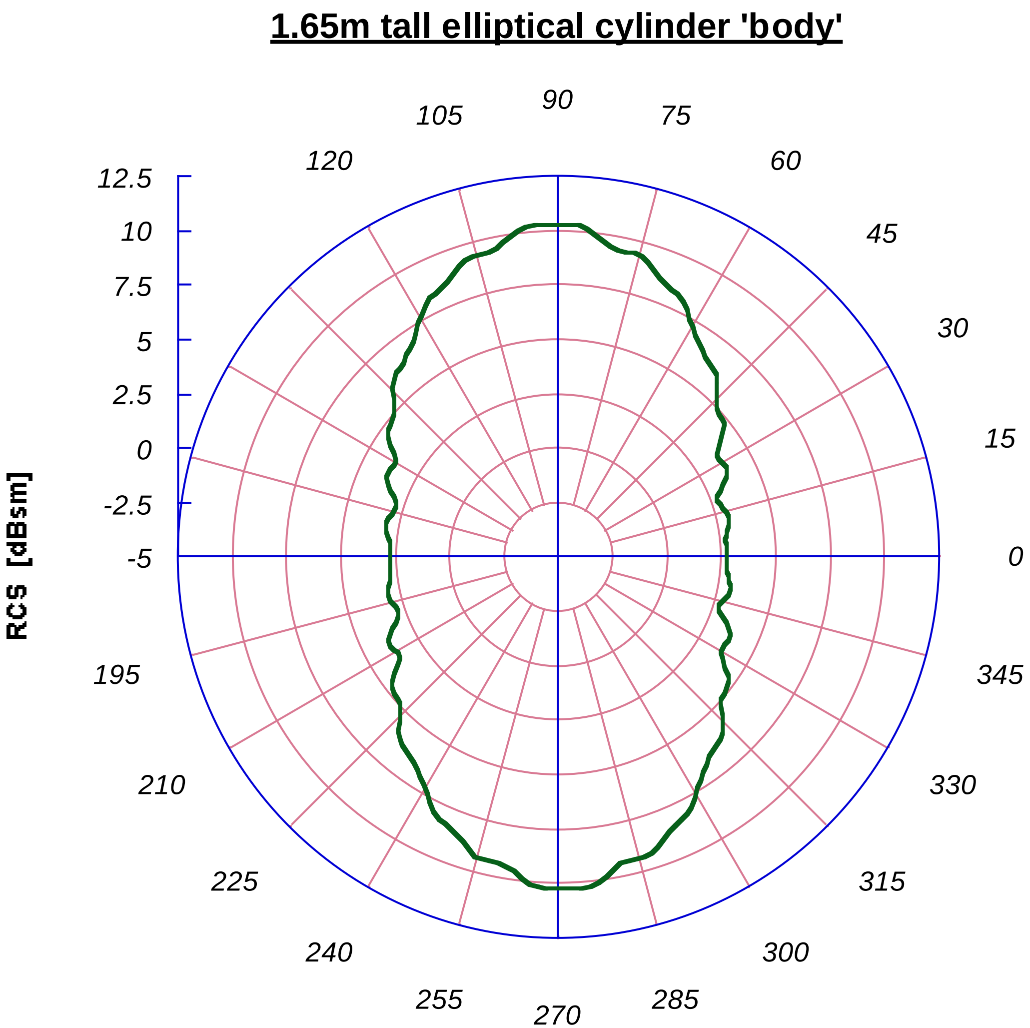
Definitions

Frequency	= 3 GHz
Length of cylinder	= 1.65m
Elliptical X semi-axis	= 180mm
Elliptical Y semi-axis	= 100mm
Dielectric epsilon	= 55
Conductivity	= 0.75 S/m



Elliptic cylinder at 3GHz





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Definitions

- Monostatic radar
  - Common antenna, single waveform , monostatic radar cross section, narrow or wideband radiation
- Bistatic radar
  - Spatial diversity of two antennas, single waveform , bistatic radar cross section, narrow or wideband radiation
- Phased array radar:
  - Spatial diversity of distributed antennas at a common location, single waveform and central processing of received signals, narrow or wideband radiation
- Multistatic:
  - Spatial diversity of distributed antennas, single transmitter and multiple receivers or vice versa, single waveform and central processing of received signals, narrow or wideband radiation
- MIMO radar
  - Spatial diversity of distributed antennas, diversity of waveforms, central processing of received signals, narrow or wideband radiation

Multi static radar

- Transmitters of choice?
- Transmitters of opportunity?
- Receivers
    - –Synchronisation of distributed network?
    - –Wireless transmission of data?
    - –Sparseness and spatial diversity?

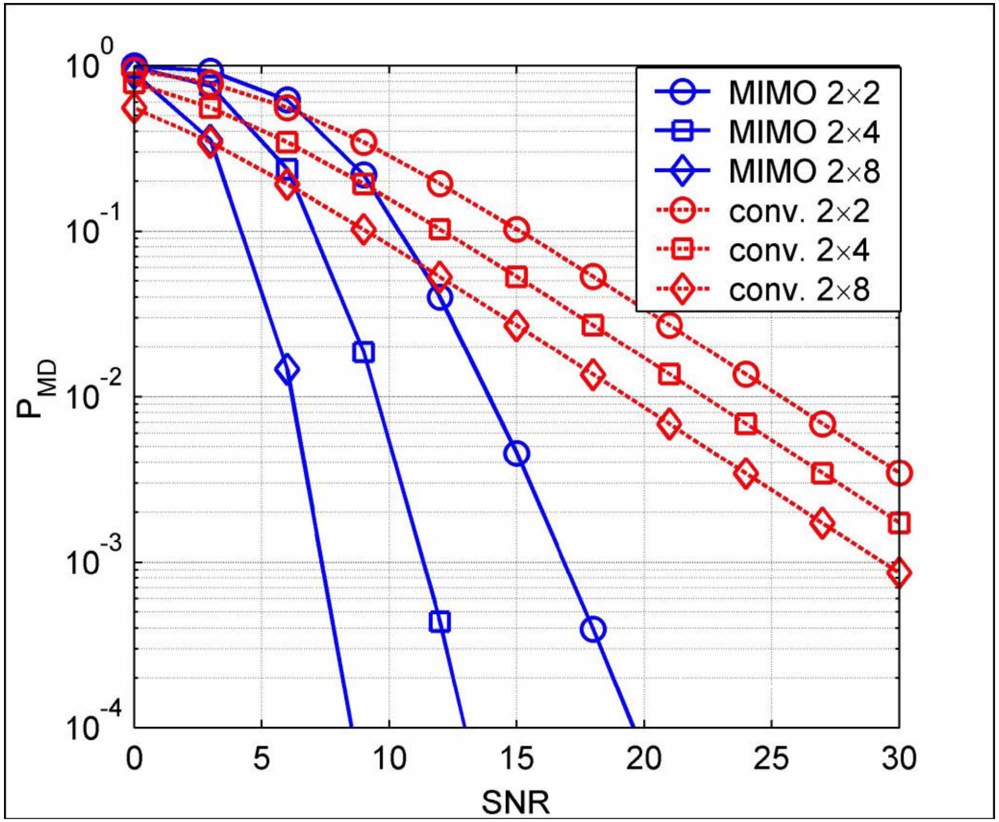
MIMO radar[1]

- Distinguishing features of non-coherent MIMO radar
  - Orthogonal waveforms
  - Time delay measurements only (non-coherent)
- Distributed sensors
  - Extended target acts as channel with spatial selectivity – target radar cross section (RCS) diversity
  - High resolution localization
  - Multiplicity of sensors supports high accuracy localization
  - Handling of multiple targets
  - Improved Doppler processing through diversity of look angles and mitigation of the problem of low radial velocities
- MIMO "gain"
  - Illumination of full surveillance volume
  - Exploit RCS diversity
  - Geometric dilution of precision (GDOP) advantage of the radar system footprint

(1 = Haimovich)

MIMO radar

- Miss probability of MIMO radar compared to conventional phased-array.
- Miss probability is plotted versus SNR for a fixed false alarm probability of 10^{-6}



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Questions

- Selection of waveform orthogonality
  - UWB versus narrow band radar cross section?
  - Modulation – impulse, noise, FM or SF,code
- Spatial sampling

  Spatial recognition as a function of angle
  Dimensionality
- Polarisation

MIMO radar

- How much does processing gain does waveform diversity provide?
- What impact does waveform diversity have on imaging given that--
- Walls may often act as a low pass filter.
- What impact does this bandwidth limitation have on processing gain?
- What impact does multipath have on non coherent MIMO?

Questions

- Will MIMO outperform SAR given its sparsity?
- Will multiple sources and receivers be acceptable to the military or security customer?
- How can they be deployed?

Finale

- Thank you for your attention.
- Questions please?