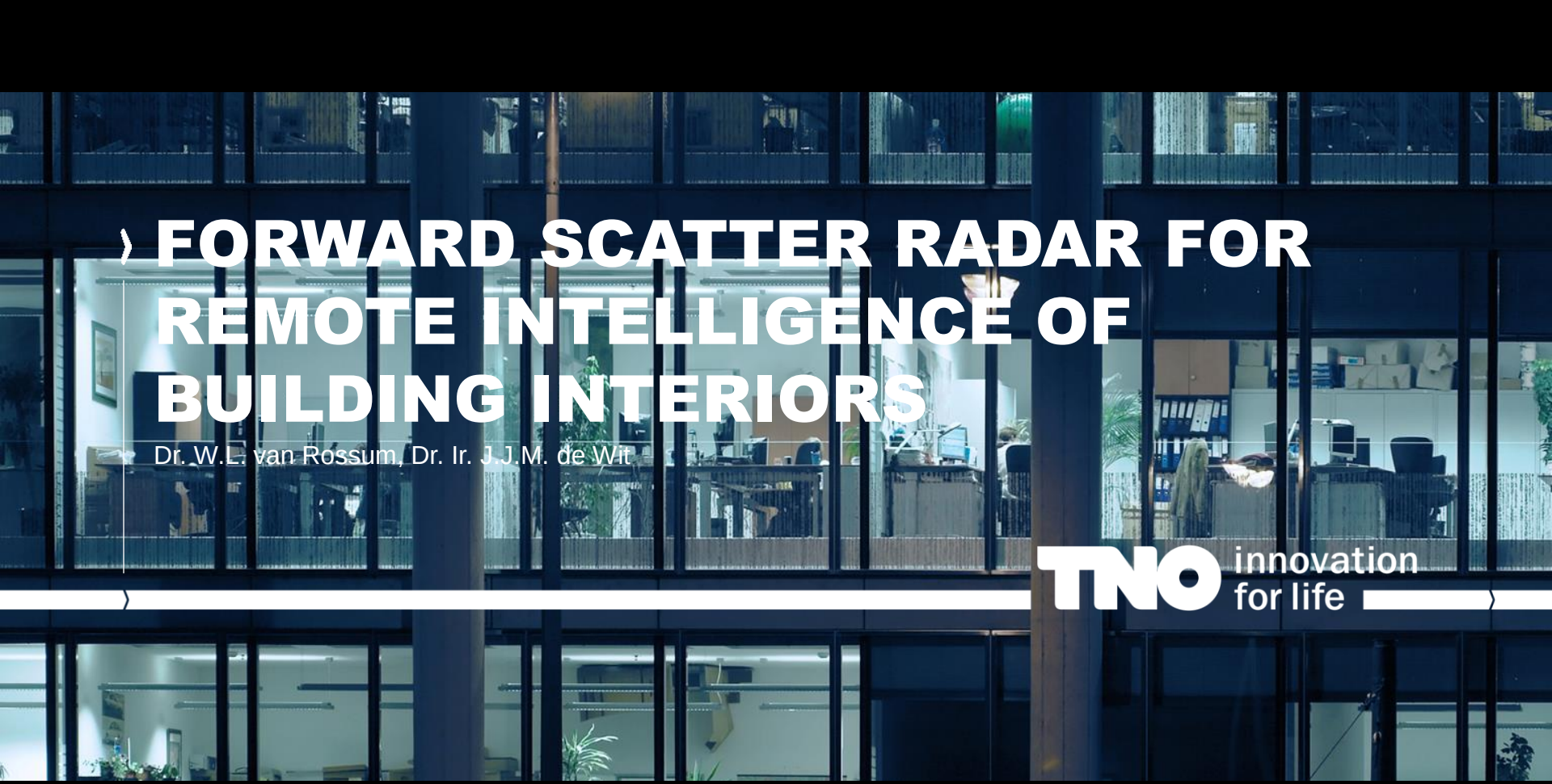


FORWARD SCATTER RADAR FOR REMOTE INTELLIGENCE OF BUILDING INTERIORS

Dr. W.L. van Rossum, Dr. Ir. J.J.M. de Wit

TNO innovation for life

CONTENT

- Backscatter Radar
- Examples of Backscatter Experiments

- Forward Scatter Radar
- Forward Scatter Experiments

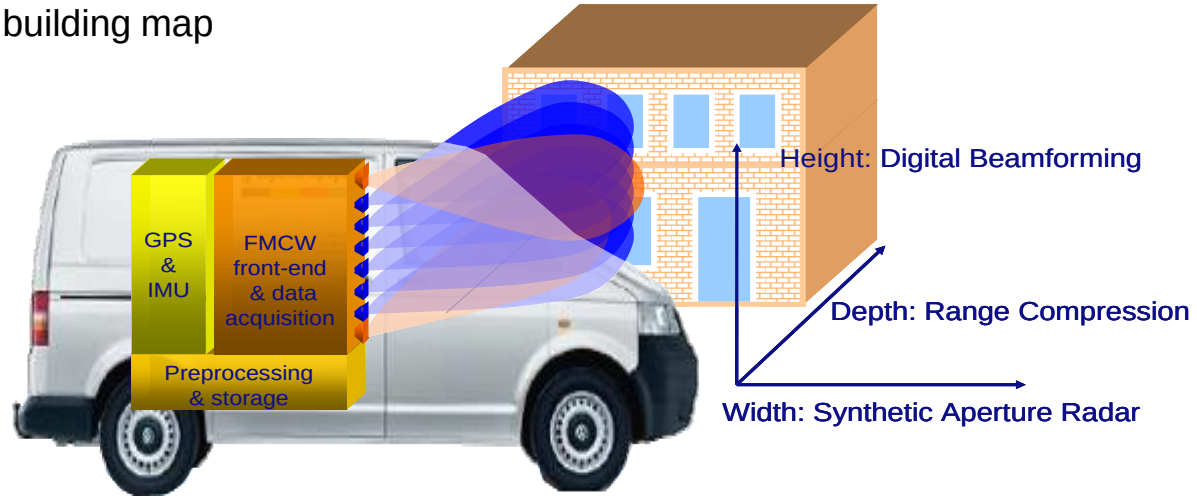
- Future work

BACKSCATTER RADAR: SAPPHIRE

- 0.5 m resolution in 3D at 10 m distance
- Fully polarimetric aperture sampling
- MIMO array: 4 Tx elements, 8 Rx elements
  - → 32 virtual MIMO T/R elements
- Waveform: sequence of 16 FMCW sweeps
  - → 4 Tx positions x 4 polarisation combinations

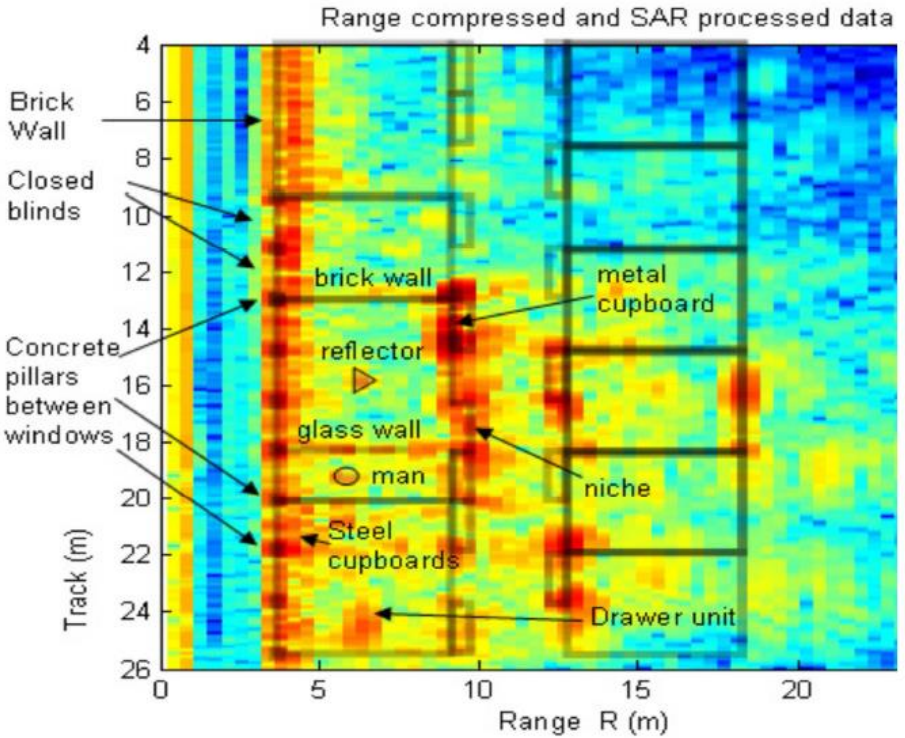
SAPPHIRE: PROJECT

- Funded by EMRS-TDC
- Mapping of buildings with stand-off polarimetric FMCW SAR radar
- Drive by a building and build-up 3D building map



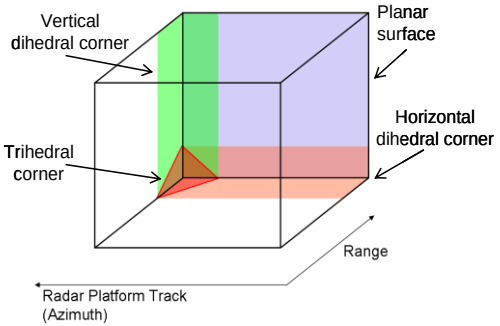
SAPPHIRE: RESULTS (2D) BUILDING MAPPING

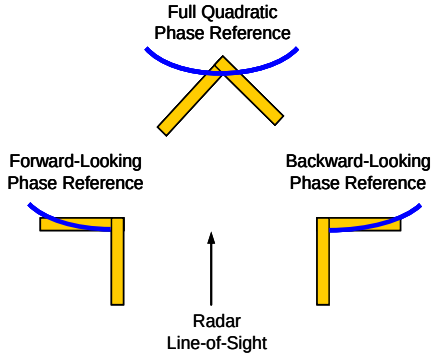
building map
measurement



SAPPHIRE: MAPPING AND FEATURE EXTRACTION

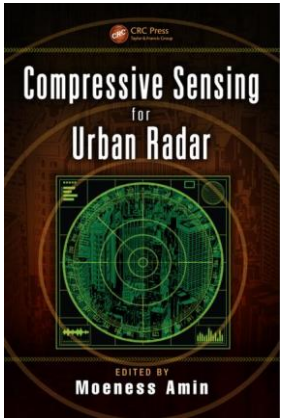
- 3D imaging based on back projection
- Building feature extraction
  - building structure can be represented by principal scatterers
  - principal scatterers have different phase behaviour in 3D
  - phase behaviour can be used to identify and locate different scatterers

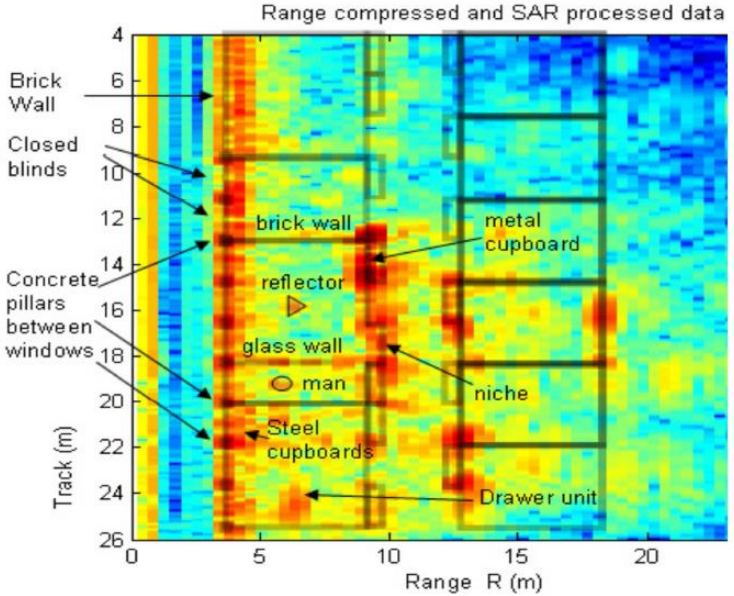


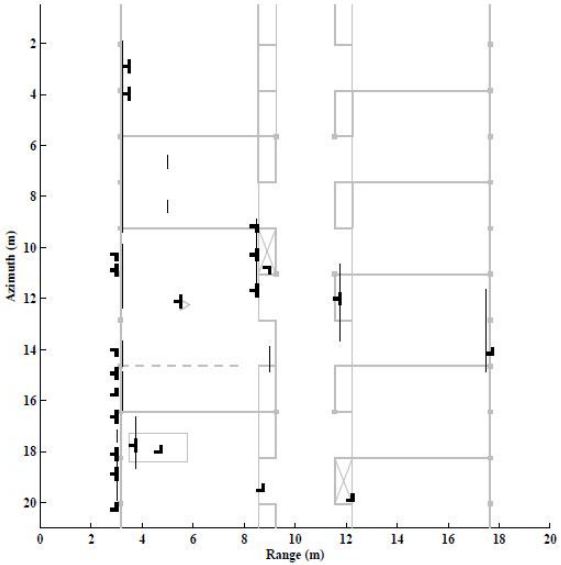


SAPPHIRE: RESULTS FEATURE EXTRACTION

corners
wall
building map
measurement

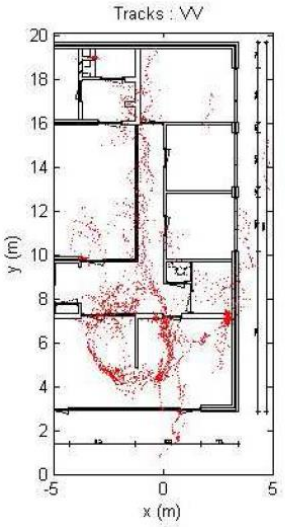


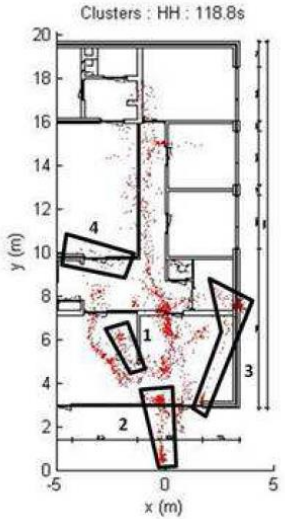




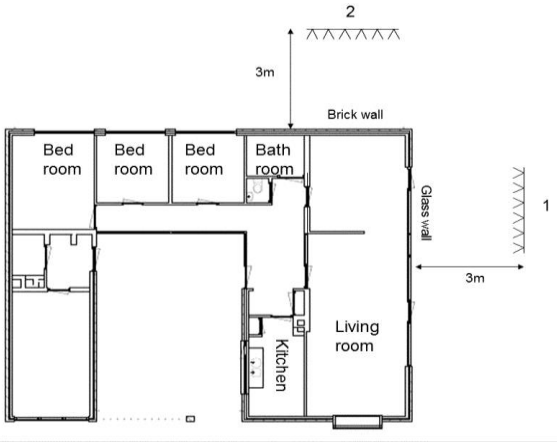
RIBA: PROJECT

- EDA-funded project, i.c.w. BAE Systems Advanced Technology Centre
- Tracking of moving people and transponders was shown to be promising
- By tracking over a longer period of time extra information about the inside of a building was obtained, i.e., doors used
- Multipath effects occur during tracking, further research is needed to suppress multipath reflections





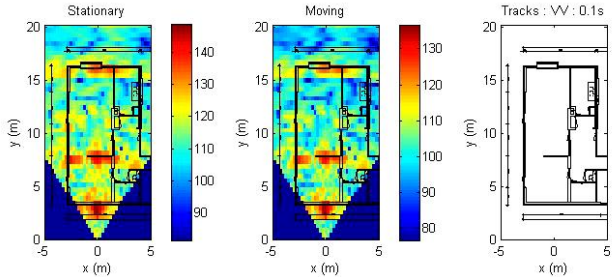
RIBA: RESULTS PERSONNEL TRACKING

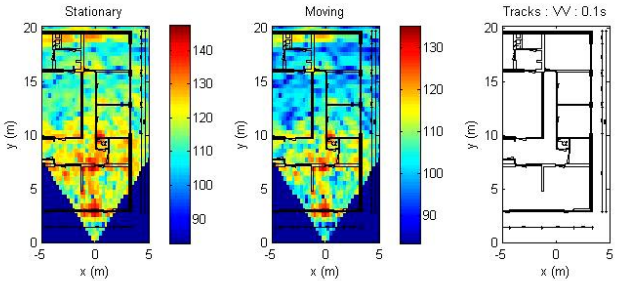


Stationary set-up:

Multi-room tracking

TRACKING

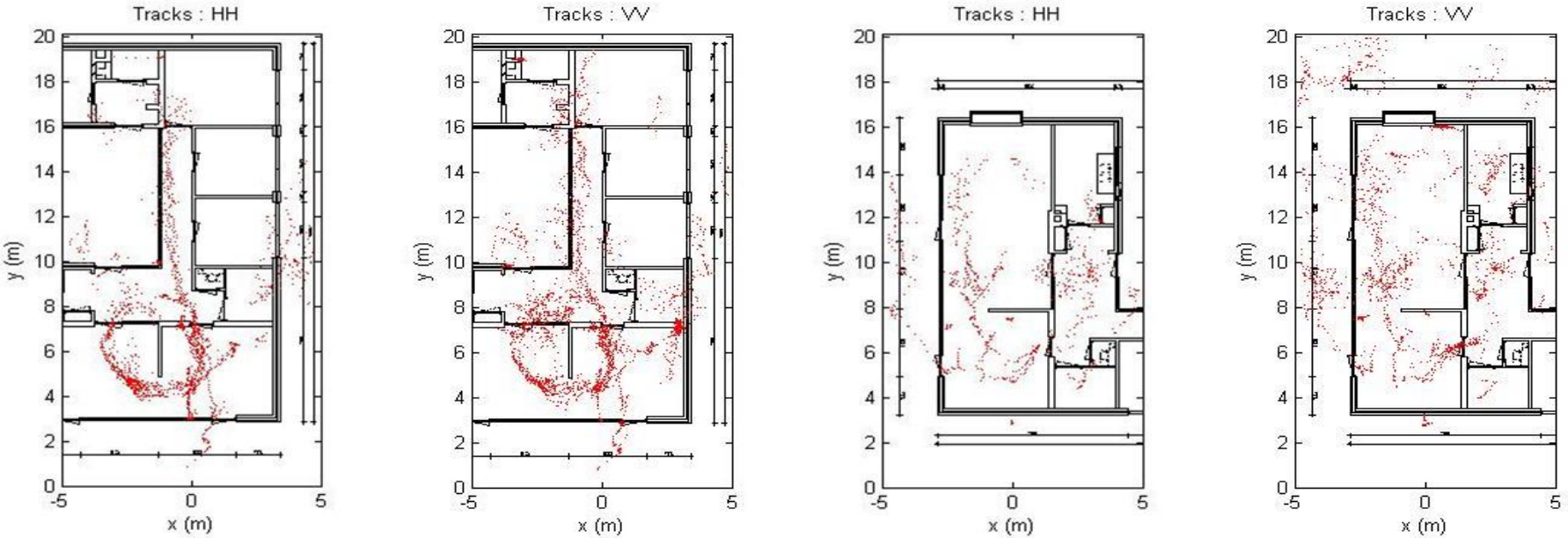

Stationary
Moving
Tracks : W : 0.1s
y (m)
x (m)


Stationary
Moving
Tracks : W : 0.1s
y (m)
x (m)

RIBA: RESULTS PERSONNEL TRACKING

Clusters of well-established tracks:

Position 1 **Position 2**

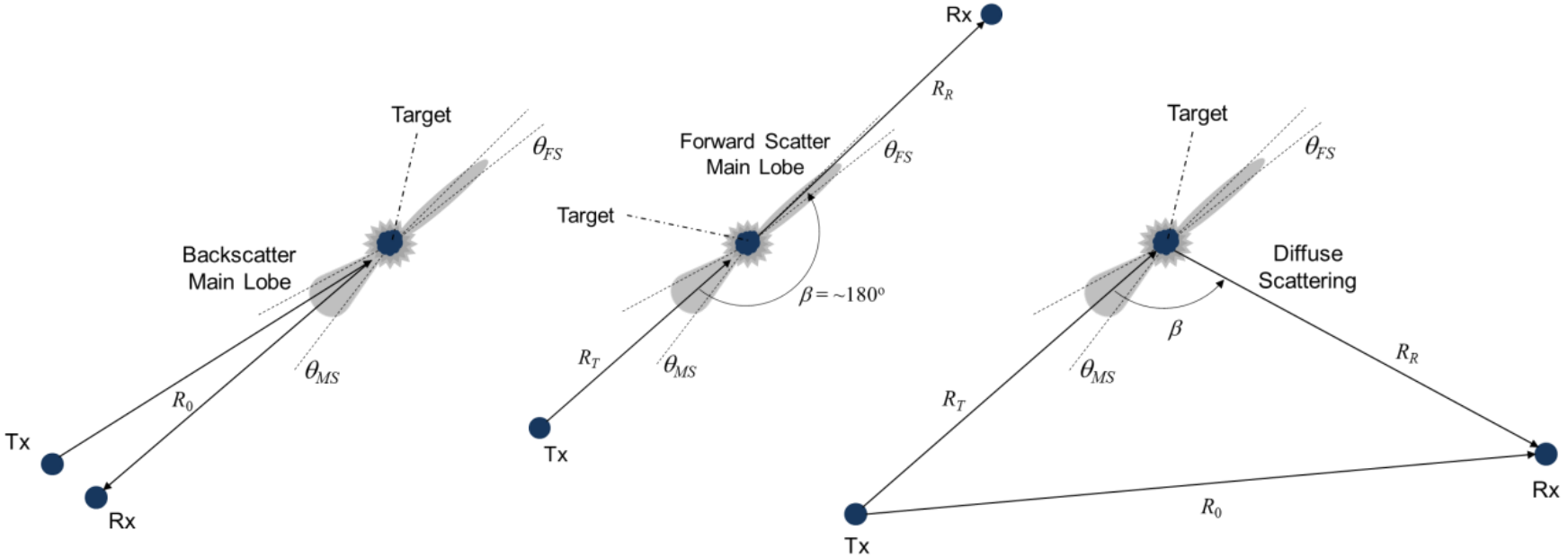


BACKSCATTER VS. FORWARD SCATTER

- Through-wall radar is a common technique for building mapping and inside-building tracking of people
  - typically operation is based on (monostatic) backscatter radar (BSR)
  - backscatter of people is low and many multipath reflections may occur in a cluttered environment
  - the monostatic reflection of a person and multipath reflections may be of comparable strength making reliable detection and tracking difficult

- Forward Scatter Radar (FSR) is based on the forward scatter of a person
  - for opaque objects, including humans, the forward scatter may be higher than the backscatter
  - the high forward scatter mitigates the effect of multipath reflections

SCATTER MECHANISMS



FORWARD SCATTER CROSS SECTION

- Given the radar wavelength λ, the Forward Scatter Cross Section (FSCS) of an object is:

$$\sigma_{FSR} = \frac{4\pi A^2}{\lambda^2}$$

- If an object is opaque, the FSCS depends only on the area A of the object
- Consequently, the use of stealth designs or Radar Absorbent Materials (RAM) does not reduce the FSCS
- This is the main reason Forward Scatter Radar is typically applied as ‘fence detection’

FORWARD SCATTER CROSS SECTION

- In literature, a human is typically modelled as a cylinder of height H and diameter D, with area $H \cdot D$,
- Then the FSCS follows as: $\sigma_{FSR} = \frac{4\pi(HD)^2}{\lambda^2}$ and the BSCS follows as[1]: $\sigma_{BSR} = \frac{\pi H^2 D}{\lambda}$

- For H = 1.8 m, D = 0.5 m and 12.5 cm wavelength, the FSCS is 28.1 dBm^2 and the BSCS is 16.1 dBm^2
  - The FSCS is a factor 16 higher than the (monostatic) BSCS

[1]B.R. Mahafza, “Radar systems analysis and Design using Matlab,” Chapman & Hall/CRC, Boca Raton, 2000

FORWARD SCATTER LOCALISATION

- Approximately the resolution for backscatter is:
  - driven by antenna length L

$$\Delta x_{BSR} \approx \frac{\lambda}{L} \cdot R$$

- Assume resolution for forward scatter:
  - diameter of first Fresnel zone

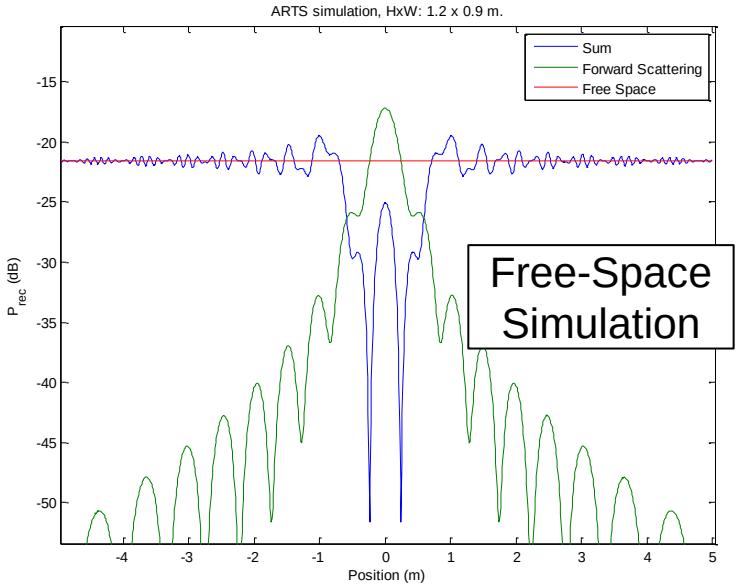
$$\Delta x_{FSR} \approx \sqrt{2R \cdot \lambda}$$

- Resolution forward scatter and backscatter about equal:
  - at 2.4 GHz and an object at 5 m: L = 0.55 m

$$L \approx \sqrt{\frac{\lambda R}{2}}$$

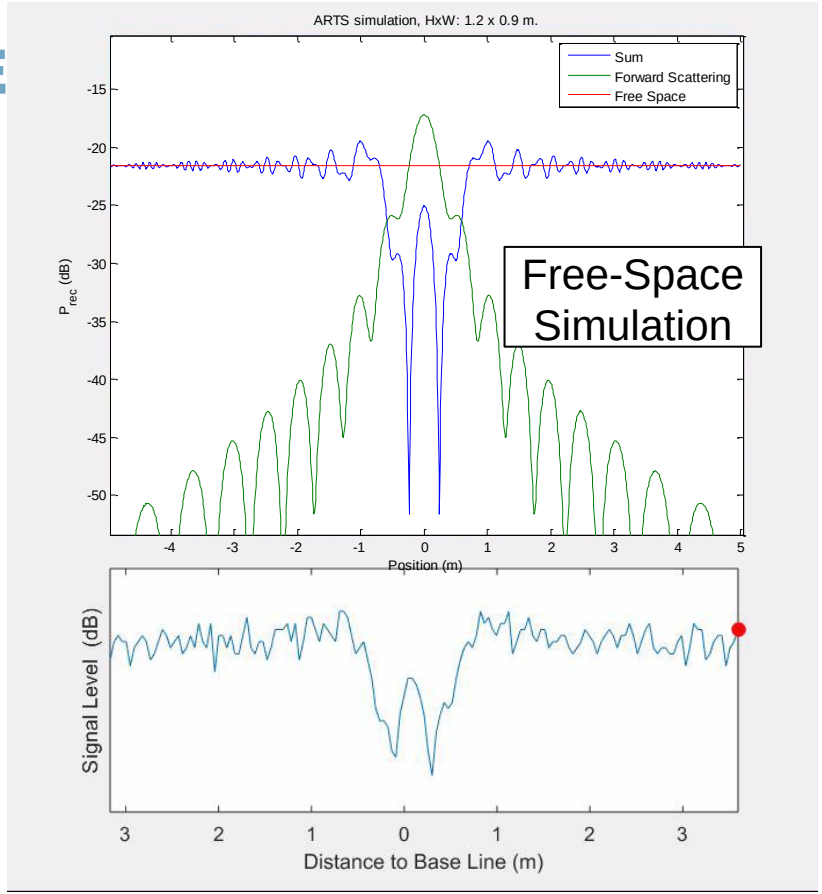
FSR DETECTION: SIMULATION

- In FSR the received signal is the sum of the direct signal and the signal scattered forward by an object
- If the direct signal is stationary, changes of the received signal indicate the presence of an object
- Because the forward scatter is relatively large the changes in the received signal are significant, allowing reliable detection on the basis of the received signal's amplitude



FSR DETECTION: FREE SPACE

- In FSR the received signal is the sum of the direct signal and the signal scattered forward by an object
- If the direct signal is stationary, changes of the received signal indicate the presence of an object
- Because the forward scatter is relatively large the changes in the received signal are significant, allowing reliable detection on the basis of the received signal's amplitude



FSR DETECTION

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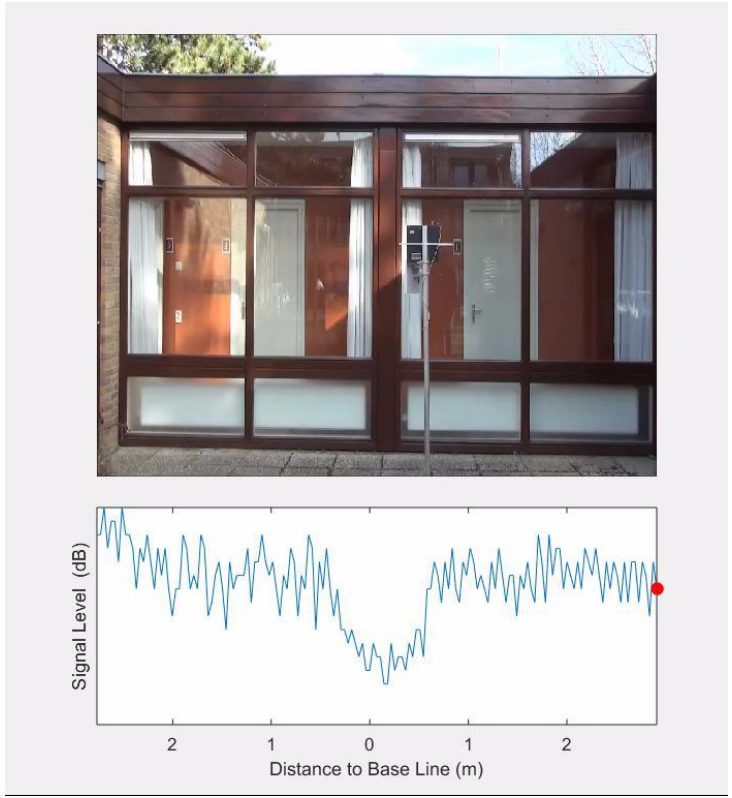
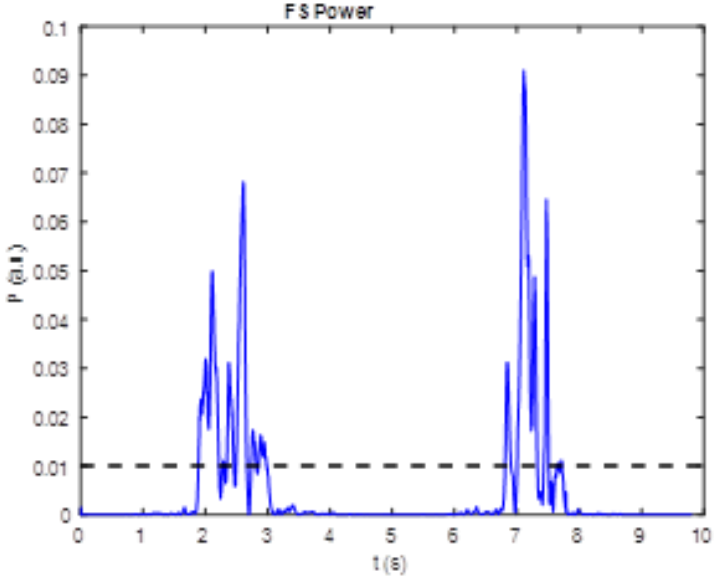
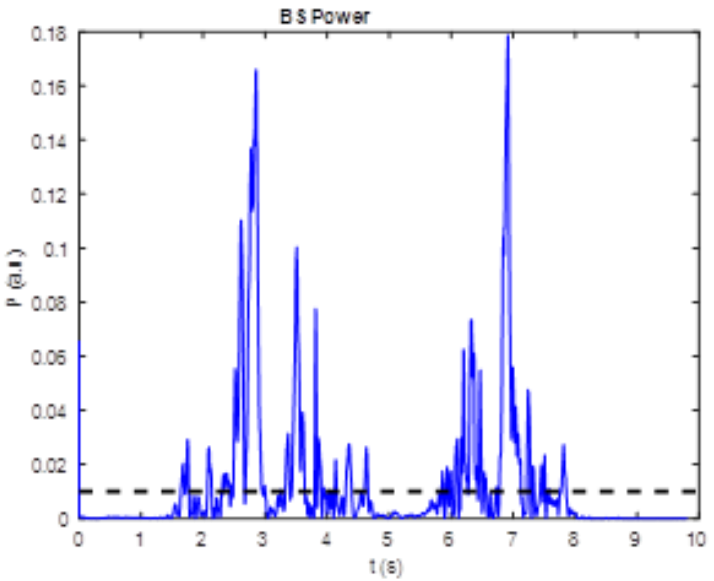


FSR/BSR DETECTION MEASUREMENTS

FSR/BSR DETECTION MEASUREMENTS





CONCLUSION

- The measurements have shown that reliable and consistent detection of people crossing the FSR baseline is feasible even in difficult through-building scenarios
- However, in realistic through-building scenarios, due to multipath and the geometry, the signal power for FSR was lower than for BSR
- The width of the FSR response was more narrow than the width of the BSR response
- Combining FSR and BSR in a single system will yield the benefits from both scattering processes

ARTS: ACTIVE RANGING TRANSPONDER SYSTEM

- ARTS is a 2.4 GHz network of portable transponders for first responder location support inside buildings
- Each transponder measures the distance to all other transponders using an FMCW-like technique
- The transponders are not locked thus frequency and timing offsets lead to distance errors
- Synchronisation and calibration is performed wireless to correct frequency and timing offsets and measure range and speed
- All transponders communicate range data

FUTURE WORK

- ARTS concept provides wireless synchronisation, communication and positioning functionality
- SAPPHIRE concept provides MIMO backscatter and forward scatter radar functionality
- Combining the ARTS and SAPPHIRE technologies would lead to an integrated RF solution for wireless synchronisation, communication, blue-force positioning and multistatic radar:

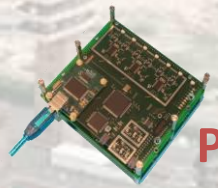
NEFRITE: iNside Edifice Forward-scattering Radar Integrated with Transponder Equipment

AMBER
Reconfigurable

EMERALD
Programmable

SAPPHIRE
Polarimetric

TNO
Radar Technology

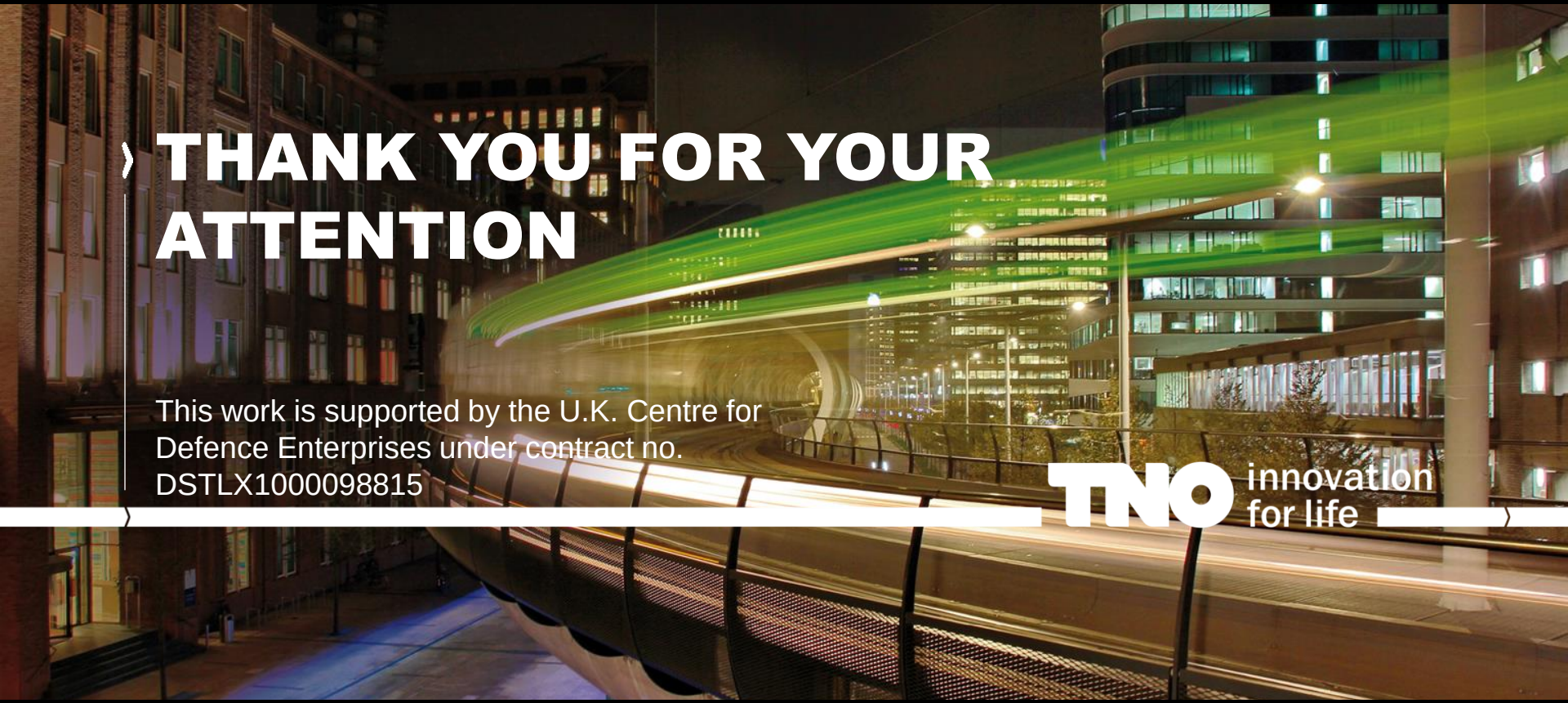


RUBY
Portable

NEFRITE
Wireless

OPAL
Miniature

DIAMOND
Distributed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