# Through-Wall Detection and Imaging of a Vibrating Target Using Synthetic Aperture Radar

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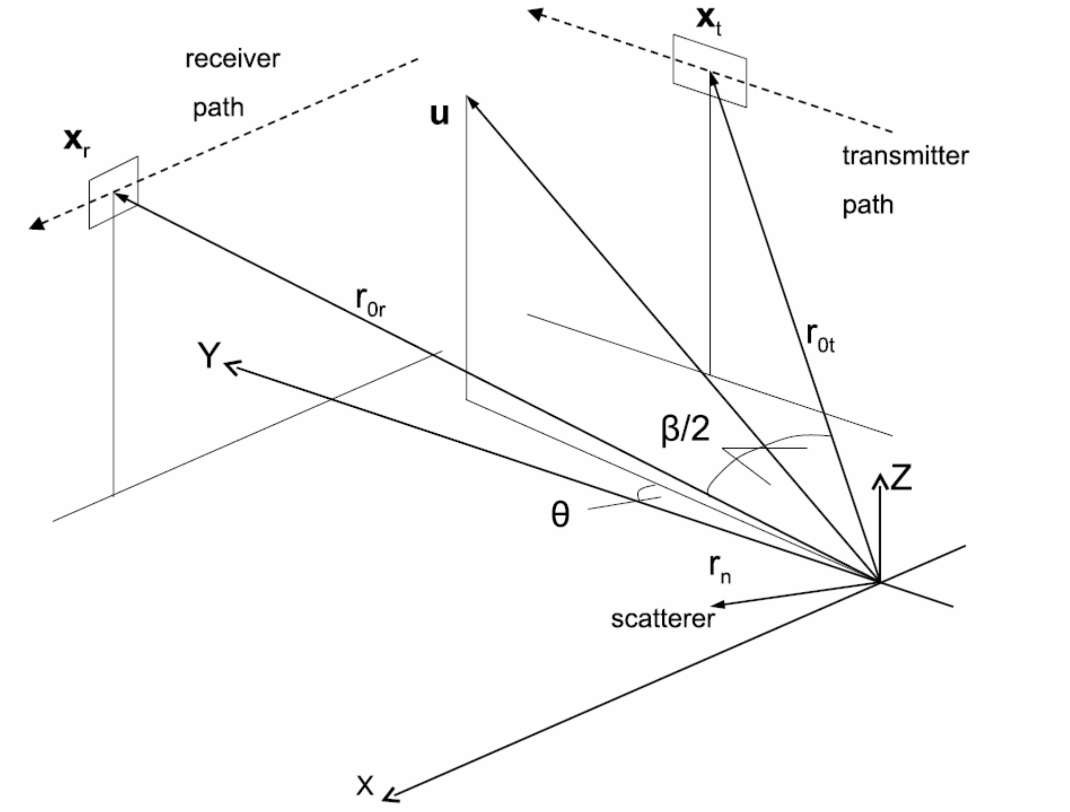
# Introduction

- One of the key desirable outcomes of the Remote Intelligence of Building Interiors (RIBI) programme is in the detection of objects and activities within closed buildings.
- One such activity of interest is the use of running machinery.
- Low frequency synthetic aperture radar can provide one such solution, to through-wall remote sensing.
- Therefore the detection and imaging of a vibrating target behind a wall, using SAR, will be the focal point of this piece of research.

# Quick Introduction to SAR Theory




[1] Halcrow, G. & Mulgrew, B. Nonlinear k-space mapping method for SAR Fourier imaging. *2006 IEEE Conference on Radar,* **2006**, 4-pp

# SAR Theory – Vibrating Target

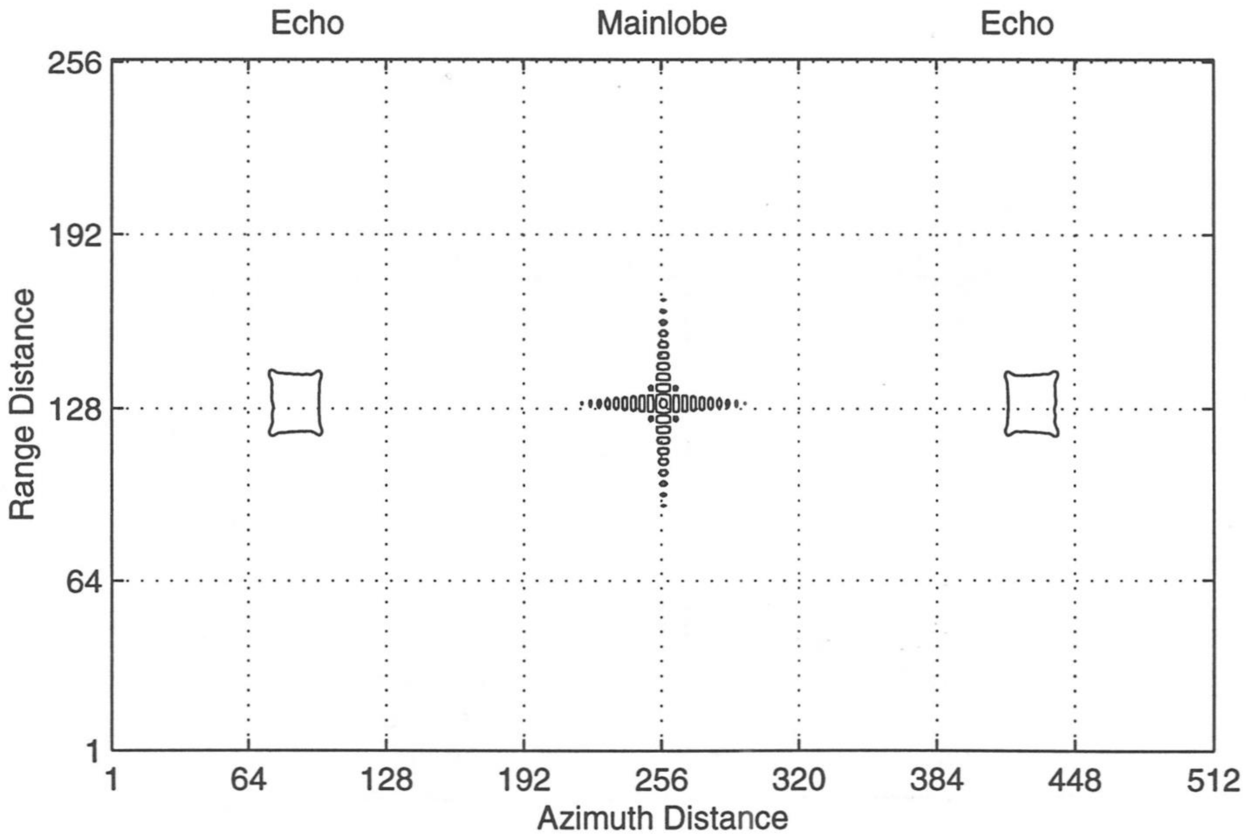
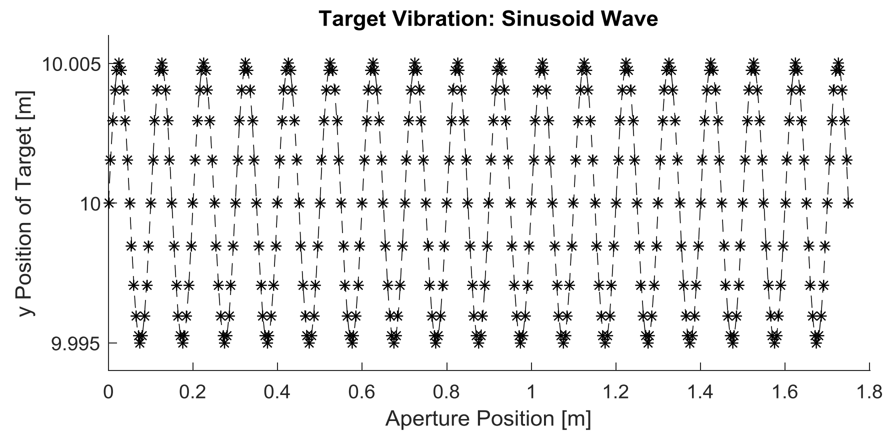



**Figure 9.27** Contour plot in usual SAR image.

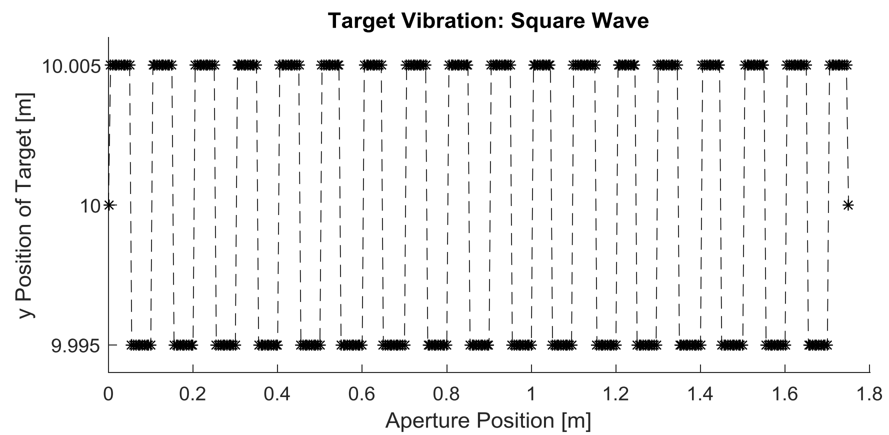

[2] Carrara,W. and Goodman, R.: 'RMM. Spotlight Synthetic Aperture Radar Signal Processing Algorithms', Artech House, 1995

# Simulation - Vibrating Target Displacement

$$y_{vib}(N_x) = y_0 + A_{vib} \cdot \sin\left(\omega_{vib} \frac{Ap(N_x)}{2}\right)$$




$$y_{vib}(N_x) = y_0 + A_{vib} \cdot \text{signum}\left(\sin\left(\omega_{vib} \frac{Ap(N_x)}{2}\right)\right)$$



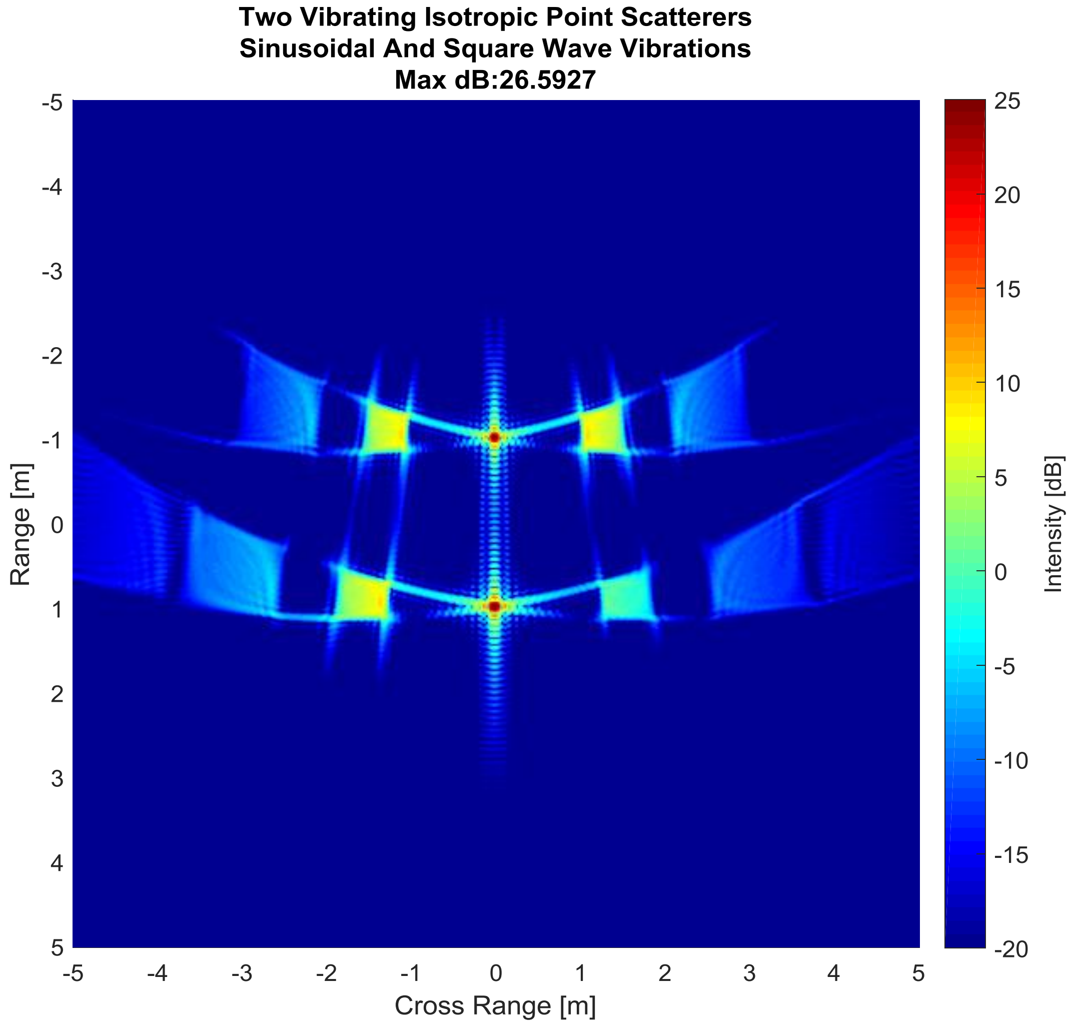

*A* $10\ [Hz]$ *vibrational frequency, over the* $3.5\ [m]$*, is therefore equivalent to a* $2.06\ [m/s]$ *constant antenna velocity.*

[3] Weisstein, E.:. 'Square Wave. Mathworld-A Wolfram Web Resource', URL: http://mathworld.wolfram.com/ SquareWave.html., 2017

# Simulation - SAR Image of a Vibrating Target

Sinusoidal Vibration

Square Wave Vibration



# Simulation - Parameters

| Parameter | Value |
|---|---|
| Aperture [m] | 3.5 |
| Azimuthal Samples | 351 |
| Centre Frequency [GHz] | 5.5 |
| Bandwidth [GHz] | 2 $(f_{max} = 6.5$ & $f_{min} = 4.5)$ |
| Frequency Samples | 801 |
| Antenna Height [m] | 2.79 |
| Range to Wall & Image Centre [m] | 10 |
| Range to Target [m] | 9,11 |
| Image Formation Algorithm | Backprojection [6] |
| Filters | None |
| Windowing e.g. Hamming | None |
| Nominal Resolution [m] | 0.08 |

[4] Gorham, L and Moore, L.: 'SAR image formation toolbox for MATLAB', SPIE Defence, Security, and Sensing. International Society for Optics and Photonics, 2010

# Simulation – Through-Wall Signal Model

## Electromagnetic Wave Propagation

$$\hat{k} = \alpha + i\beta \longrightarrow \text{Wavenumber}$$

$$\alpha = \omega\sqrt{\frac{\mu\epsilon}{2}\left[\sqrt{1+\left(\frac{\sigma'}{\omega\epsilon}\right)^2}-1\right]} \longrightarrow \text{Attenuation}$$

$$\beta = \omega\sqrt{\frac{\mu\epsilon}{2}\left[\sqrt{1+\left(\frac{\sigma'}{\omega\epsilon}\right)^2}+1\right]} \longrightarrow \text{Phase Constant}$$

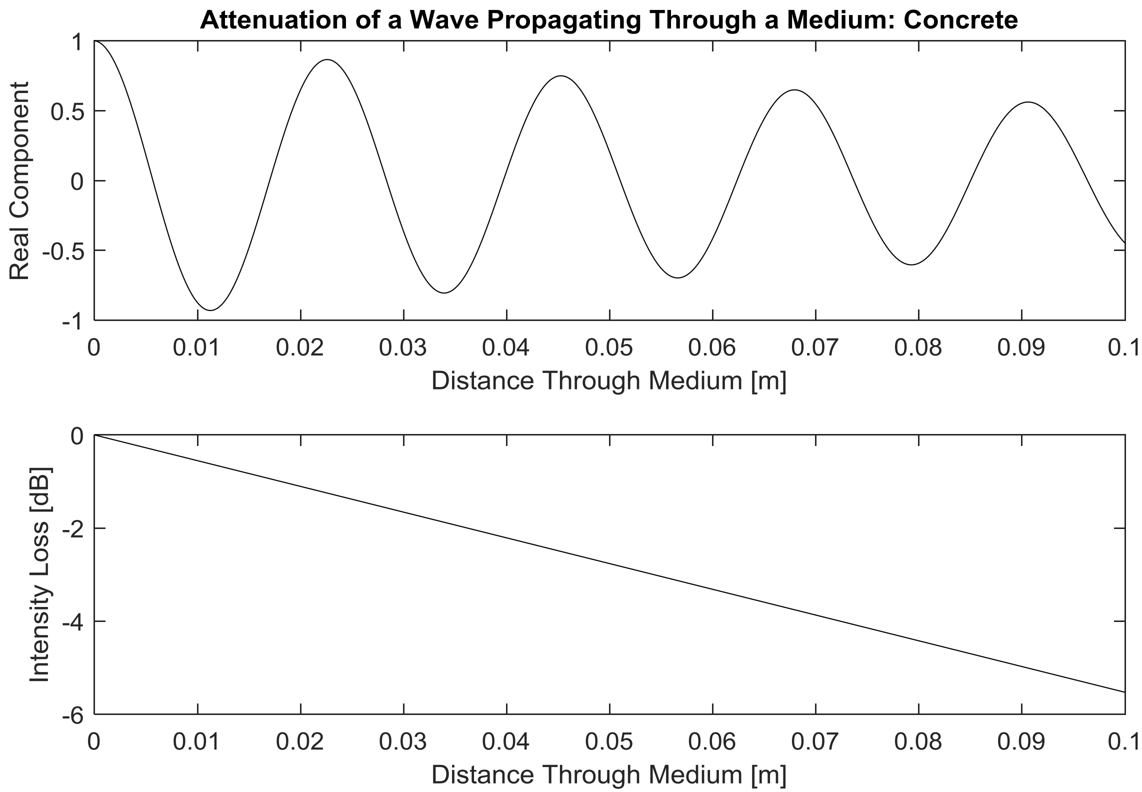
$$\epsilon = \epsilon_r\epsilon_0 = \left(\epsilon_r' - i\frac{\sigma'}{\epsilon_0\omega}\right)(8\times10^{-12}) \longrightarrow \text{Absolute Permittivity}$$

$$\mu = \mu_r\mu_0 = (1)(4\pi\times10^{-7}) \longrightarrow \text{Absolute Permeability}$$

[5] Sadiku, M.: ‘Elements of Electromagnetics’, Sixth Edition. Oxford University Press, 2014, pp.410-472
[6] Balanis, C.: ‘Advanced Engineering Electromagnetics’. John Wiley & Sons, 1989
[7] Morrow, I and Van Genderen, P.: ‘A polarimetric near-field backpropagation algorithm for application to GPR imaging of mines and minelike objects’, Proceedings of SPIE, the International Society for Optical Engineering, 2001

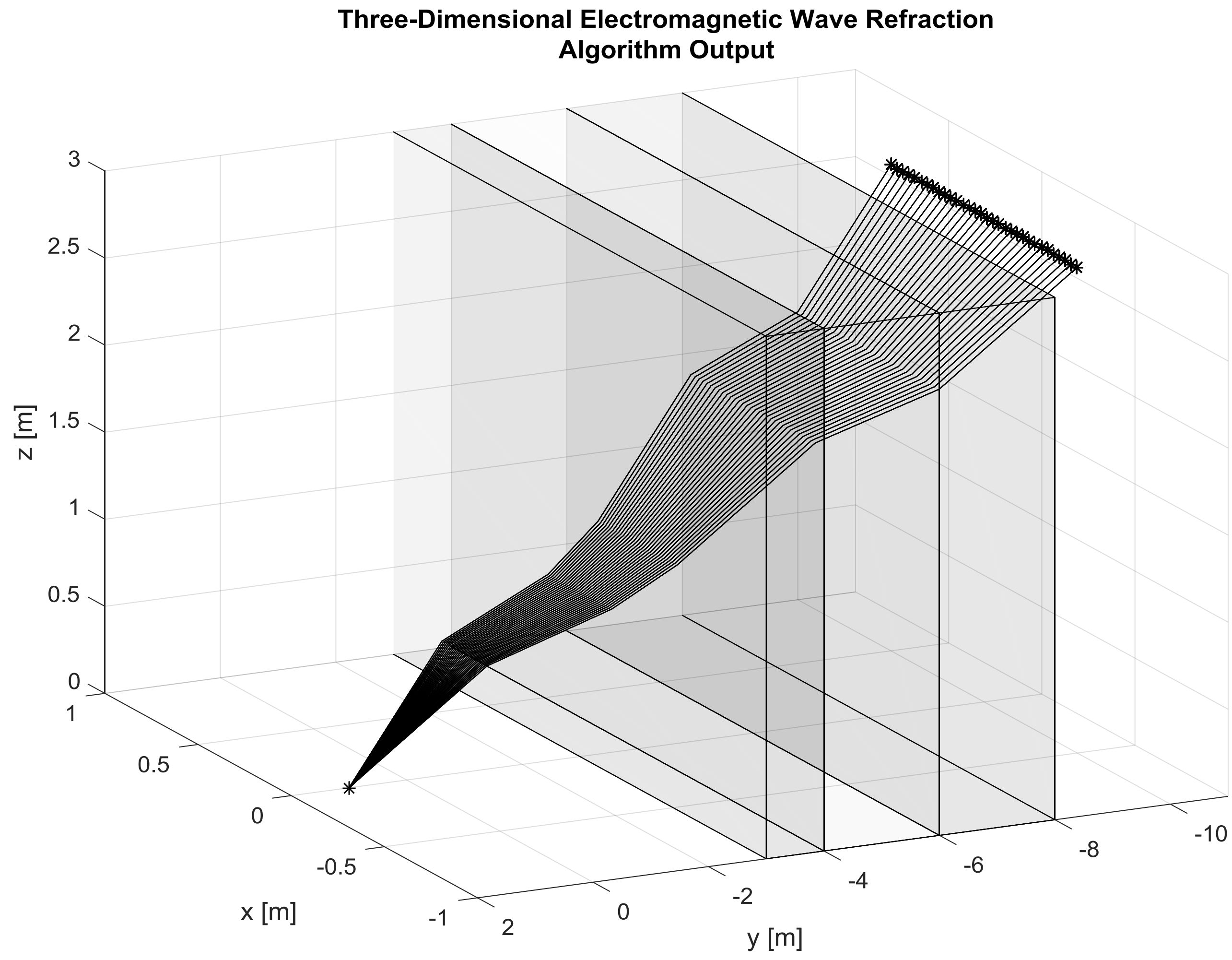
# Simulation – Through-Wall Signal Model

## Electromagnetic Wave Propagation




$\epsilon_r{}' = 7$ $\sigma' = 1 \times 10^{-1.25}\ [{}^{S}/_{m}]$

# Simulation – Through-Wall Signal Model



# Simulation – Through-Wall Signal Model

$$P_h(k_l, r_m) = e^{-i(k_l r_m)}$$

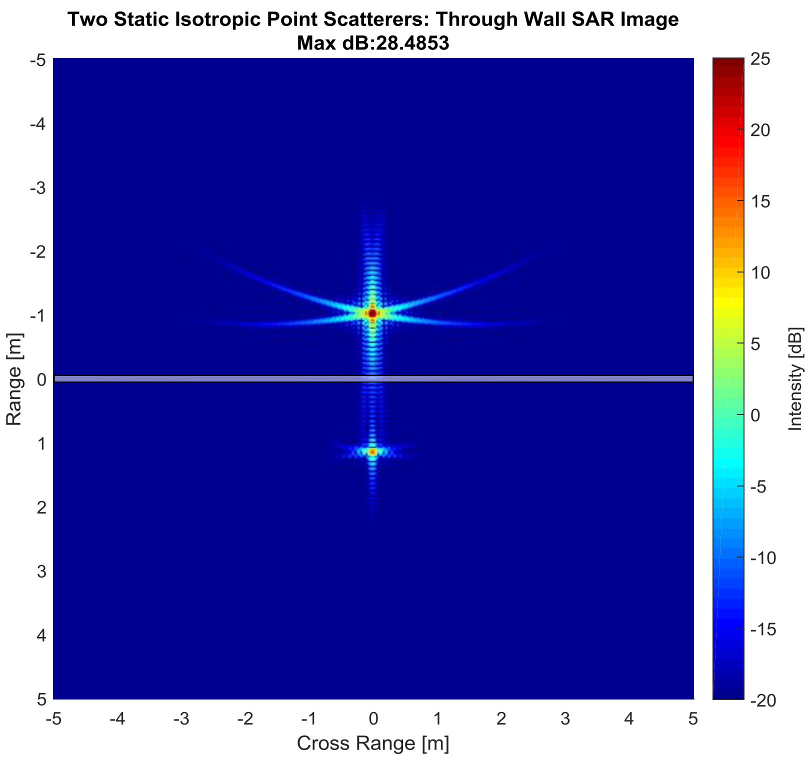
$$k_l = \frac{2\pi f_l}{c}$$

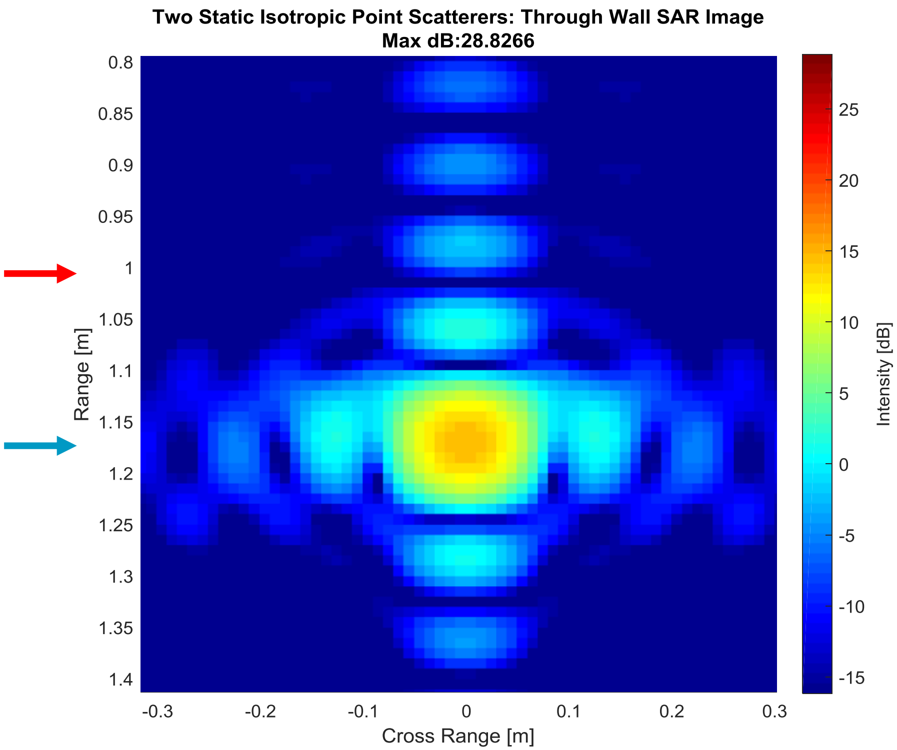
"No Wall" Signal Model: Phase History

$$P_{hc} = e^{-i\left(\sum_{m=1}^{m_t} \hat{k}_m R_m\right)} \cdot e^{-i(k R_{sc})}$$

"Through-Wall" Signal Model: Phase History

# Simulation – Through Wall SAR Image

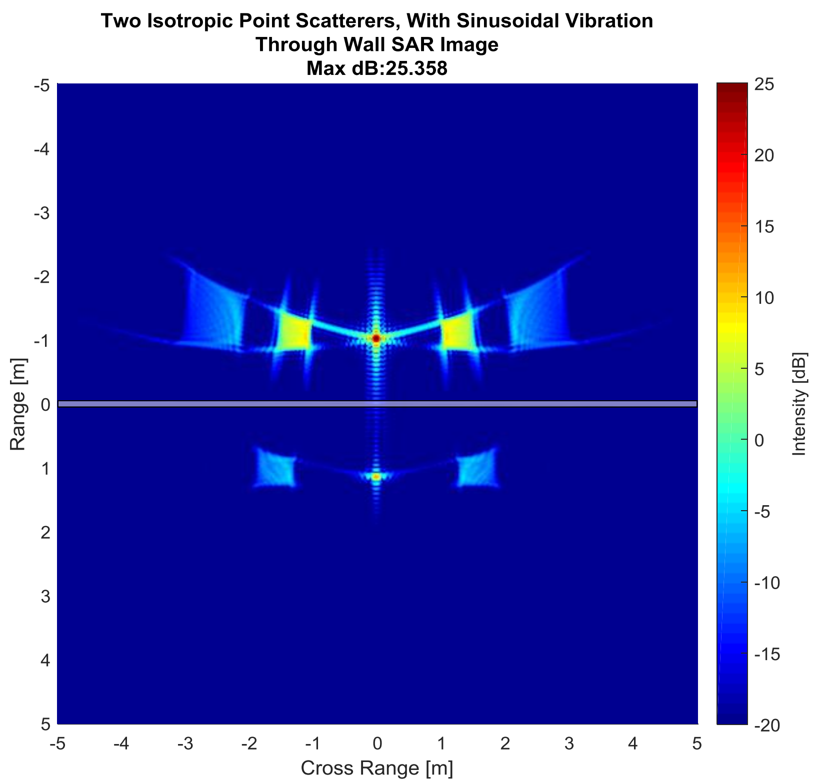


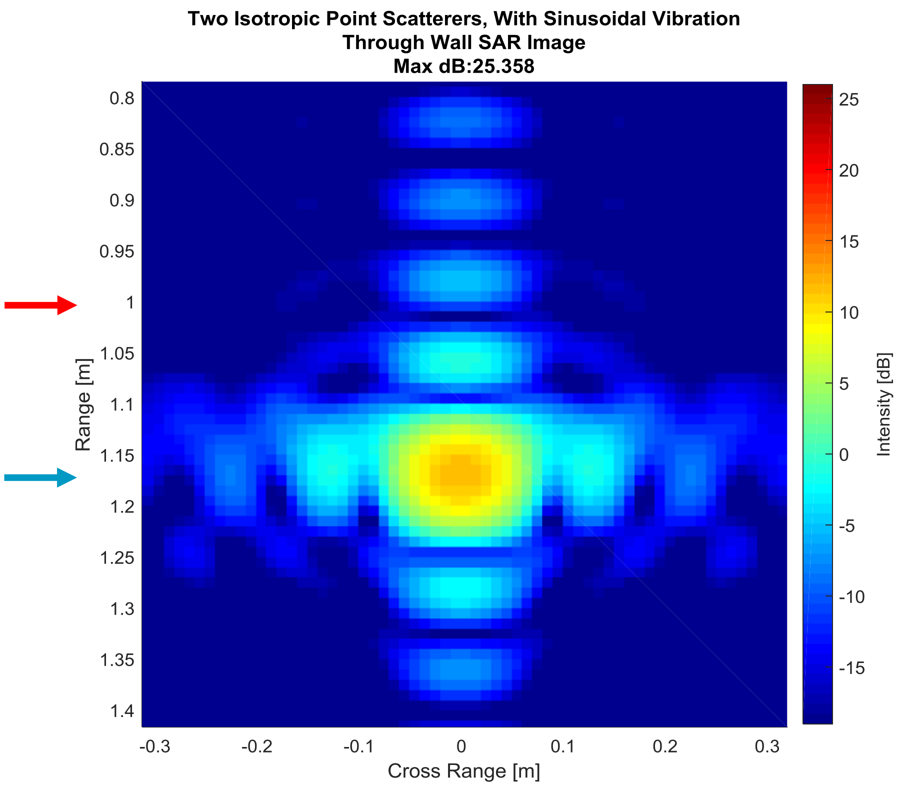




→ = "Real world" location of scatterer.

→ = "Shifted" location of scatterer, within SAR Image

# Simulation – Through Wall & Target Vibration

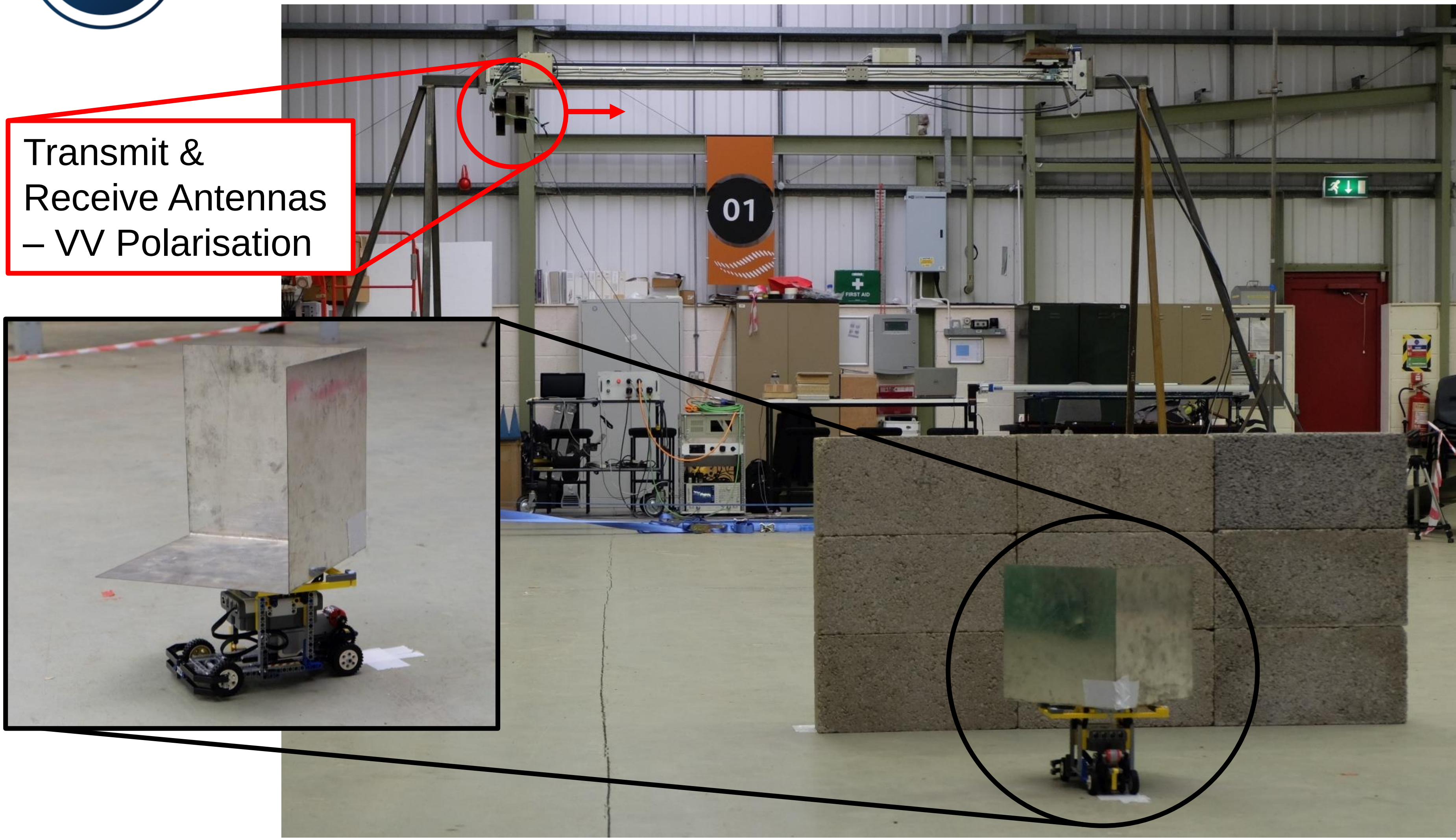



= "Real world" location of scatterer.

= "Shifted" location of scatterer, within SAR Image

# Experimentation – Cranfield GBSAR Laboratory



# Experimentation – Measurement Parameters

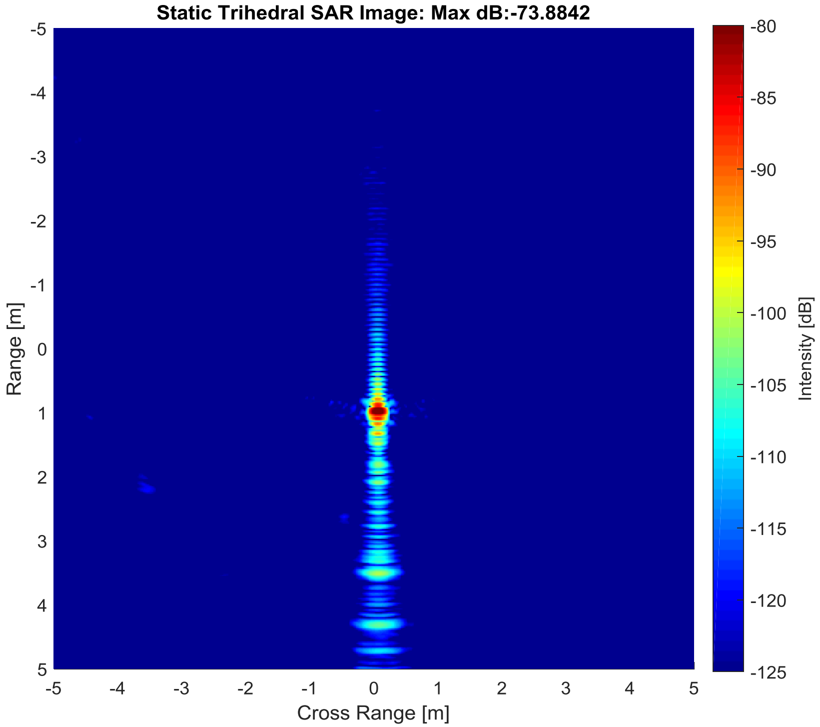
| Parameter | Value |
|---|---|
| Aperture [m] | 3.5 |
| Azimuthal Samples | 351 |
| Centre Frequency [GHz] | 5.5 |
| Bandwidth [GHz] | 4 ($f_{max} = 7.5$ & $f_{min} = 3.5$) |
| Frequency Samples | 1601 |
| Antenna Height [m] | 2.79 |
| Range to Wall & Image Centre [m] | 10 |
| Range to Target [m] | 11 |
| Wall Material | Standard Concrete Masonry Unit "Breezeblock". |
| Wall Height [mm] | 645 |
| Wall Width [mm] | 876 |
| Wall Thickness [mm] | 97 |
| Target | Trihedral |
| Target Size [mm] | 250 × 250 × 250 |

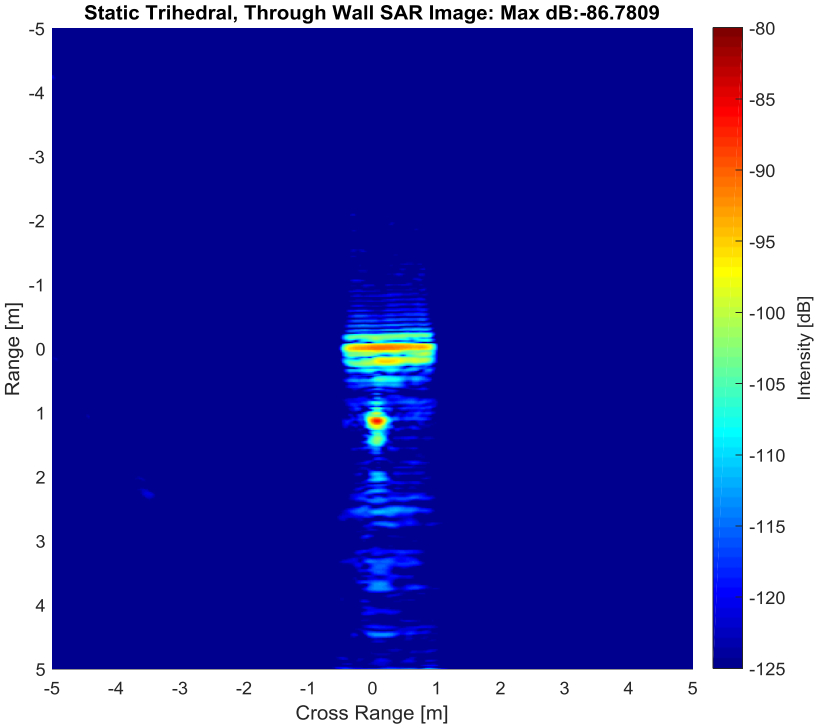
# Experimentation – Image Formation Parameters

| Parameter | Value |
| --- | --- |
| Image Formation Algorithm | Backprojection [6] |
| Filters | None |
| Windowing e.g. Hamming | None |
| Nominal Resolution [m] | 0.08 |
| Image Orientation | Ground plane. |

[4] Gorham, L and Moore, L.: 'SAR image formation toolbox for MATLAB', SPIE Defence, Security, and Sensing. International Society for Optics and Photonics, 2010

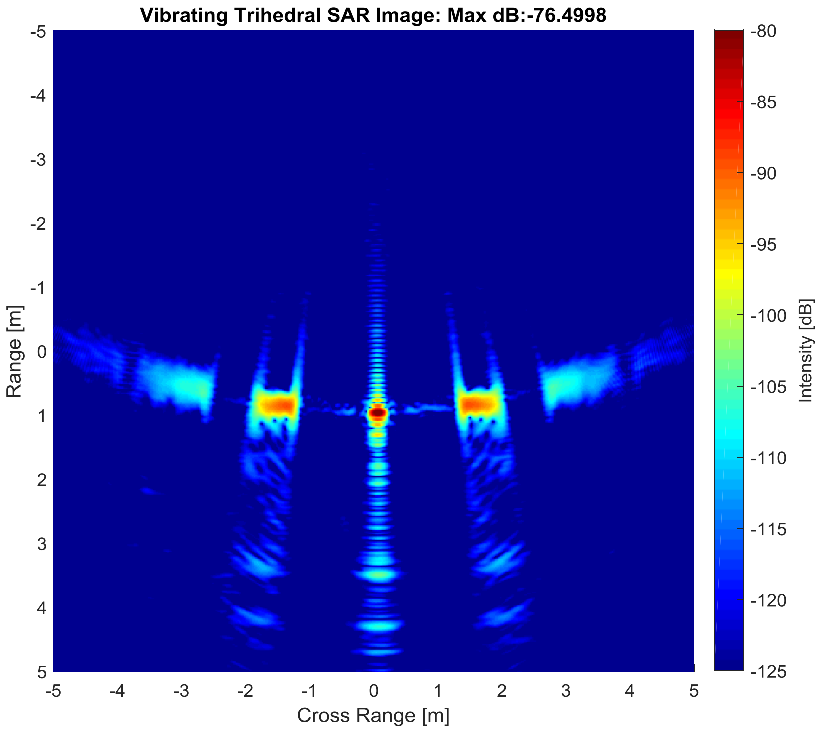
# Experimentation – Monostatic Measurements

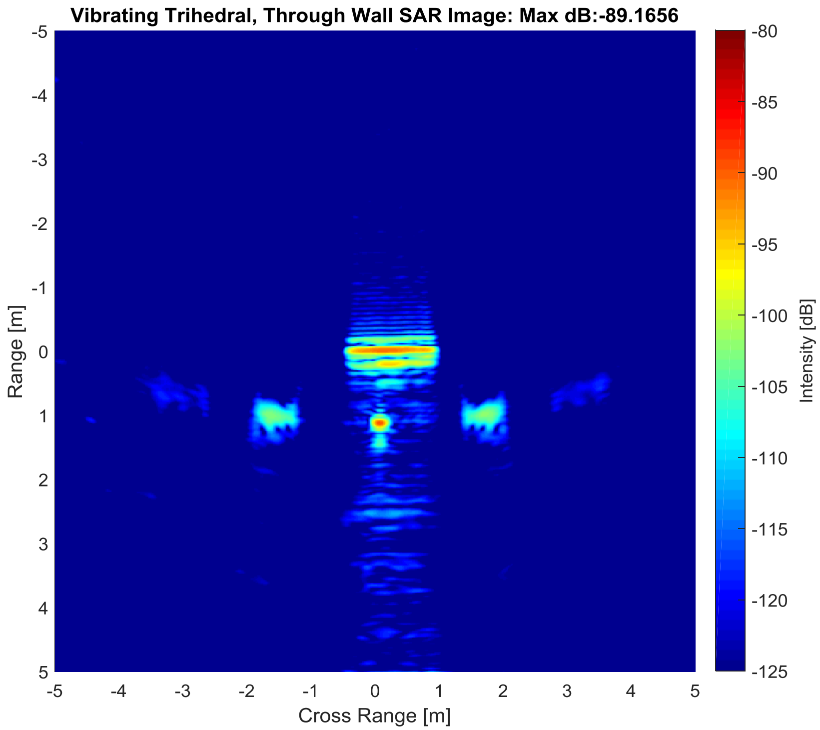


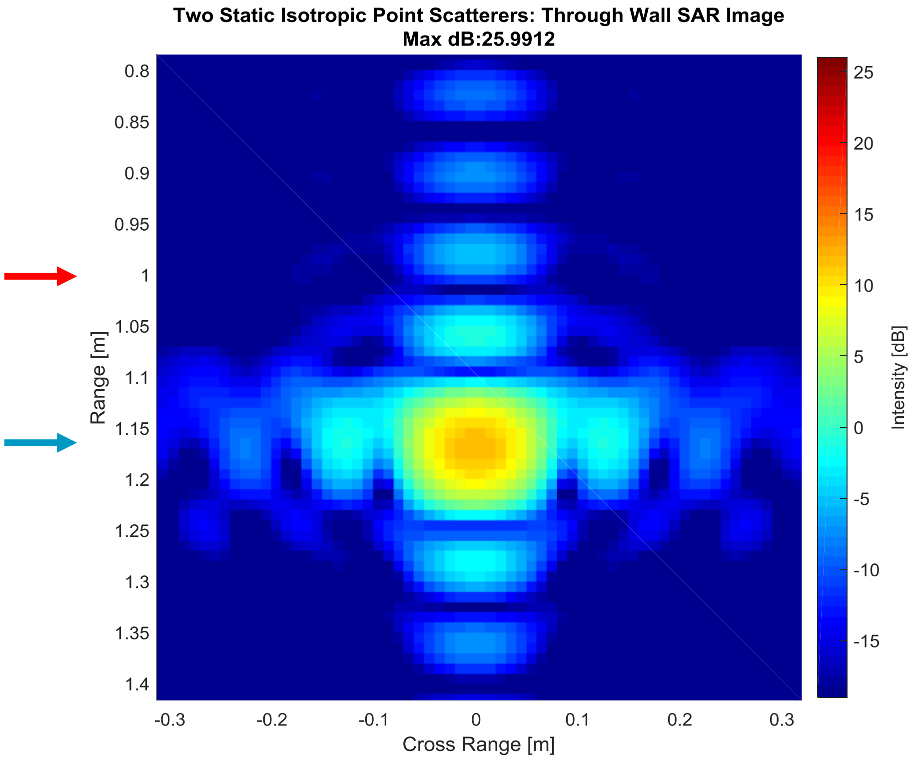
# Experimentation – Monostatic Measurements

- $10\ [Hz]$ vibrational frequency, with a $5\ [mm]$ amplitude.
- Hence representing an effective $2.06\ [m/s]$ constant antenna velocity.

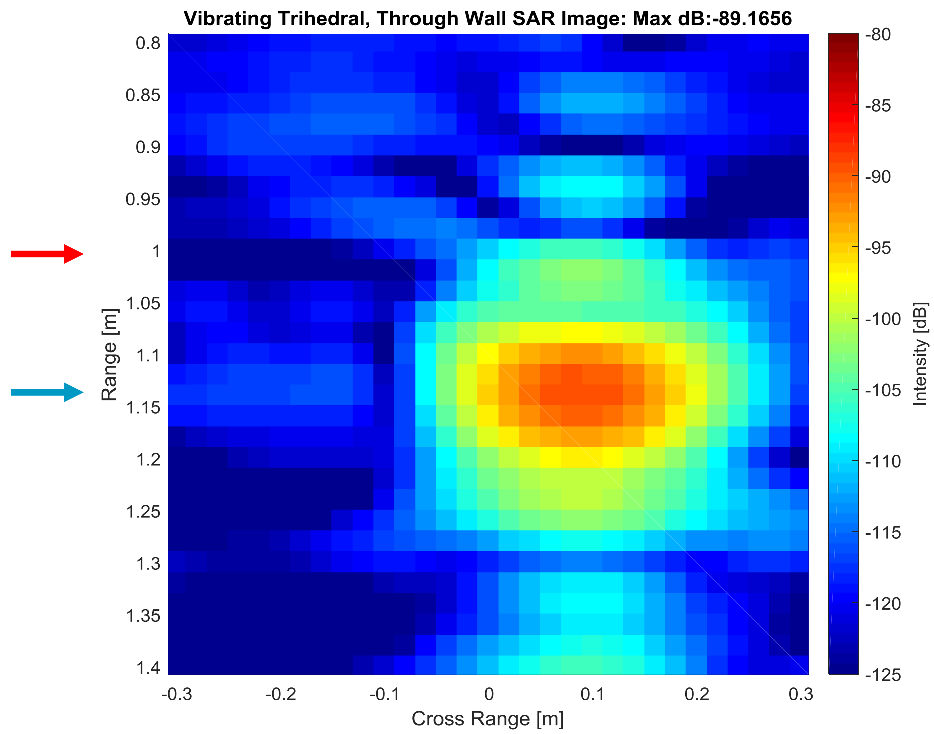


# Target "Shift" Comparison




Simulation



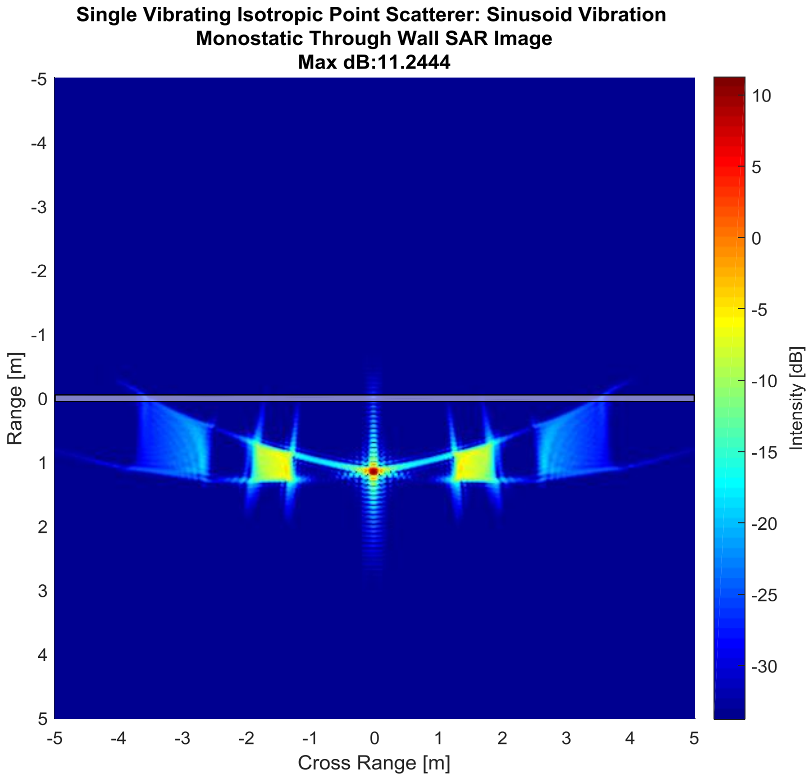

Measurement

→ = "Real world" location of scatterer.

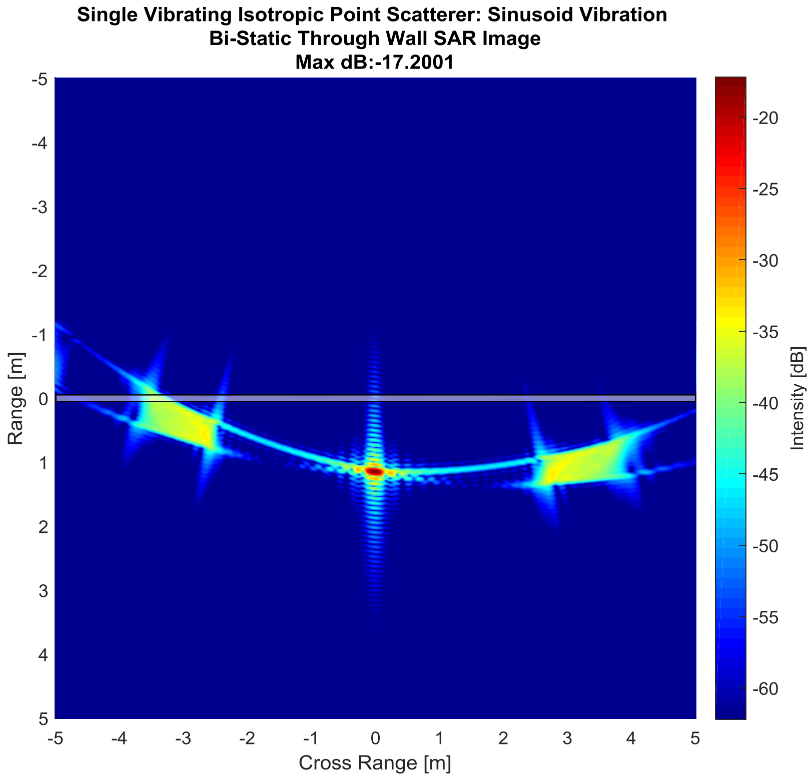
→ = "Shifted" location of scatterer, within SAR Image

# Generating A Multistatic Data Set

- Combination of multiple radar scans undertaken at the same time.

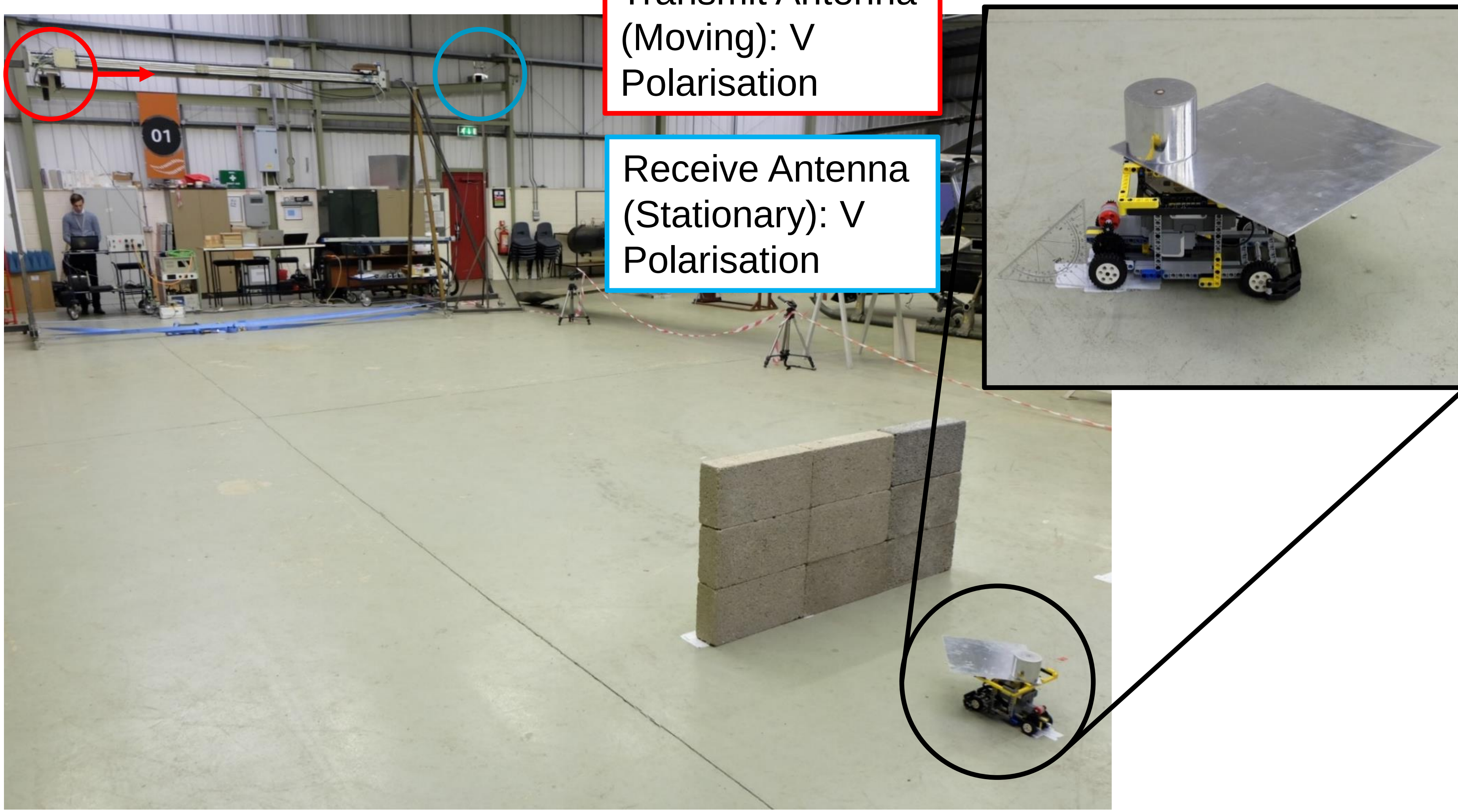



Monostatic Simulation

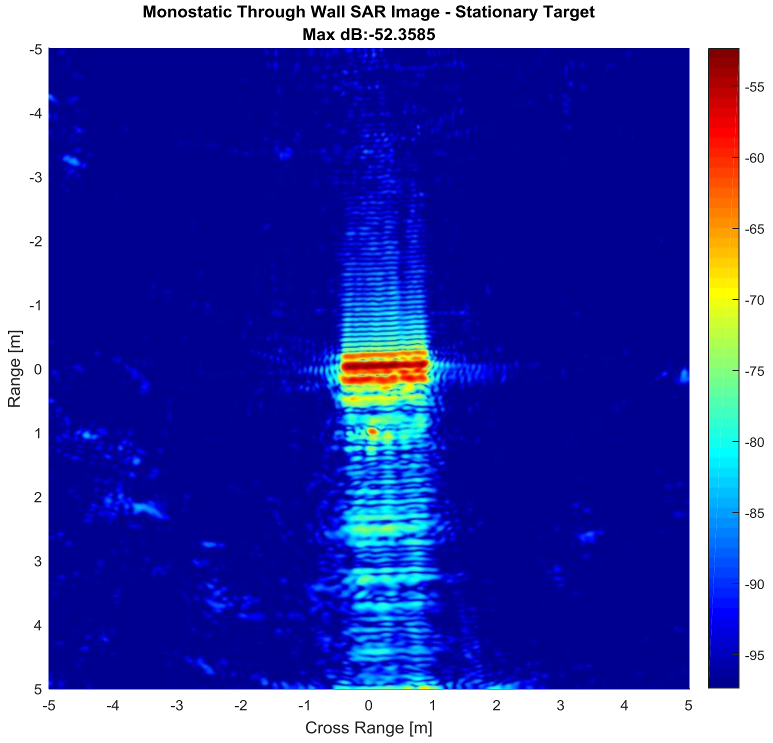


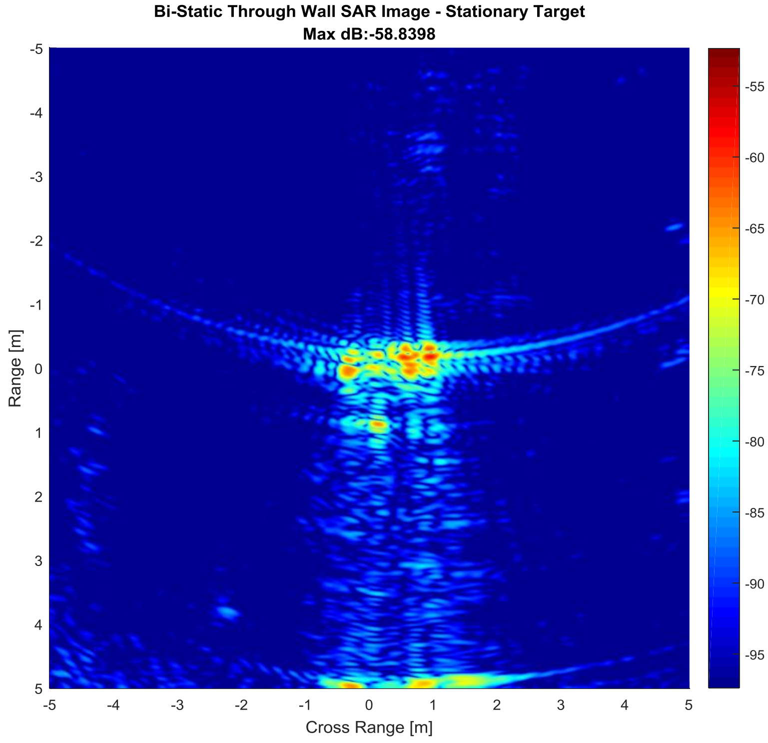

Bi-Static Simulation

# Experimentation – Multistatic Dataset

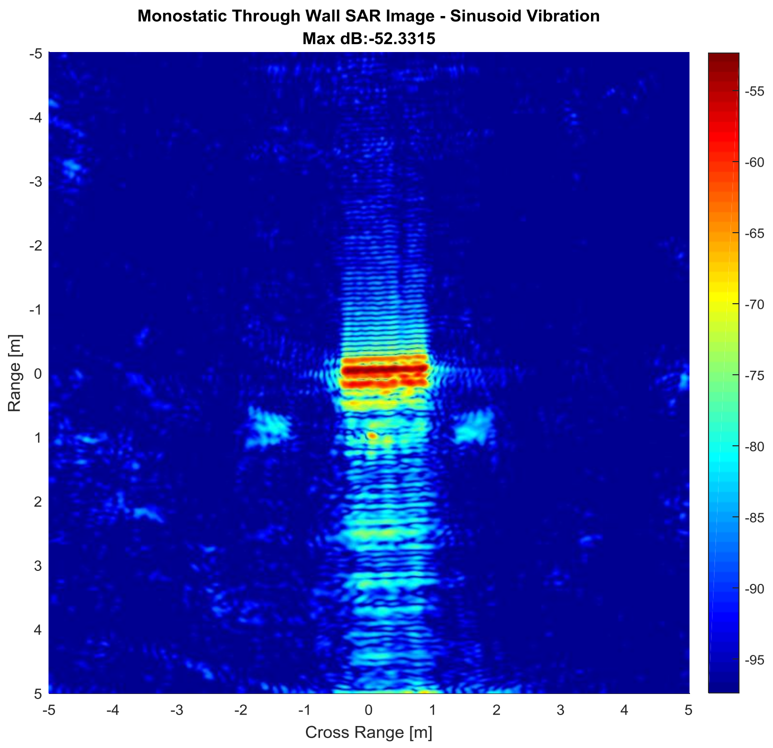


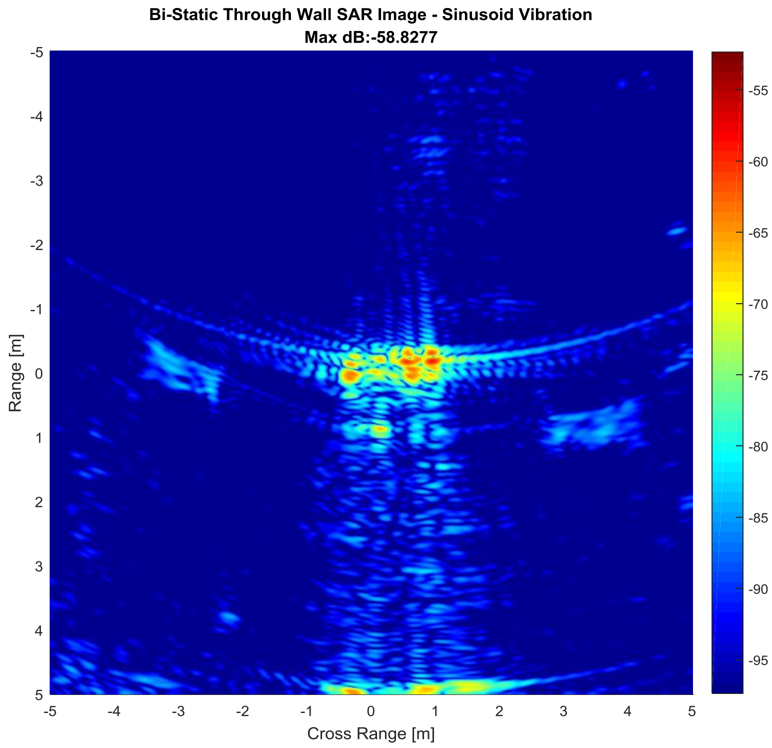
# Experimentation – Multistatic Dataset



# Experimentation – Multistatic Dataset



# Conclusion

- The results show a vibrating target can be detected and imaged behind a wall, using low frequency SAR.
- A through-wall SAR image collection of a vibrating target has been successfully modelled within a simulation environment.
- Simulation results have been successfully validated against experimental measurement data using the Cranfield GBSAR system.
- Multistatic datasets show how different radar geometries can reveal new aspects of a vibrating targets paired echoes location, size and occurrence and therefore how they appear within the SAR image.
- The Cranfield GBSAR system is currently being upgraded to a full SAR 3D collection system. This will allow for complete 3D SAR datasets to be collected, and therefore high resolution 3D SAR images to be produced.

**Thank you to DSTL for funding this piece of work under the RIBI programme.**

# Thank You for Listening

## Any Questions?

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