EKAS – ELECTROMAGNETIC CHARACTERIZATION OF COMPOSITE STRUCTURES

Project within NFFP6 (NFFP – National Aviation Engineering Research Programme).

Torleif Martin *et.al.*

OUTLINE

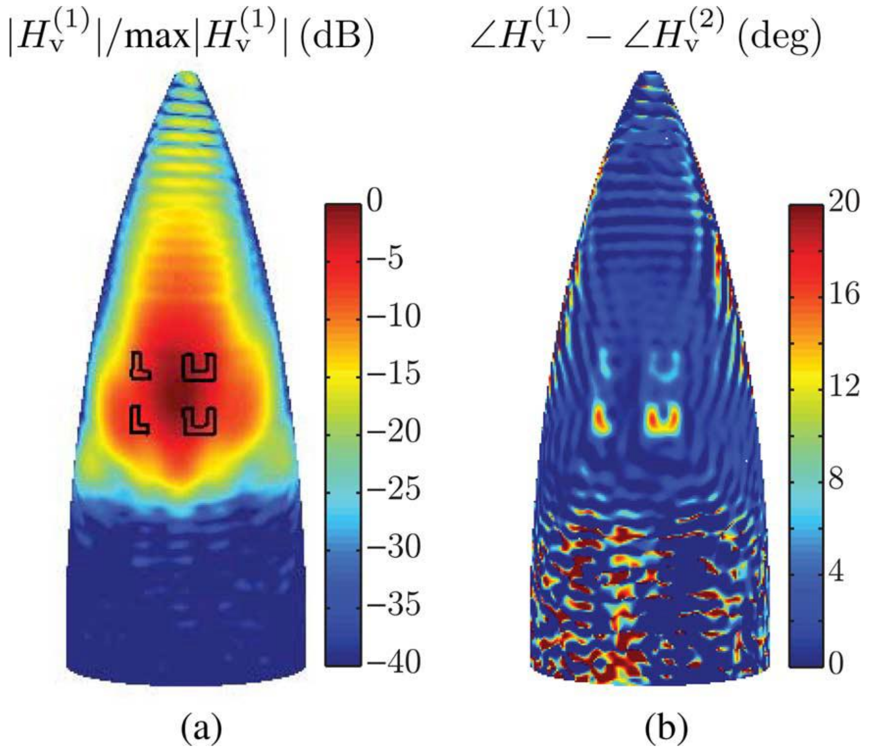
- Background
- Project overview
- Transmission measurements
- Data processing and image formation
- Results for test panels
- Conclusions and future work

BACKGROUND

- Radar absorbing structure (RAS) and radomes are made of composites.
- Complex material compositions, design and manufacturing.
- Need to verify quality of parts or assembled parts using non-destructive-testing.
  - Mechanical properties
  - Electromagnetic properties
- Conventional methods such as ultrasonic testing not suitable.
- Imaging methods based on near-field electromagnetic propagation and “back-projection” suitable.

BACKGROUND

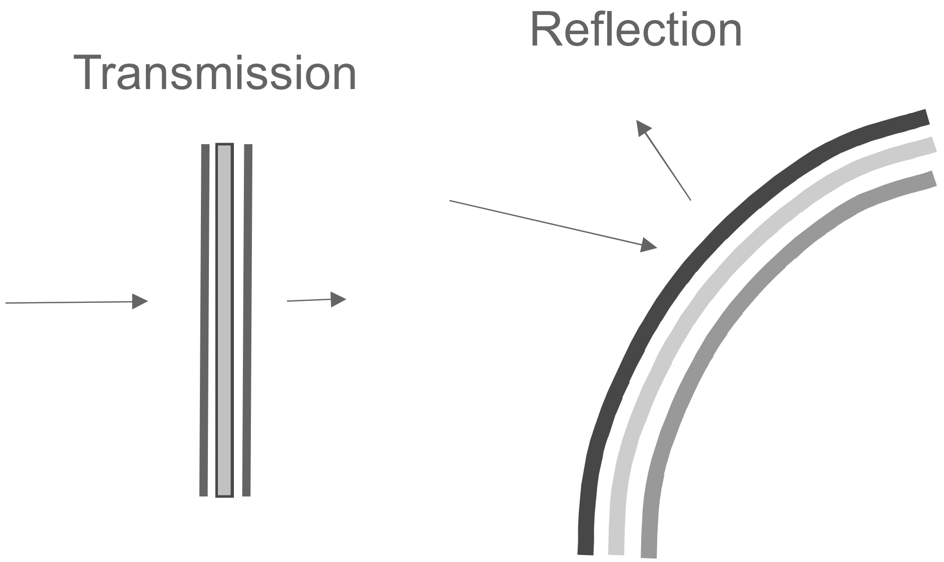
- Results from earlier project, see [1].
  - Characterization of radomes.
- Transmission through radome characterizes the material (back-projection)
- The idea of using a similar technique for the “reflection case” arise.



[1] K. Persson, M. Gustafsson, G. Kristensson, and B. Widenberg, “Radome diagnostics — source reconstruction of phase objects with an equivalent currents approach,” IEEE Trans. Antennas Propagat., vol. 62, no. 4, 2014.

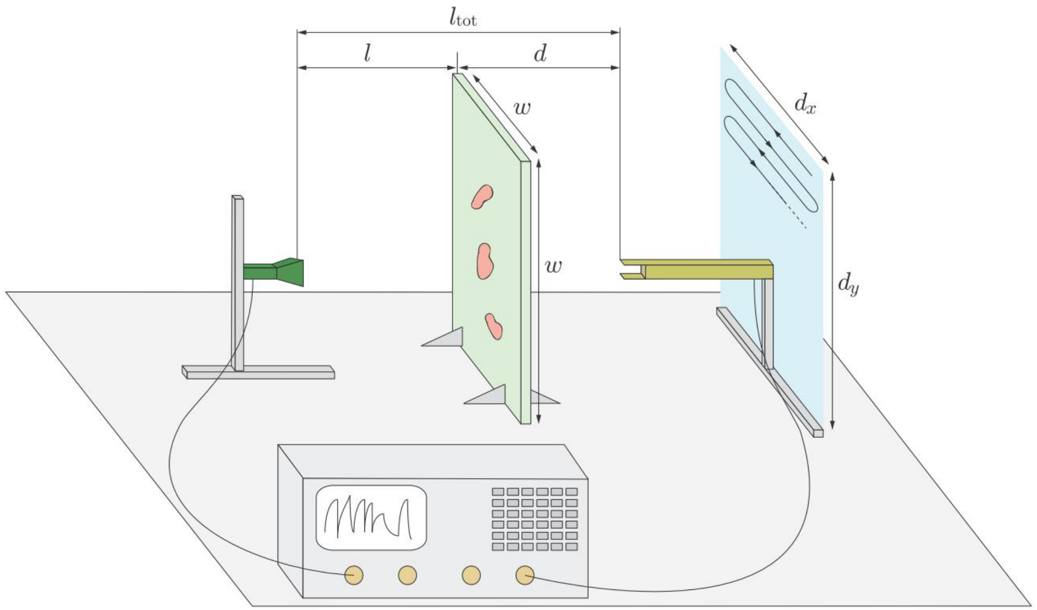
PROJECT OVERVIEW

- Project within NFFP6 (NFFP – National Aviation Engineering Research Programme).
- Project Team
  - Torleif Martin, Saab Aeronautics & Lund university (PM)
  - Jakob Helander, Andreas Ericsson, (PhD stud.) Lund university
  - Mats Gustafsson, Daniel Sjöberg, Lund university
  - Christer Larsson, Saab Dynamics & Lund university
  - Björn Widenberg, ACAB – GKN Aerospace.
- 3-year project, Mid 2014 – mid 2017.
- Aim: to investigate and demonstrate the potential of the local electromagnetic scattering for characterizing composite structure.
  - Transmission measurements
  - Reflection measurements
  - Images of defects/ inhomogeneous material properties.
- Work presented here is performed by Lund university.



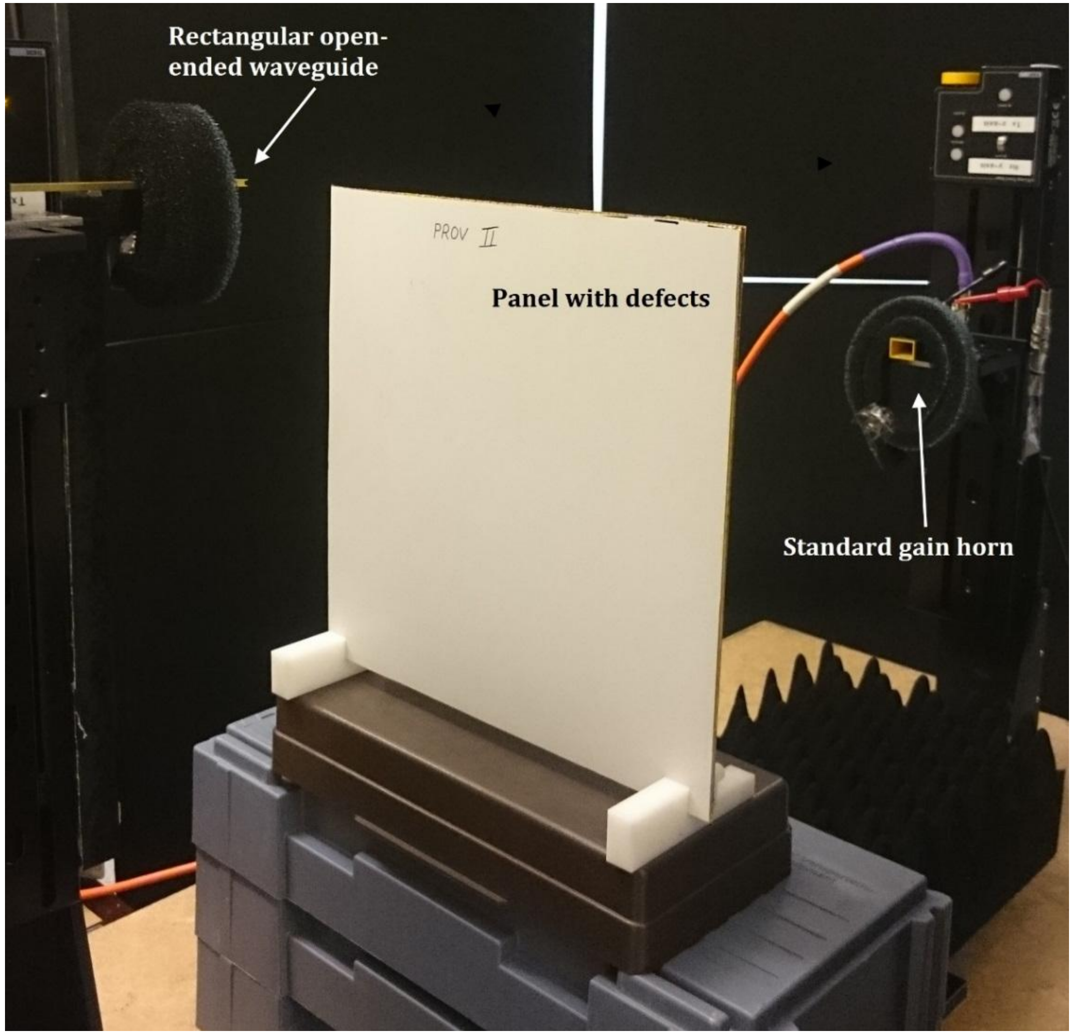
TRANSMISSION MEASUREMENTS

- Characterization of defect composite panels.
- High frequency (~60 GHz).
  - Improved image resolution compared to lower frequencies.
  - Small equipment size – laboratory scale.



TRANSMISSION MEASUREMENTS

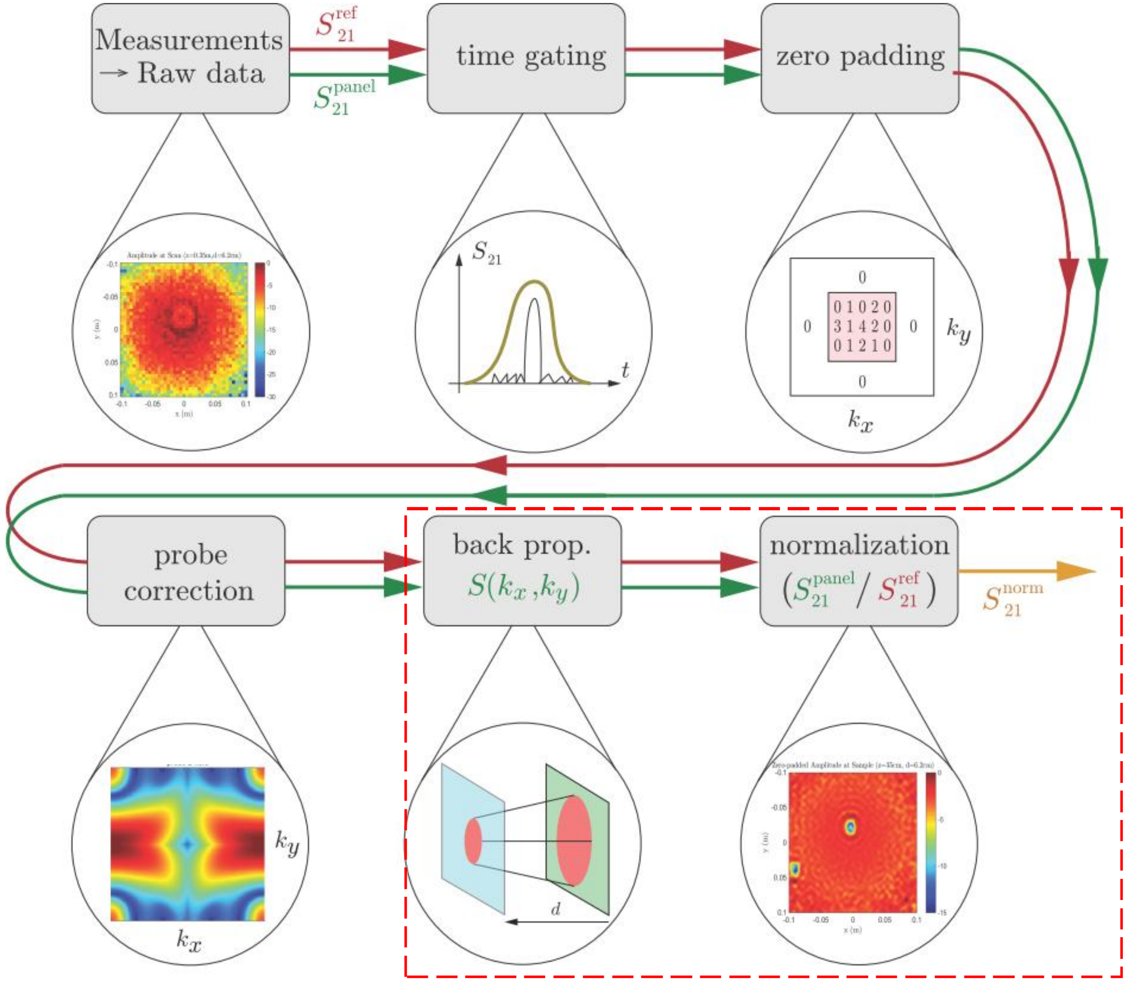
- Transmitting antenna: Standard gain horn (50 − 67 GHz).
- Probe: Rectangular open-ended waveguide.
- 67 GHz Agilent E8361A vector network analyzer.
- Positioners for moving the probe.
- LNA at the receiver to increase dynamic range.
- Note, probe/antenna does not measure Electric field (probe correction needed).



DATA PROCESSING

- Post-processing of measured data.
  - Time-gating in order to suppress multipath components.
  - Zero-padding for interpolation of the data.
  - Probe correction to compensate for probe's far-field pattern.
  - Image formation (3 different approaches)

- Image formation
  - Time-reversal (back-propagation of data)
  - Linear inverse problem formulation (source separation)
  - Compressive Sensing (L^1-minimization)



TIME REVERSAL (BACK-PROPAGATION)

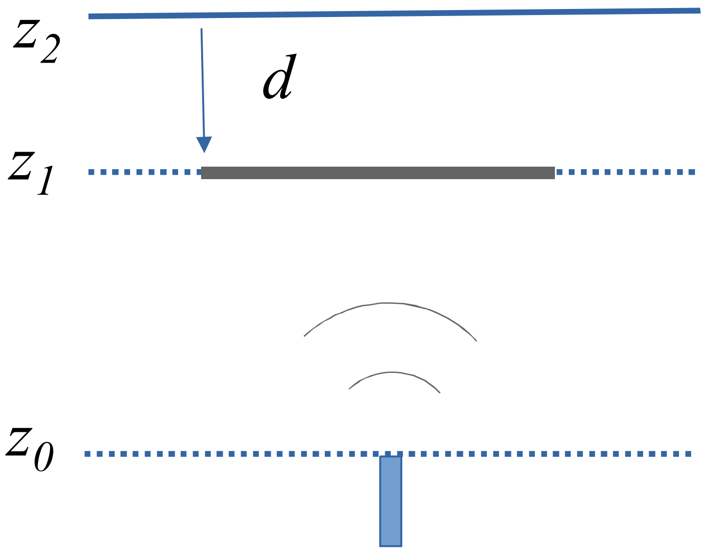
- 2D Fourier transform of the measured signal.

$$\boldsymbol{S}(k_x, k_y, z_2) = \iint_A \boldsymbol{s}(x, y, z_2)\, e^{-j(k_x x + k_y y)}\, dxdy$$

- Propagate the spectrum to a new position z_1:

$$\boldsymbol{S}(k_x, k_y, z_1) = e^{jk_z d}\, \boldsymbol{S}(k_x, k_y, z_2)$$

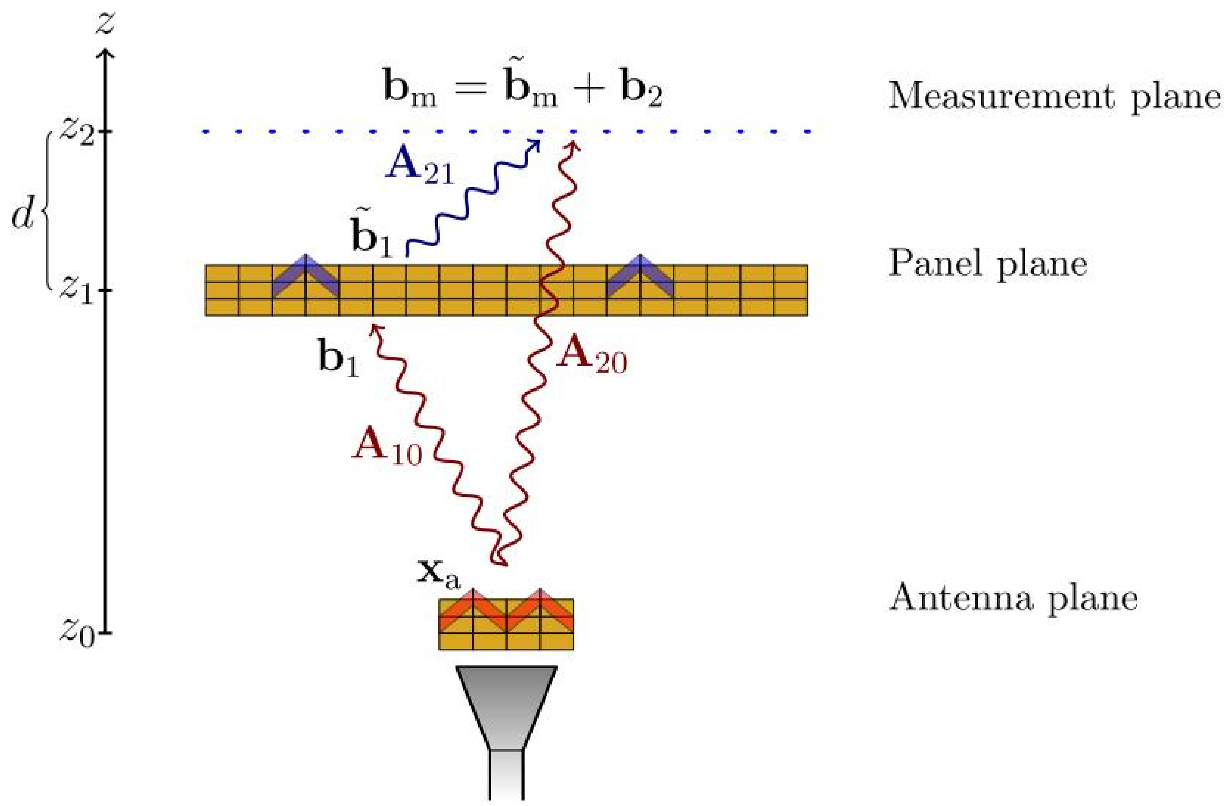
$$k_z = \sqrt{k^2 - (k_x^2 + k_y^2)}$$



- Drawbacks
  - Dense sampling (λ/2) means long measurement times.
  - Reference measurement needed.
  - Truncation effects

LINEAR INVERSION – SOURCE SEPARATION

- Sparse signal, if the sources can be separated
- Discretize and expand the current density in basis functions.
- Remove illuminated field b_2 from antenna using the operator $\mathbf{A}_{20}$ (by SVD – Singular Value Decomposition).
- Use back-propagation (time-reversal) of $\tilde{b}_m$ to get $\tilde{b}_1$.
- Smoothly varying fields removed.
- No reference measurement needed.
- Improved image quality.

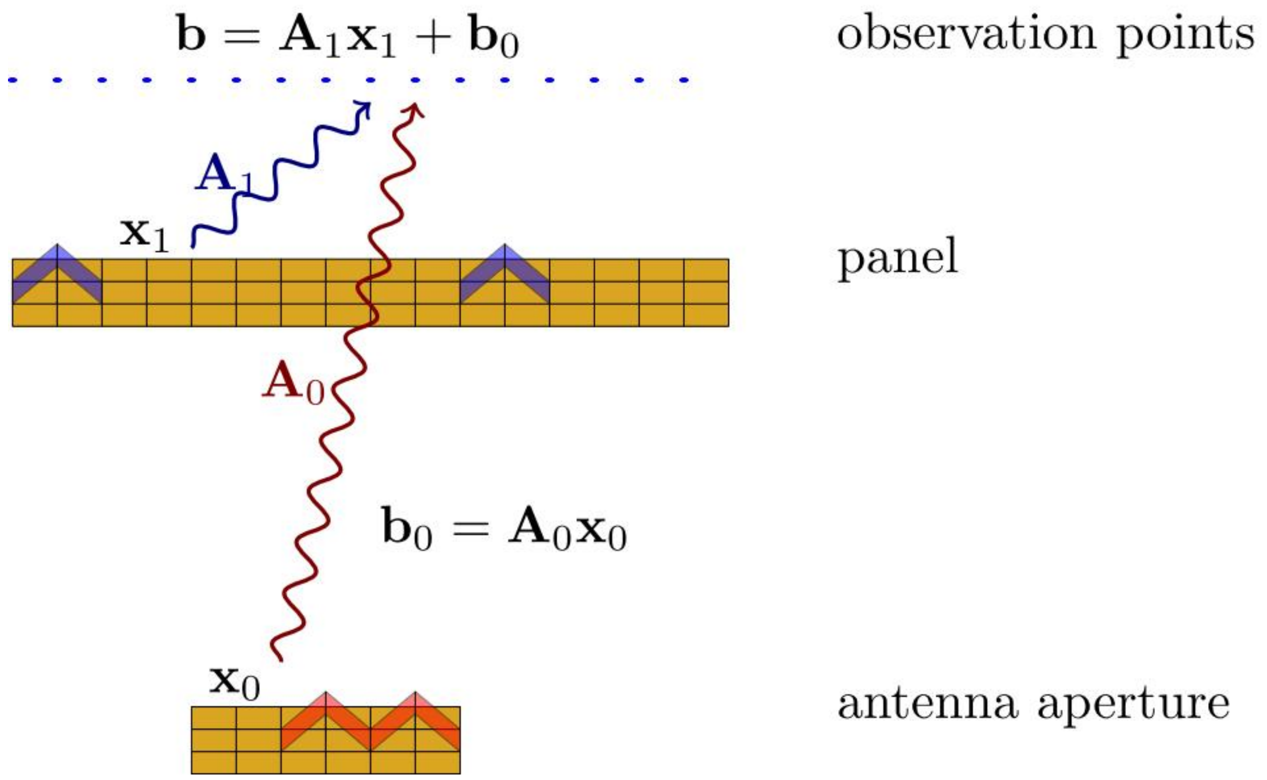


COMPRESSED SENSING (L^1-MINIMIZATION)

- Solve the regularization problem:

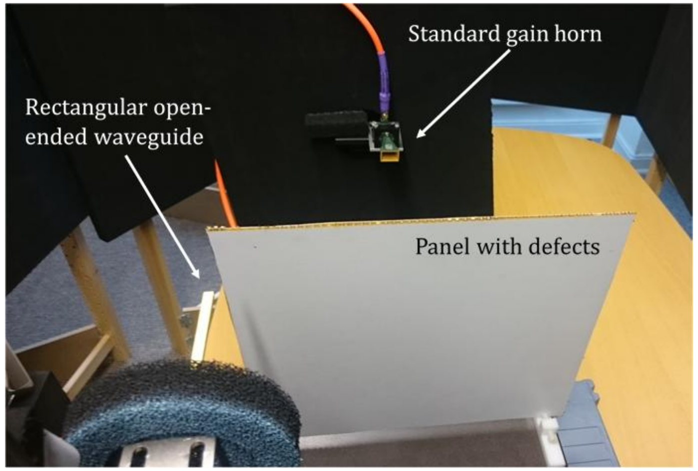
$$\text{minimize} \quad \|\mathrm{x}_1\|_1$$

$$\text{subject to} \quad \|\mathrm{A}_1\mathrm{x}_1 + \mathrm{b}_0 - \mathrm{b}\|_2 \le \delta$$

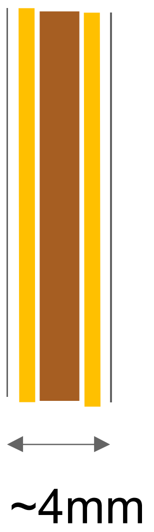


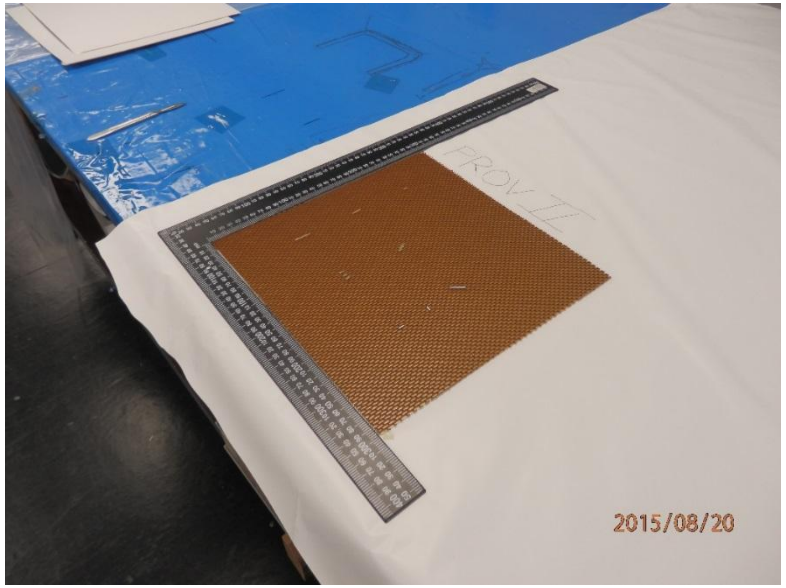
- Utilize only a fraction of measured data (few defects – sparse problem).
- No reference measurement needed.
- This allows reduced measurement times.

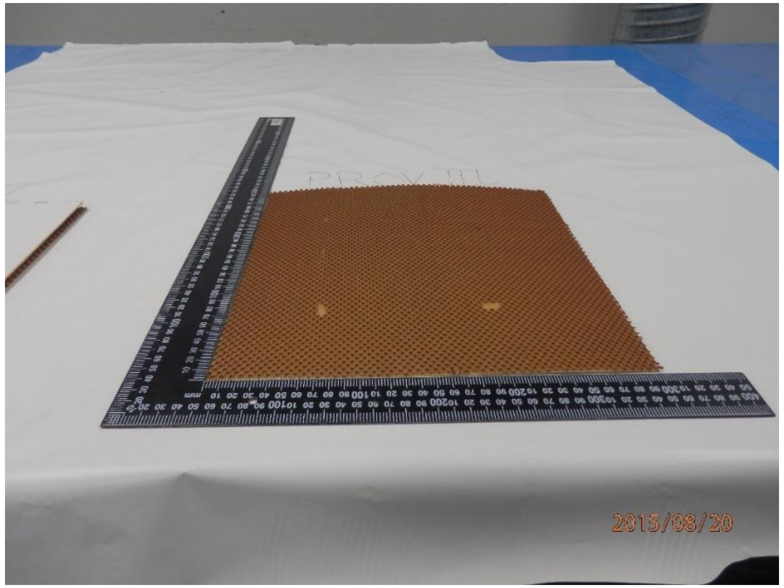
TEST PANELS



- 4 Test panels manufactured at Saab.
- Outer skin: 1mm Cyanate Ester + Quartz Fabric.
- Over-expanded Nomex Honeycomb
- Cover: Fluoropolymer film.
- Defects inside panels





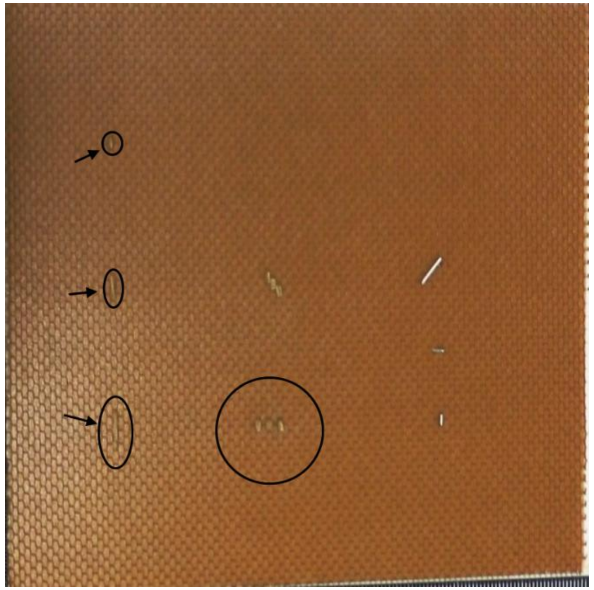


TEST PANELS

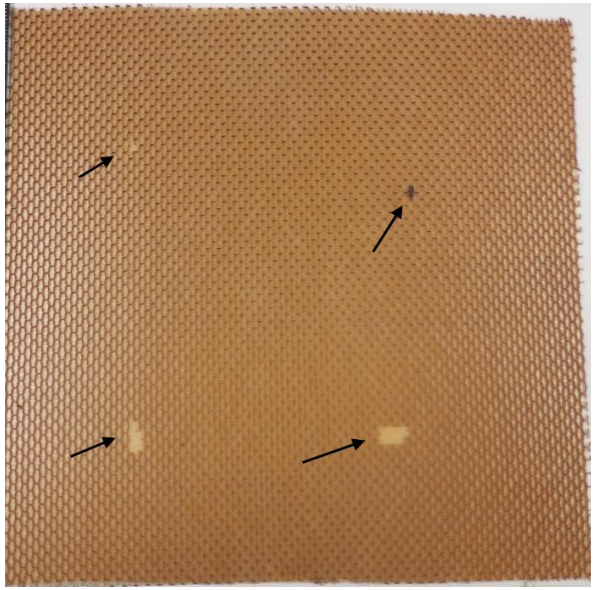
- Size: 30cm x 30cm

Reference

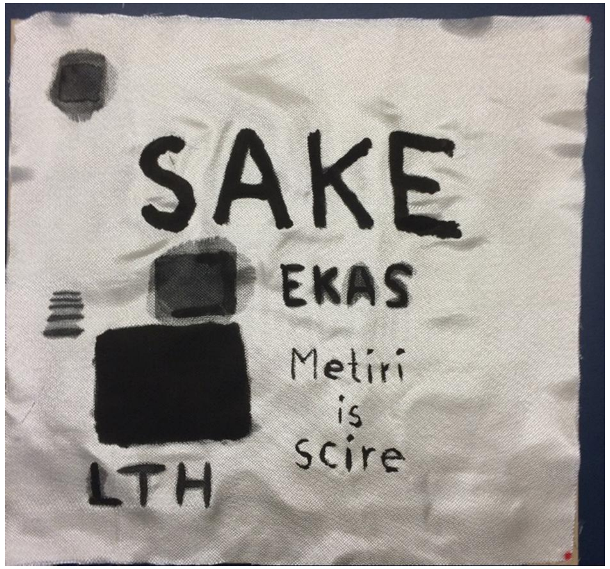
Mechanical defects
- material added
(glue and metal)



Mechanical defects
- material removed
(and magnetic added)

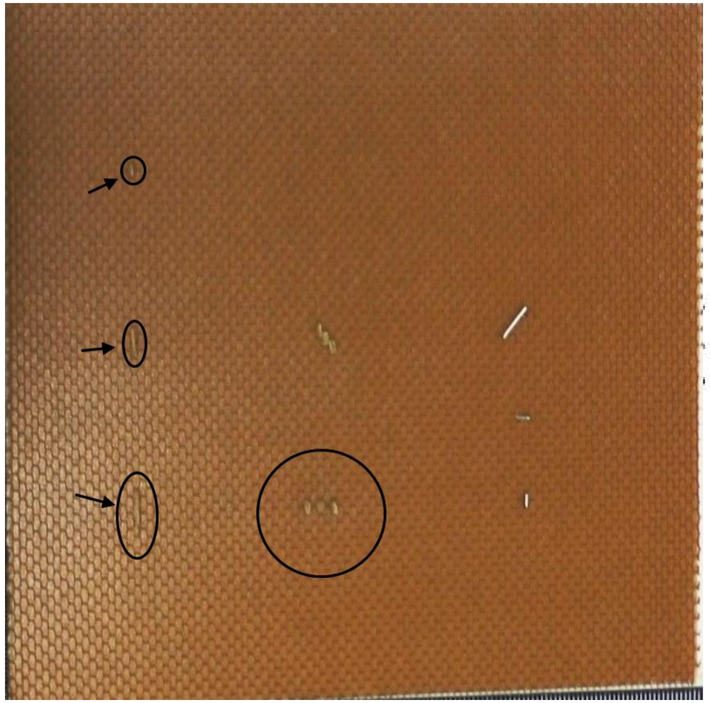


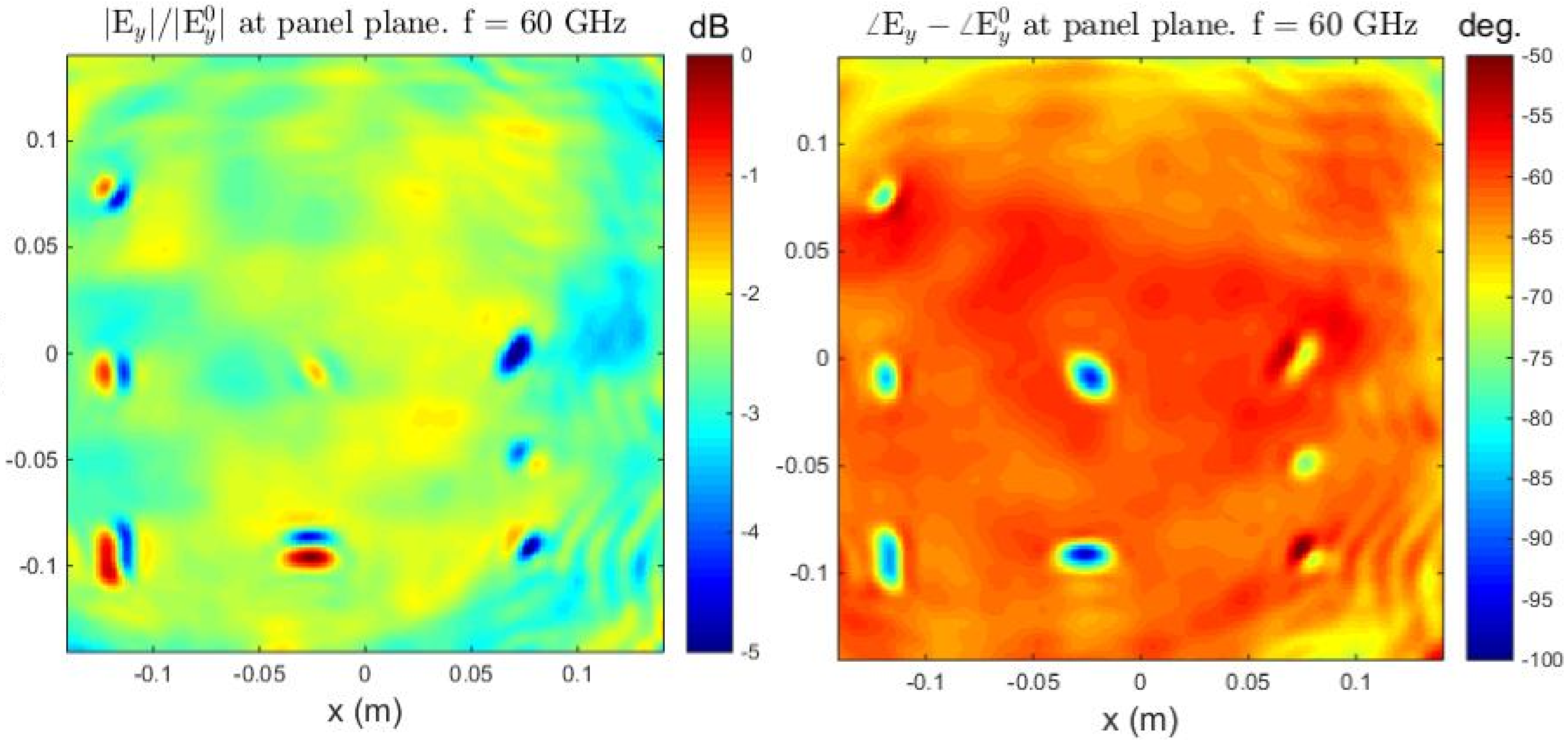
Electrical “defects/variations
(conductive ink on
quartz fabric)



RESULTS

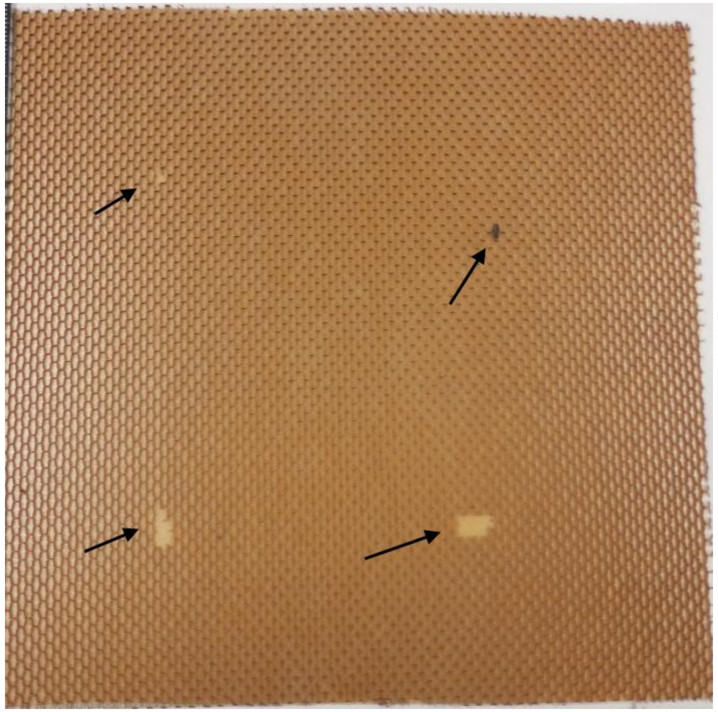
- Back-propagation – panel 2.

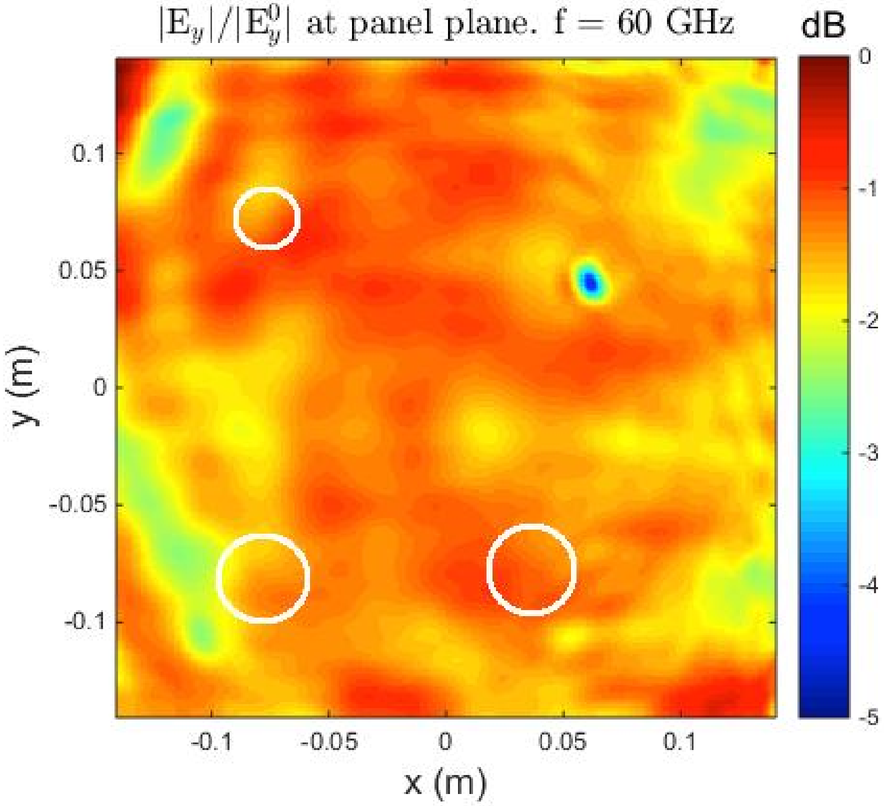


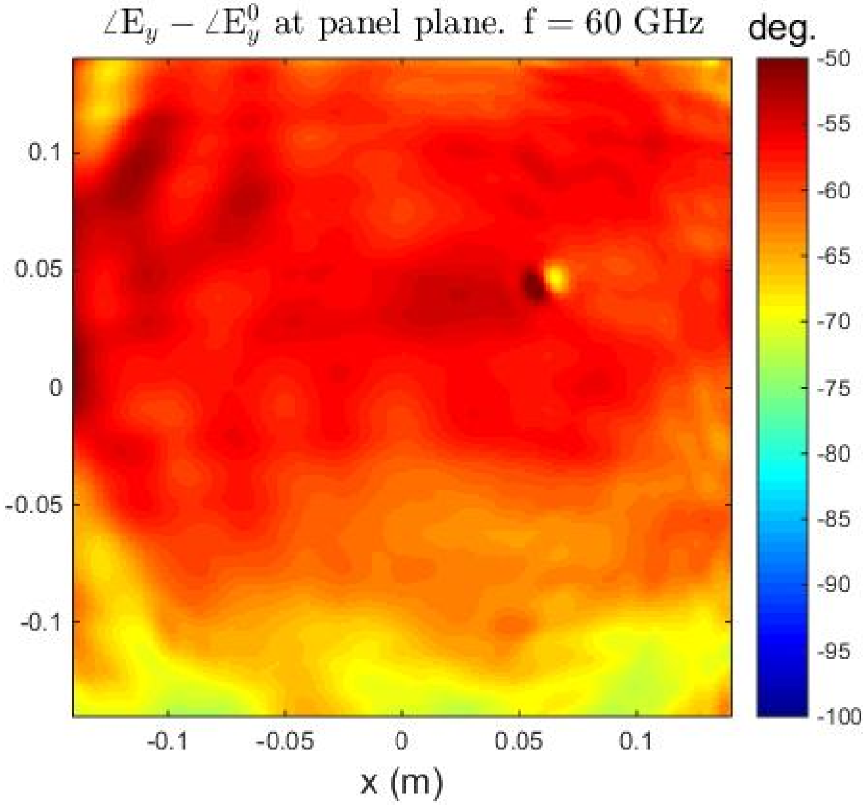


RESULTS

- Back-propagation – panel 3.

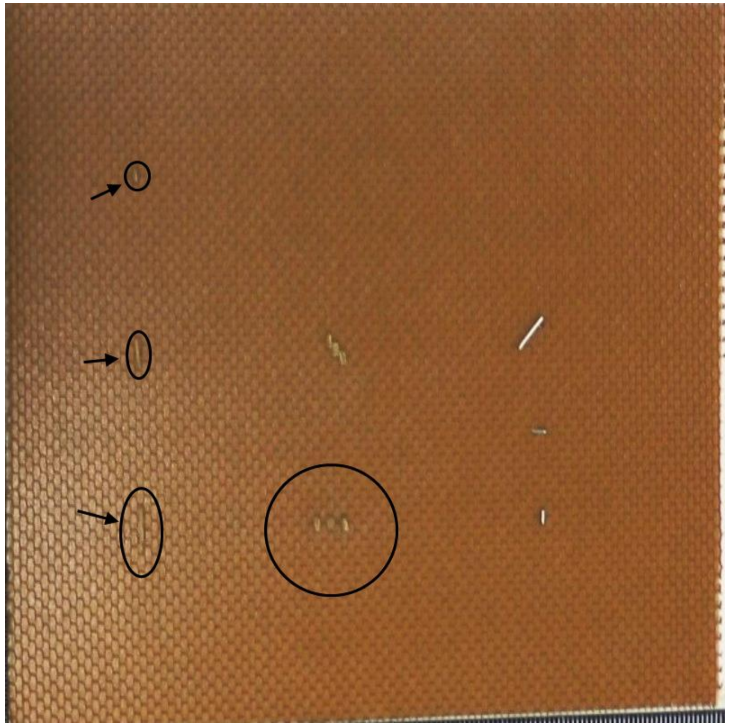


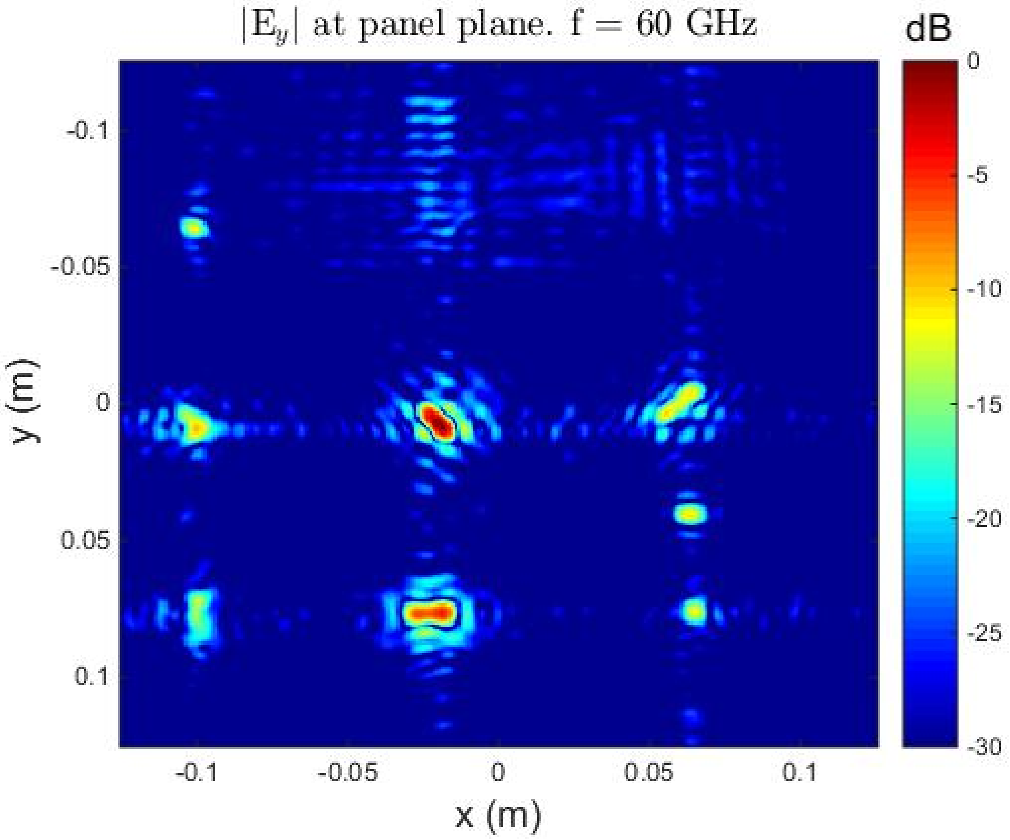




RESULTS

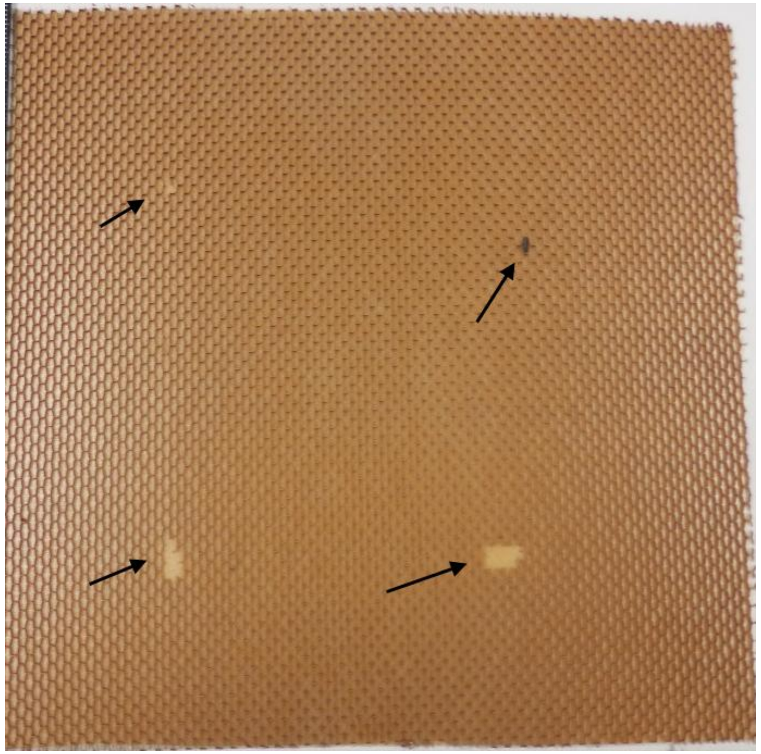
- Inversion + back-propagation – panel 2

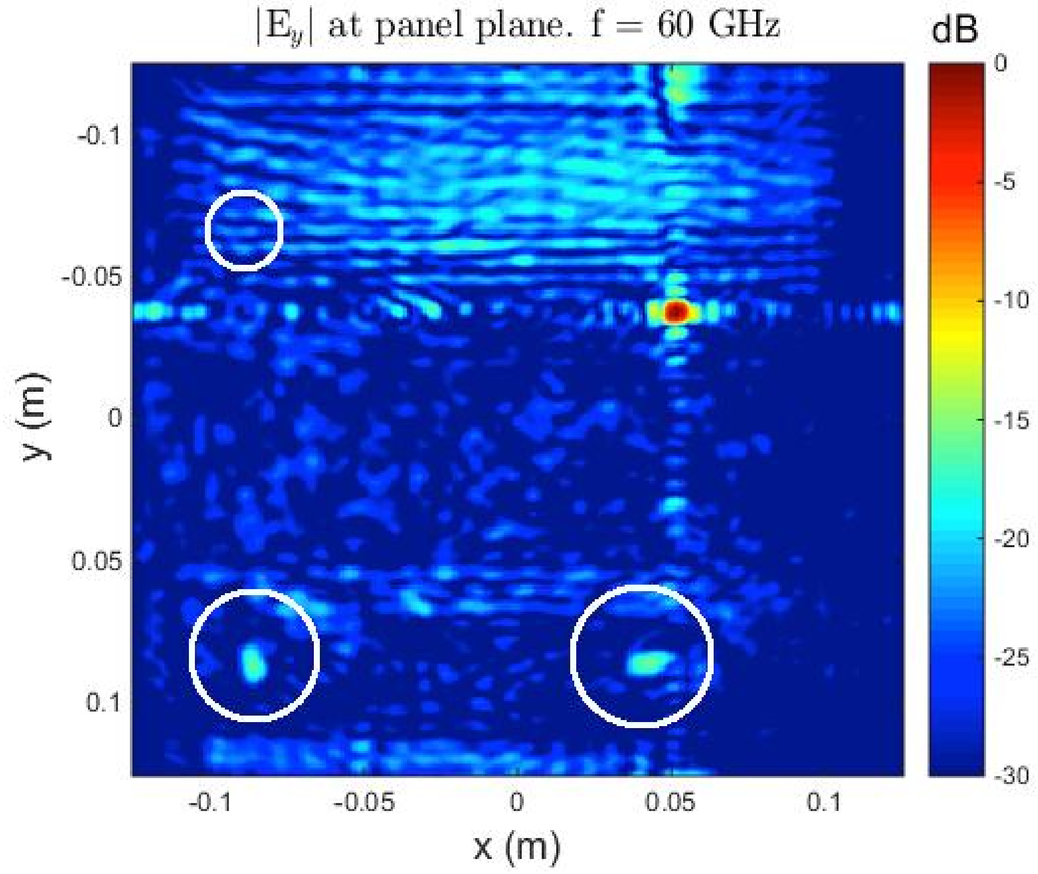




RESULTS

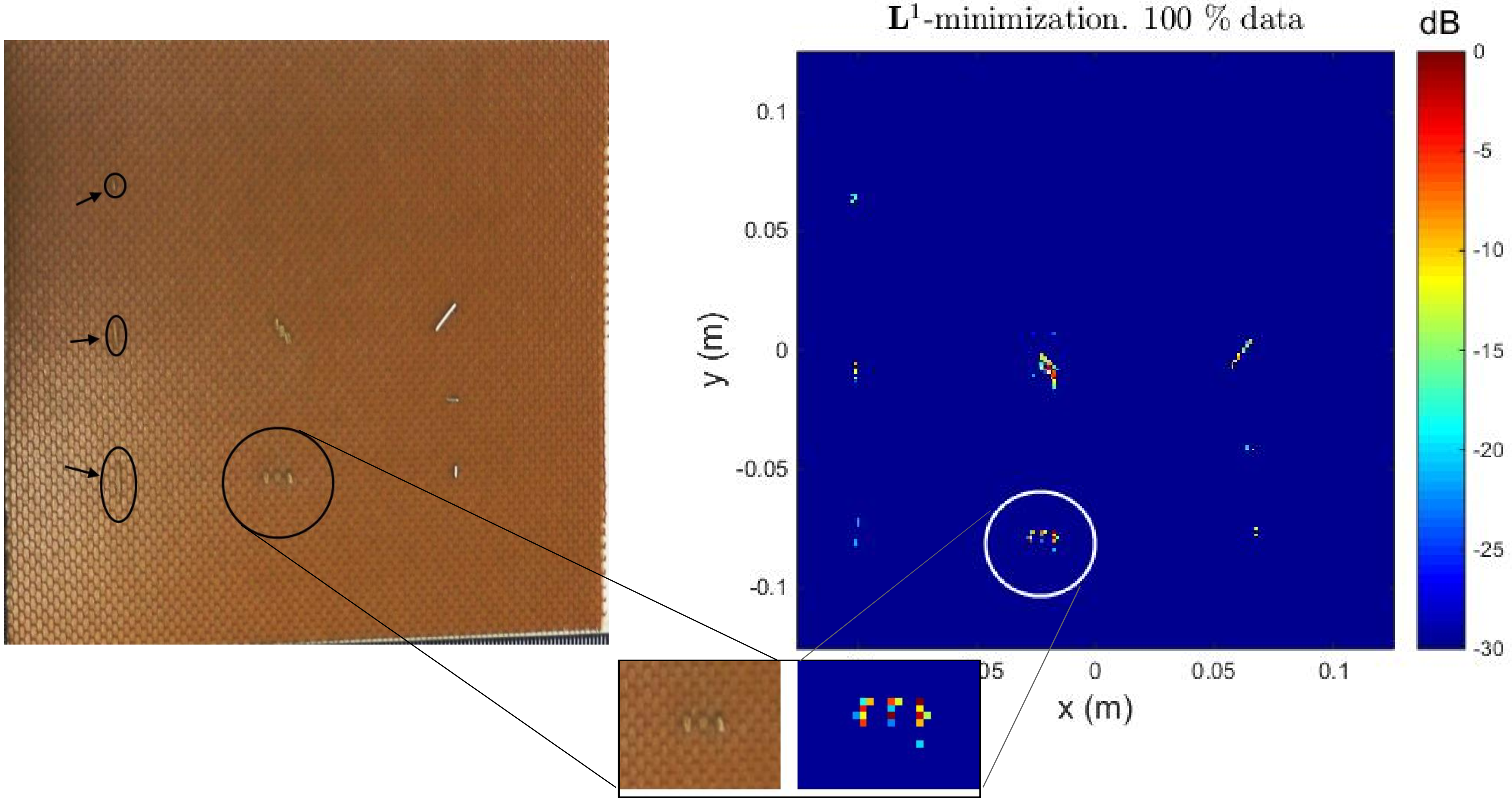
- Inversion + back-propagation – panel 3





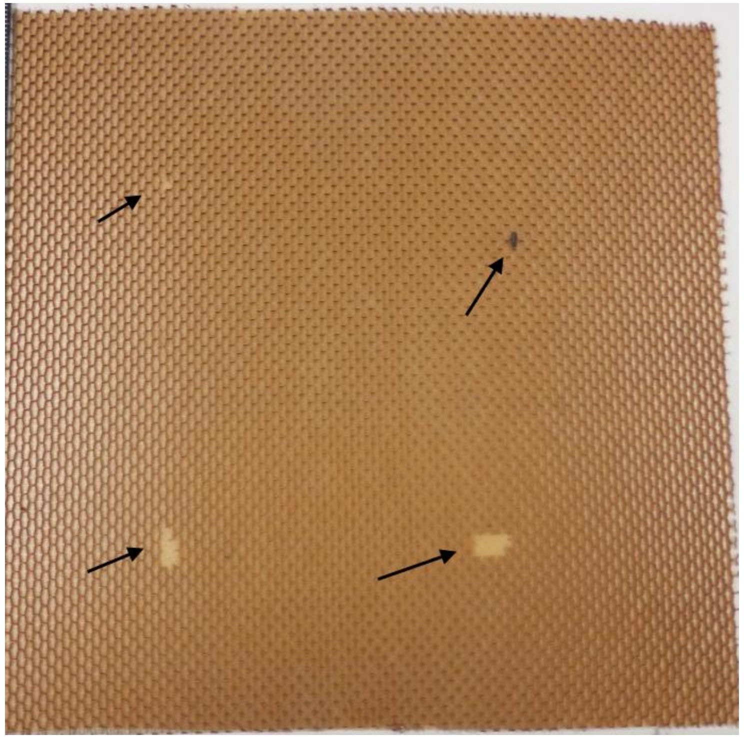
RESULTS

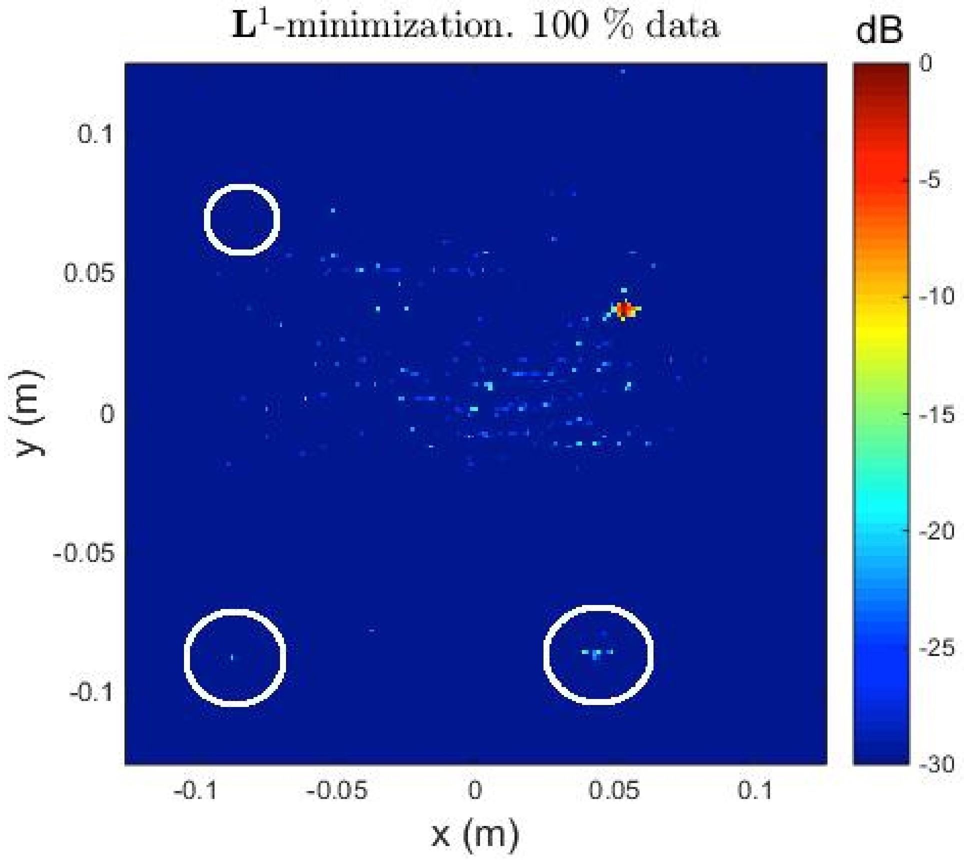
- Compressive sensing – panel 2



RESULTS

- Compressive sensing – panel 3





RESULTS

- Inversion + back-propagation – panel 4.

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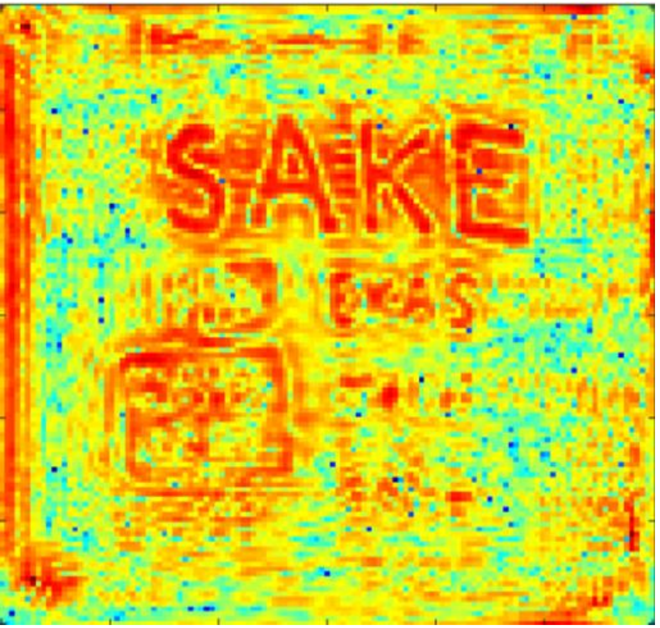

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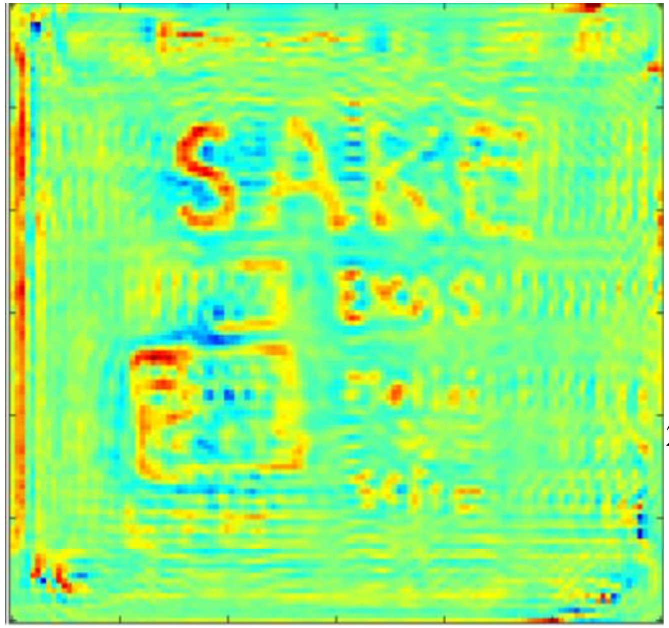

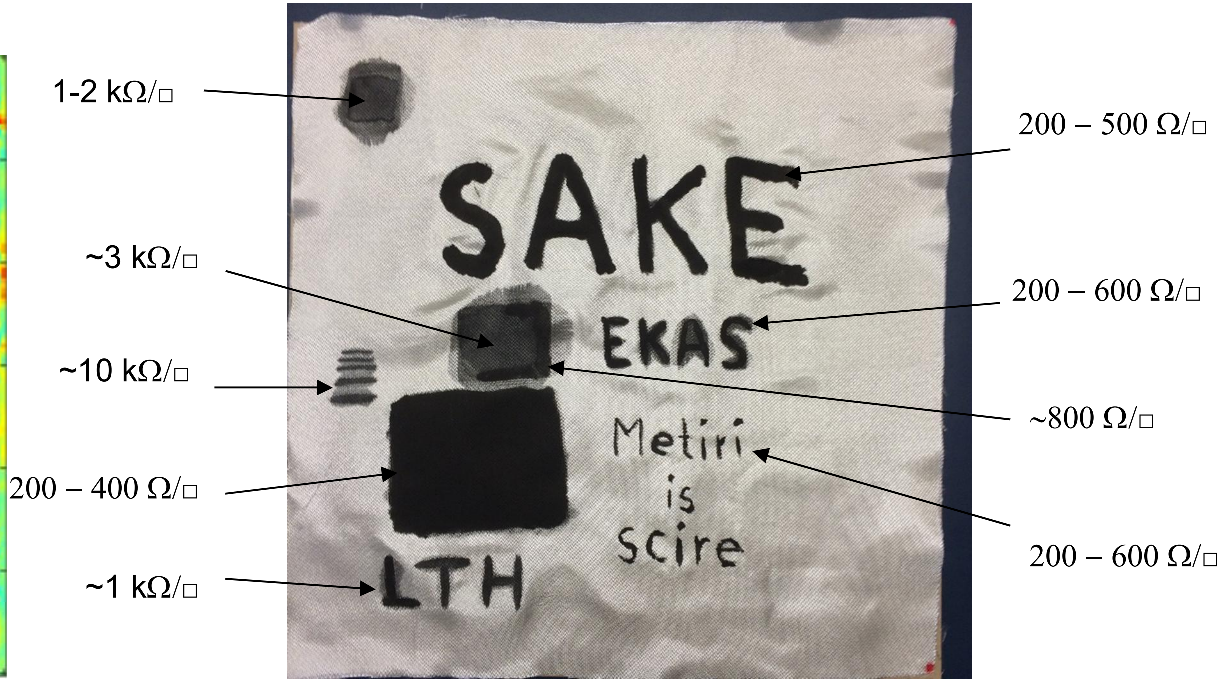

CONCLUSION AND FUTURE WORK

- Transmission measurements have been carried out on composite test panels with defects.
- Different image formation algorithms have been tested for detection of the defects.
- So far single frequency analysis has been performed. Utilization of frequency bandwidth can improve the results – ongoing work.
- Next phase:
  - Scientific paper
  - Perform *reflection* measurements on metal backed panels.
  - Measurements of test objects in anechoic chambers at Saab Dynamics and ACAB.

Acknowledgement

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THANK YOU