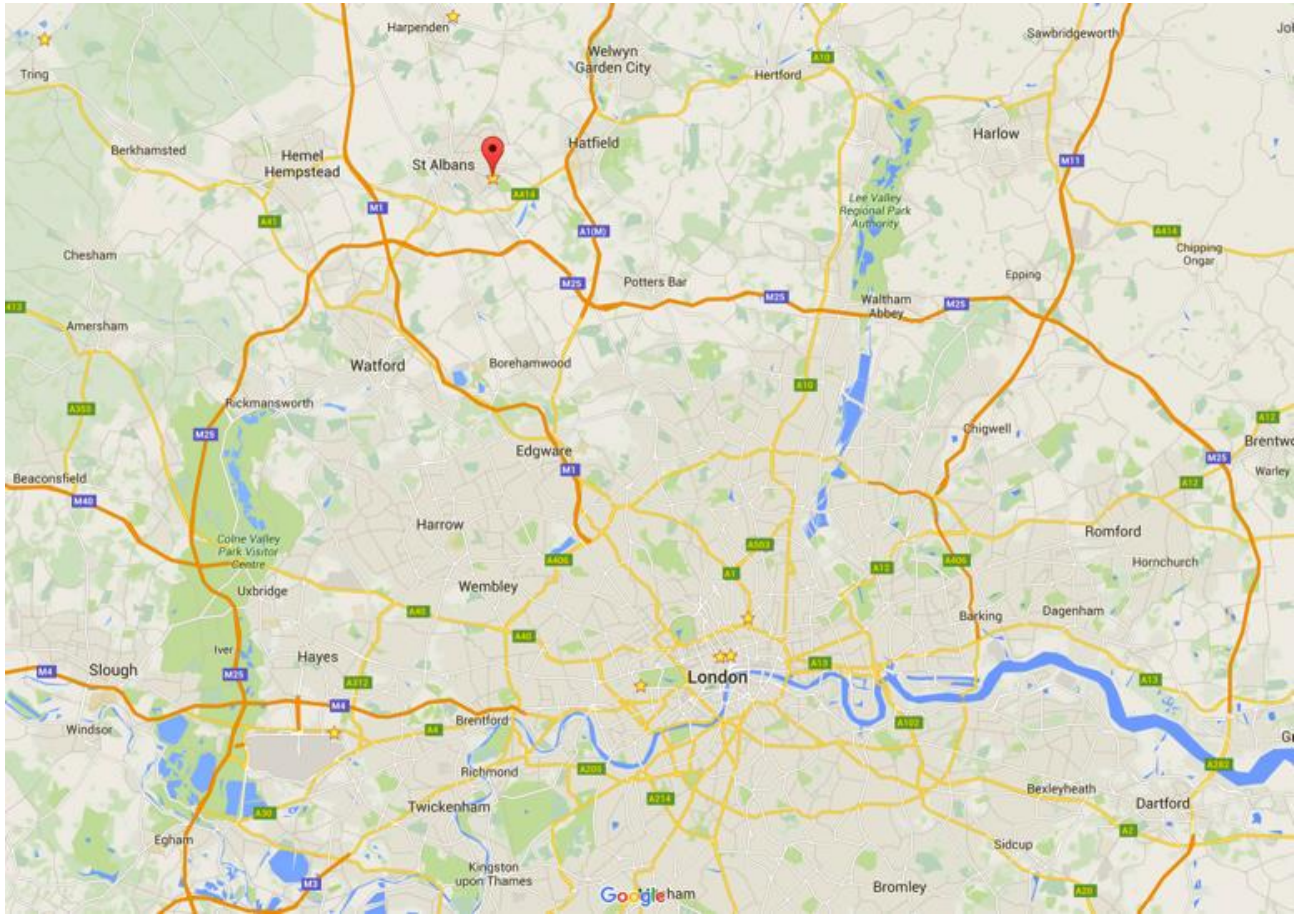
Advancements in Eddy Current Scanning of Materials: AM, Carbon Fiber, and Graphene

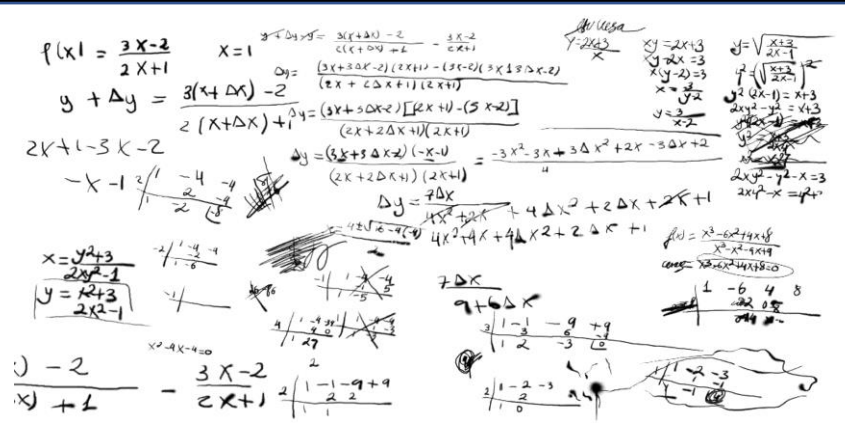
John Hansen – Co-Founder Managing Director, EThер NDE, UK

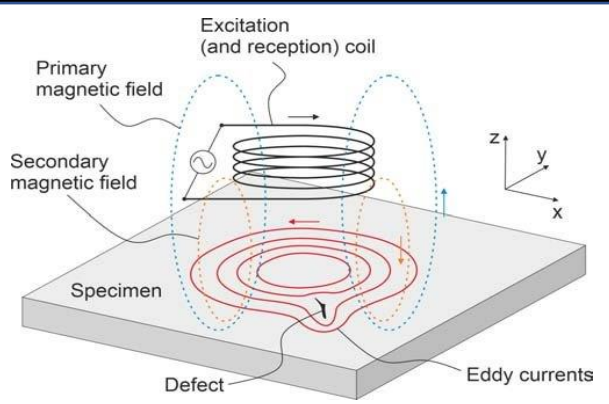
Who are *EThER NDE?*

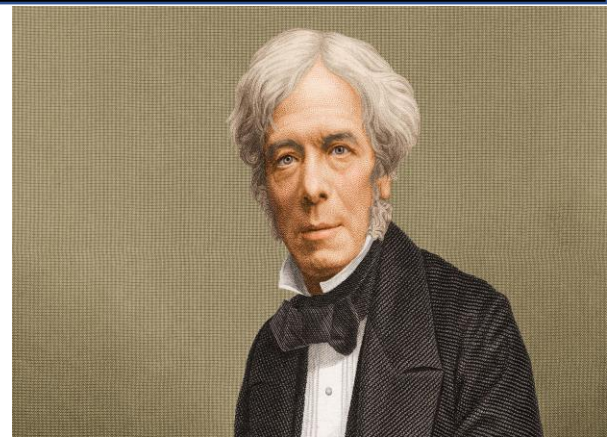
- FOUNDED IN JANUARY 2010 BY MIKE REILLY (FORMER SONATEST) AND JOHN HANSEN (FORMER HOCKING AND GE).
- SPECIALISTS DEDICATED TO EDDY CURRENT NDT TECHNOLOGY AND DEVELOPMENT.
- CURRENTLY 20 EMPLOYEES WITH OVER 450 YEARS NDT EXPERIENCE COLLECTIVELY
- BASED IN St Albans 26 MILES NORTH OF LONDON.
- OFFICES INCLUDING A PROBE PRODUCTION AND INSTRUMENT MANUFACTURING
- HAVE HAD ISO 9001 (QUALITY) SINCE 2011 AND OBTAINED ISO 14001:2015 in JUNE 2022 (ENVIRONMENTAL)
- SEE ETHERNDE.COM



Introduction

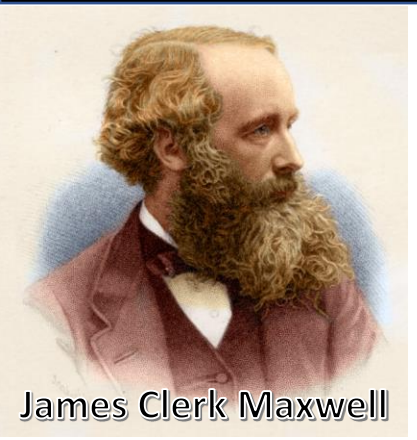


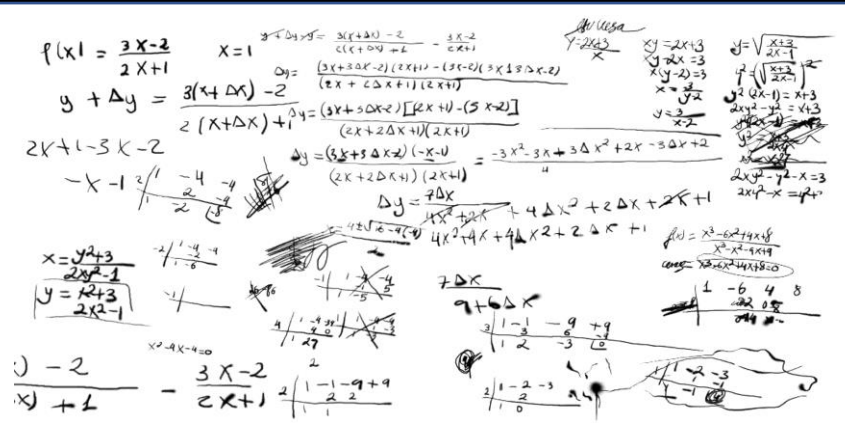


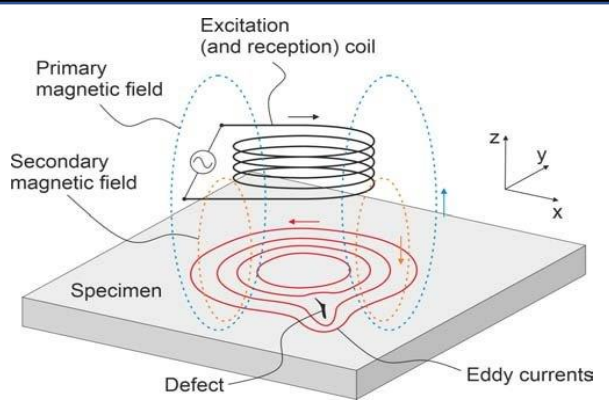


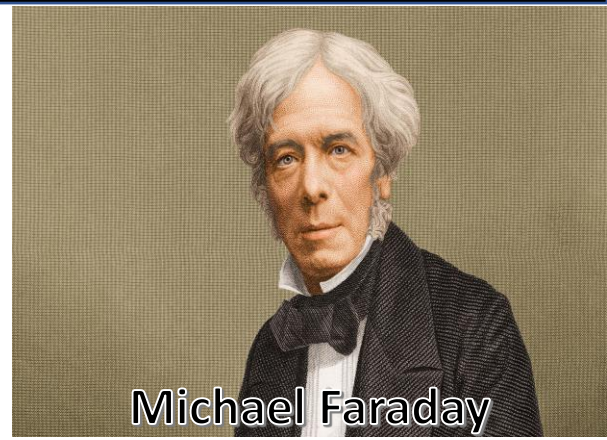
- Our historical use and understanding of Eddy Current testing methods on airframe and aerospace structures constructed of metals is well known and documented.
- From meter display instrumentation to phase plane display instruments the use of the Eddy Current method has met the challenges of the aerospace industry.

Introduction


James Clerk Maxwell






Michael Faraday

- As this industry evolves the use of other materials now adds to the test and detection challenges on not only Eddy Current but also the more conventional NDT methods such as Ultrasonics and X-Ray.
- These challenges increase with the introduction of thicker larger structures, more complex geometries and newer configurations such as engine fan blades now made from composites.

ETher NDE *PhaseCheck* Portable Instrument

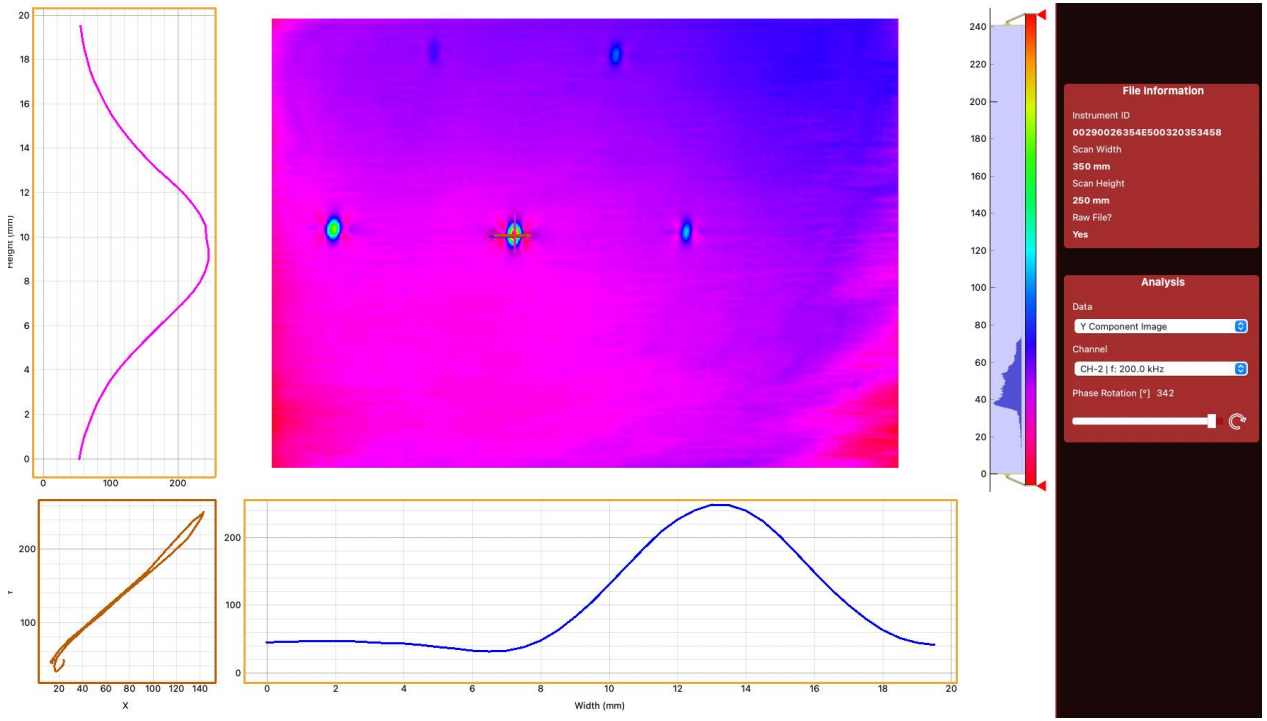
"A **picture is worth a thousand words**" – Eddy Current C-Scan imaging made easy

To date "pictures" (C-Scan) in Eddy Current has been limited to expensive large laboratory instruments.

Dual Frequency High Performance Eddy Current Flaw Detector with C-Scan Capability – allows the connection of up to two encoders and two probes

Supporting Encoders and Manipulators

The PhaseCheck instrument was used in conjunction with the ETher Imaging and Measurement Software for the detection and display analysis of these test.



ETHER NDE

Additive Manufacturing

Eddy Current as a CNC Inspection Tool using Hybrid's Ambit

AMCheck Eddy Current Unit

- Collaboration since 2010 with Hybrid Manufacturing.
- Ether designed a new dual probe ECT system called AMCheck and has released this to market.
- C-Scan capability
- USB data streaming capability
- https://etherndе.com/products/flaw-detectors/amcheck

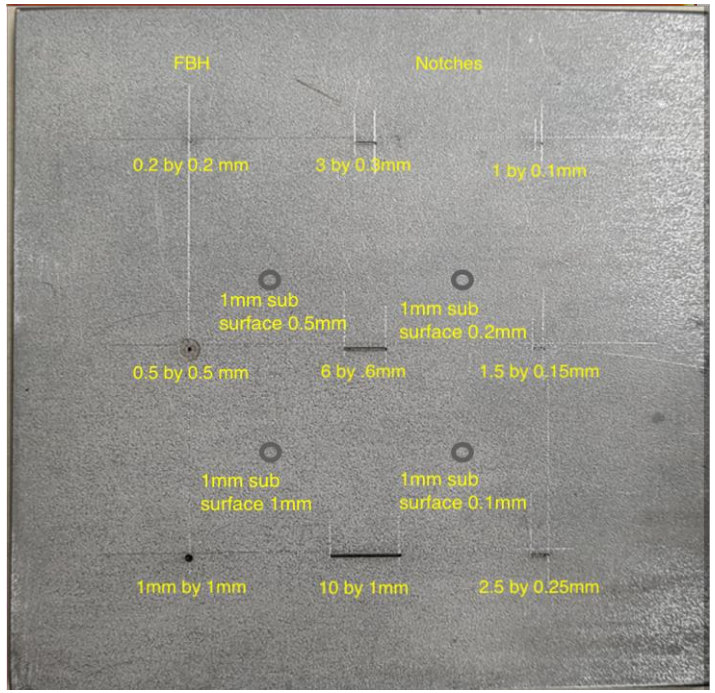
What is unique about Eddy Current?

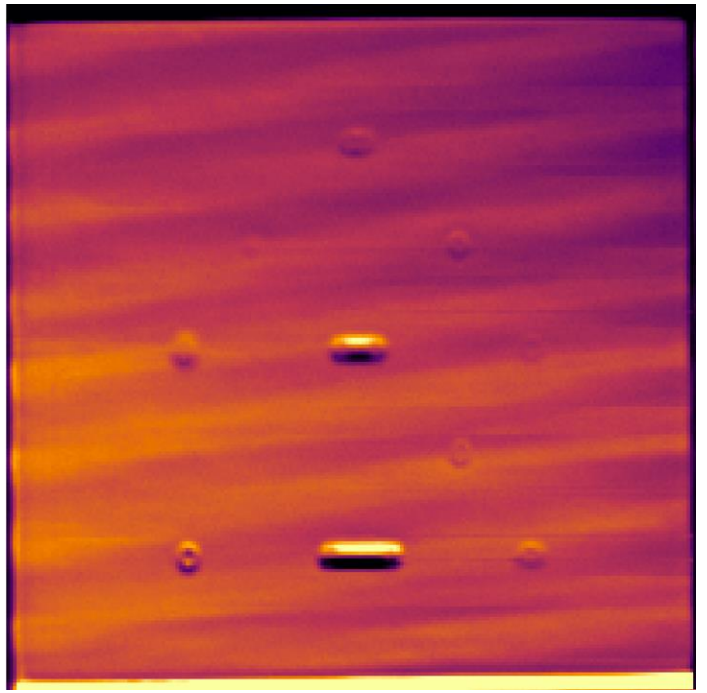
- ✓ No issues with couplant or radiation
- ✓ Can inspect layer by layer or several layers at a time. A 200kHz test frequency on Inconel, Stainless and Titanium test to a depth of 1mm and at 2MHz 0.5mm
- ✓ More sensitive to injurious stress raisers e.g. cracks
- ✓ Easier to automate as instant on
- ✓ Rapid scanning up to $5ms^{-1}$
- ✓ Potential to assess residual stress

- ✗ Problem with Powder bead Fusion but other methods (e.g. LMD and DED) are OK

Scan with 2D Differential Probe developed but not used in final tests because of Residual Stress Focus

ECT modelling at TWI was used to asses EThер developed candidate probe solutions. Two novel 2d Eddy Current probes were developed.

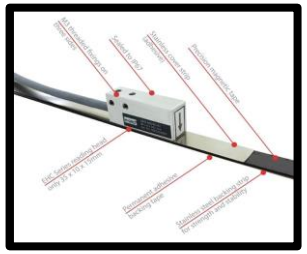


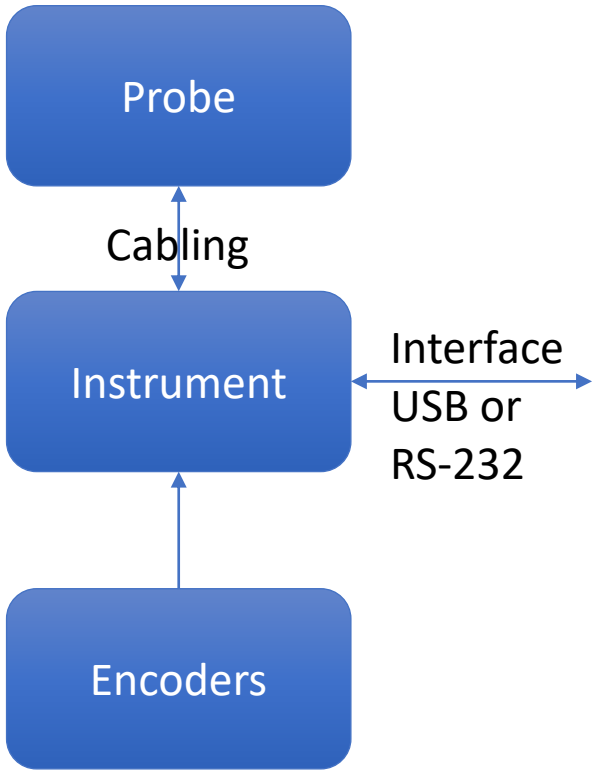


A System for on AM machine EC NDT

In order to make an automated Eddy Current NDT system what is needed is ;

- A probe - may need to be high temperature and also mounting/exchange must be considered
- Cabling – will need to be compatible with the environment
- Instrument – AMCheck or PhaseCheck
- Incremental Encoder Inputs – for C-Scan
- Interface to Machine control System



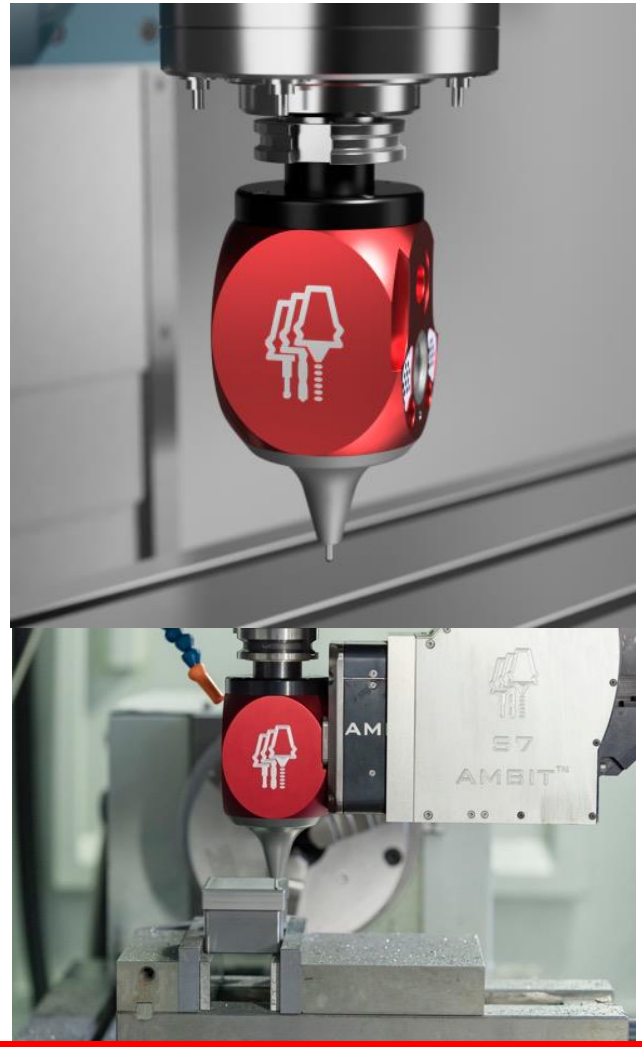


Mechanical and Electrical Interfacing System

In the EM-ReSt project Hybrid Manufacturing had already developed a solution to retrofit DED AM to an conventional CNC machine.

- The probe was built into a tool head.
- This approach gave mechanical and electrical interfacing system which enabled the coupling of the inspection probe heads independent of the laser metal additive system.
- Then the software was developed to control and synchronize input and output sensor data capture .

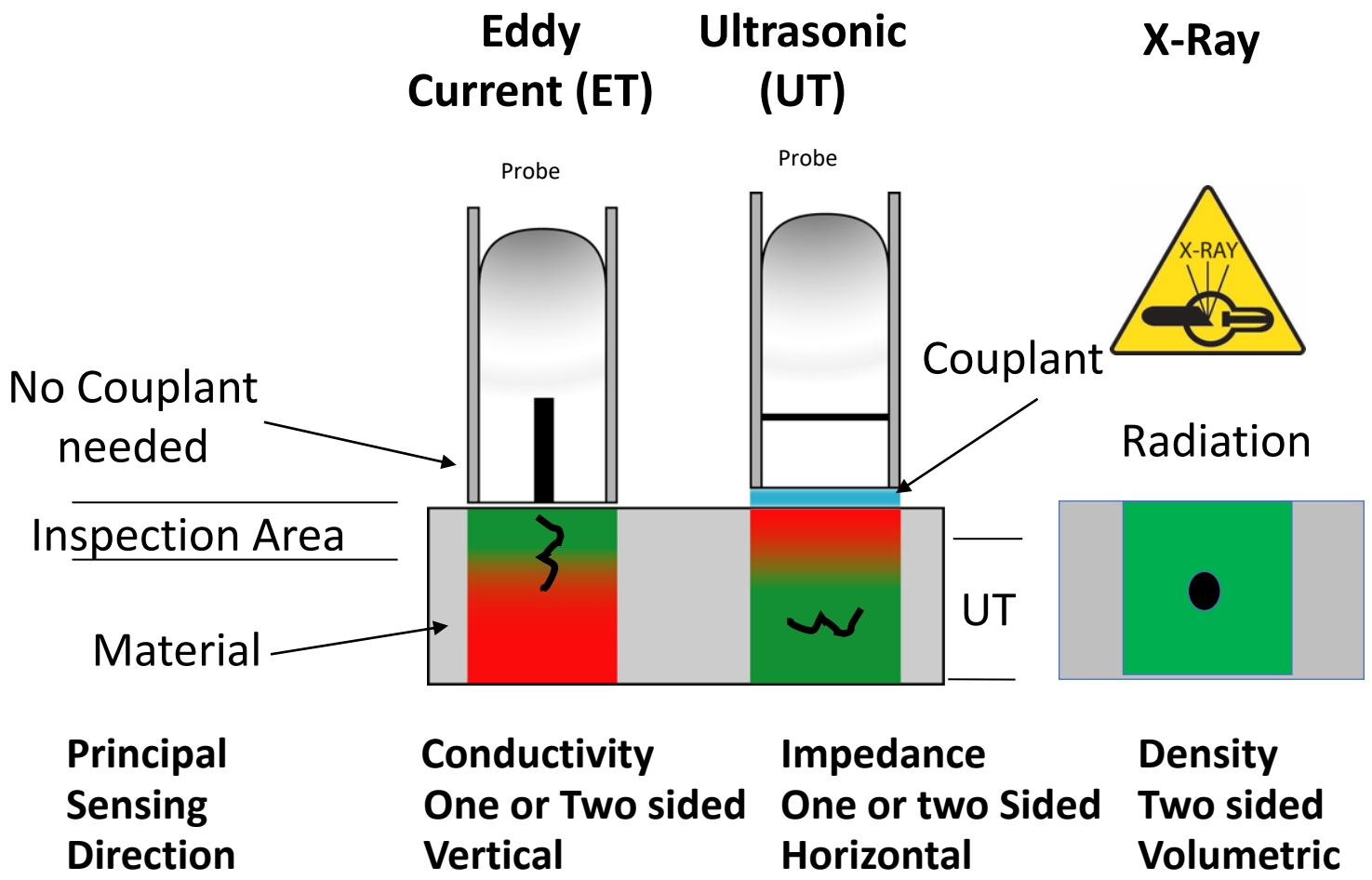
https://hybridmanutech.com/portfolio/ambit-inspection-heads-eddy/



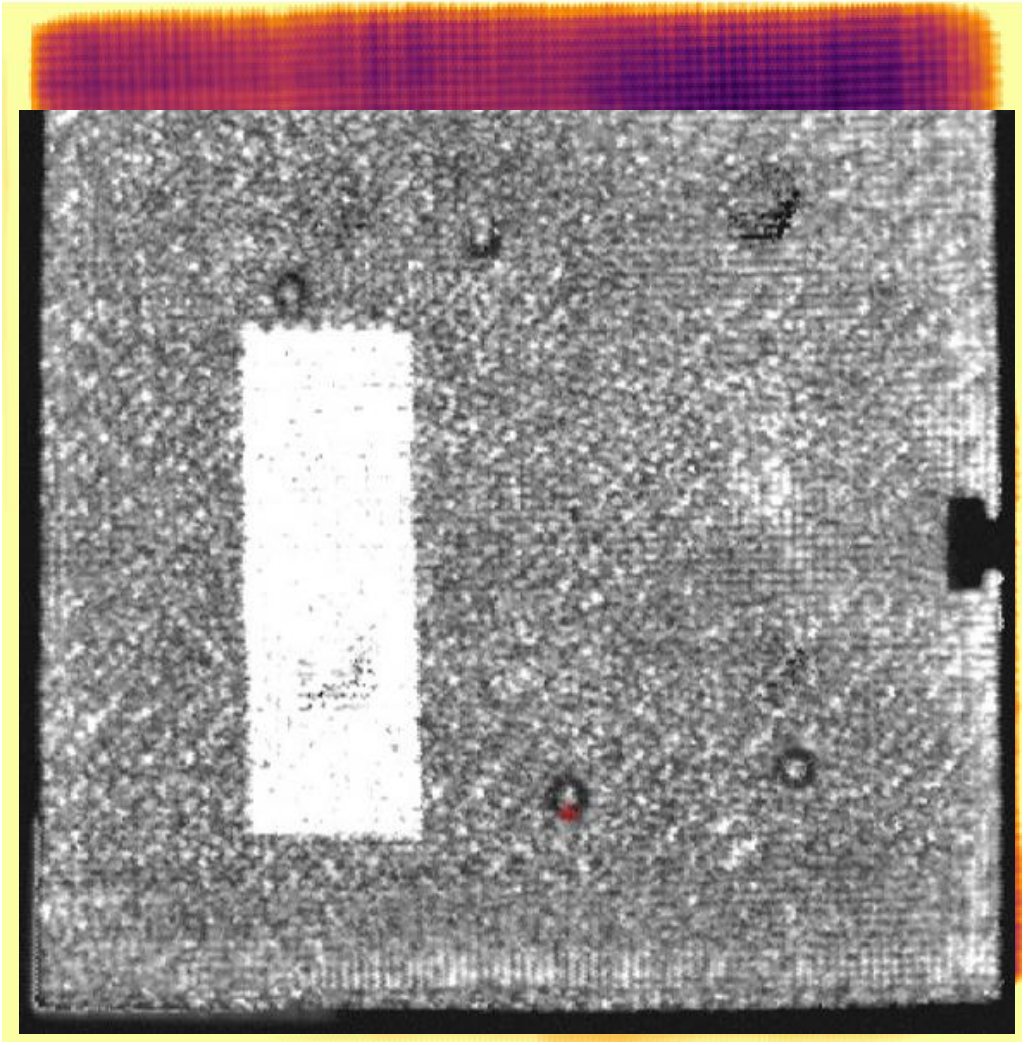
Carbon Fibre

Why use Eddy Current to inspect Carbon Fibre?

- On Carbon Fibre 2MHz is a low frequency and EC will penetrate 10 mm (conductivity circa 17 S/cm or 0.003% IACS).
- UT and EC are complementary at detecting disruptions to a structure.
- If Thru transmission used then sensitivity almost uniform through the material thickness but no depth information in phase.
- Lack of couplant means compatible with inspecting woven carbon fibre material

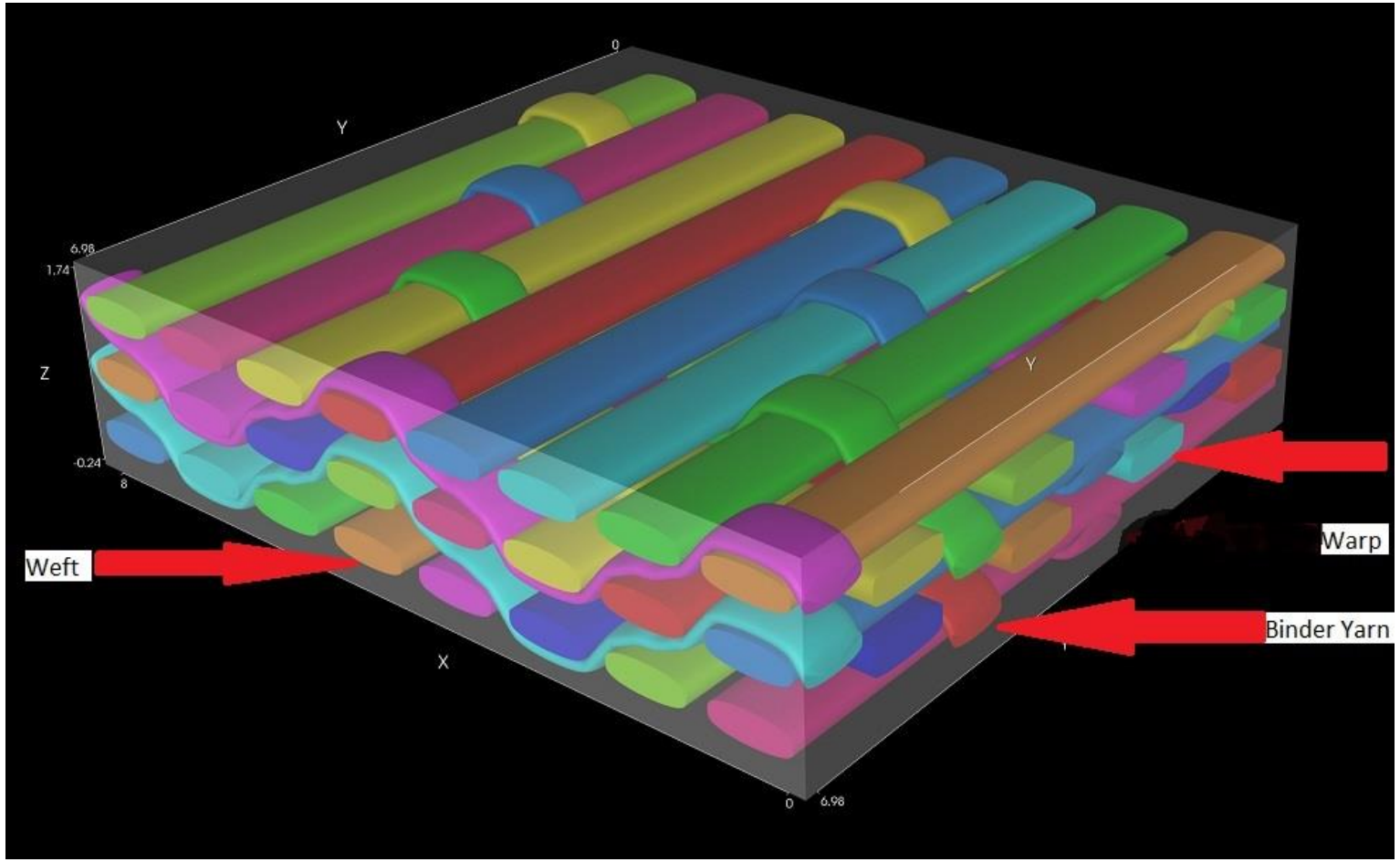


Illustrating the Orthogonal nature of UT and EC



What is 3D Woven?

- Rather than using layers the woven item is an interlinked homogeneous structure and not limited to flat so could be an I-Beam or have a varying cross-section
- Oxford Weave - A variation of a plain weave where two warp ends are weaving as one in a plain weave, over and under each pick. Typically, the yarn size of the filling yarn is at least twice the size of the warp yarn. One exception is the pinpoint Oxford, which uses warp and filling yarns of the same size.



PhaseCheck

C-Scan Video of Test

10mm Thick 3D Woven Solid Carbon Fiber;

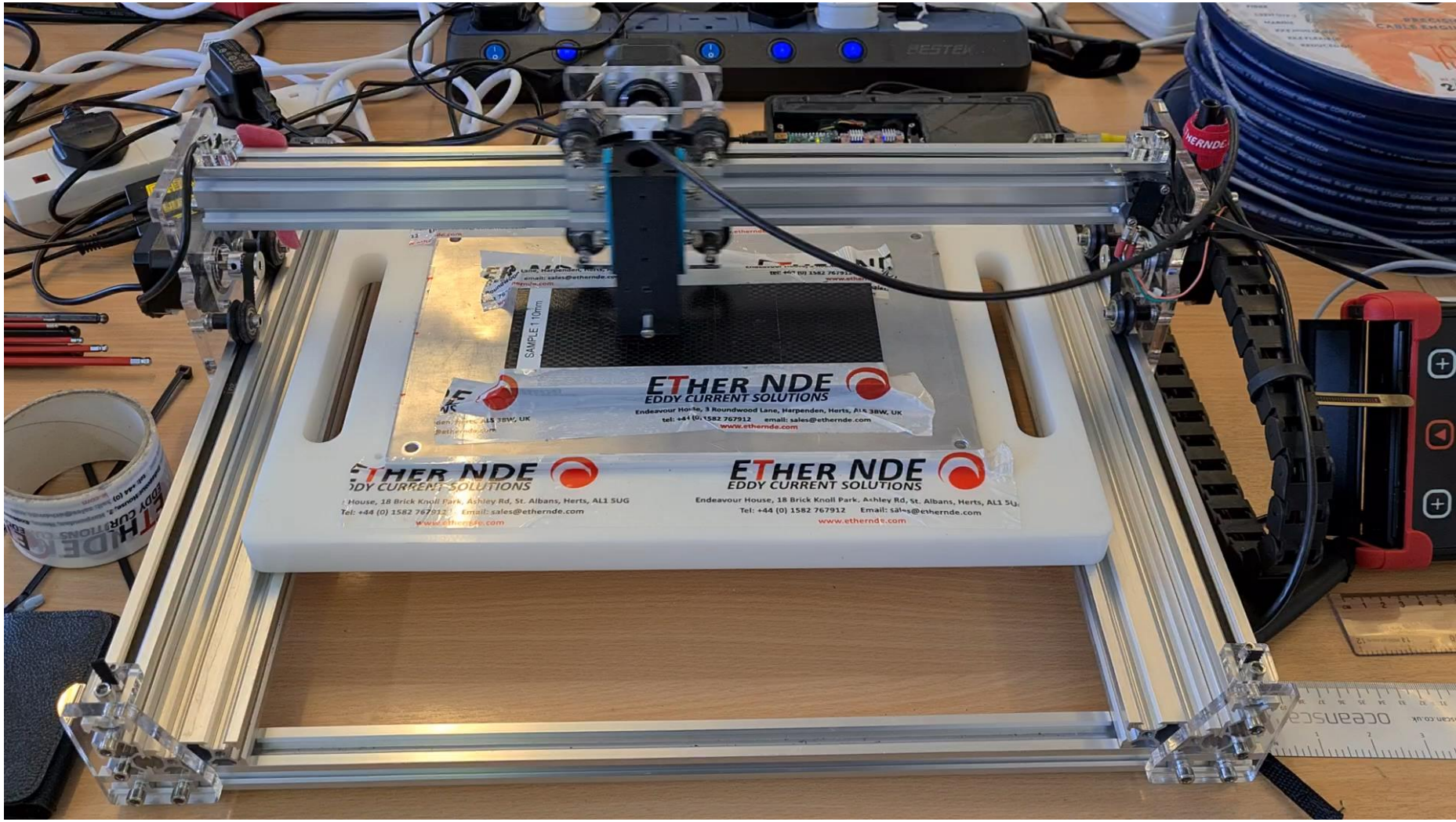
Scanning Speed 200 mm/s Scan Pitch 1mm

Component 20*10cm probe PUS16 at 200kHz

Data recorded as an array of EC XY values and position and saved to internal 32GB SD Card

Gain and phase can be adjsuted post test

ETherScanViewer allows post test analysis.



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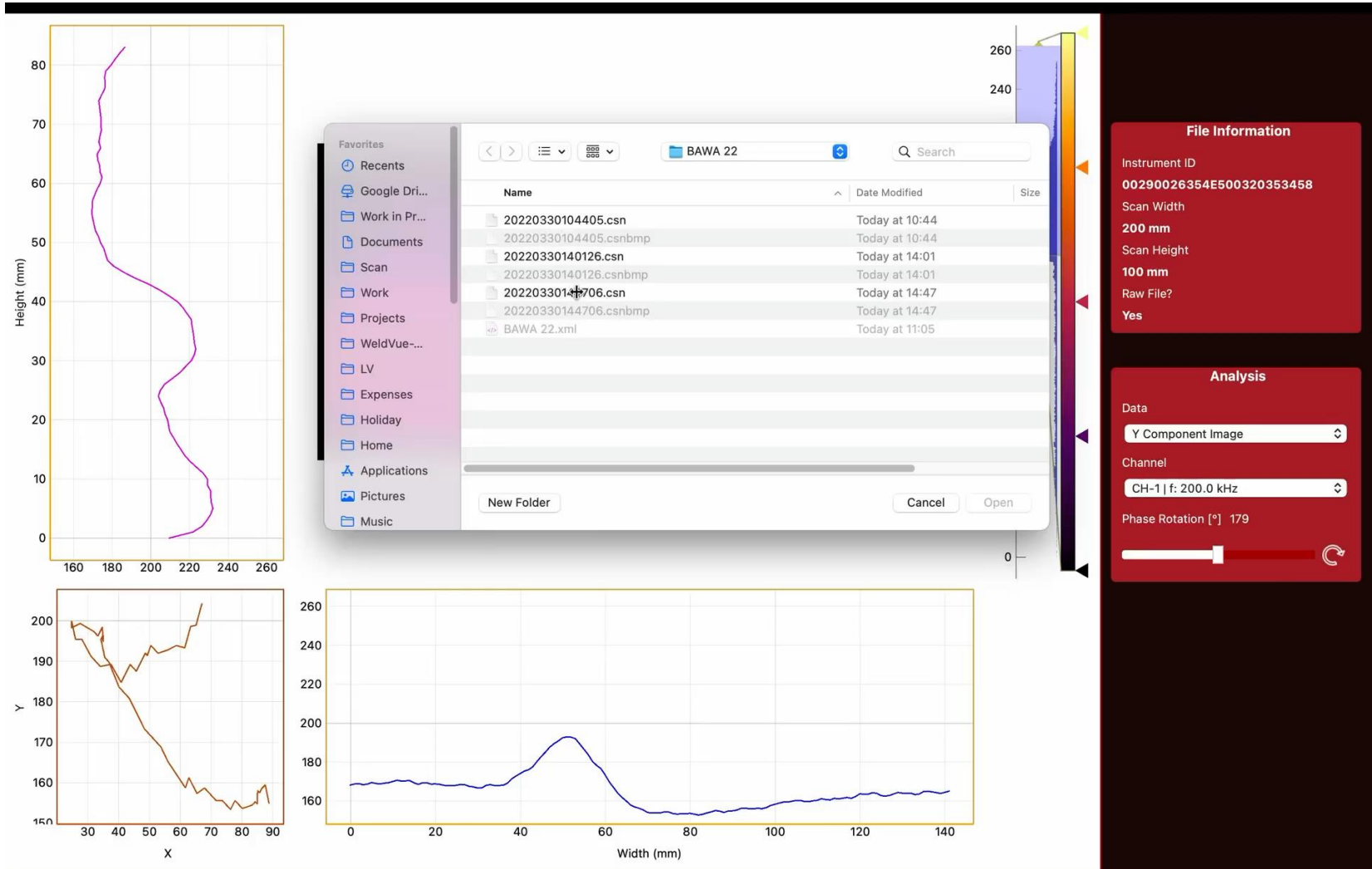
Post Test Analysis

On a personal computer data can be analysed and images saved

Colour palette can be changed

Phase and Zoom can be changed



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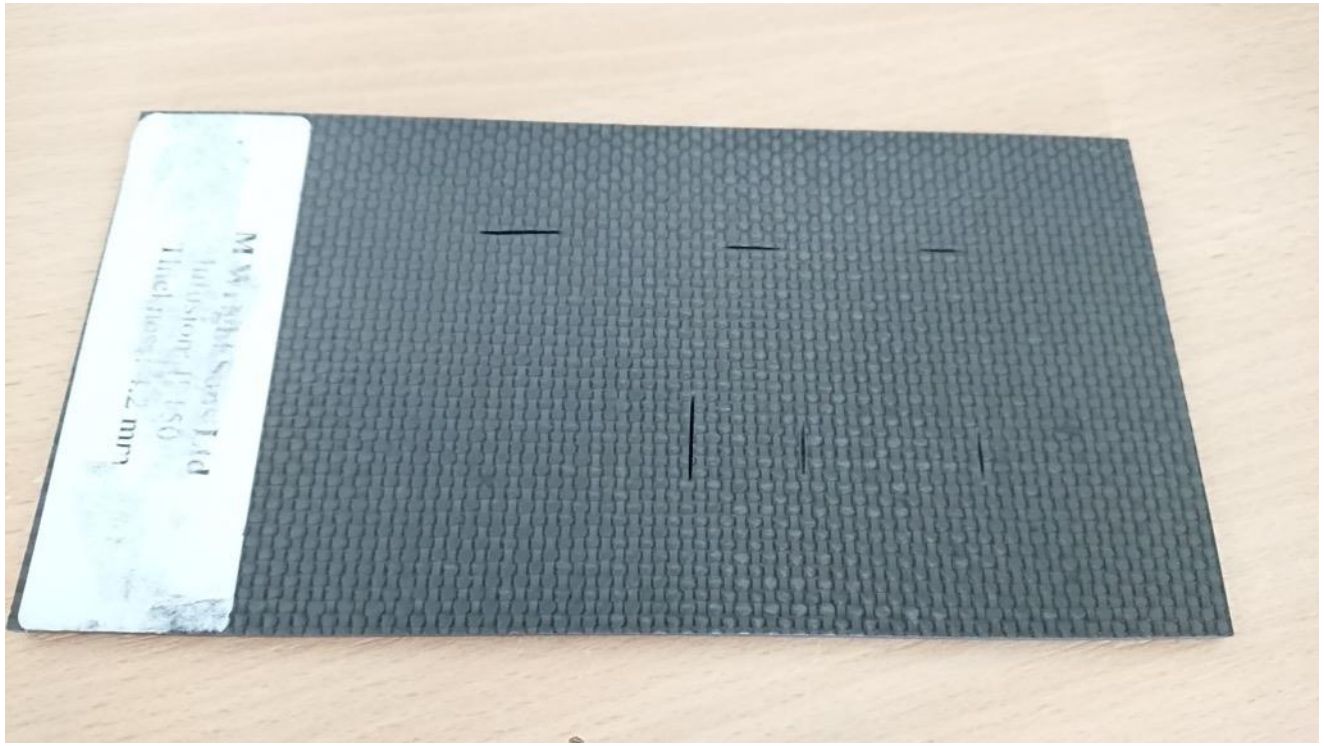
Notched 4.2 mm sample



Notches

Left to Right

Top

2.3mm deep by 17mm

1.28mm deep by 12mm

0.7mm deep by 10 mm

Bottom

2.5mm by 18mm

1mm by 11mm

0.9mm by 10.5 mm

Sample nominal 4.2mm but Right side 4.3mm left side 3.8mm

CFLUX

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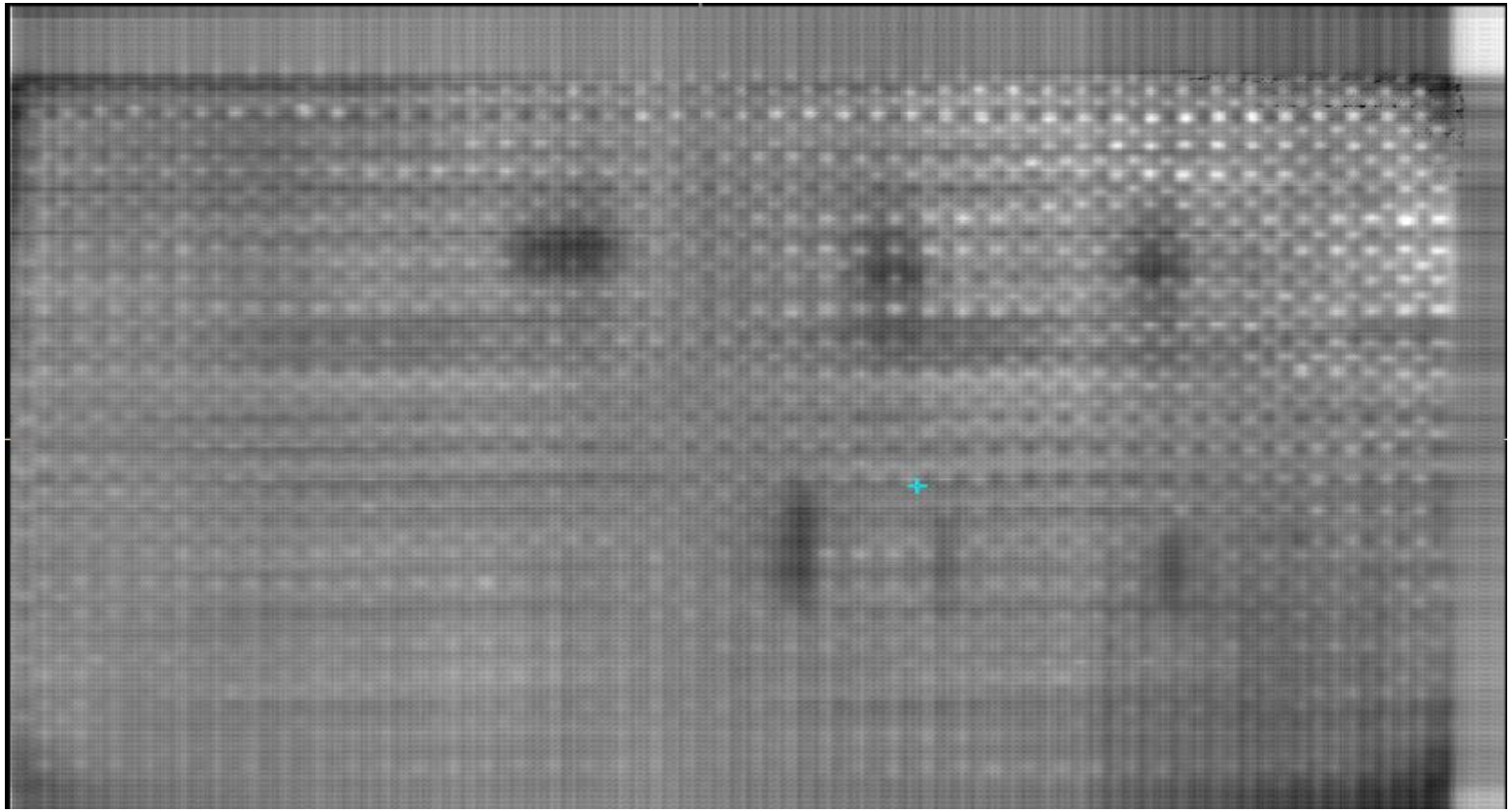
4mm Sample with surface notches



2MHz Pencil Probe at 4MHz @ 0.25 mm resolution (164215)

CFLUX

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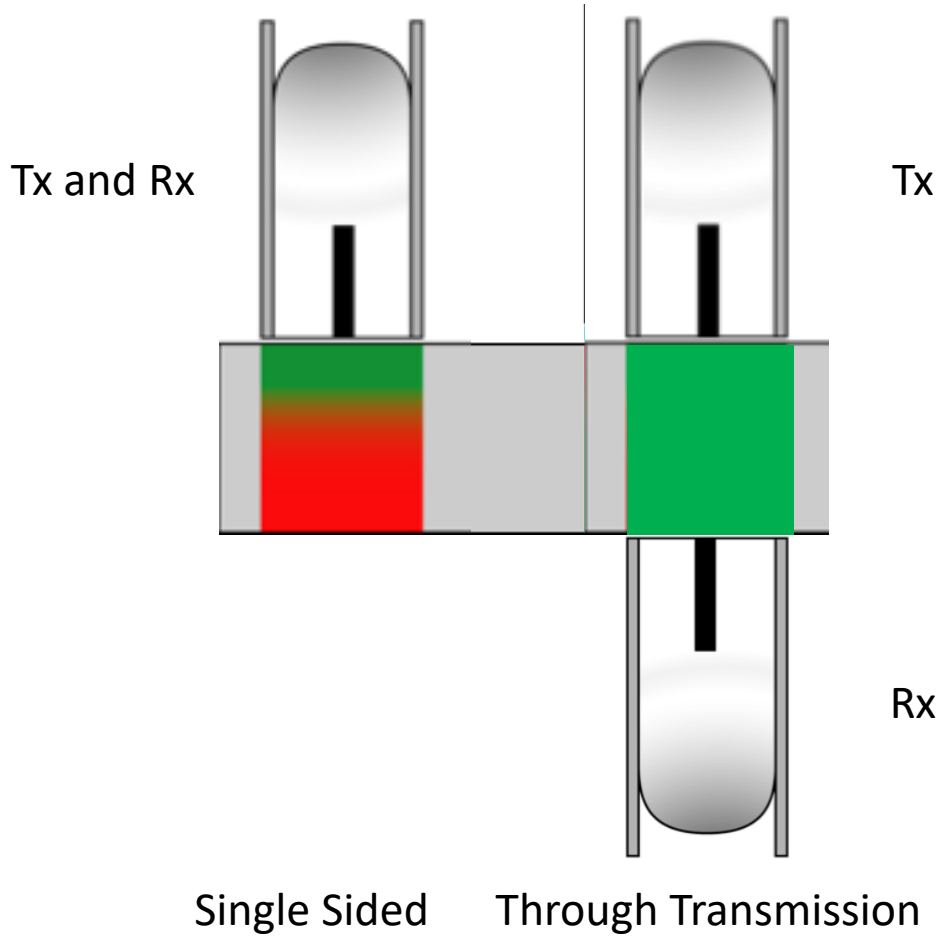
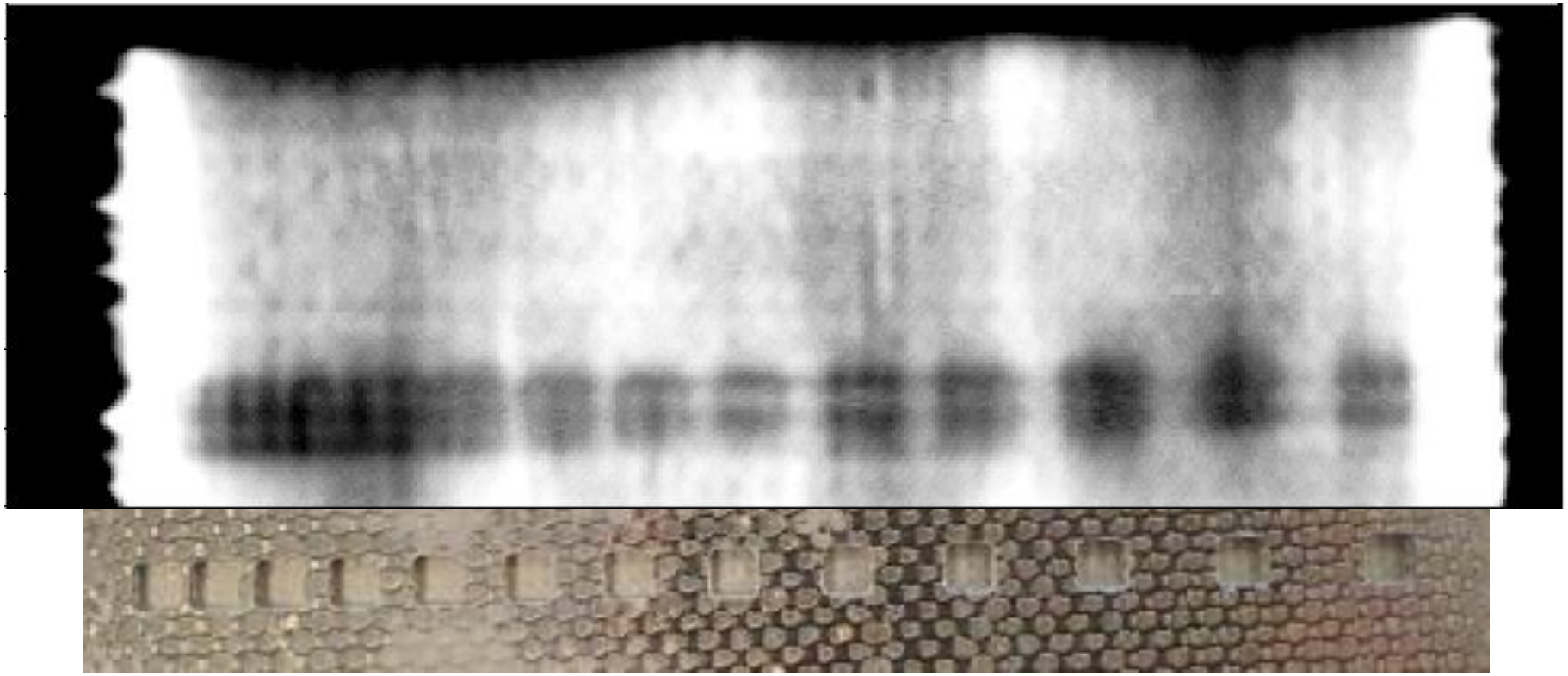
Single sided versus through transmission

- Single sided
  - Exponential decay of sensitivity with depth therefore more sensitive to surface
  - Phase shift indicates depth
- Through (thru) transmission
  - Used in UT inspection of Composites
  - Near uniform sensitivity through thickness
  - No depth information but phase shift indicates volume of defect.



4.2 mm Resolution Sample

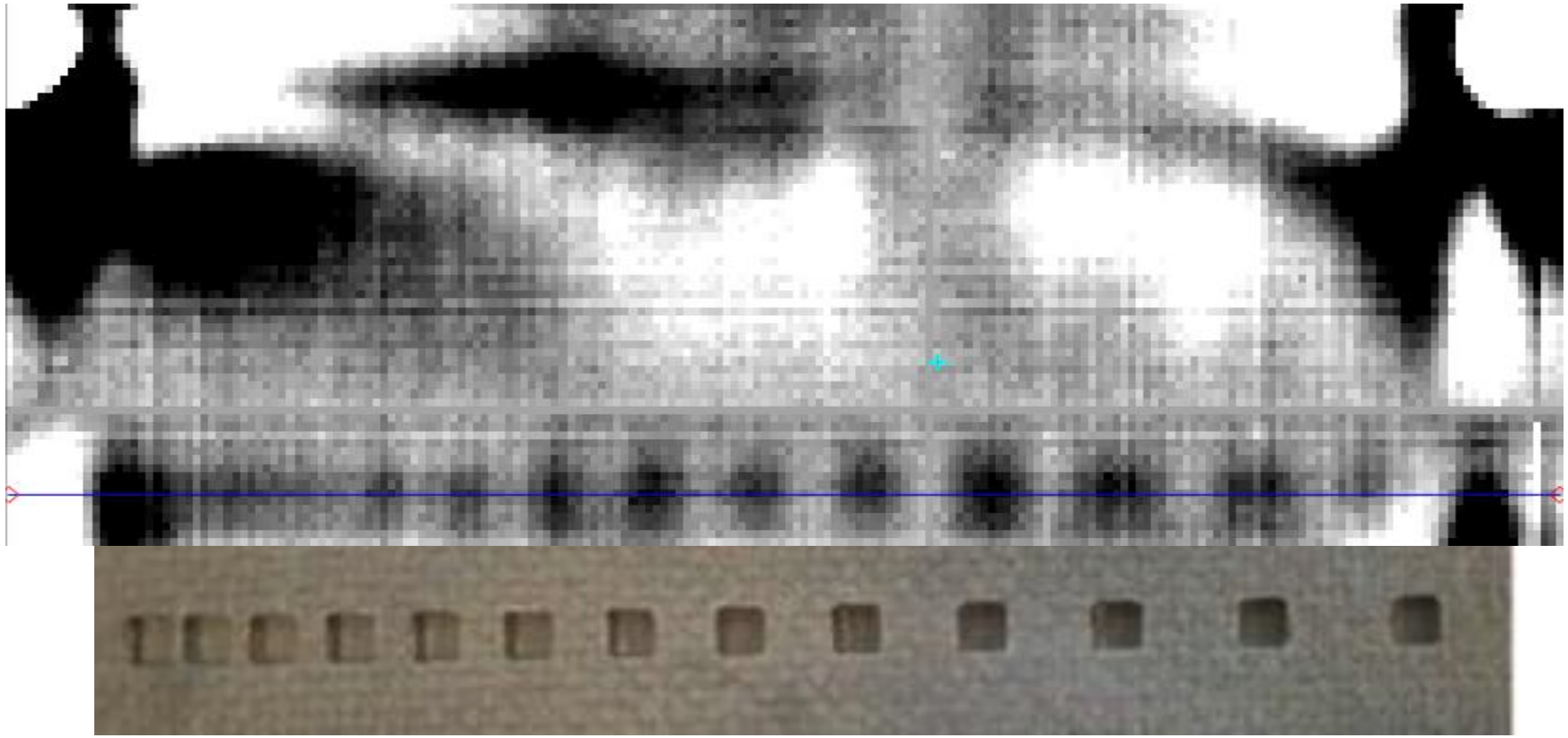


8mm TX-RX Probe @ 9MHz scan of 50% depth 6x6mm FB squares

CFLUX

ETHER NDE

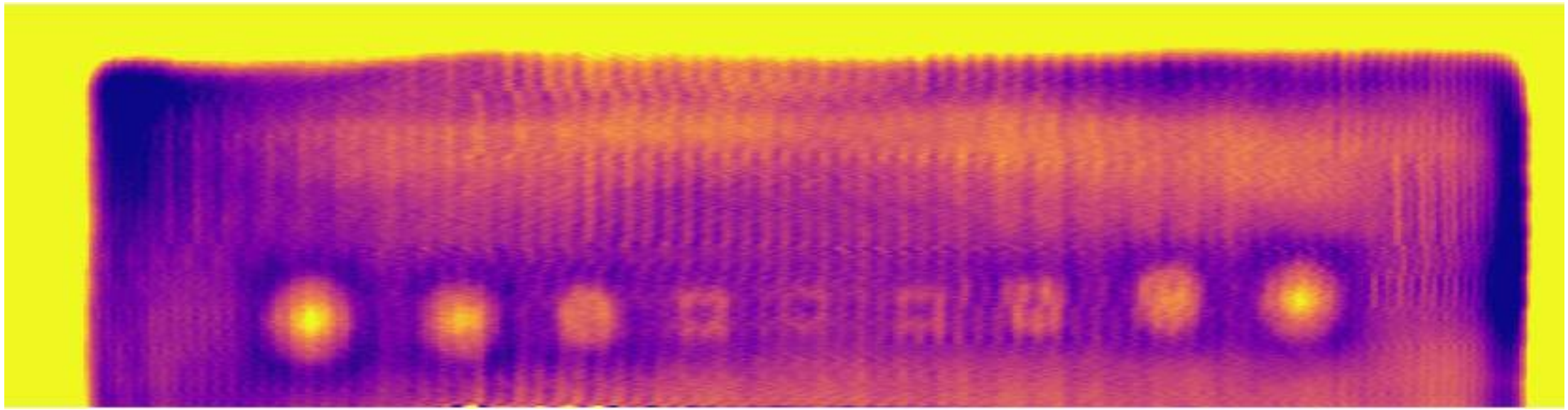
15mm resolution sample with filtering



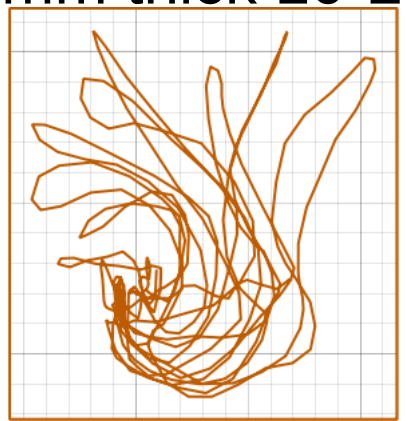
24mm TX-RX Probe @ 400kHz scan of 13% depth of 6x6 mm FB squares

CFLUX

3mm CFRP 2 by 2 Twill 8 ply Sample Scan TX-RX



9 embedded 1mm thick 10-2mm dia. discs



CFLUX

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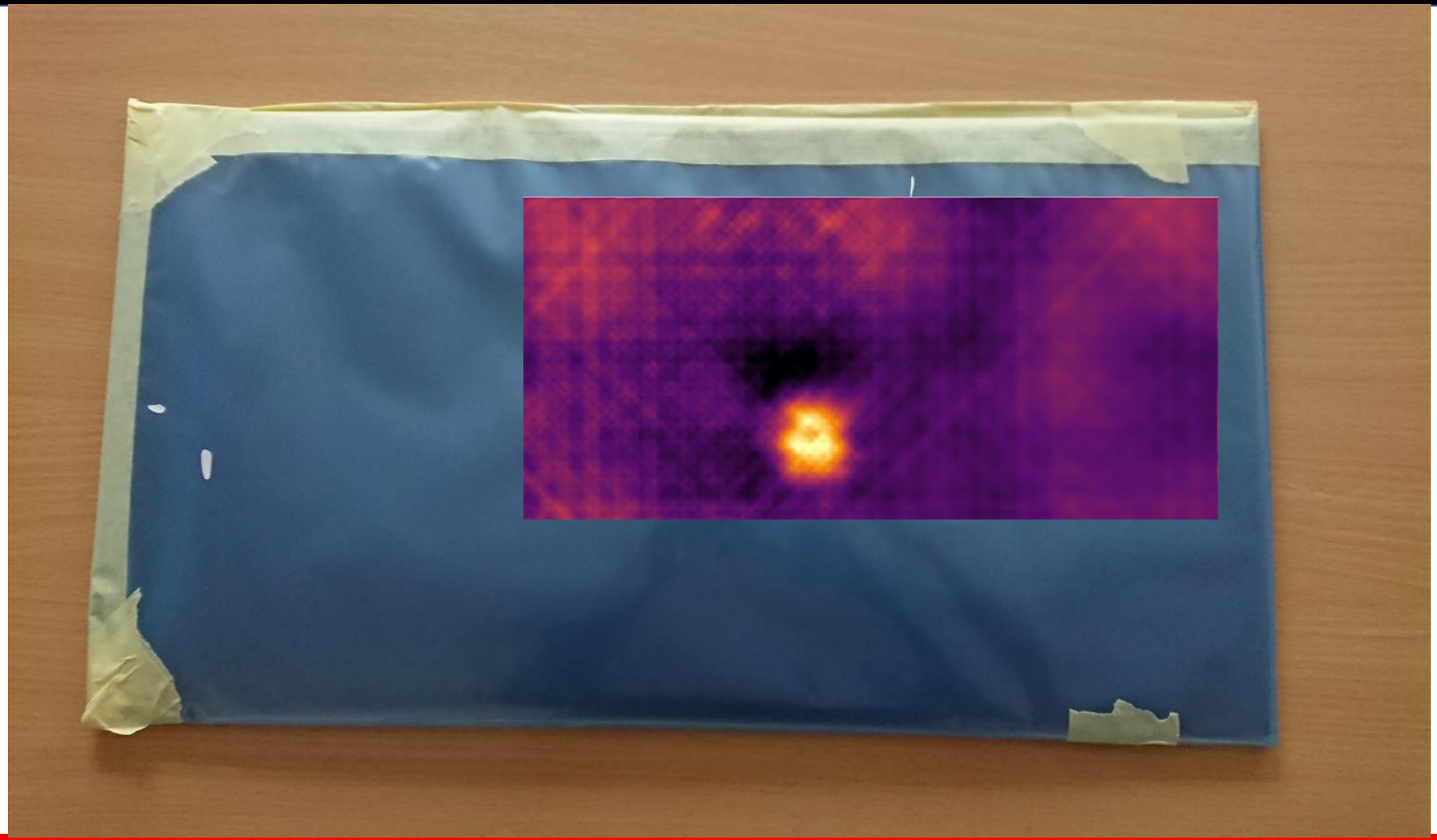
Simulated Lightning Strike On Graphene Sample

Tx-RX 2 MHz inspected in its wrapping



On Loom Inspection

Integrated a prototype system at MWS for on-line defect detection for on loom defect detection.

On Loom Inspection Video

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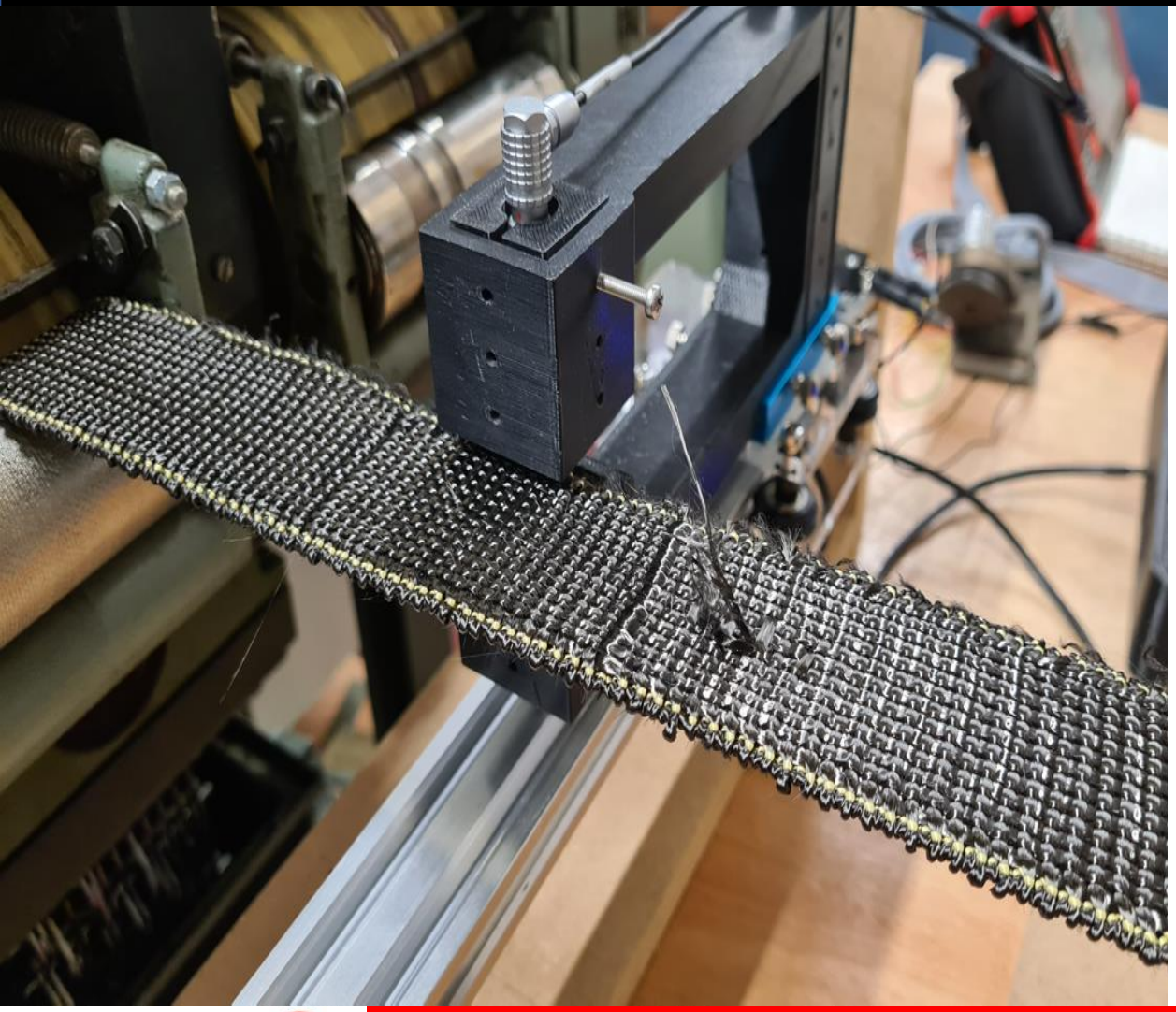
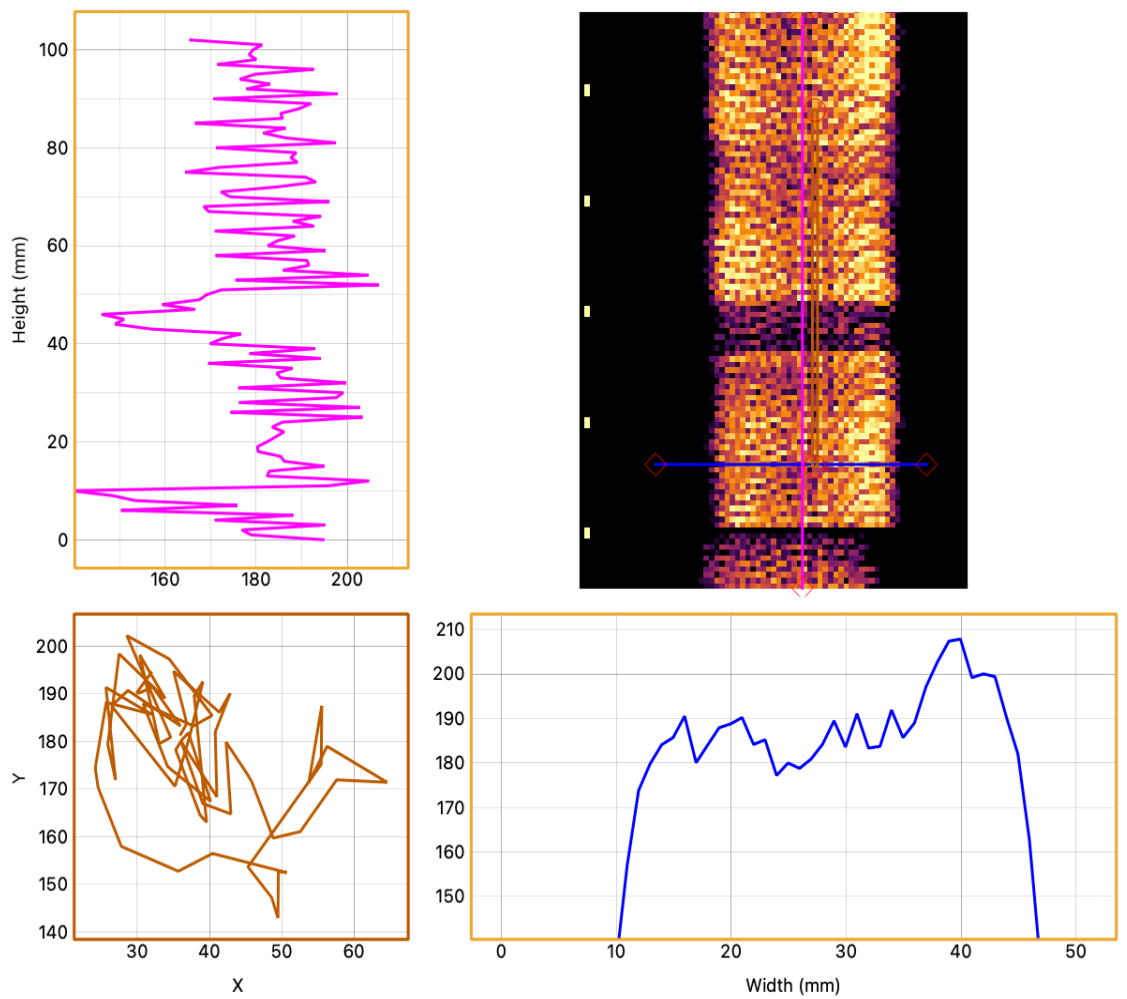
Defects detected





filename: 20210318163154.csn | channel: CH-1 | f: 3.0 MHz | image data: Y Component Image | phase rotation: 149°

Robotic Integration on Site

M.Wright & Sons Ltd.
Engineered Textile Structures
(Established 1860)

TWI

ETHER NDE

Far COMPOSITES

AHS
Advanced Hall Sensors Ltd

In-line automated eddy current scanning to identify subsurface defects in larger manufactured components

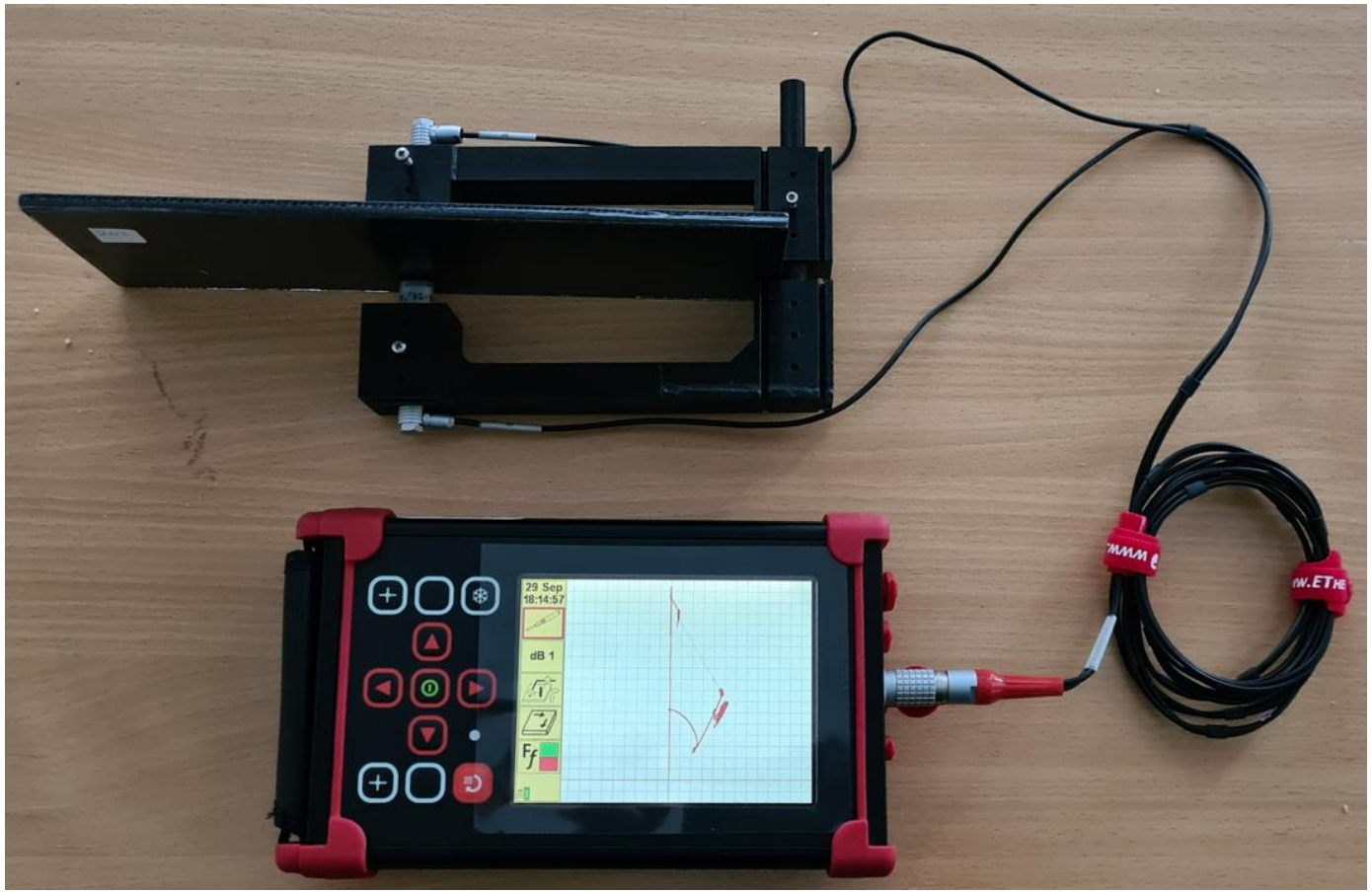
CFLUX

InnovateUK funded project 113229 - CFLUX 30236

Now for something completely different FVF

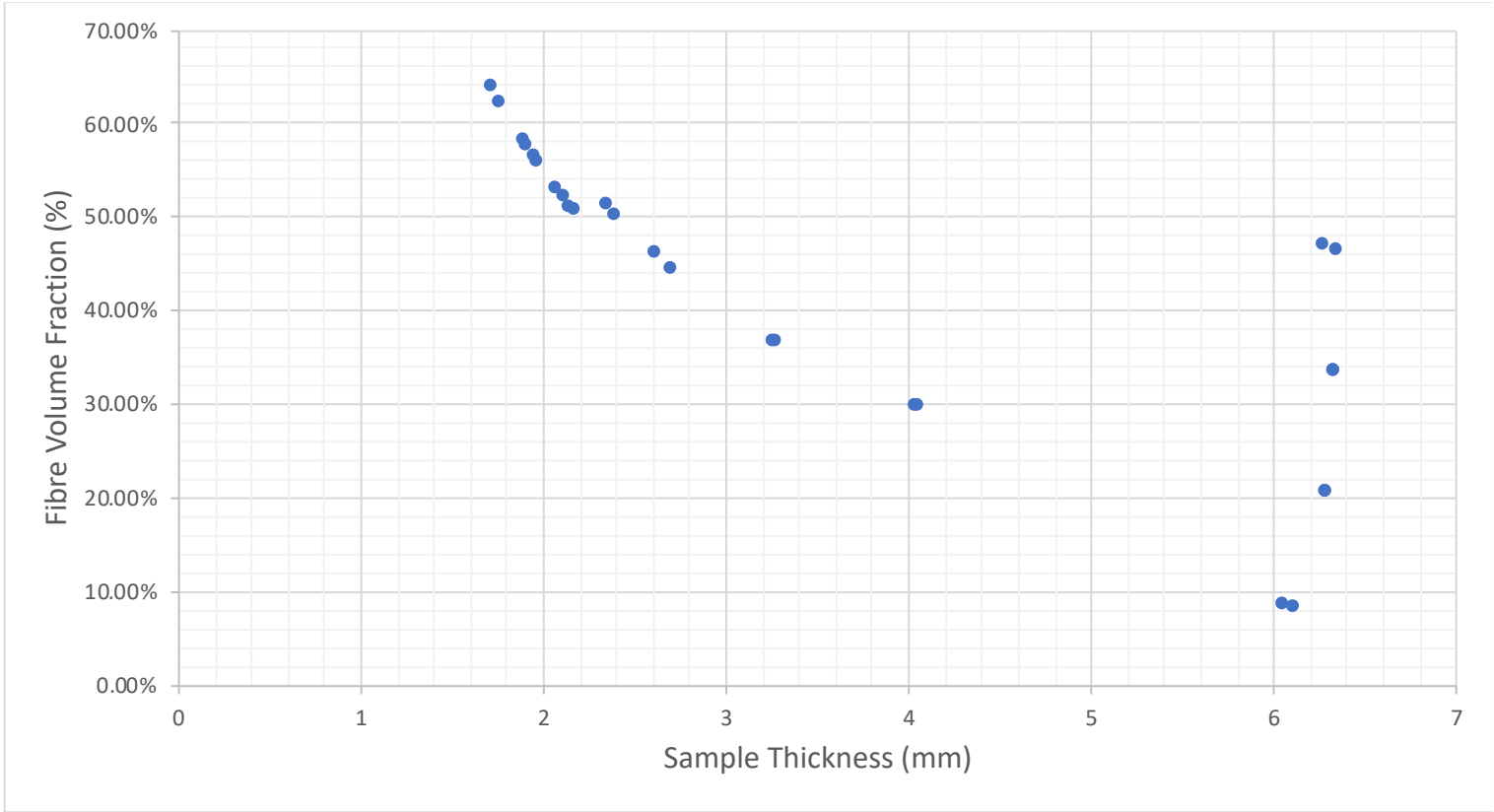
Measuring Fibre Volume Fraction

- Came out of work on optimising probe and frequency
- Used thru transmission and found by experimentation that Phase Shift per mm gave the most consistent response.

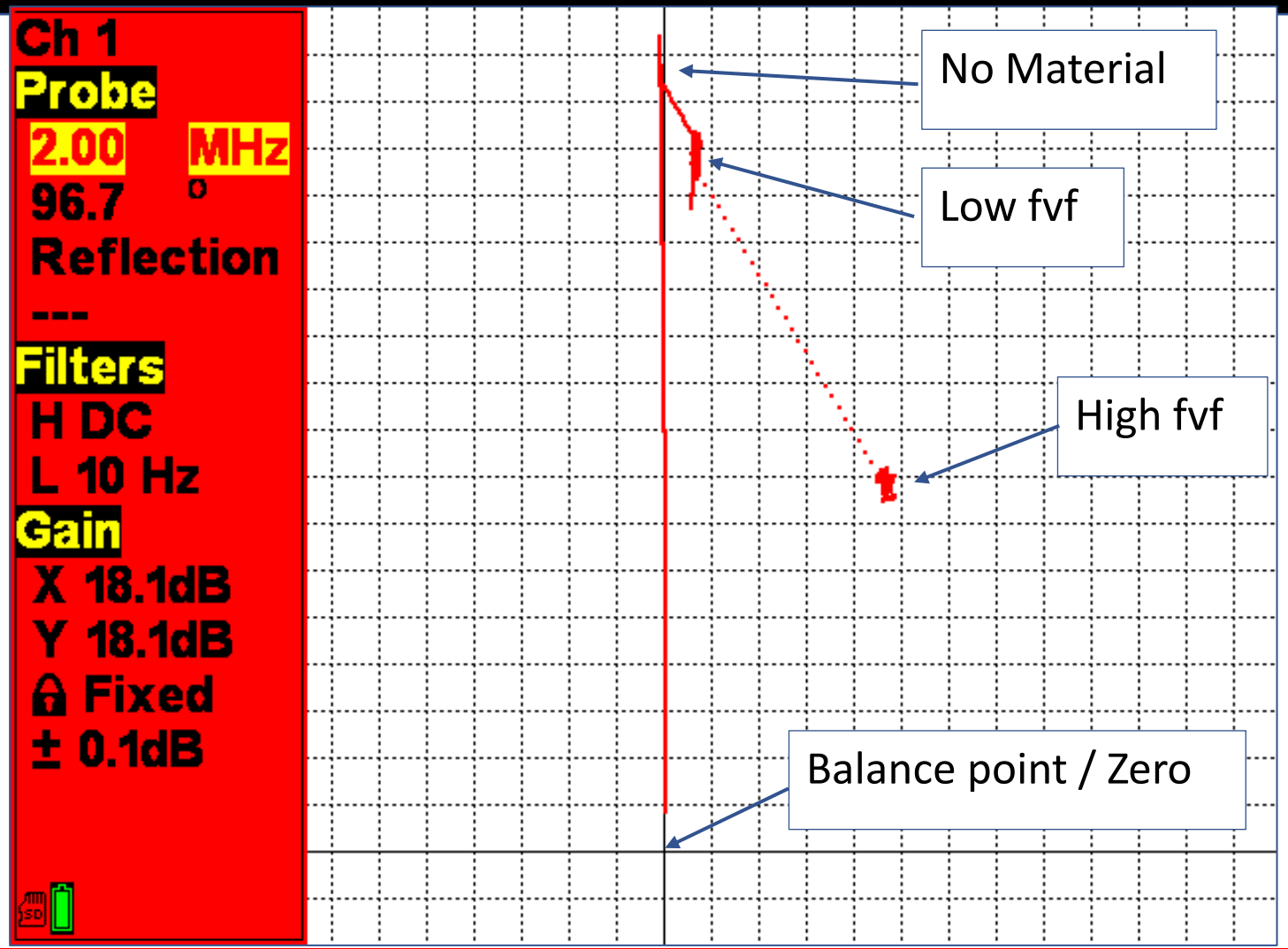


The Samples

Sample	mm	FvF	Fabric	Areal Weight g/m²	Infusion number
A a	2.7	45.1	CD107	2161.453	IF158
A b	2.7	45.1	CD107	2161.453	IF158
B a	3.3	35.8	CD107	2161.453	IF186
B b	3.3	35.8	CD107	2161.453	IF186
C a	4.1	29.0	CD107	2161.453	IF183
C b	4.1	29.0	CD107	2161.453	IF183
1	1.8	63.8	CD175	1976.36	IF189
1	1.7	63.8	CD175	1976.36	IF189
2	1.9	57.9	CD175	1976.36	IF189
2	1.9	57.9	CD175	1976.36	IF189
3	2.0	56.0	CD175	1976.36	IF189
3	2.0	56.0	CD175	1976.36	IF189
4	2.1	52.5	CD175	1976.36	IF189
4	2.1	52.5	CD175	1976.36	IF189
5	2.1	51.6	CD175	1976.36	IF189
5	2.1	51.6	CD175	1976.36	IF189
Da	2.3	50.9	CD107	2161.453	IF158
Db	2.4	50.9	CD107	2161.453	IF158
IF200A	6.1	8.0	CD104	912.2308	IF200
IF200B	6.1	8.0	CD104	912.2308	IF200
IF201A	6.3	20.0	CD101	2317.58	IF201
IF201B	6.3	20.0	CD101	2317.58	IF201
IF202A	6.3	33.0	CD91	3819	IF202
IF202B	6.3	33.0	CD91	3819	IF202
IF203A	6.4	46.0	CD103	5293.377	IF203
IF203B	6.4	46.0	CD103	5293.377	IF203

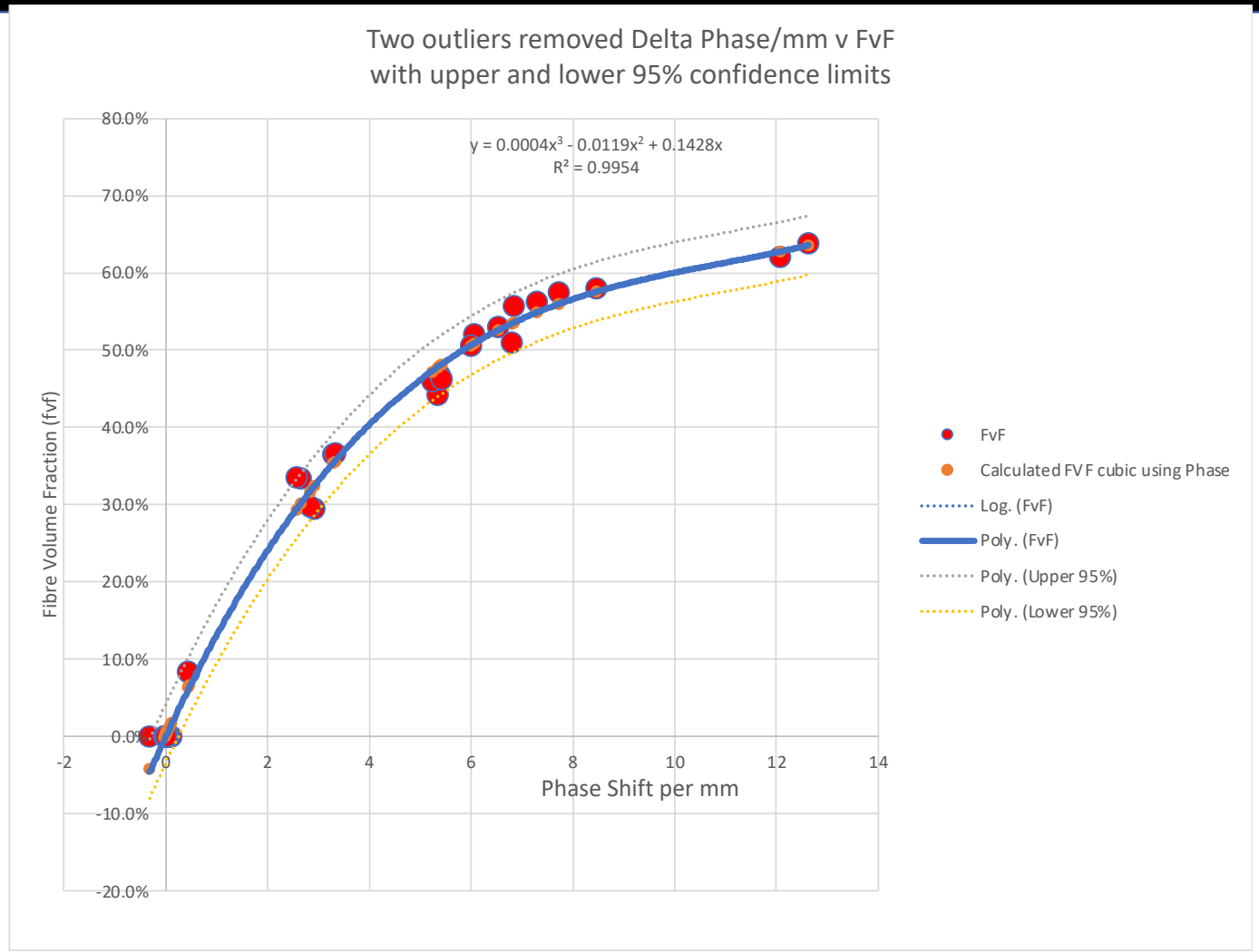


Measurements Made



The results

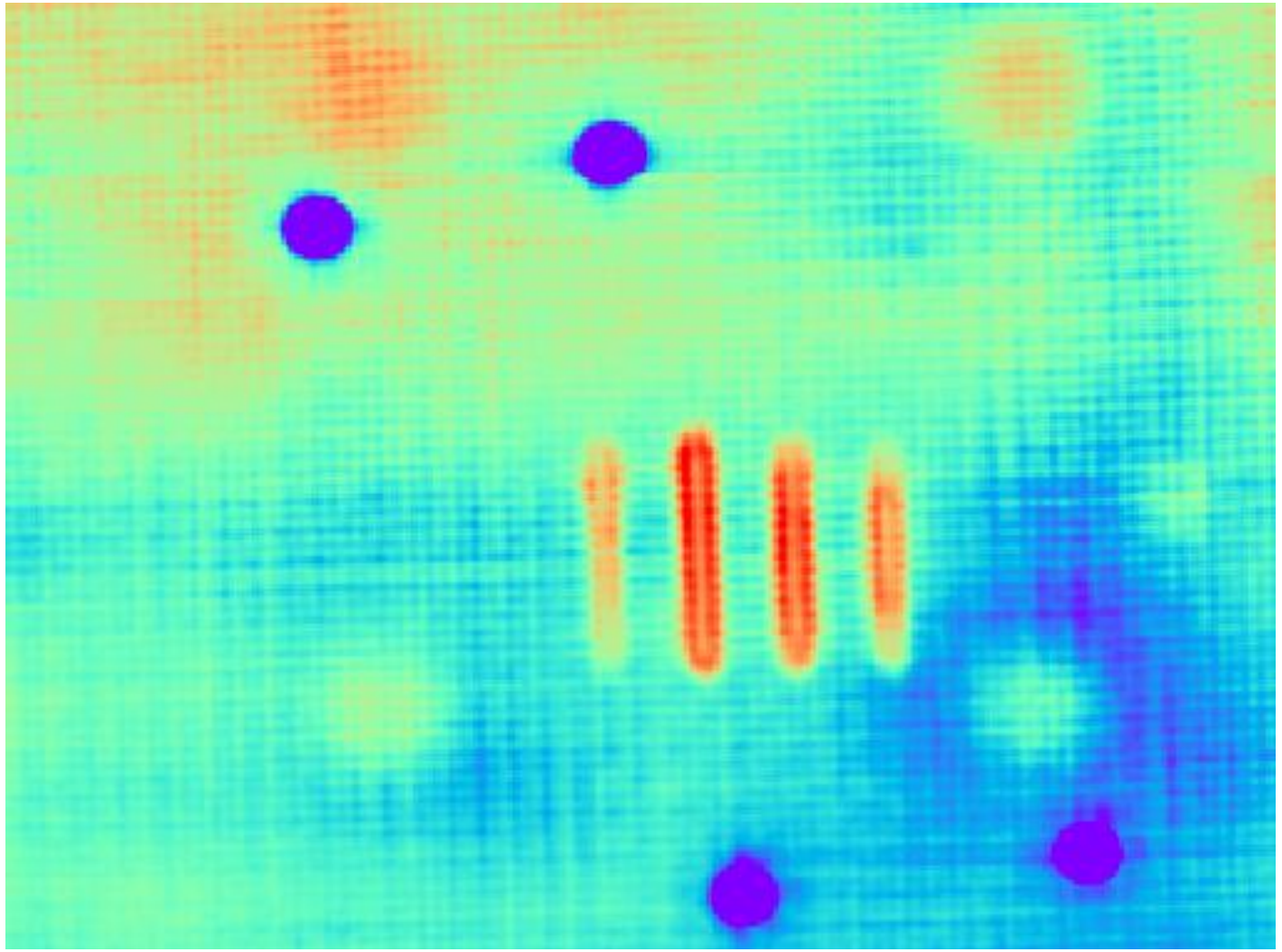
- 99.54% Correlation and 95% confidence level of +/-3.8% FvF
- Potential to offer a commercially available hand held QA tool like a conductivity meter.



Conclusion

What Next?

- ETher will sponsor an Eng.D. at Bristol Univ. starting this September to further this research.
- Seem to be able to detect both disruption to the Fibre Matrix and lack of resin. So sensitive to changes in conductivity and permittivity
- However what is shown here is already a practical solution.

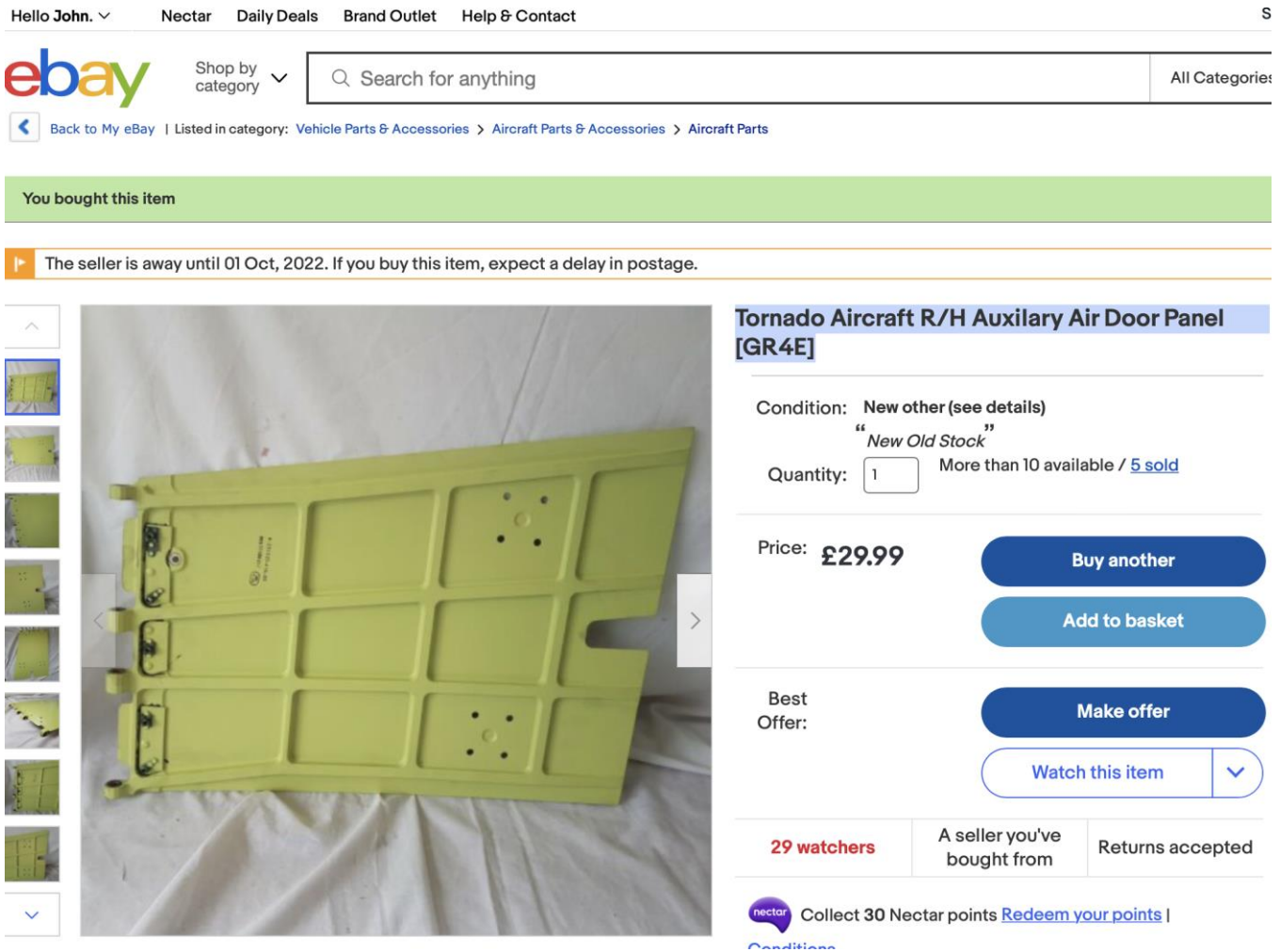


What about Aluminium?

Tornado Aircraft R/H Auxilary Air Door Panel [GR4E]

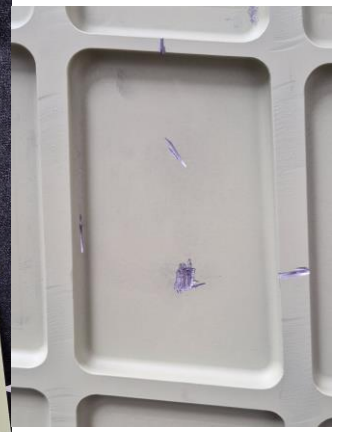
Bought on ebay

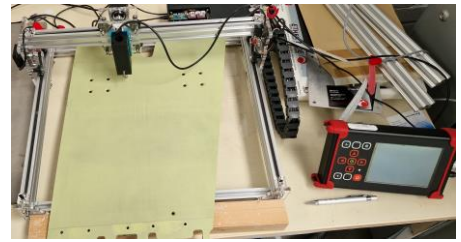
$30 still available

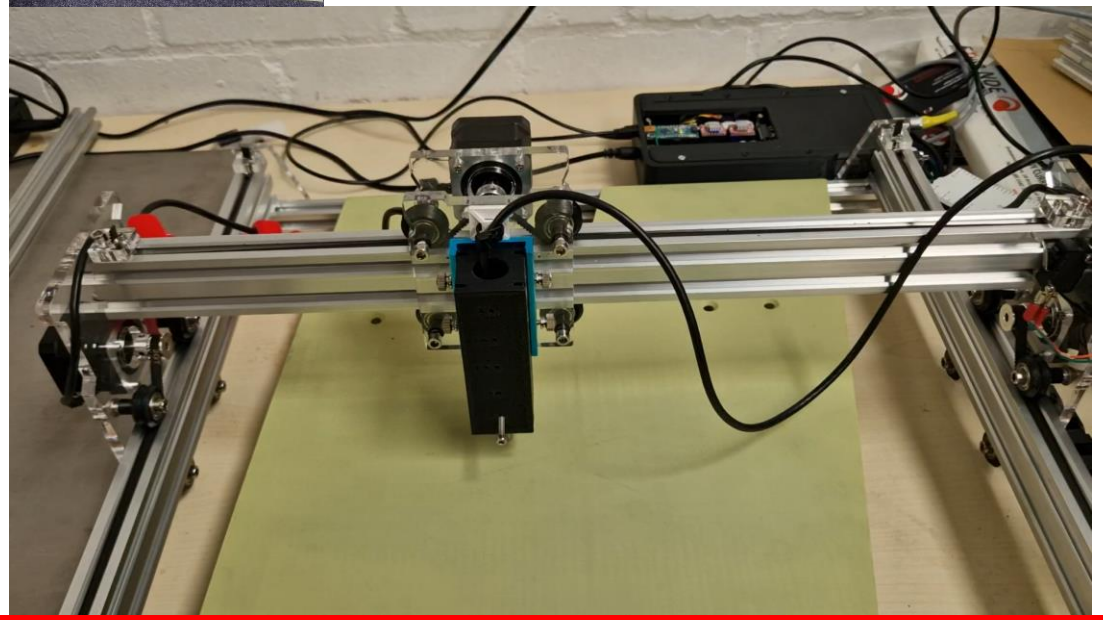


PHASECHECK Portable EC Instrument

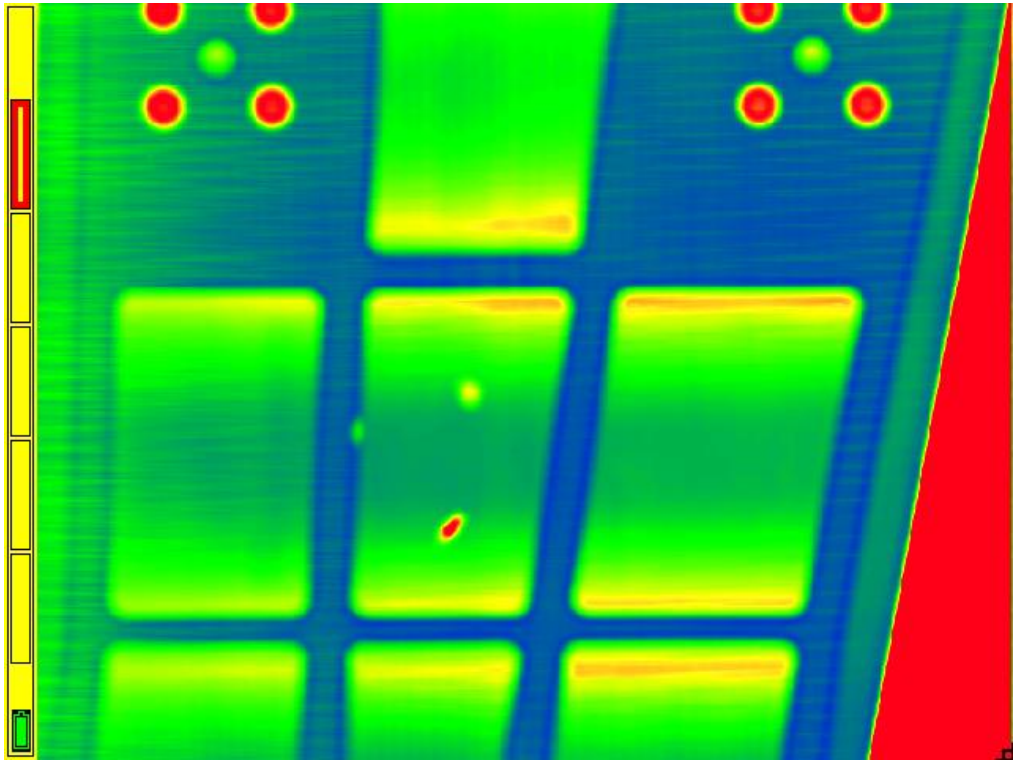
- Scanner curved component at 100mm/s with 0.5 mm resolution
- Test Frequency 10kHz and 2.5kHz

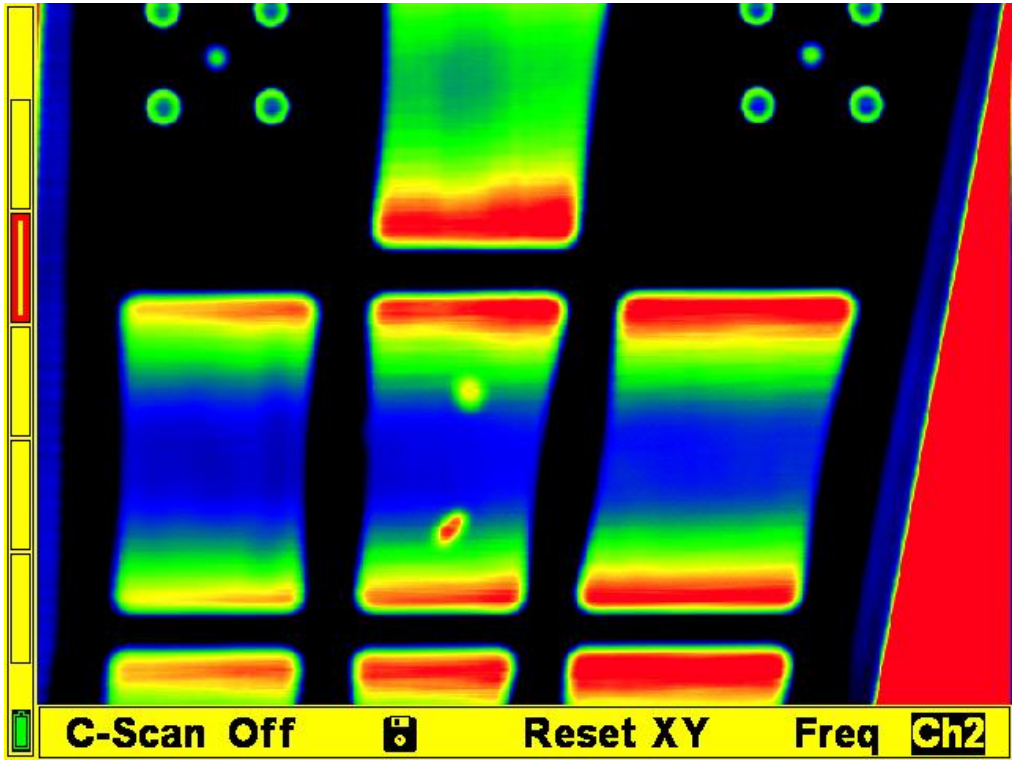


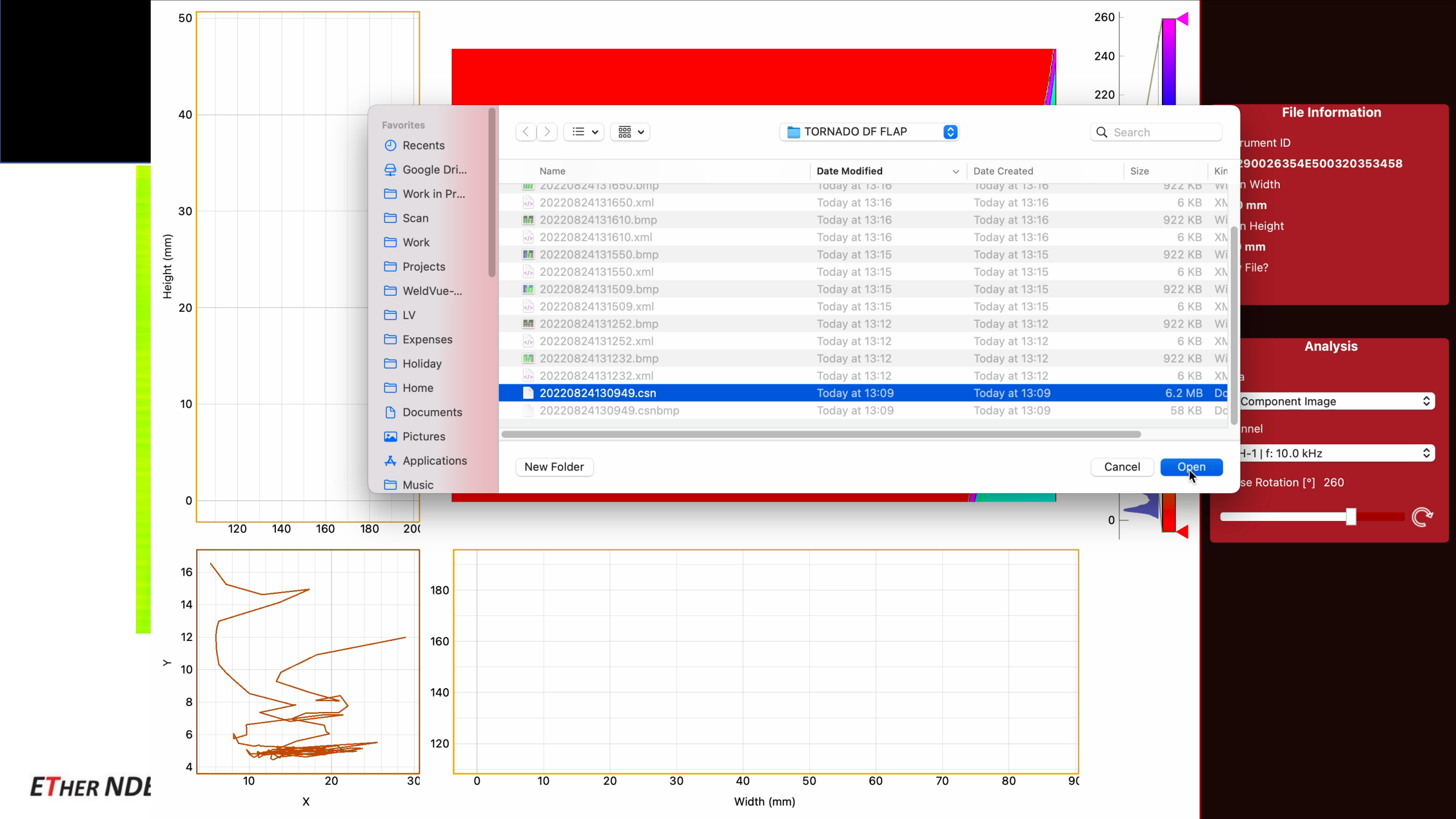




PHASECHECK Portable EC Instrument



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Recents
Google Dri...
Work in Pr...
Scan
Work
Projects
WeldVue-...
LV
Expenses
Holiday
Home
Documents
Pictures
Applications
Music
TORNADO DF FLAP
Search
Name
Date Modified
Date Created
Size
20220824131650.xml Today at 13:16 Today at 13:16 6 KB
20220824131610.bmp Today at 13:16 Today at 13:16 922 KB
20220824131610.xml Today at 13:16 Today at 13:16 6 KB
20220824131550.bmp Today at 13:15 Today at 13:15 922 KB
20220824131550.xml Today at 13:15 Today at 13:15 6 KB
20220824131509.bmp Today at 13:15 Today at 13:15 922 KB
20220824131509.xml Today at 13:15 Today at 13:15 6 KB
20220824131252.bmp Today at 13:12 Today at 13:12 922 KB
20220824131252.xml Today at 13:12 Today at 13:12 6 KB
20220824131232.bmp Today at 13:12 Today at 13:12 922 KB
20220824131232.xml Today at 13:12 Today at 13:12 6 KB
20220824130949.csn Today at 13:09 Today at 13:09 6.2 MB
20220824130949.csnbmp Today at 13:09 Today at 13:09 58 KB
New Folder
Cancel
Open
Height (mm)
Y
X
Width (mm)
File Information
Analysis
Component Image
Rotation [°] 260

Thank-you for your attention

Any Questions?