Phased Array Ultrasonic Testing
Initial Trials Using D1.5 Annex K
and
A Look at NCHRP 14-35 / Report 908

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High Steel Structures

QAW

15 February 2020

Traditional RT

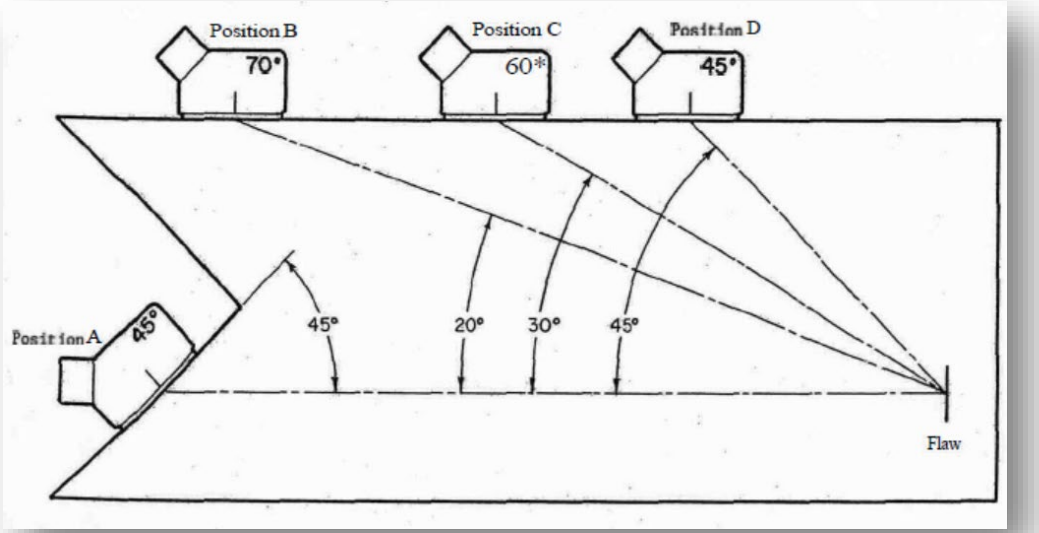
- Bridge Welding began in the 50s / 60s
- RT acceptance criteria adopted
  - Workmanship based – i.e., the acceptance criteria are based on the quality that can be expected from a welder
  - Not based on fitness for purpose
- Successful performance of millions of flange and web splices
  - No weld that passed the acceptance criteria has ever cracked
  - One weld is known to have cracked from a weld defect – the I-79 bridge; however, that weld had a huge defect (from an improper repair) that would not have met acceptance criteria

Traditional RT - downsides

- Limited to butt splices (not tees or corners)
- Not strong for finding planar defects, like tight / thin cracks, sidewall lack-of-fusion (LOF), and lamination
- Safety hazard / shop disruptions
- Depth of defects that are discovered is not known (hampers repairs); UT is used to establish depth
- Delayed results when using film (digital does provide instant results)

Traditional UT

- Adopted in the late 60s
  - D1.0-69
  - D2.0-69
- Sound is sent through the weld
  - If the sound strikes a discontinuity, it bounces back
  - Acceptance is based on the amount of sound that comes back
  - Acceptance is also dependent upon the scanning angle (originally to adjust for the fact that you cannot send sound through the weld at 90 degrees to the weld)



Application of ultrasonic testing to a groove weld

Ultrasonic Testing Requirements of the AWS 1969 Building Code and Bridge Specifications

presents explanation and discussion of Appendix C in AWS D1.0 and D2.0 and concludes that Appendix C provides a very workable method for the ultrasonic testing of groove welds

BY GEORGE A. SHENEFELT

In 1969 the American Welding Society issued new editions of the Code for Welding in Building Construction (AWS D1.0-69) and Specifications for Welded Highway and Railway Bridges (AWS D2.0-69). Appendix C—Ultrasonic Testing of Groove Welds was a part of these documents. This is the first ultrasonic testing procedure issued by the Society and covers the ultrasonic testing of groove welds between the thickness of 5/16 and 8 in., inclusive. The welds may be either butt, tee, or corner welds and may be either full or

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Traditional UT

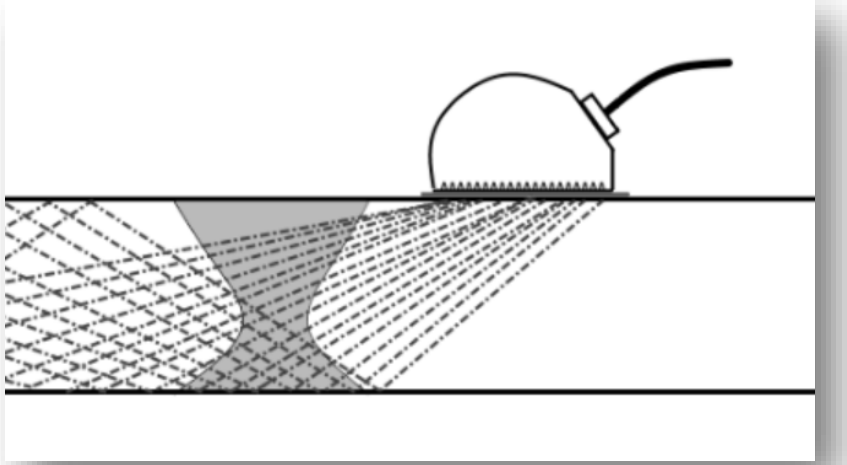
- Comparable to RT for overall workmanship and performance assurance
  - Some states, like MD and NJ, use it instead of RT
- Advantages
  - Useful for all types of complete joint penetration (CJP) welds, includes tee and corner joints – is common for these joints; not just butt splices (like RT)
  - Good for planar defects / cracks (and other volumetric defects)
  - Provides defect depth
- Downsides
  - No image with the report – a concern for some owners

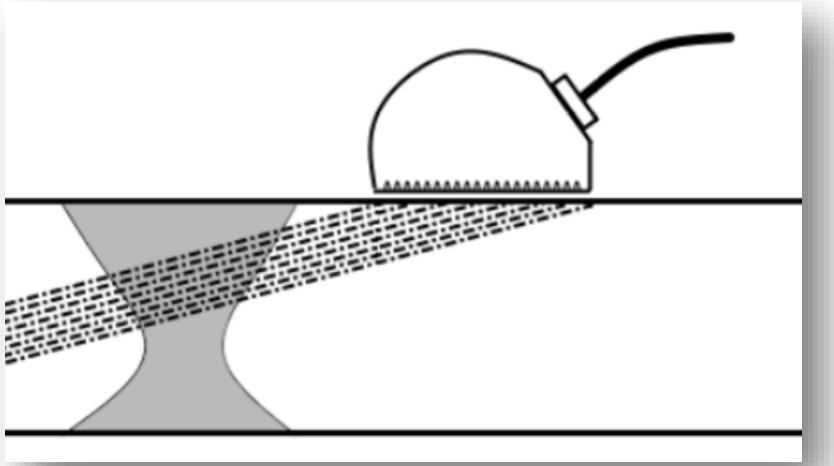
Traditional UT – Alternate Approach

- Adopted in the mid 70's by the D1 committee – Annex S
- Developed by Myron Hoitomt who wanted better correlation between UT and RT
- Not used in the bridge community
- Note: no documentation of its development or adoption is available (Myron defended it to the D1 committee, who adopted it into D1.1)

Phased Array Ultrasonic Testing (PAUT)

- Enhanced version of UT
- Multiple sound paths instead of one – more efficient scanning
- Multiple angles instead of one – much better chance of striking the discontinuity square (and thereby getting the most sound back)
- Encoding
  - PAUT can be done without it, but D1.5 mandates it
  - Provides electronic documentation of the test – thus overcoming the objections that some folks have with traditional UT
- Less operator sensitive – once the scan plan is established, the technician simply executes the scan plan by moving the transducer along the index axes prescribed in the scan plan





PAUT Acceptance Criteria (Annex K)

- Mark Davis lead the task group; he came up with three proposals
  - 1) linear scan – thought it would be more equivalent to Clause 6 UT, but the committee wanted to take advantage of having multiple angles
  - 2) sector scan – and swept angle – graded to the nearest typical traditional angle; angles give you a better chance of hitting the flaw at 90 degrees
  - 3) research D1.1 Annex S (now Annex Q) as another option; Mark had used it for a powerplant; it's a DAC curve approach (instead of TCG, which corrects by adding gain); presented to the committee; committee liked it; saw that it was equivalent or better than RT; committee adopted as a TCG in Annex K
- Hence the original basis of D1.5 Annex K is D1.1 Annex S (now D1.1 Annex Q) which the committee saw provided good correlation with RT criteria
- Subsequent comparisons have also found good correlation between Annex K and RT criteria
  - Florida DOT study
  - High Steel comparisons
- Fracture mechanics – can do beam spread and height corrections – but more sophisticated and time consuming

PAUT NCHRP Study

- The D1.5 committee felt that
  - We were probably over-repairing welds, and
  - Perhaps PAUT (or other advanced NDE techniques) could be used to facilitate the use of new and more logical acceptance criteria
  - Using allowances such that were fit-for-purpose based, repairs could be reduced to a more rational volume
- Research studied allowable discontinuities using fracture mechanics and allowable stress ranges
  - Got much smaller allowable discontinuities
  - Discovered calibration discrepancies with TMCP plates

High Steel Comparisons

- On two Virginia bridges, used PAUT for flange splices and one web splice
  - Performed RT on any indication above the disregard level (DRL, which is 6db below SSL), as scanned
  - Evaluated NCHRP need for rastering (anything above 10% full screen height, as evaluated)
  - Evaluated NCHRP need for repair
  - Looked at some joints with UT as well

Piece Mark Splice	Scan	Thickness	Length	Transition (Y/N)	PAUT			CONVENTIONAL	
					Annex K	NCHRP	NCHRP Raster	RT	UT
VA1180201A-1									
G8A WA	270F	.625"	.84"	N	C 26.6%REJ.	42.1%	R	REJ.	N/A
G8A WA	90F2	.625"	1.28"	N	C 37.1%REJ.	58.7%	R	REJ.	N/A
G8A WA	270F2	.625"	.24"	N	D 14.2%	23.0%	R	ACC.	N/A
G8B BFA	90N	2.0"	.197"	N	D 13.6%	22.0%	R	Not found	N/A
G8B TFA	270N	2.0"	.275"	N	D 15.8%	24.9%	R	Not found	N/A
G9B TFA	90F	2.0"	.5"	N	D 13.3%	21.0%	R	Not found	N/A
G11B TFA	270N	2.0"	.236"	N	D 18.6%	29.4%	R	Not found	N/A
G11B BFA	edge	2.0"	N/A	N	C 27.0%		*	Not found	Not found
G11C BFA	90N	1.25"	.196"	N	D 25.1%	39.6%	R	Not found	N/A
G11C TFA	90N	1.25"	.158"	N	D 13.3%	21.0%	R	Not found	N/A
G11C TFA	90N	1.25"	.197"	N	D 14.5%	23.0%	R	Acc.	N/A
G13A TFA	90F	1.5"	.158"	N	C 27.5%	43.5%	R	Not found	N/A
G13A TFA	270N	1.5"	.197"	N	D 17.0%	26.9%	R	Not found	N/A
G13A BFA	90N	1.5"	.276"	N	D 7.7%	12.2%	N/A	Acc.	Acc. +20
G13B BFA	90m	2.0"	.276"	N	C 34.9%	55.3%	R	Not found	Acc. +11
G13C BFA	edge	1.25"	edge	N	D 16.1%	24.9%	*	Not found	Acc. +19
G13C BFA	270N	1.25"	.237"	N	D 13.9%	22.0%	R	Not found	Not found
G13C BFA	270N	1.25"	.275"	N	D 15.8%	24.9%	R	Not found	Not found
G13C BFA	270N	1.25"	.197"	N	D 13.0% (67.5)	20.6%	R	.03" Acc	+7 Rej. (70)
G9C TFA	90N	1.25"	.196"	N	C 29.4%	46.5%	R	.05" Acc.	N/A
G9C BFA	90F	1.25"	.393"	N	D 14.5%	23.0%	R	Not found	N/A
G10C BFA	270N	1.25"	.197"	N	D 11.8%	18.6%	R	Not found	N/A
VA1180201H-11									
G1B TFA	90N	1.25-2	.196"	Y	D 13.3%	21.0%	R	.07" Acc	N/A
G1B TFB	270N	1.25-2	.197"	Y	D 14.2%	22.5%	R	Not found	N/A
G3B TFA	270N	1.25-2	.315"	Y	D 16.1%	25.4%	R	Not found	+18
G4A BFA	90N	1.125"	.196"	N	D 13.3%	21.0%	R	Not found	N/A
G4B BFA	90N	1.5-2	.315"	Y	D15.7%	22.9%	28.4%	Not found	N/A
G5A TFA	90F	1.0"	.630"	N	C 26.6% (56)	42.1%	R	1.0"	+11 (70) .63"
G4C BFA	90N	1.125"	.276"	N	D 23%	37.4%	39.9%	Not found	N/A
G4C BFA	270N	1.125"	.276	N	D 24.9%	41.1%	32.2%	Not found	N/A
						R = NCHRP Raster scan required			
						* = Found with raster scan of edge			
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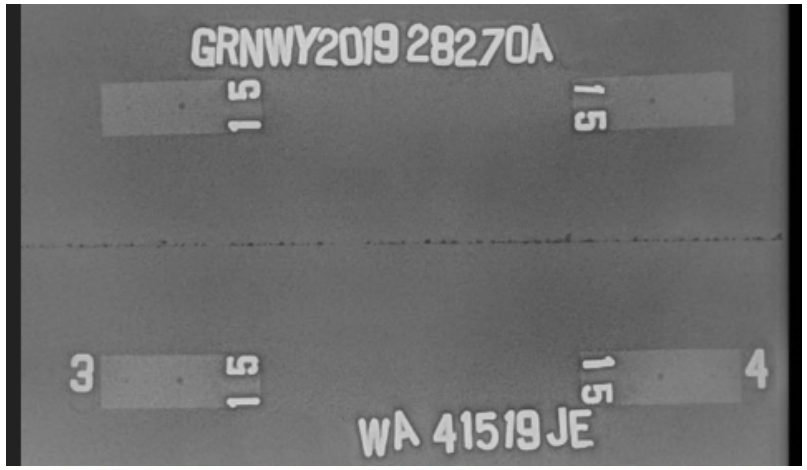
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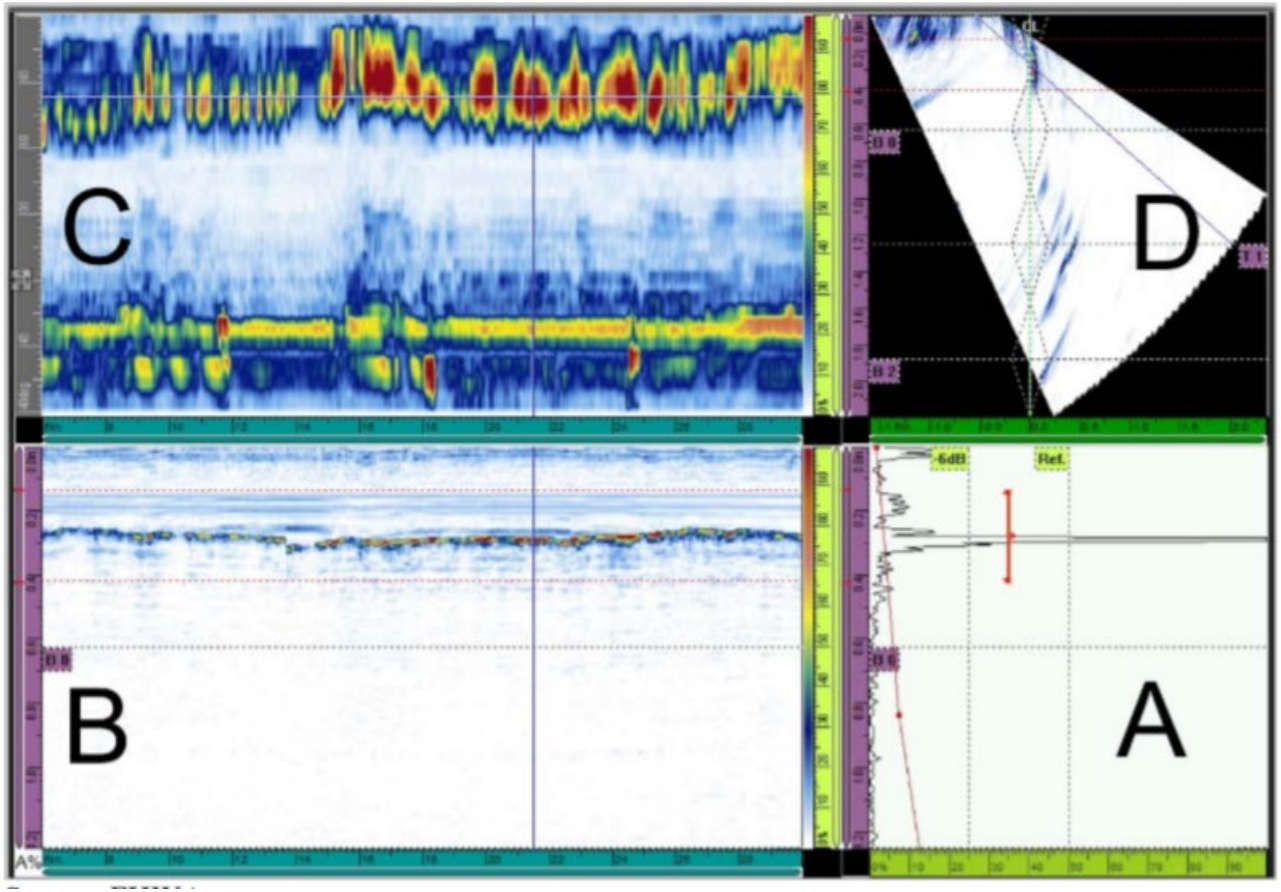
PAUT views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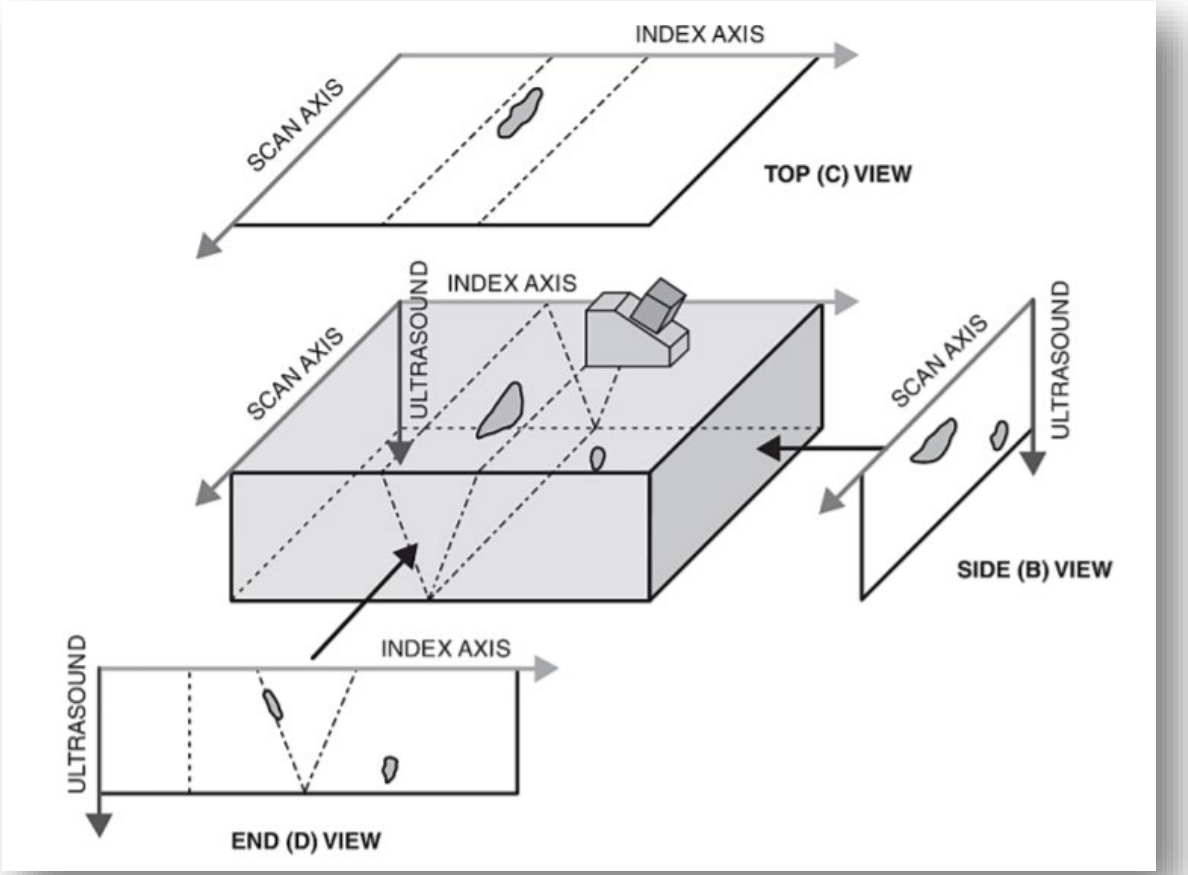
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ULTRASOUND
END (D) VIEW

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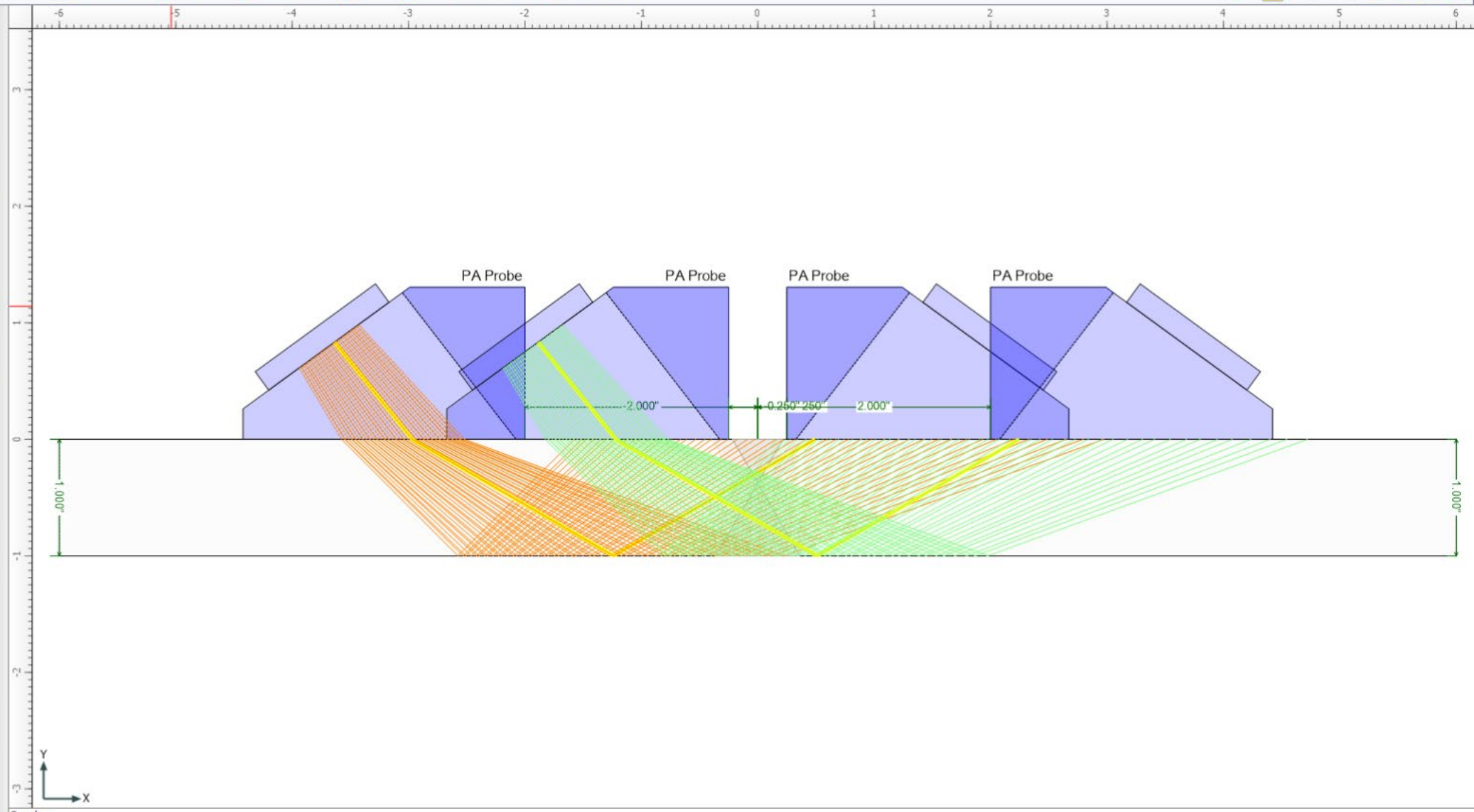

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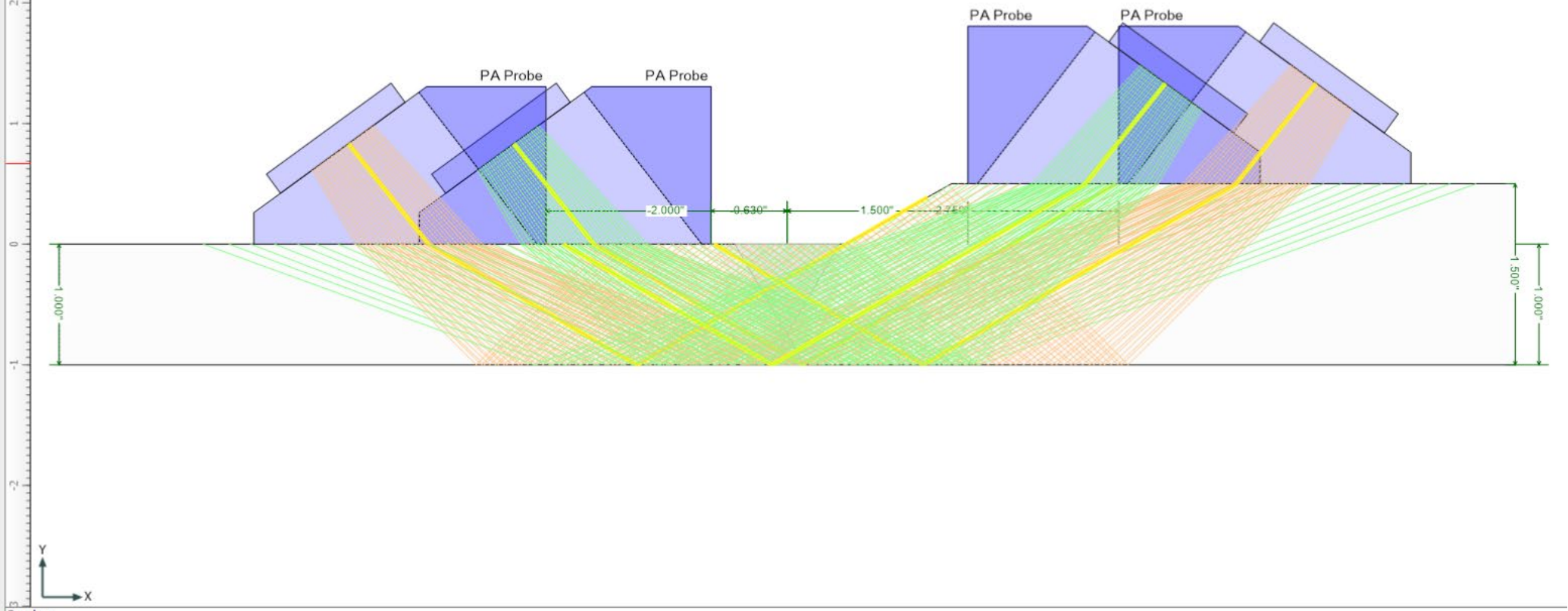

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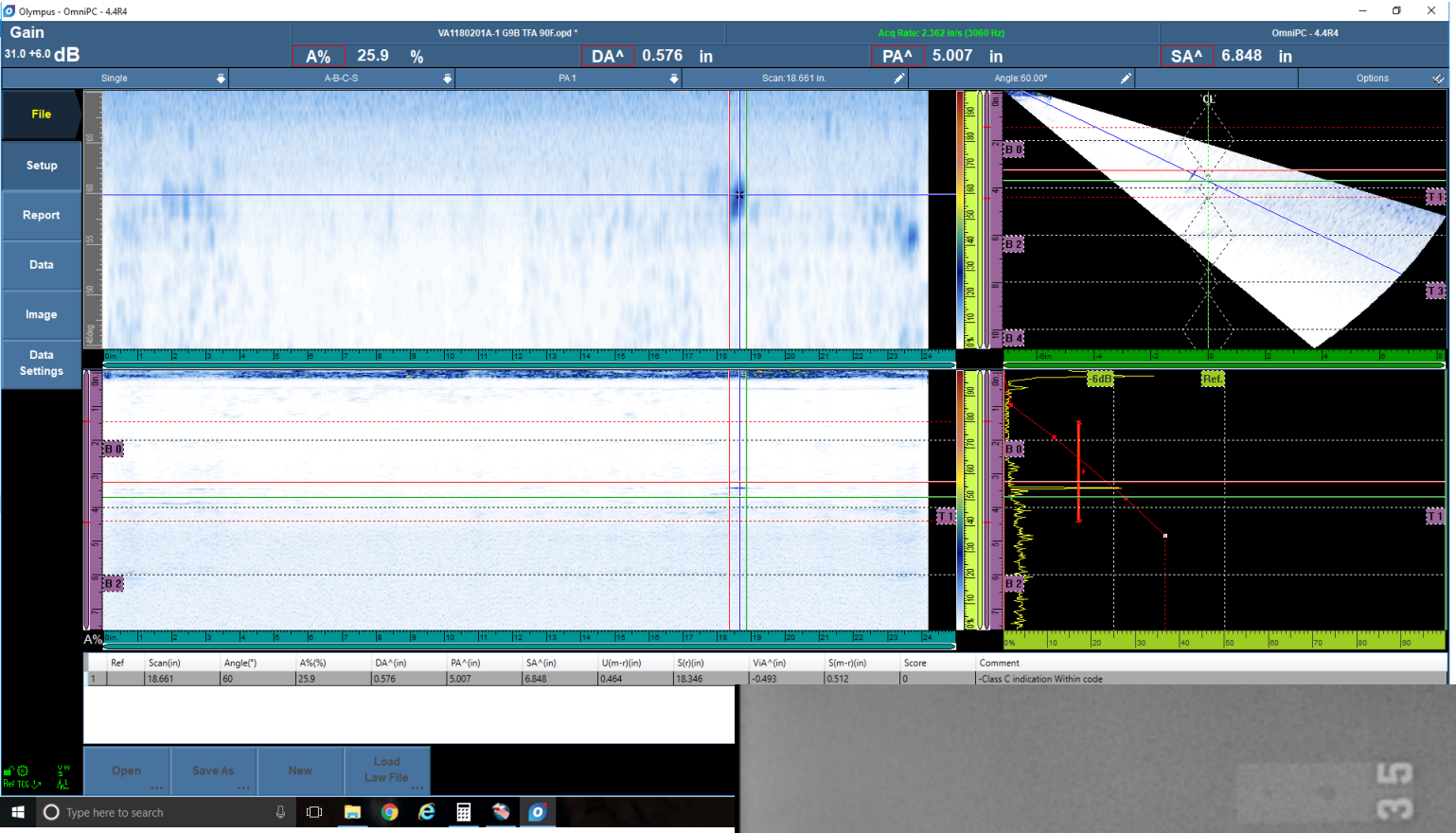
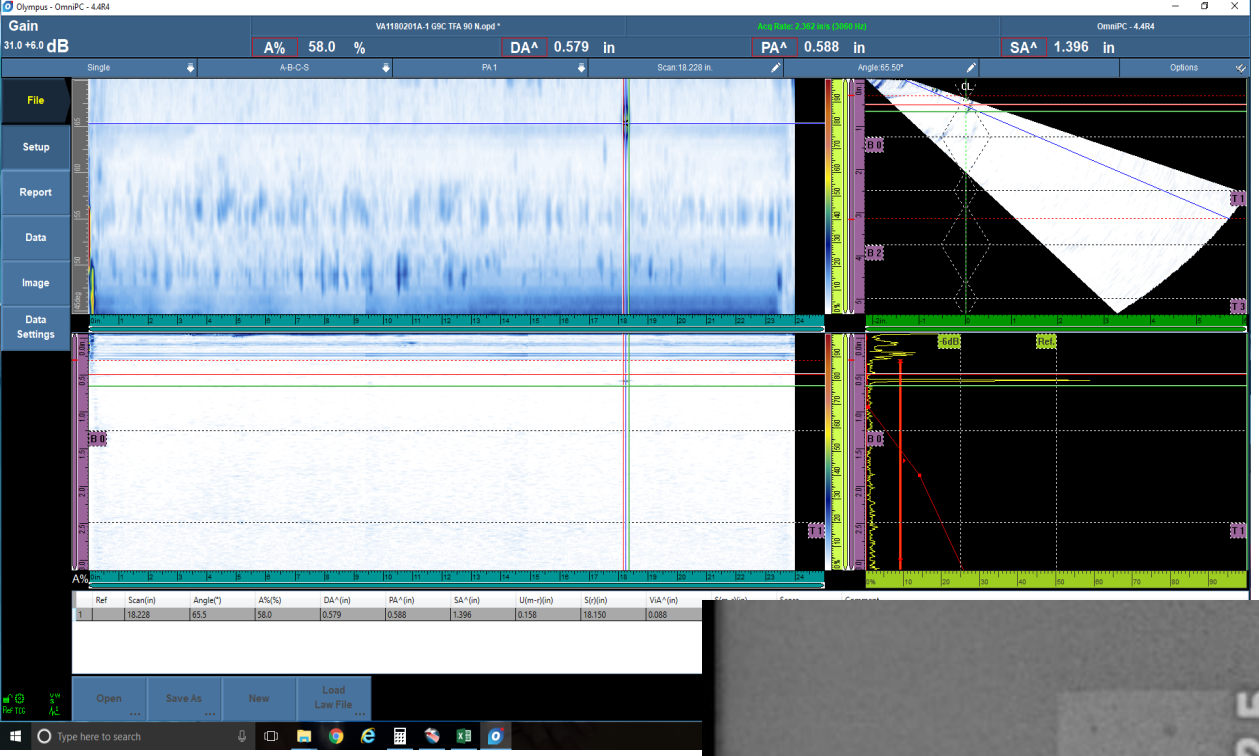


- RT result: clear
- PAUT result
  - Annex K: class D,13% - pass
  - NCHRP: 21% raster
- UT result: not tested

G9B TFA (A1)



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  - Annex K: class C,29.4% - pass
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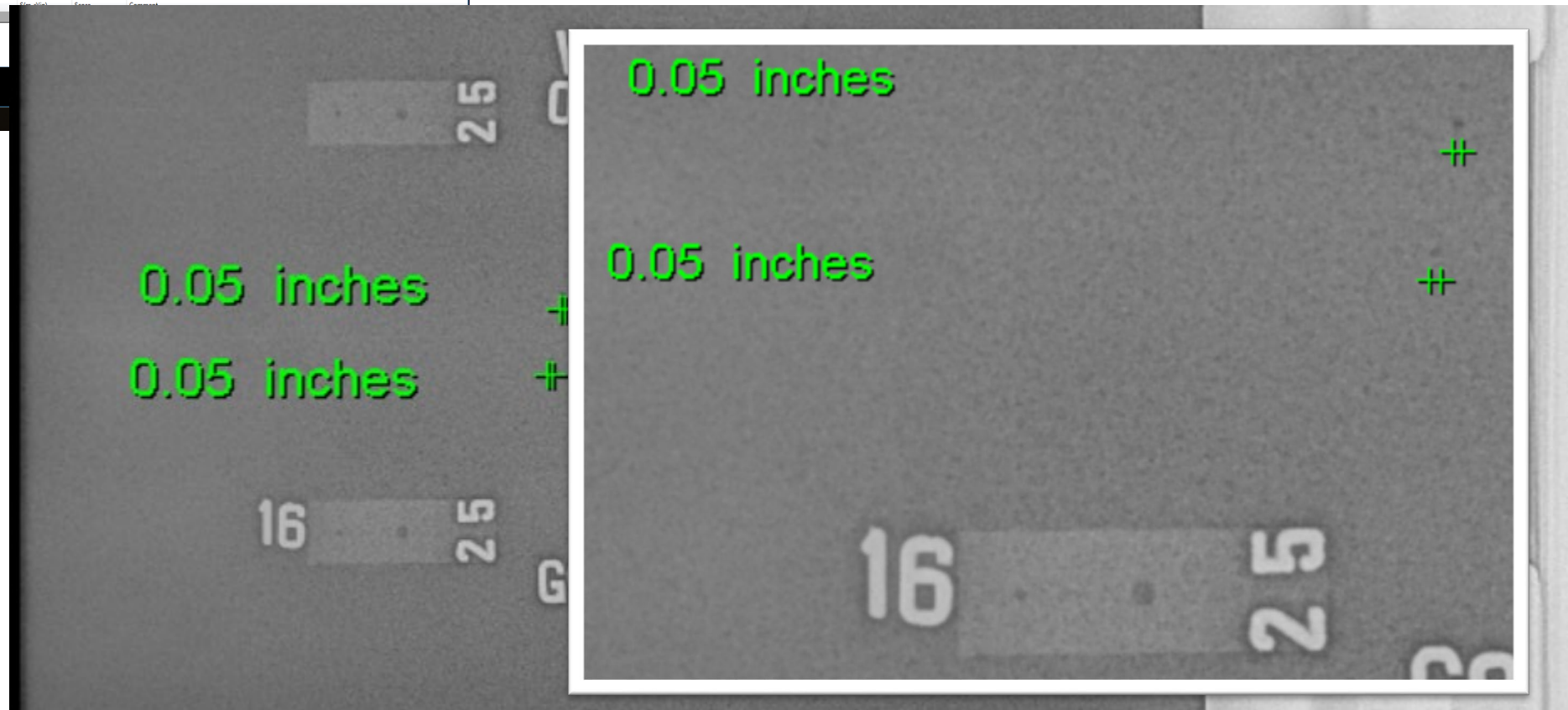
- UT result: not tested



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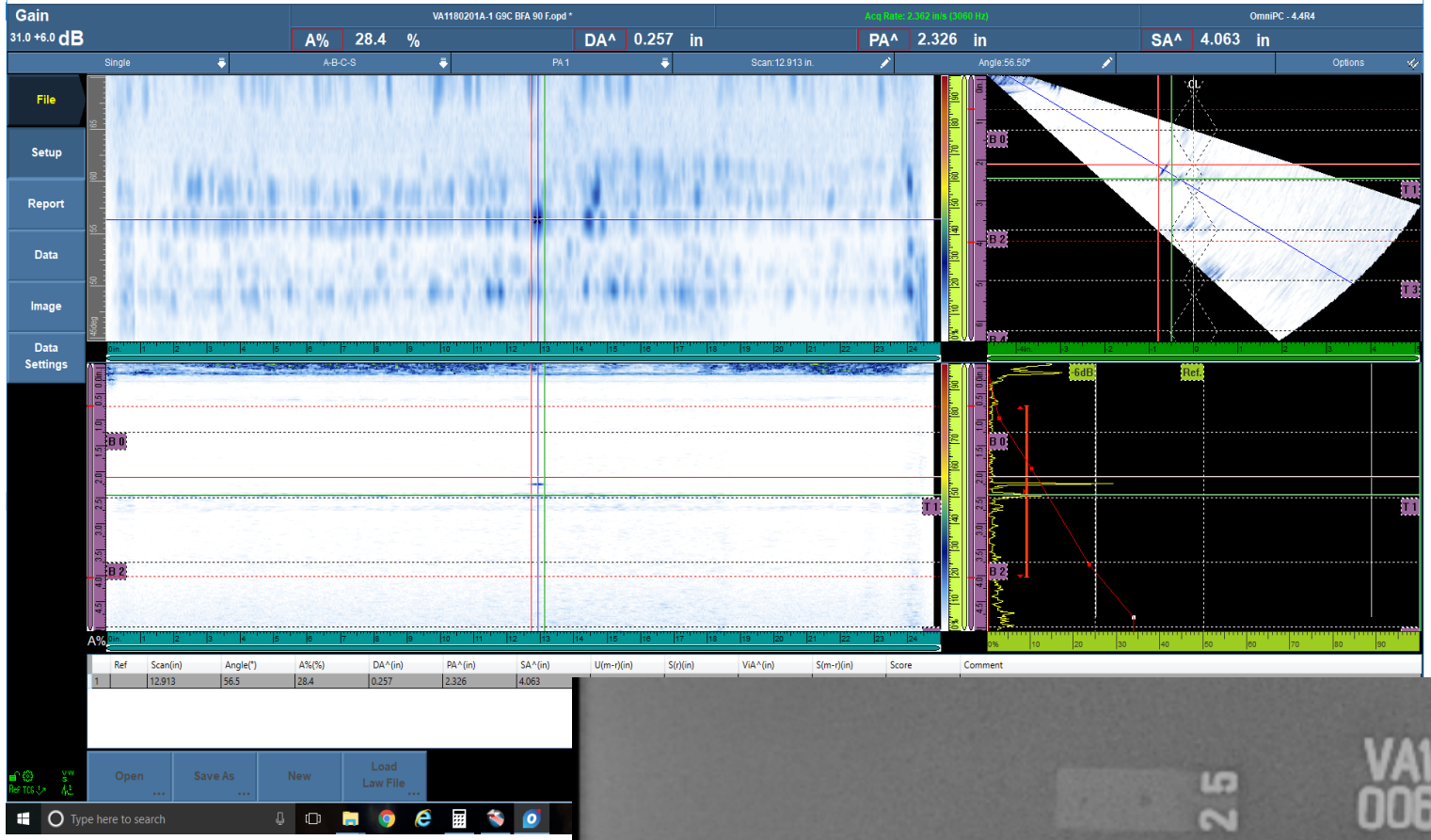
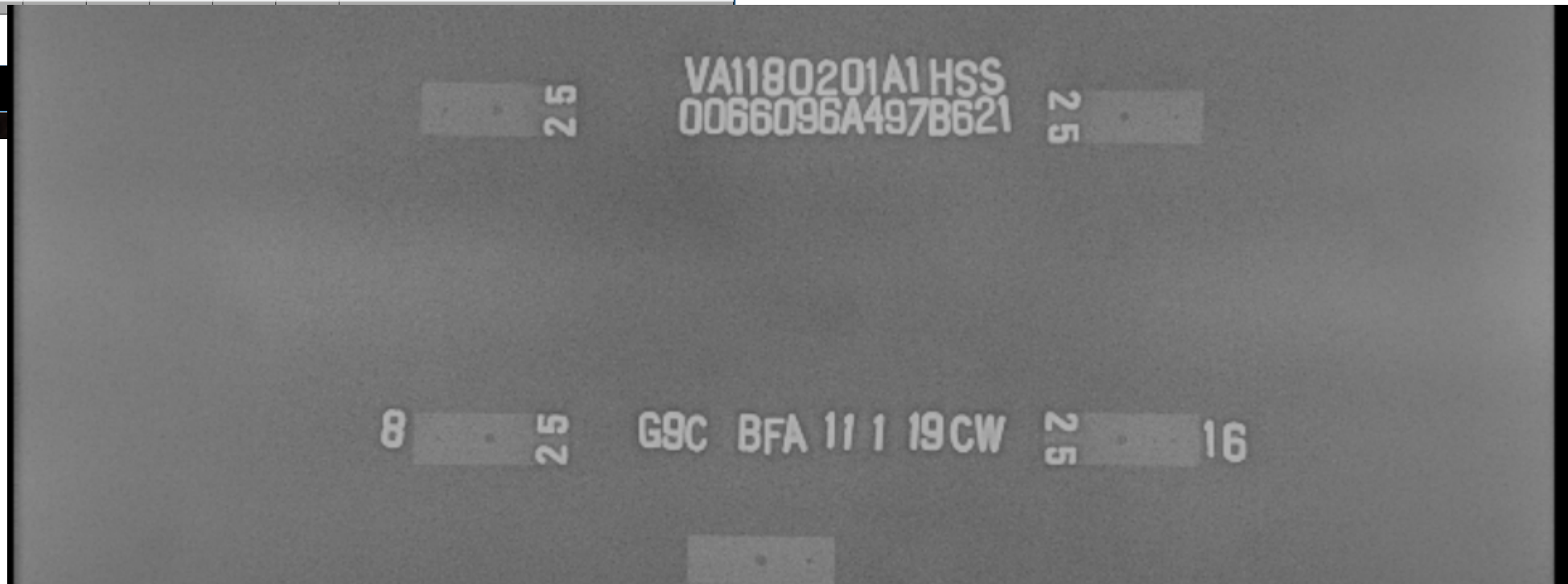
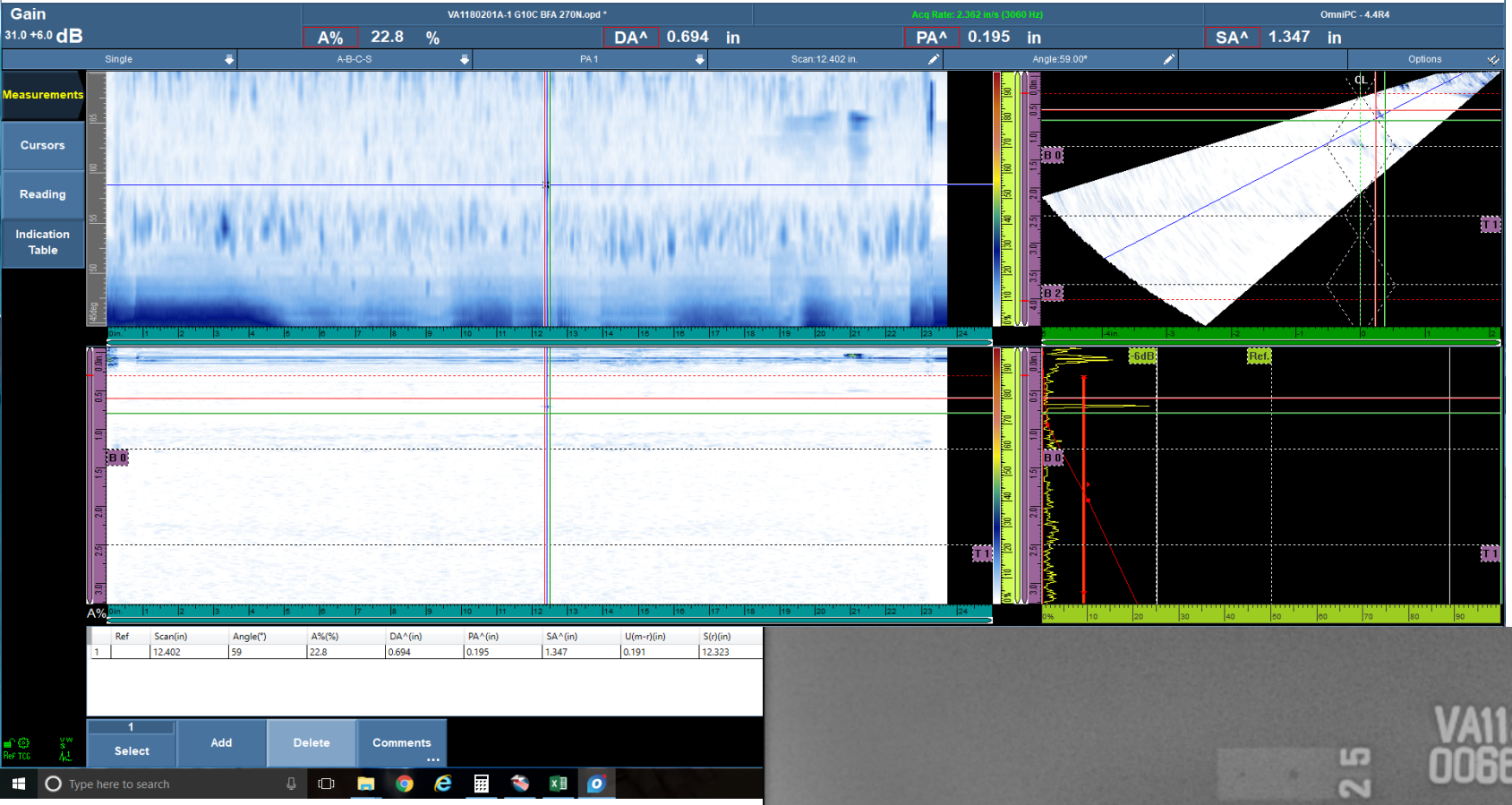


- RT result: not found
- PAUT result
  - Annex K: class D, 14.5%
  - NCHRP: 23%, raster
- UT result: not tested

G9C BFA (A1)





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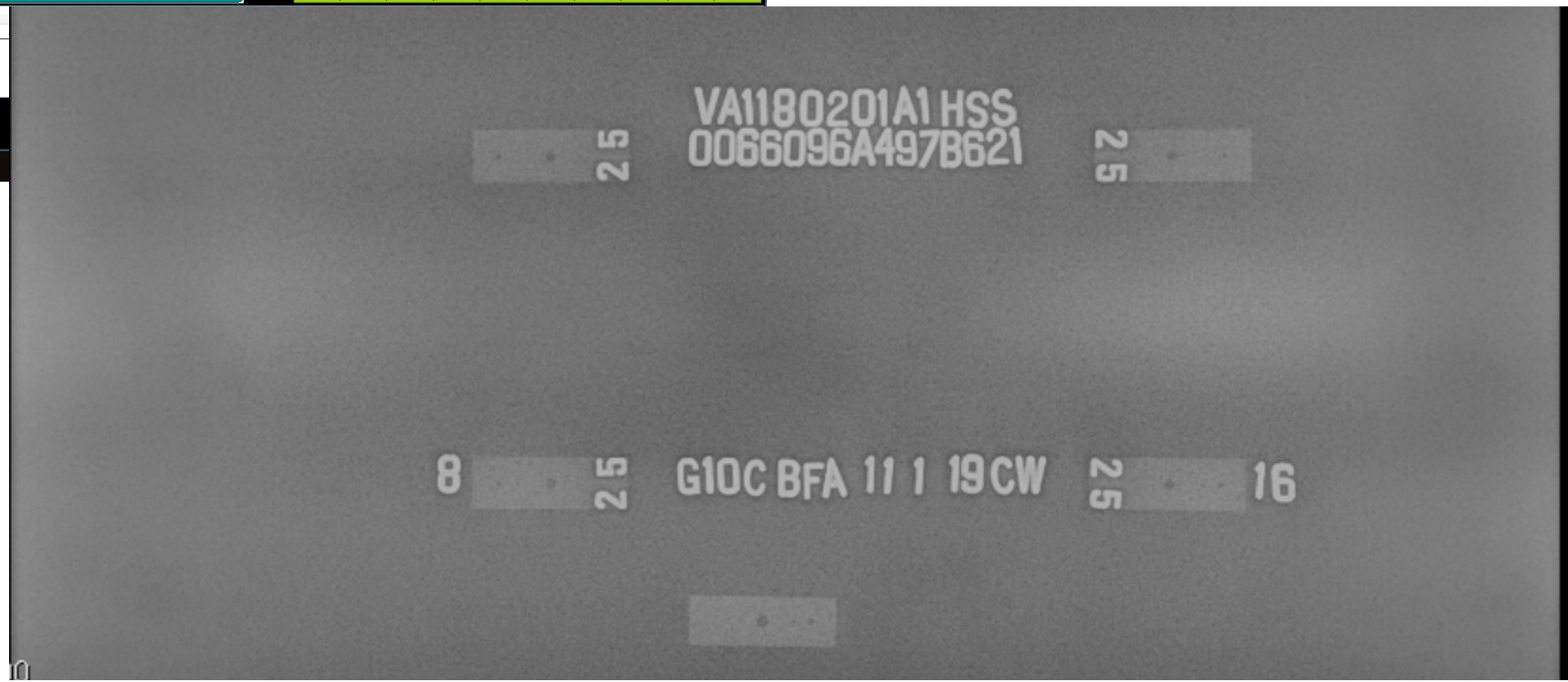
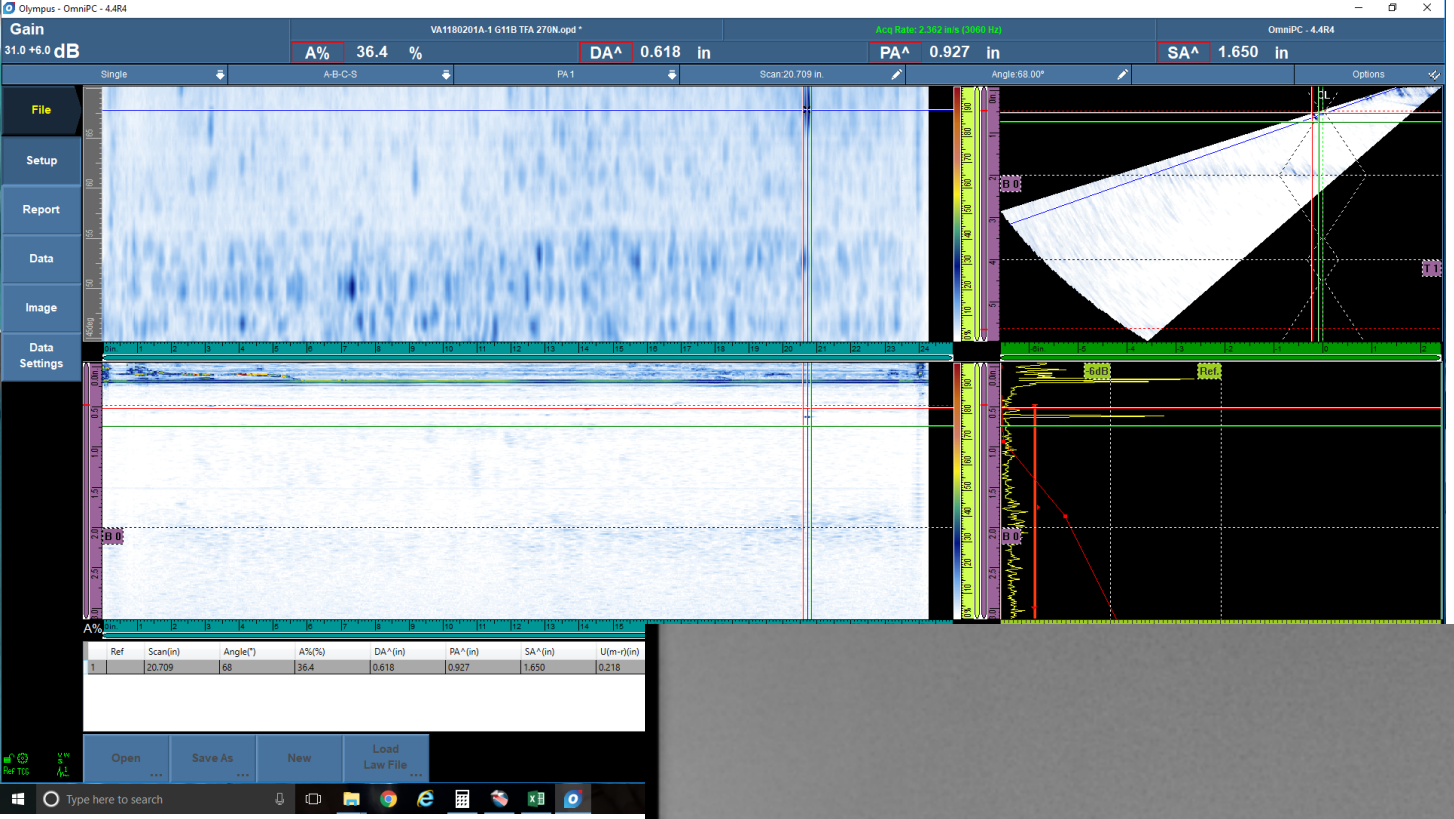
- UT result: not tested

G10C BFA (A1)





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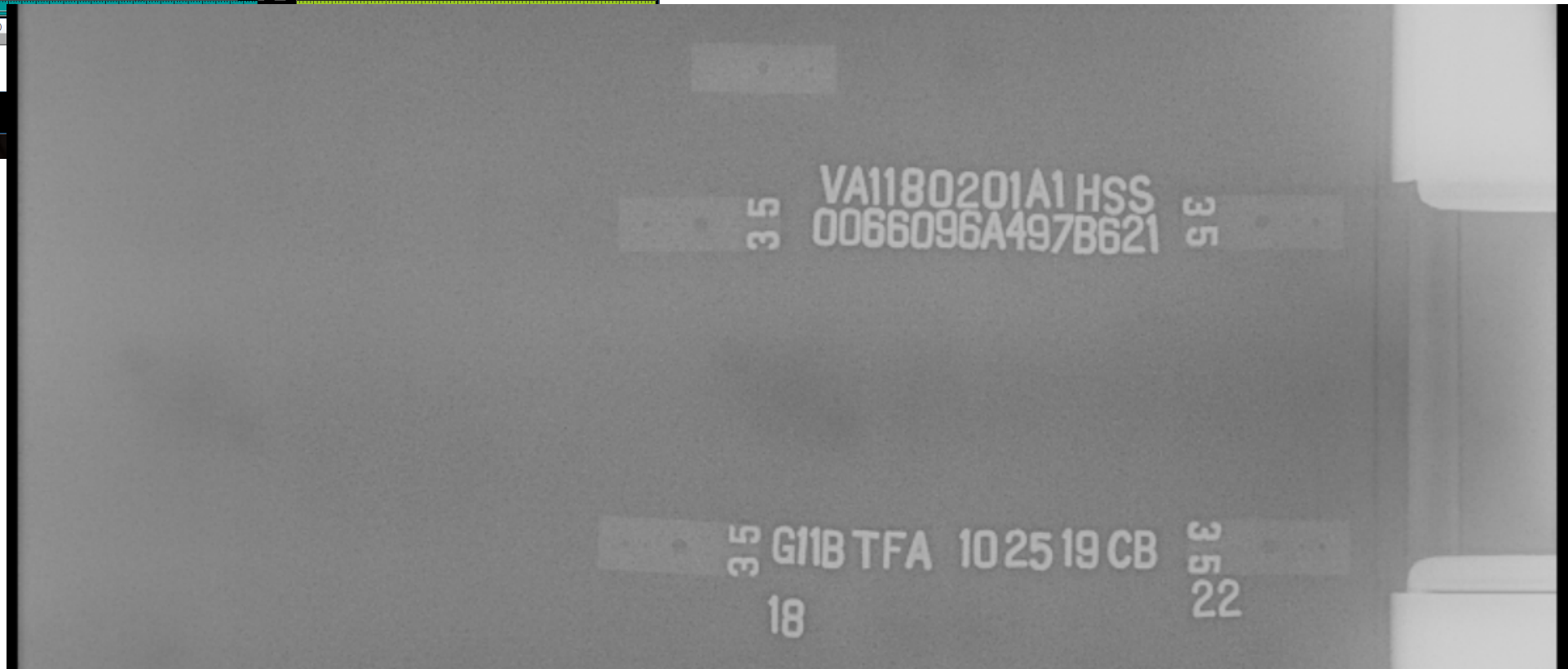
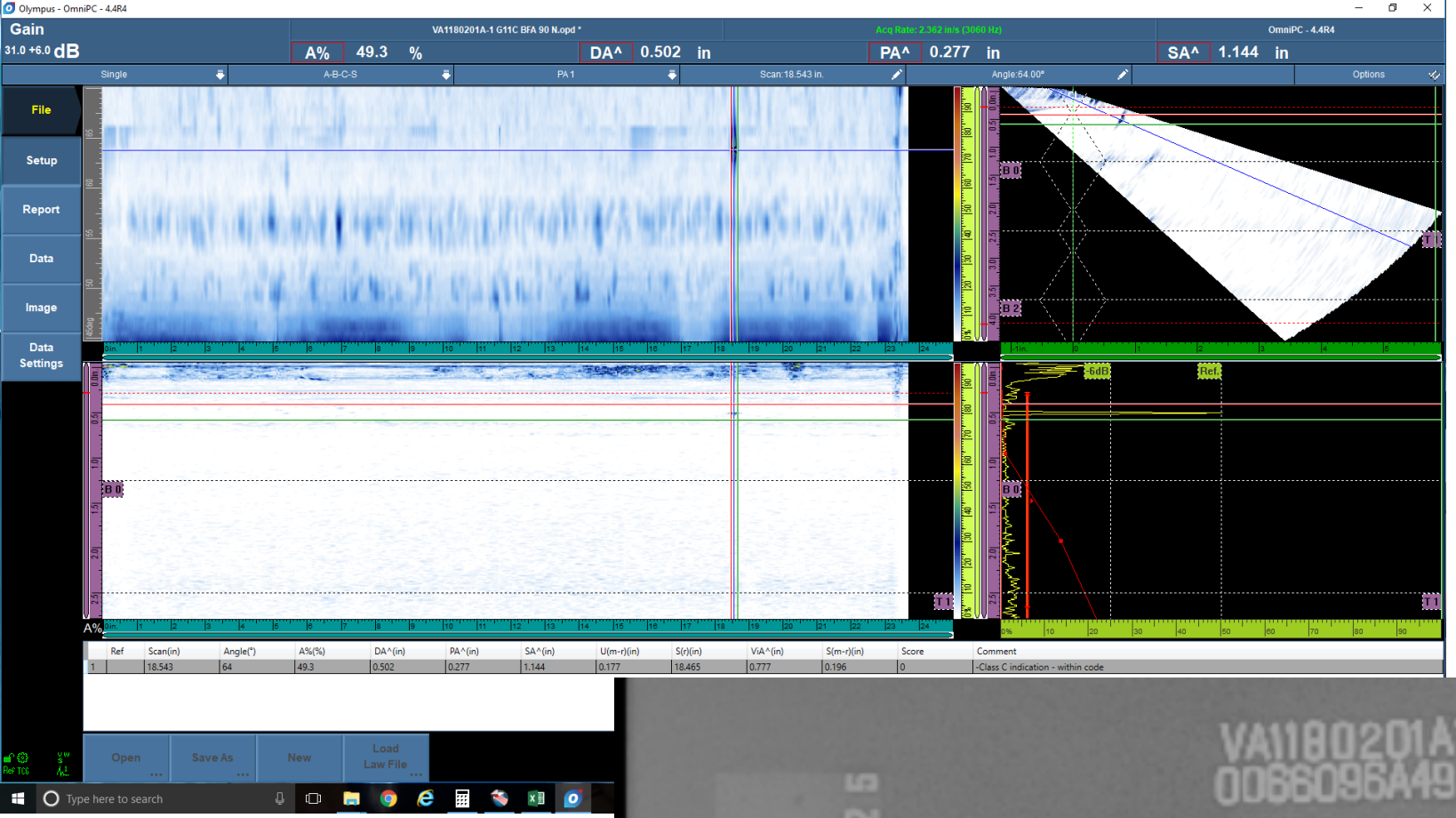
- UT result: not tested

G11B TFA (A1)





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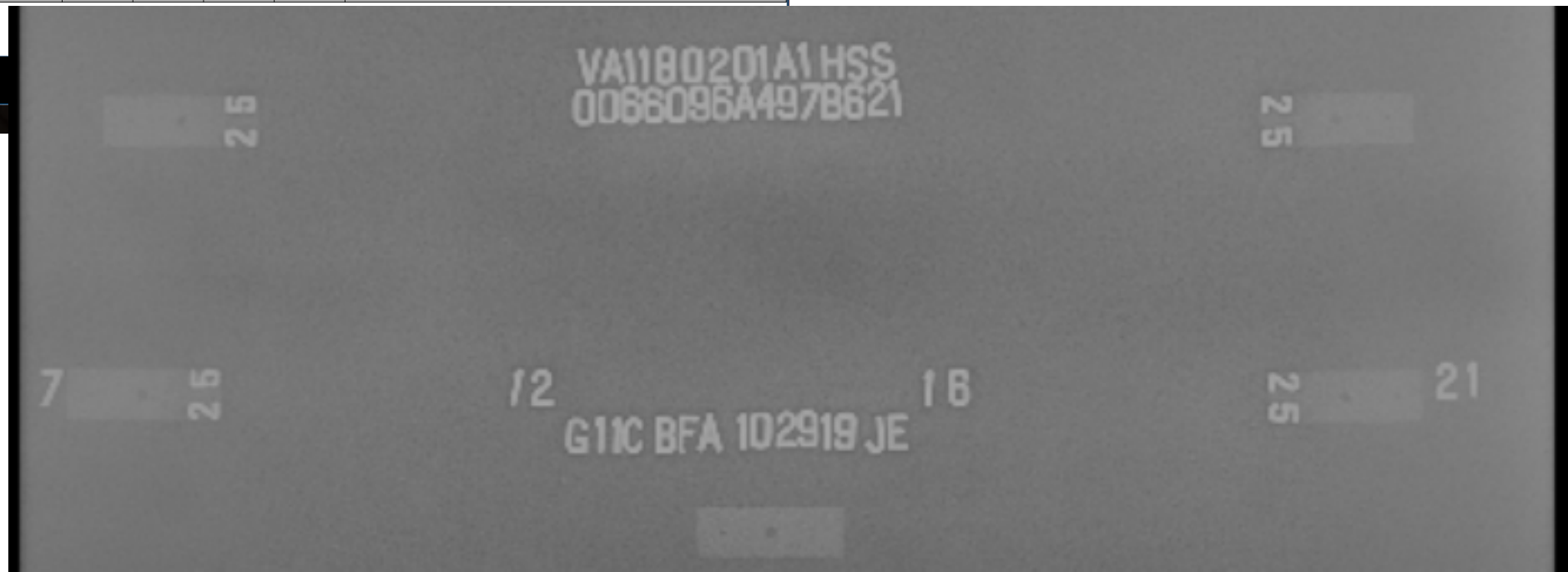
  - NCHRP: 39.6%, fix
- UT result: not tested

G11C BFA (A1)



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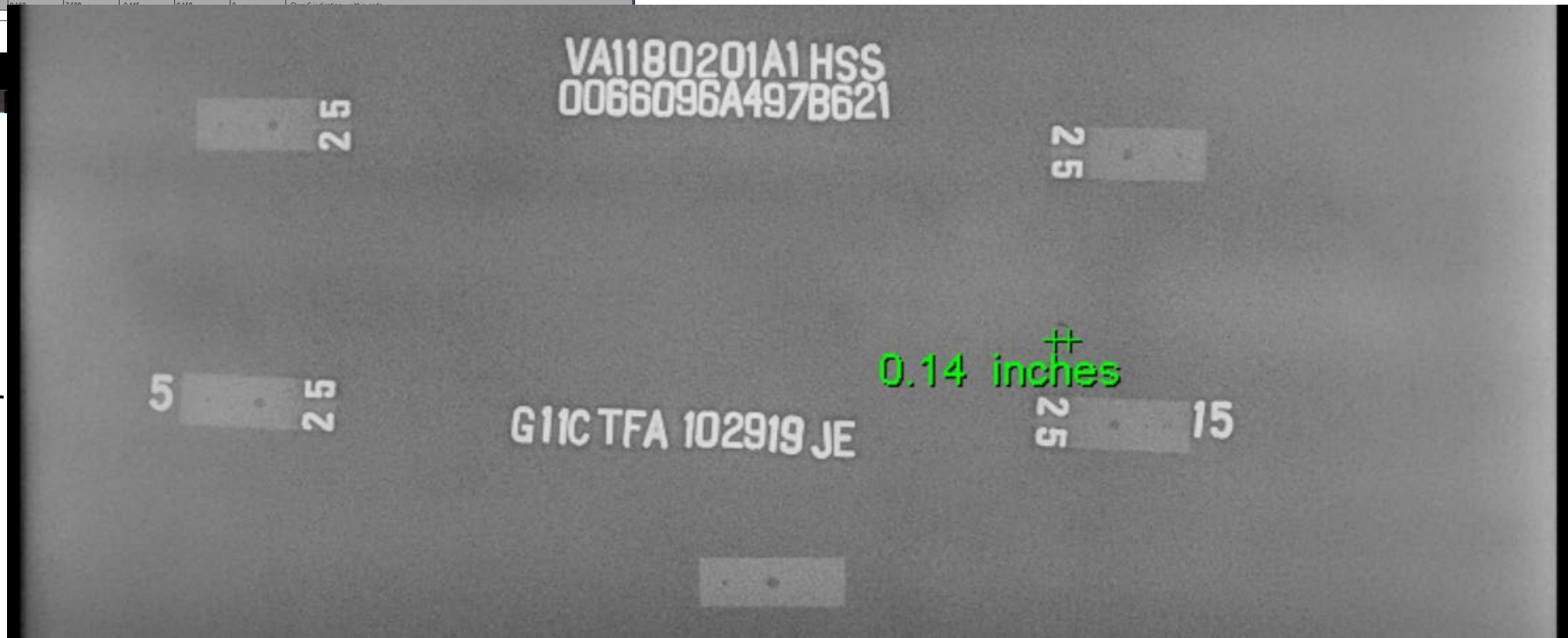
  - NCHRP: 23%, raster
- UT result: not tested

G11C TFA (A1)



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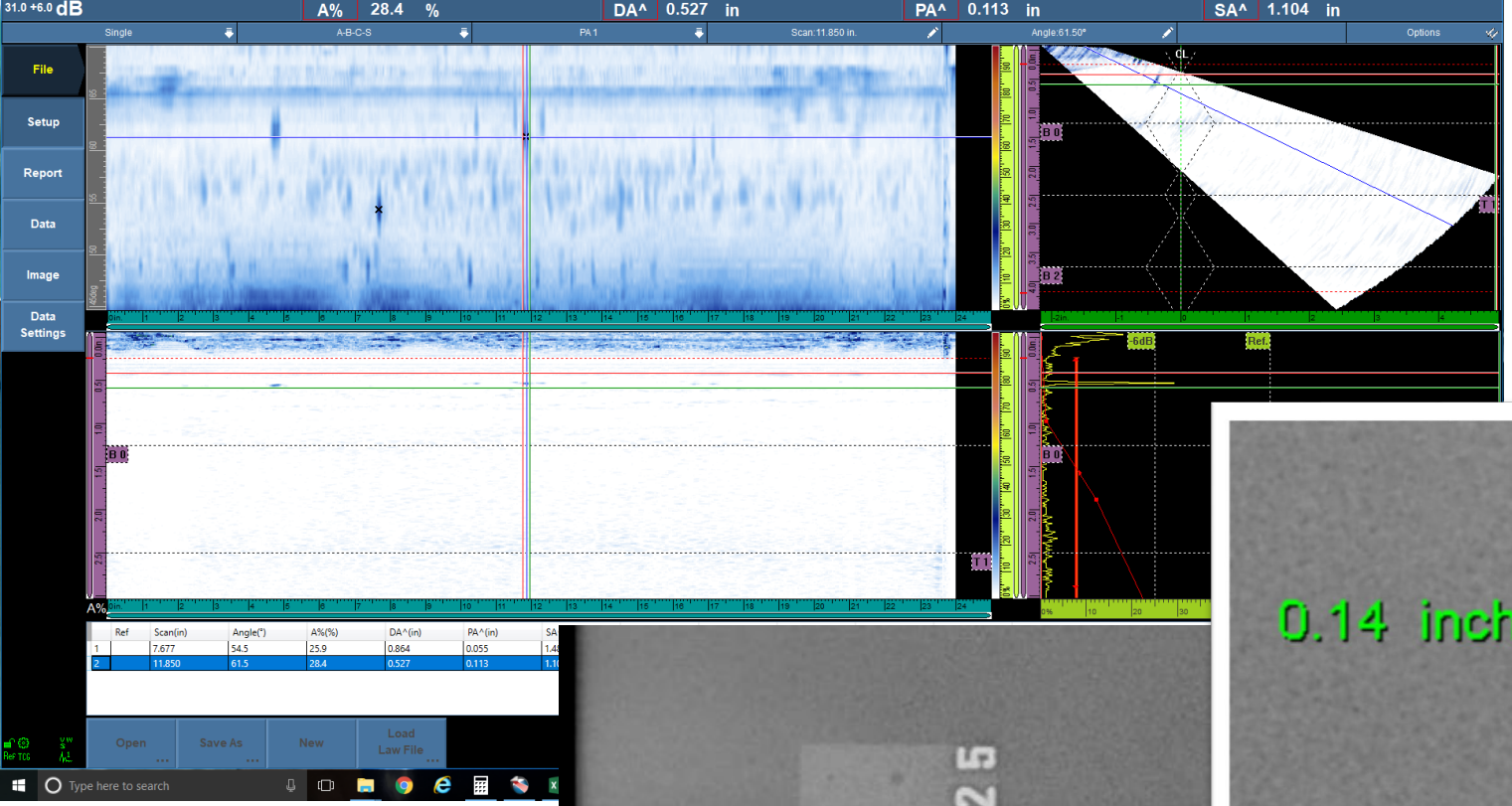
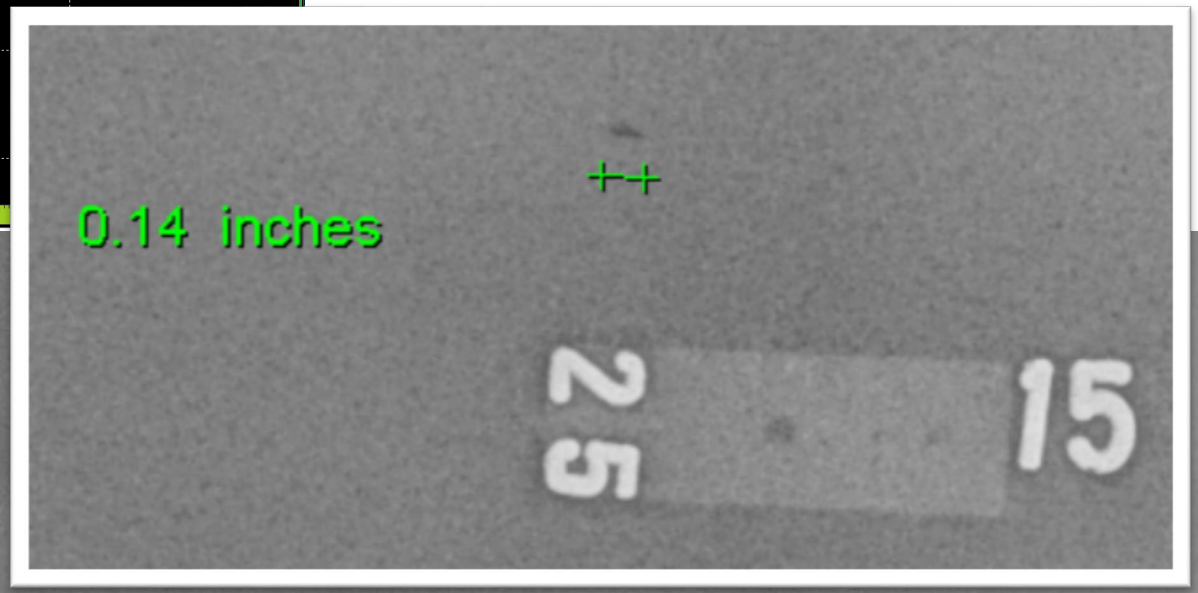
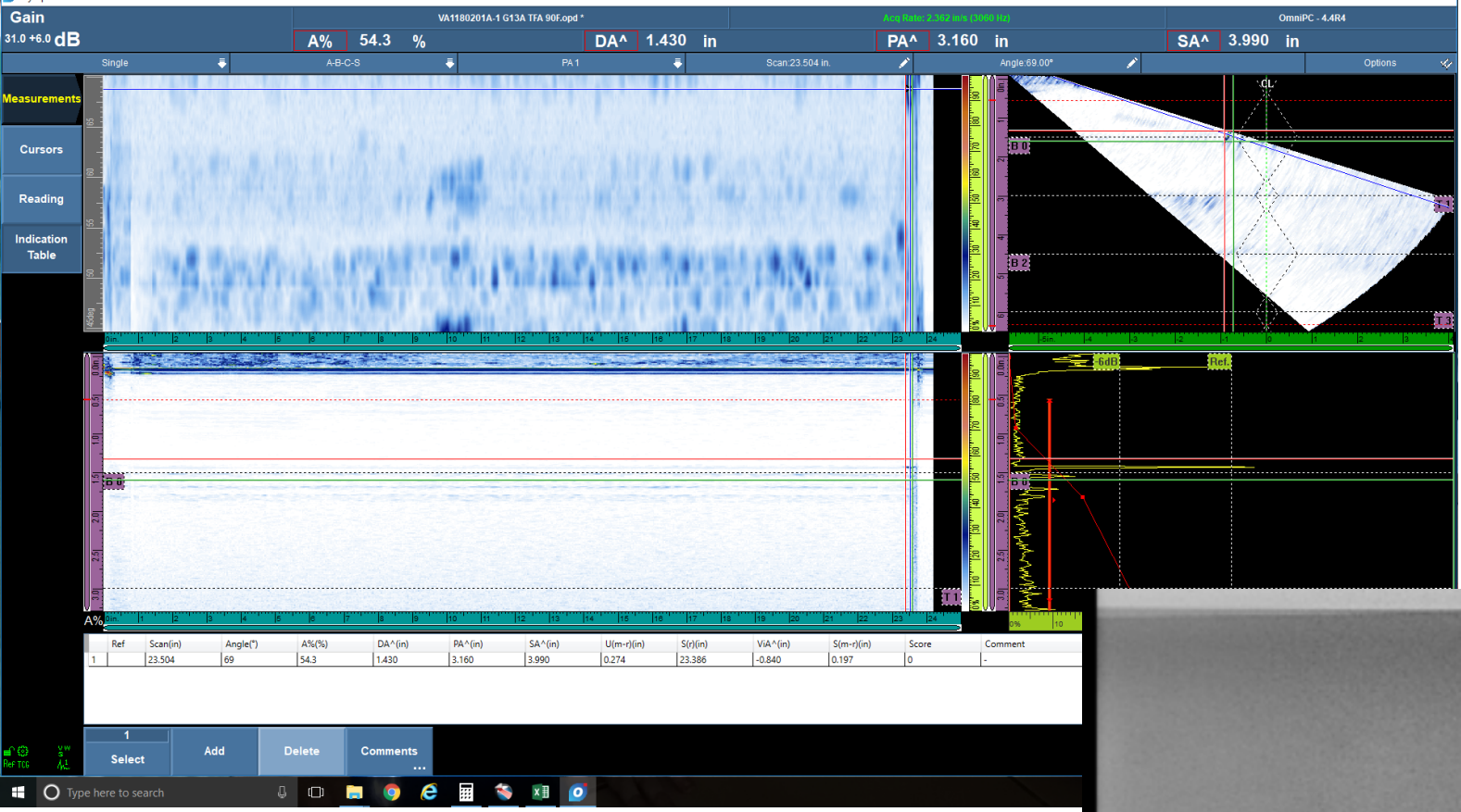
- UT result: not tested

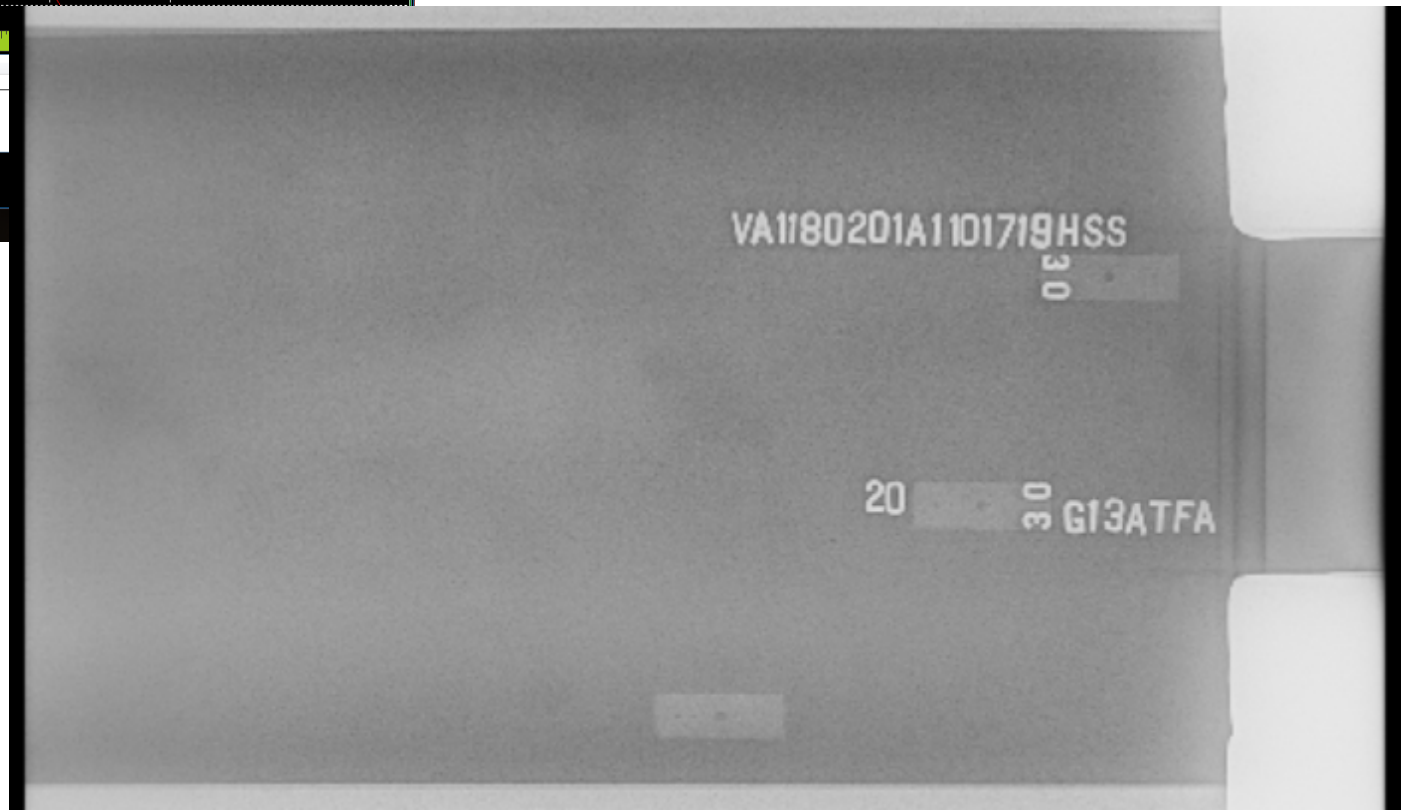




G11C TFA (A1)

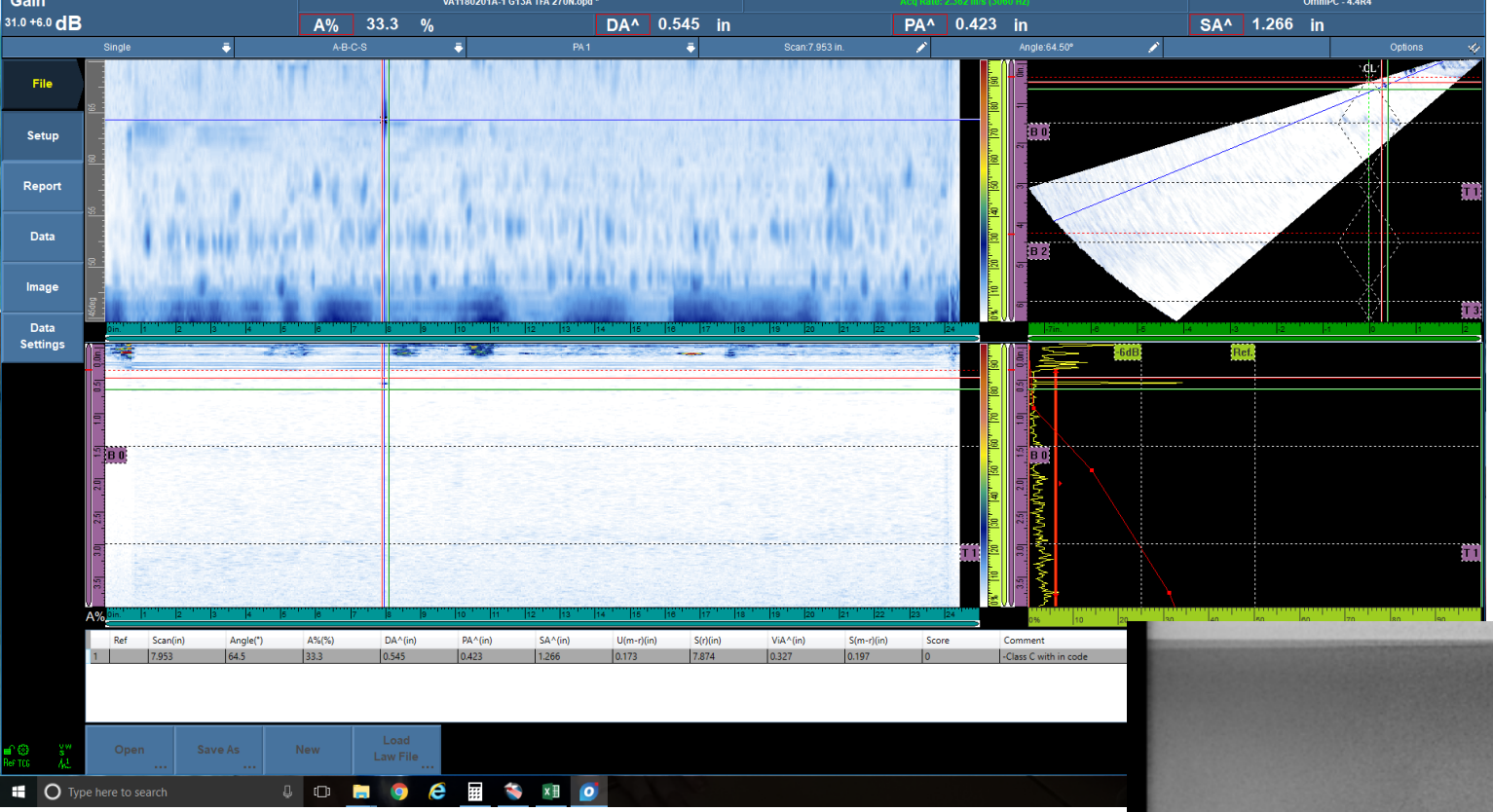
- RT result: not found
- PAUT result
  - Annex K: C, 27.5%; D17.0%
  - NCHRP: 43.5%, fix; 26.9%, fix
- UT result: not tested

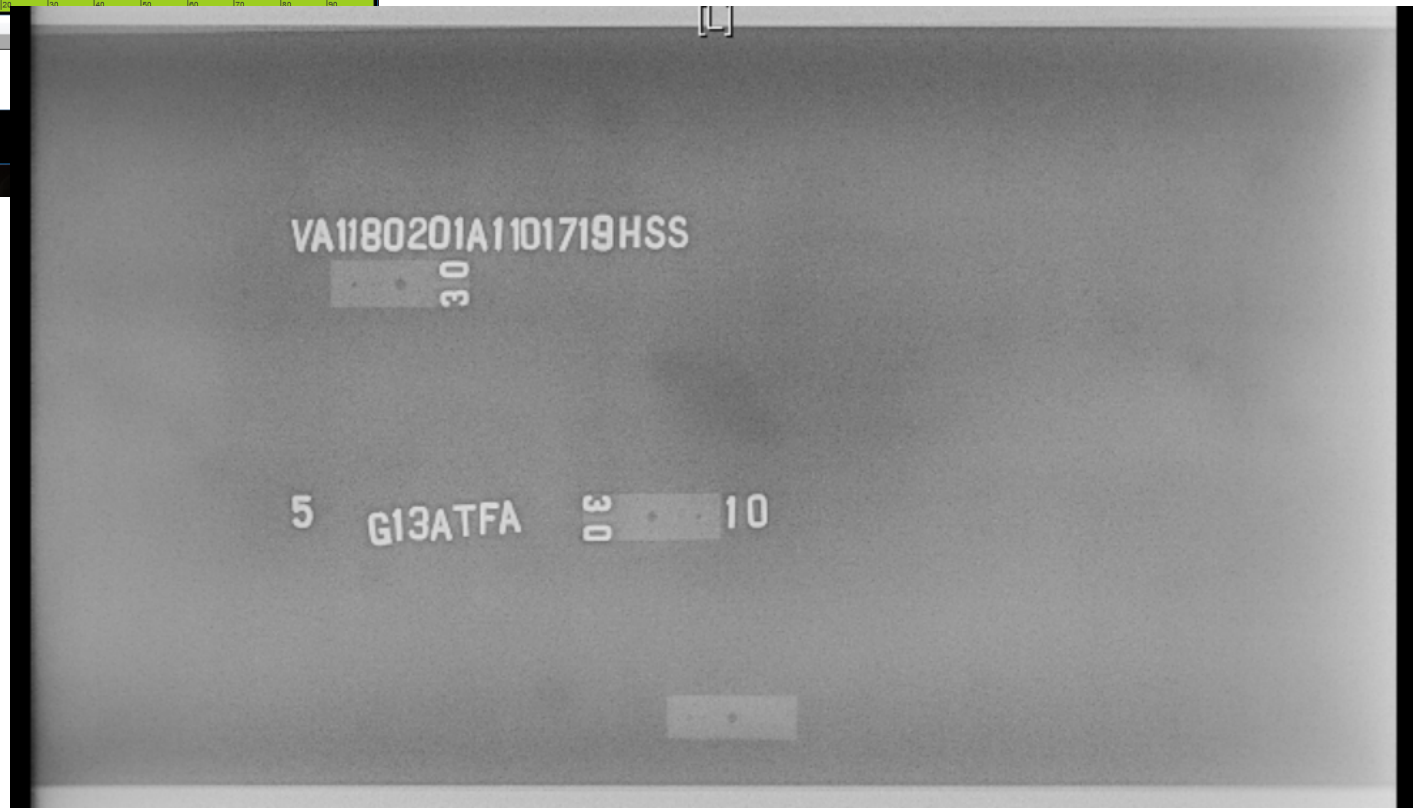




G13A TFA (A1)

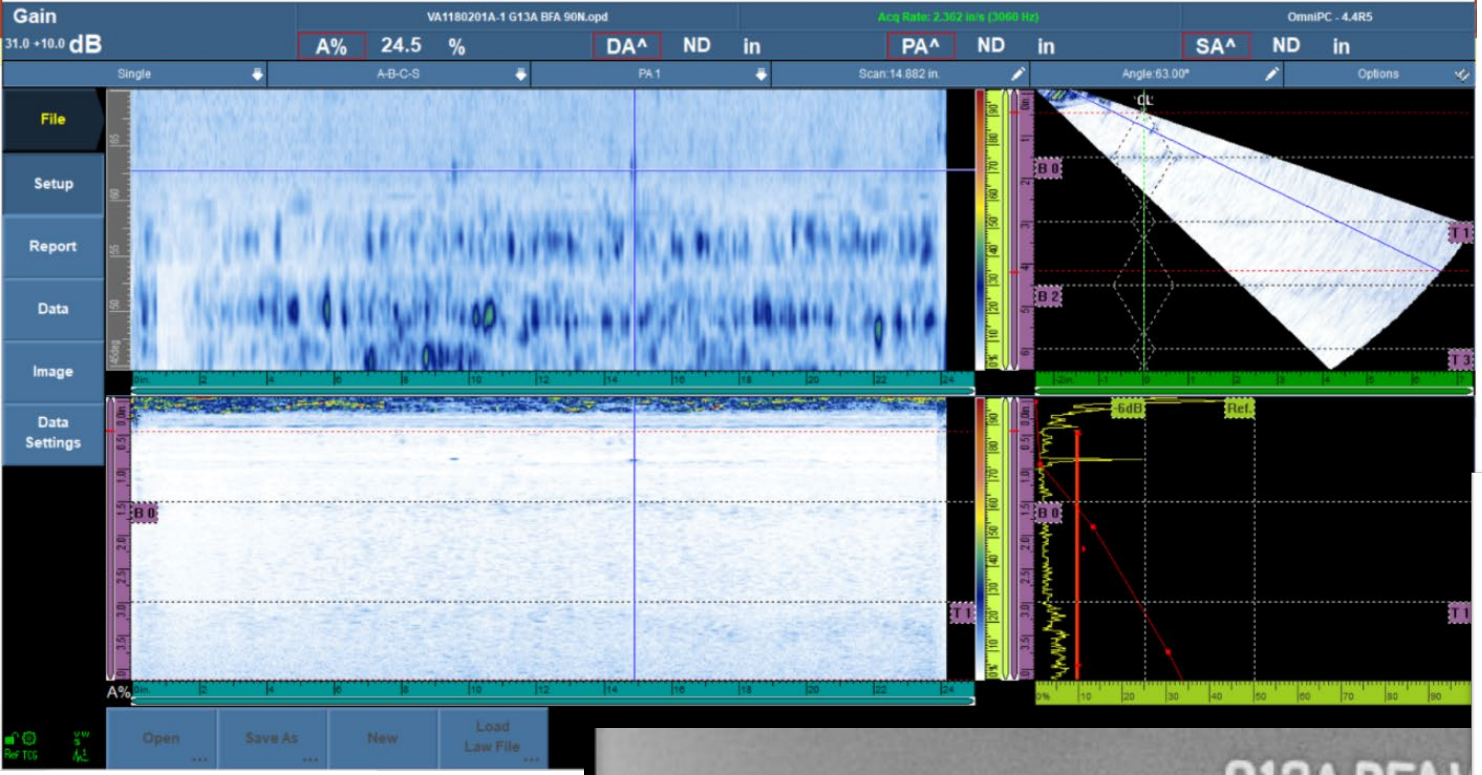
- RT result: not found
- PAUT result
  - Annex K: C, 27.5%; D17.0%
  - NCHRP: 43.5%, fix; 26.9%, fix
- UT result: not tested

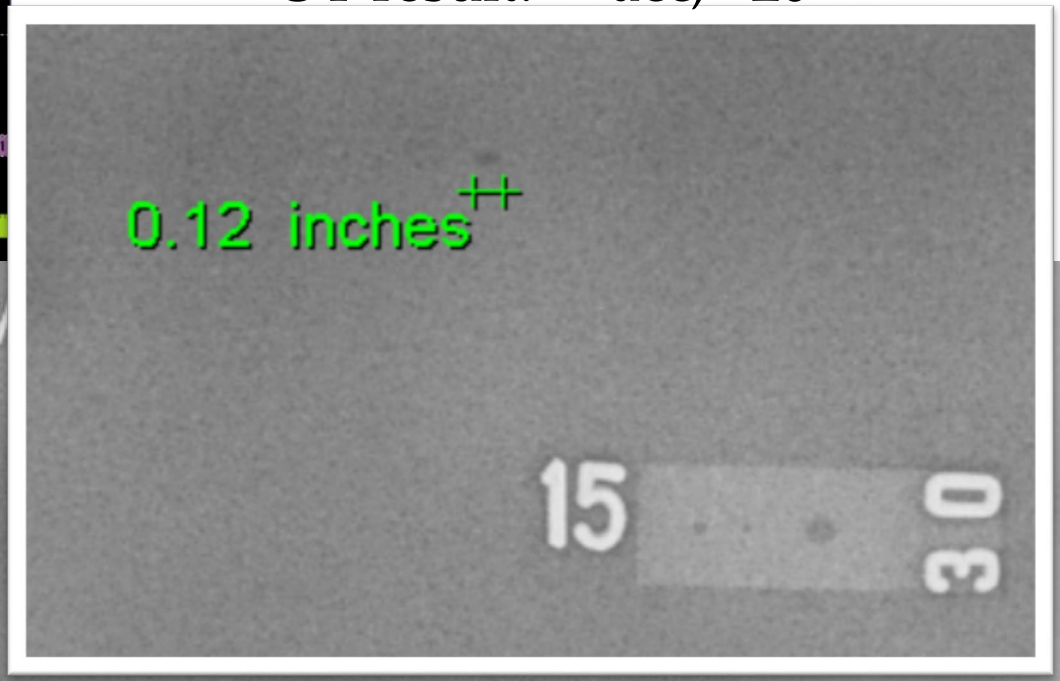




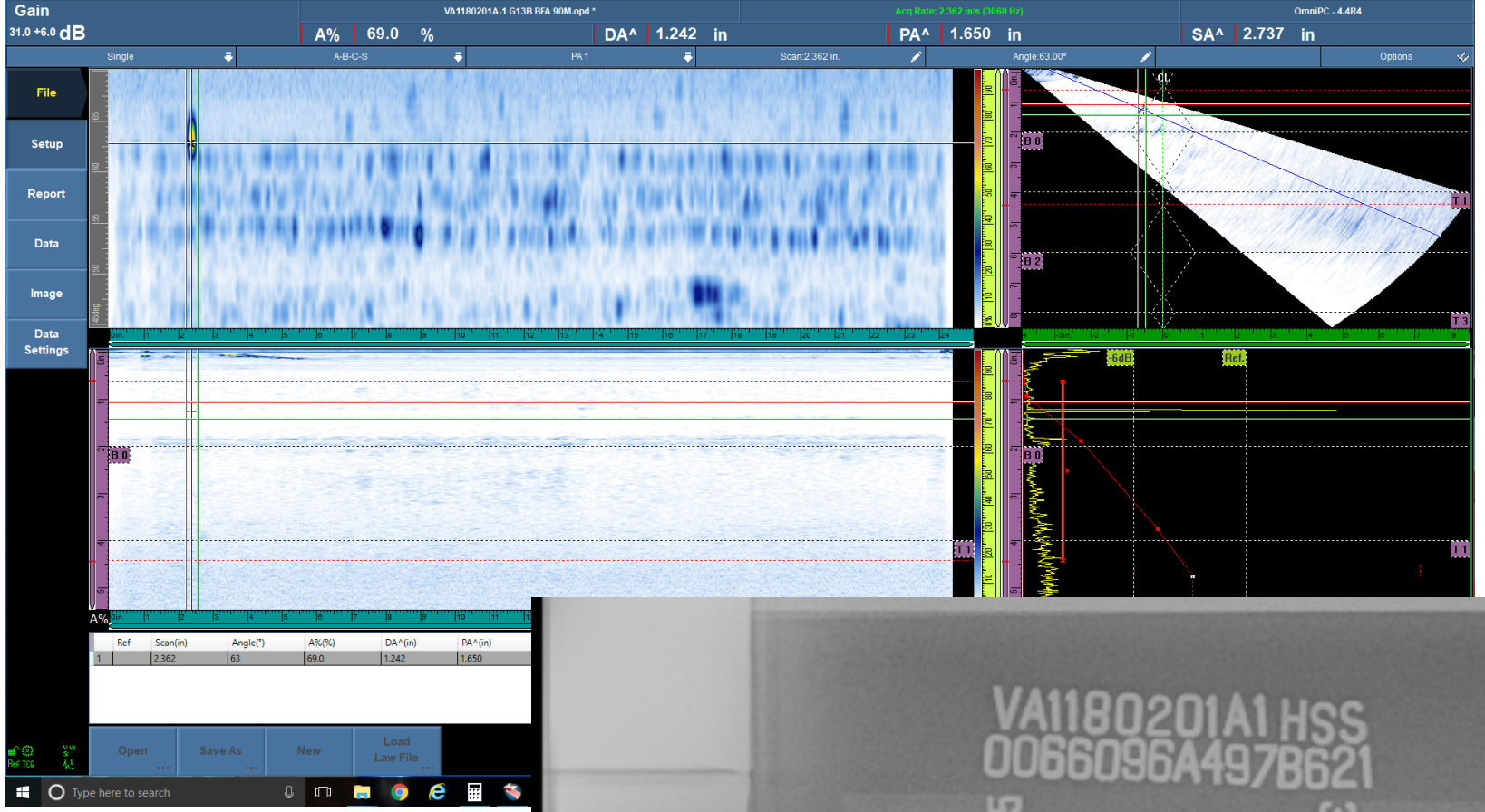
G13A TFA (A1)

- RT result: acc
- PAUT result
  - Annex K: D, 7.7%, acc
    - Note – this screen shot includes +10 db for scanning
  - NCHRP: 12.2%, acc
- UT result: acc, +20



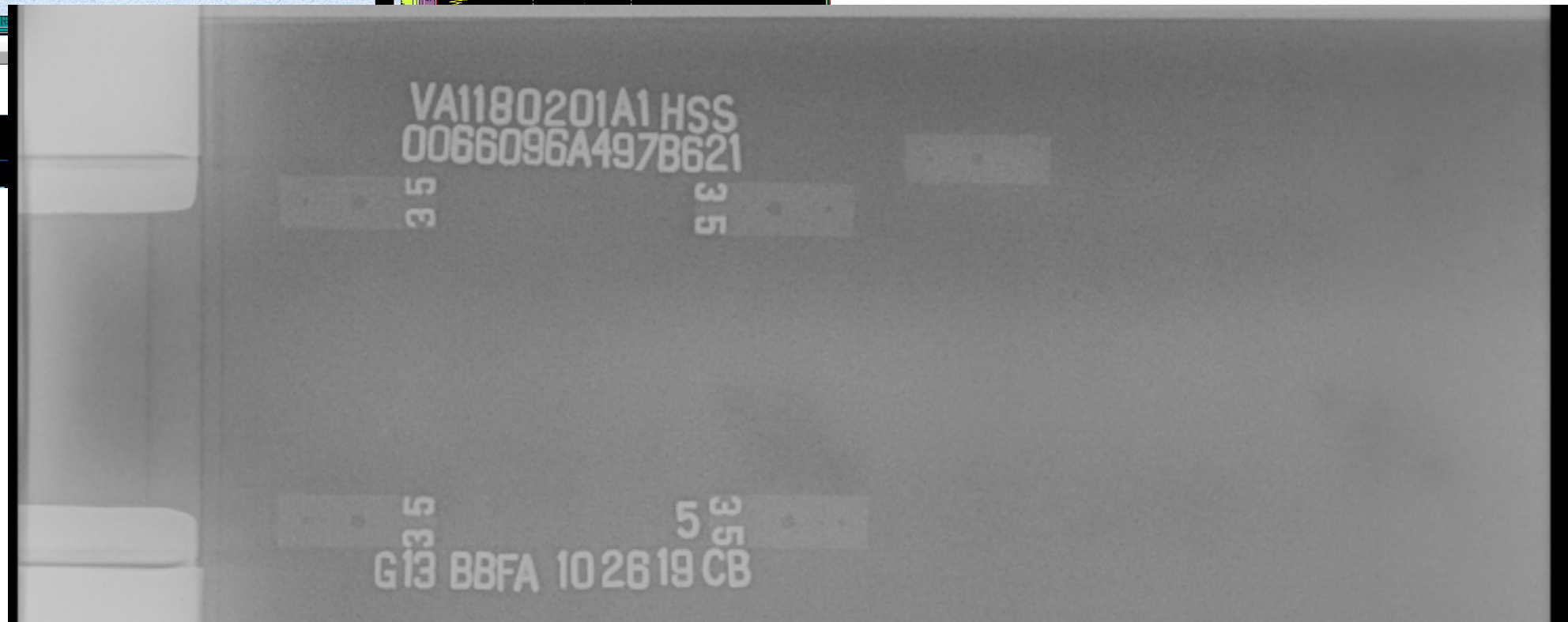


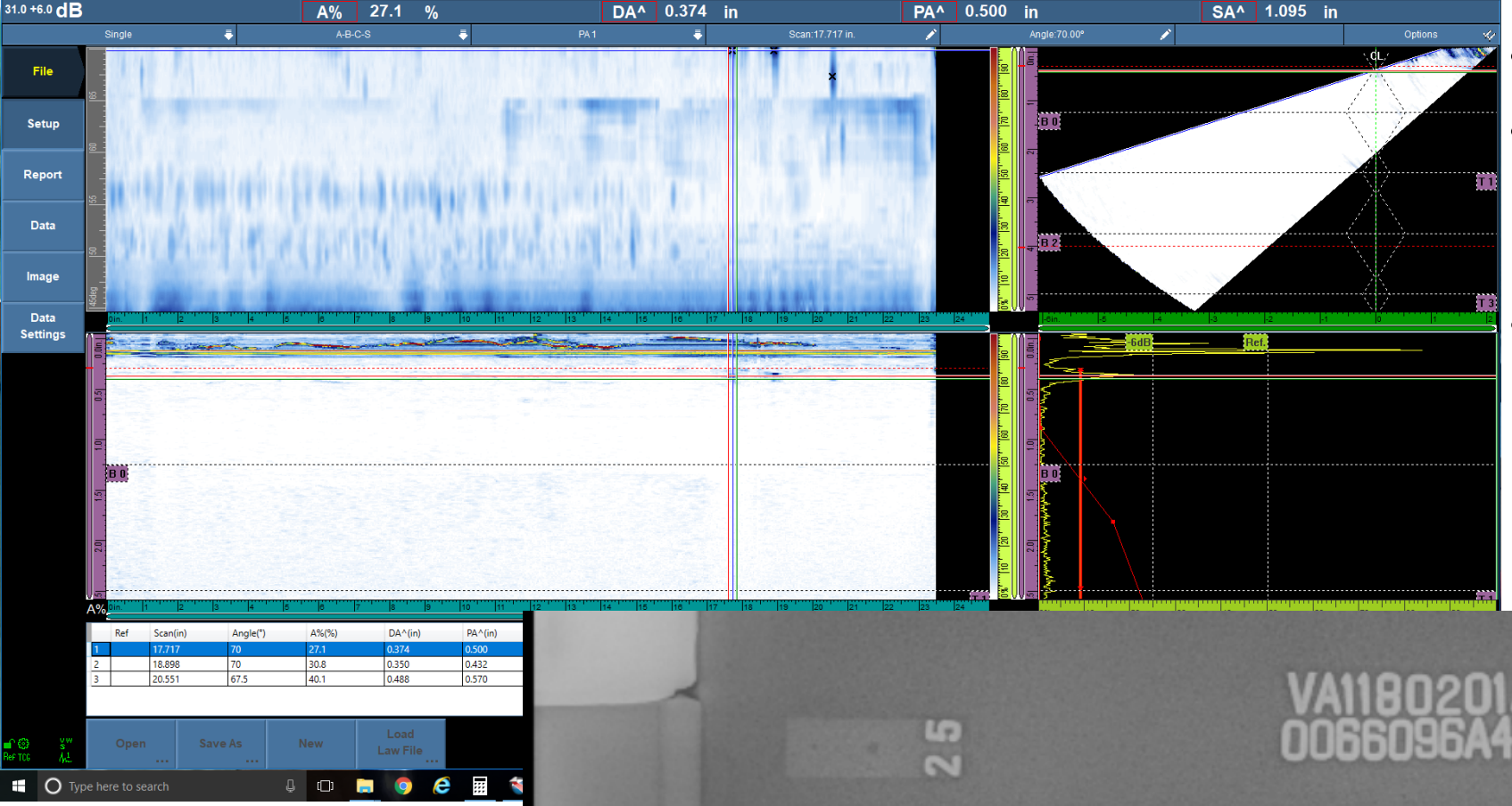
G13A BFA (A1)



- RT result: acc
- PAUT result
  - Annex K: C, 34.9%, acc
  - NCHRP: 55.3%, fix
- UT result: acc, +11

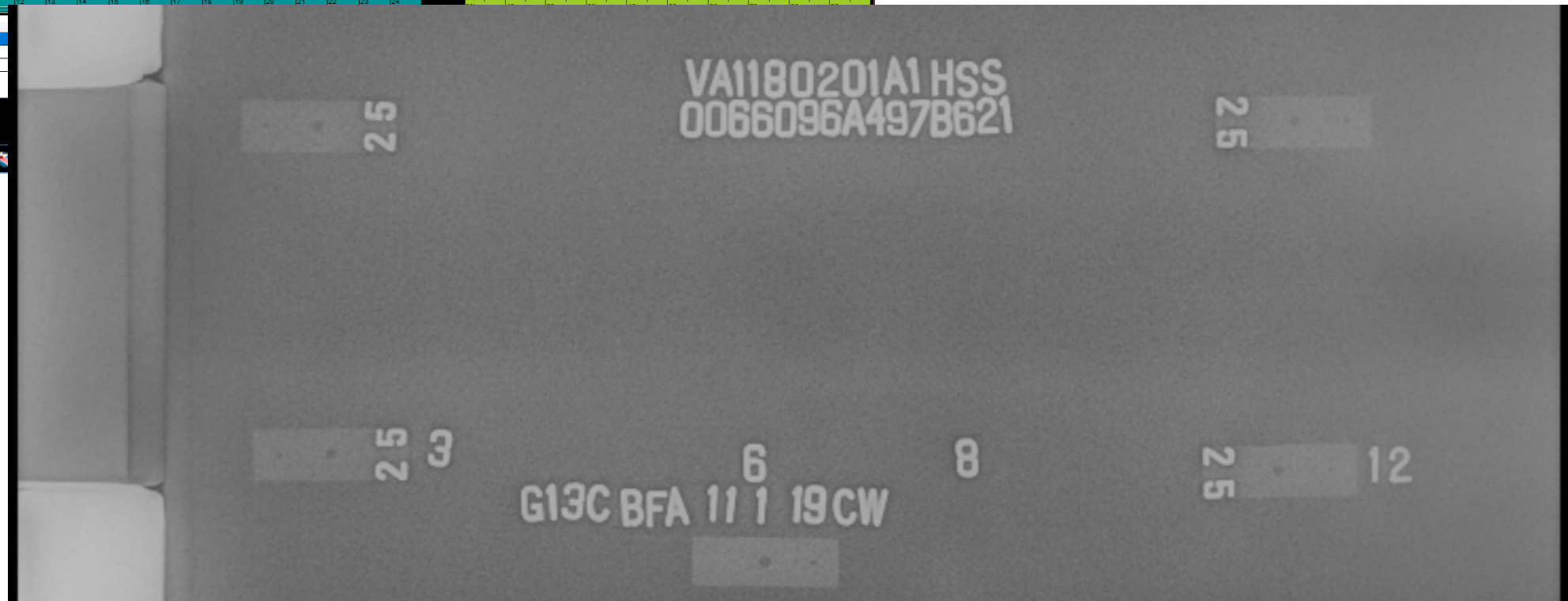
G13B BFA (A1)

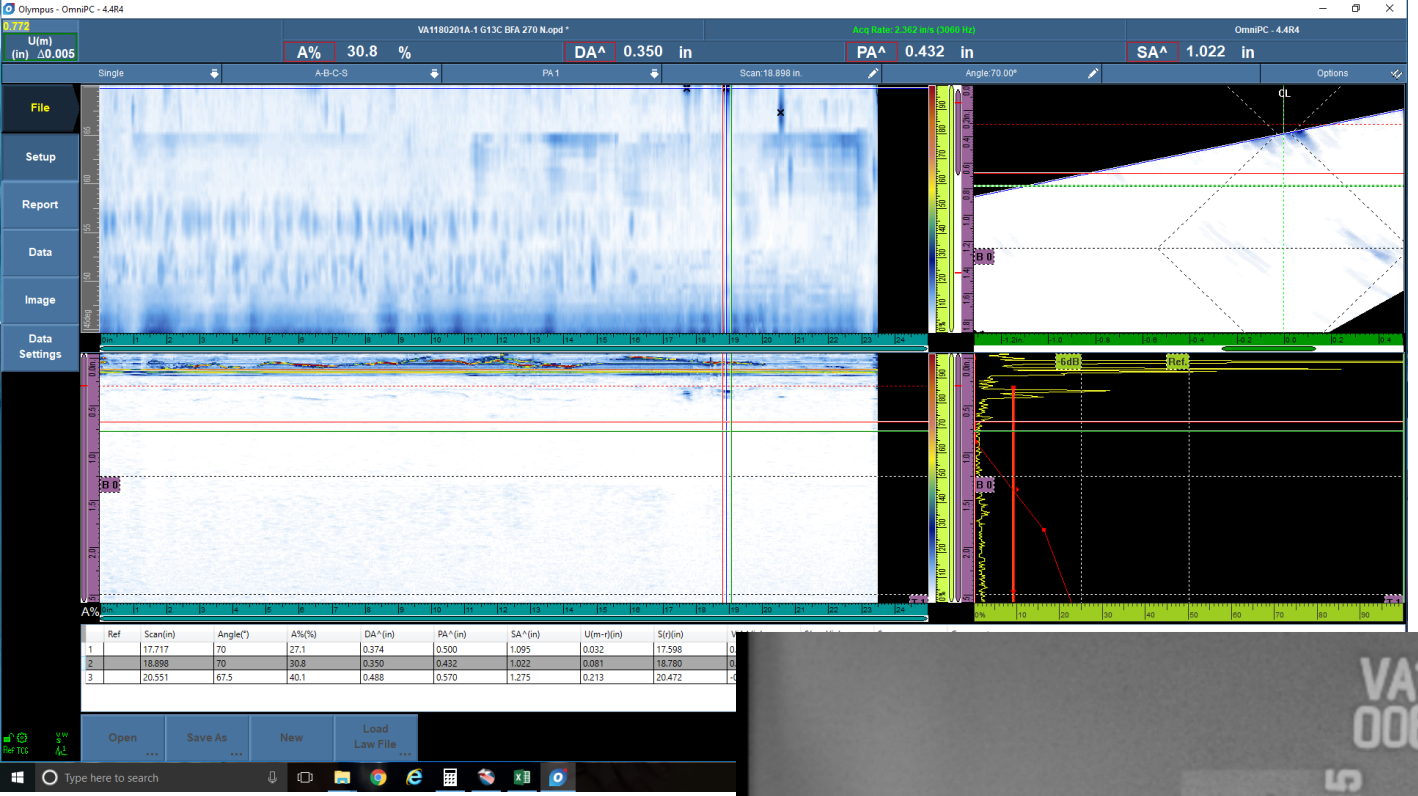




- RT result: not found
- PAUT result
  - Annex K: D, 13.9%, acc
  - NCHRP: 22.0%
- UT result: not found

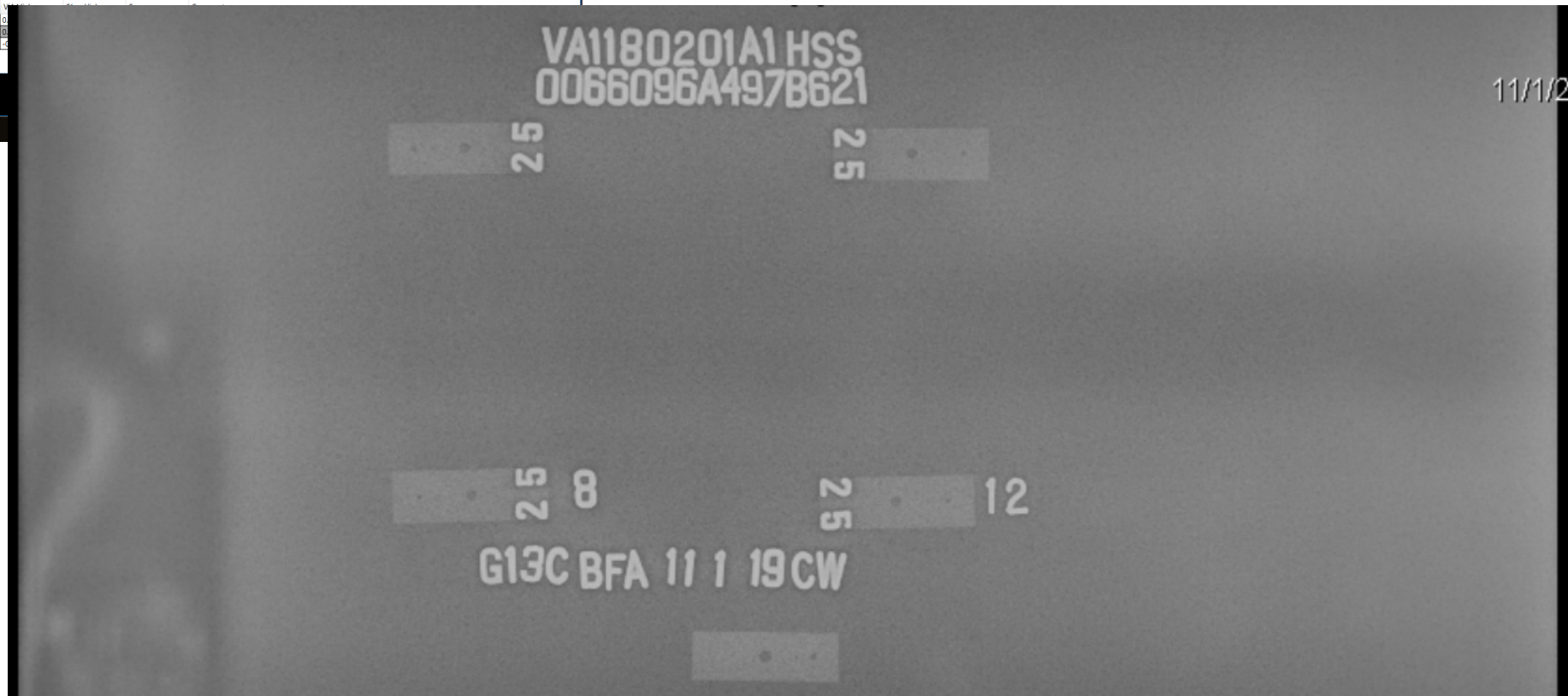
G13C BFA #1 (A1)

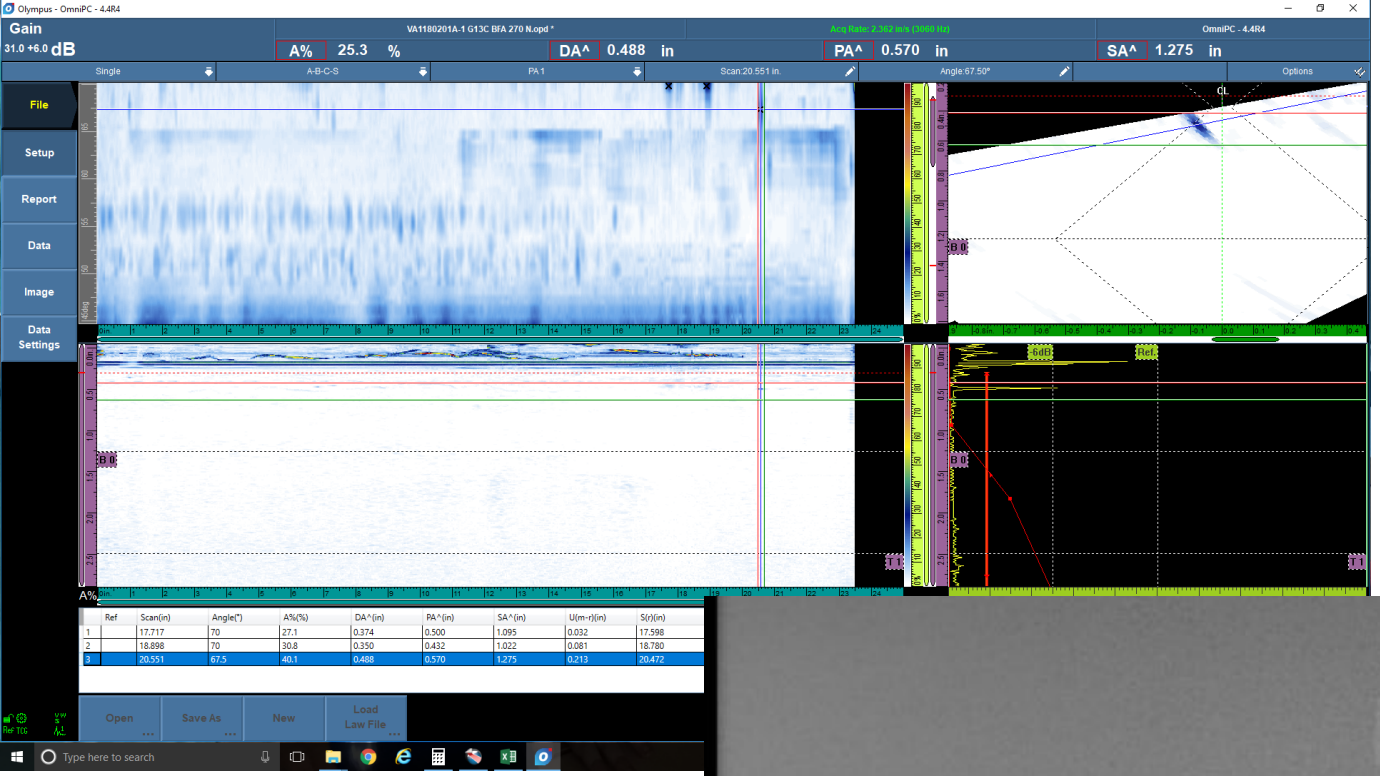




- RT result: not found
- PAUT result
  - Annex K: D, 15.8%, acc
  - NCHRP: 24.9%, fix (probably)
- UT result: not found

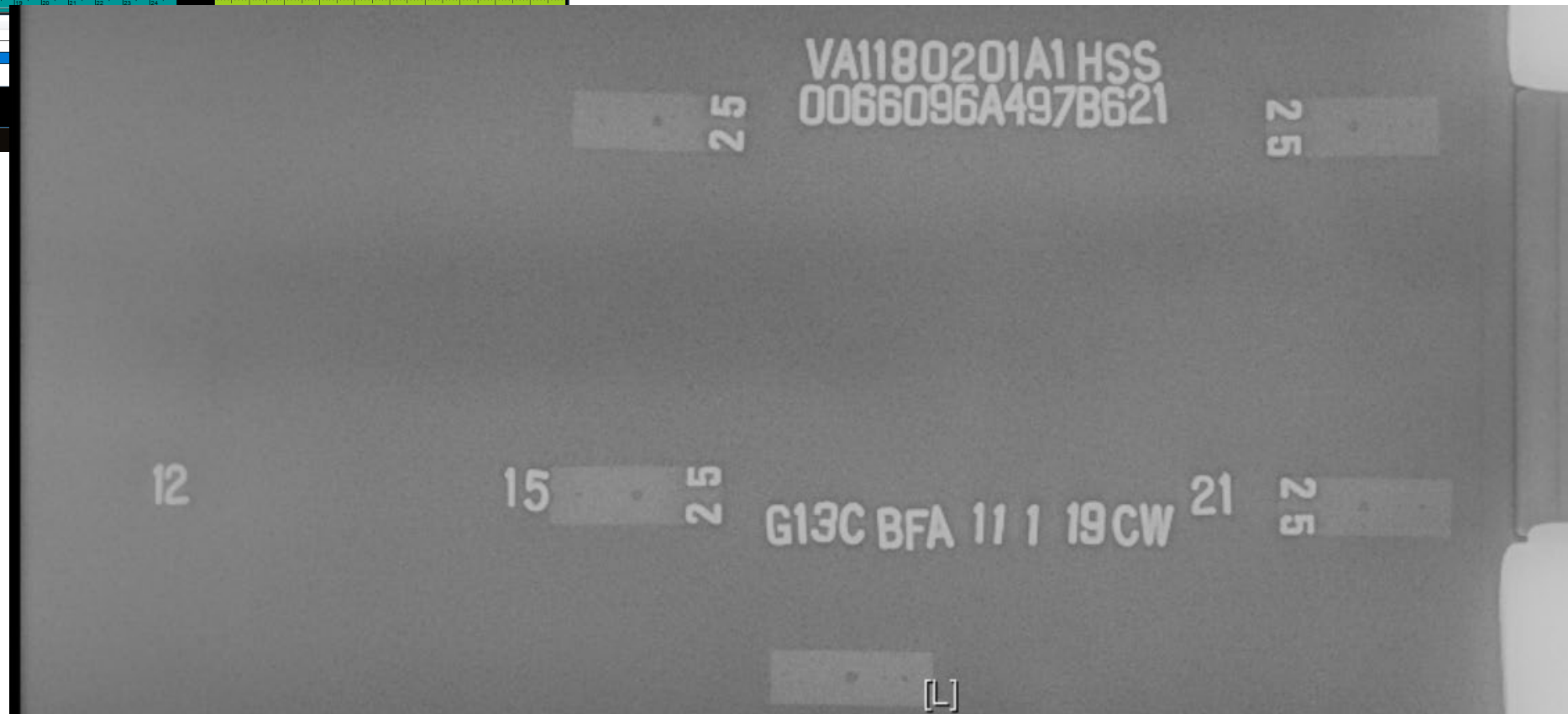
G13C BFA #2 (A1)

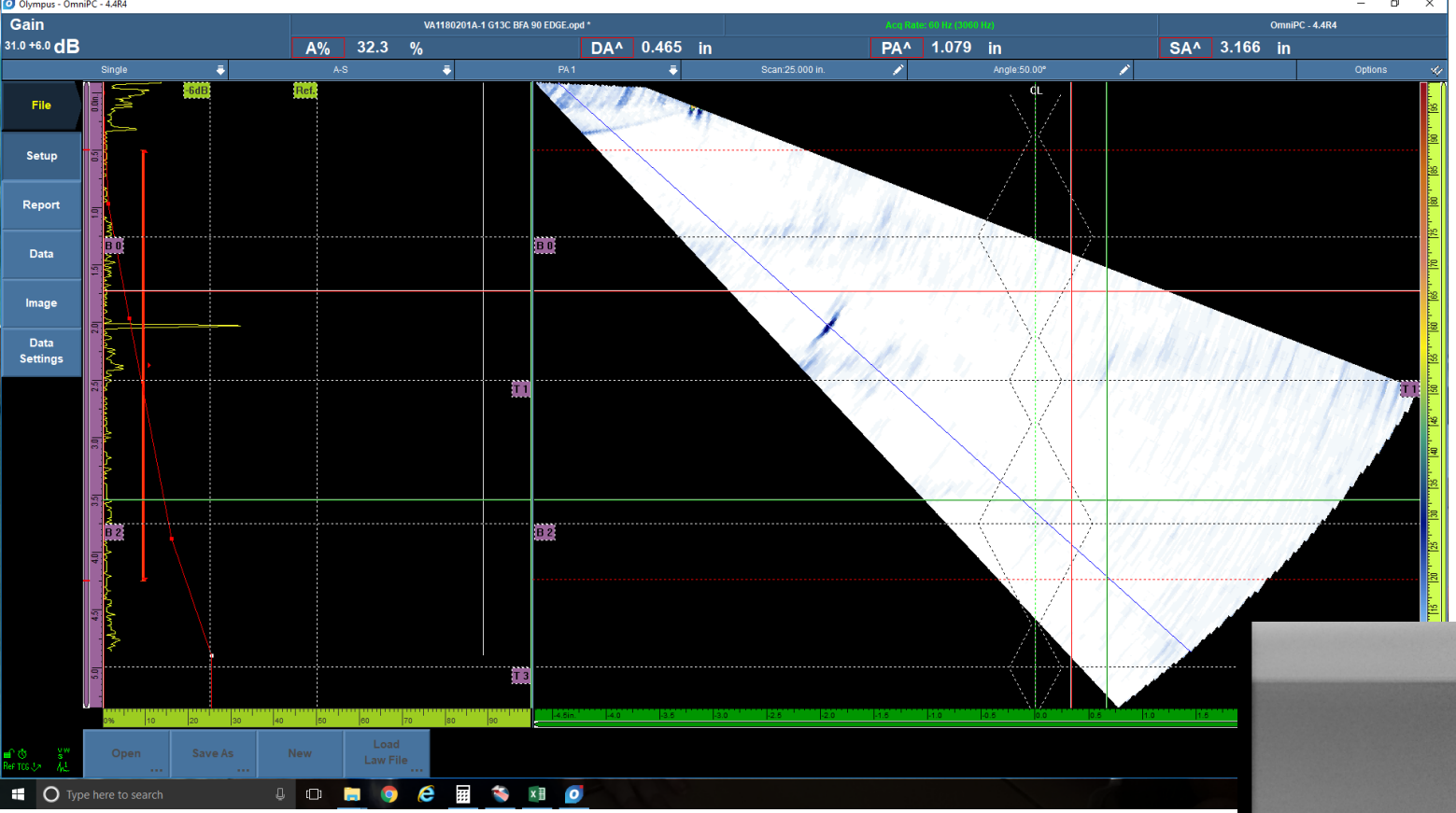




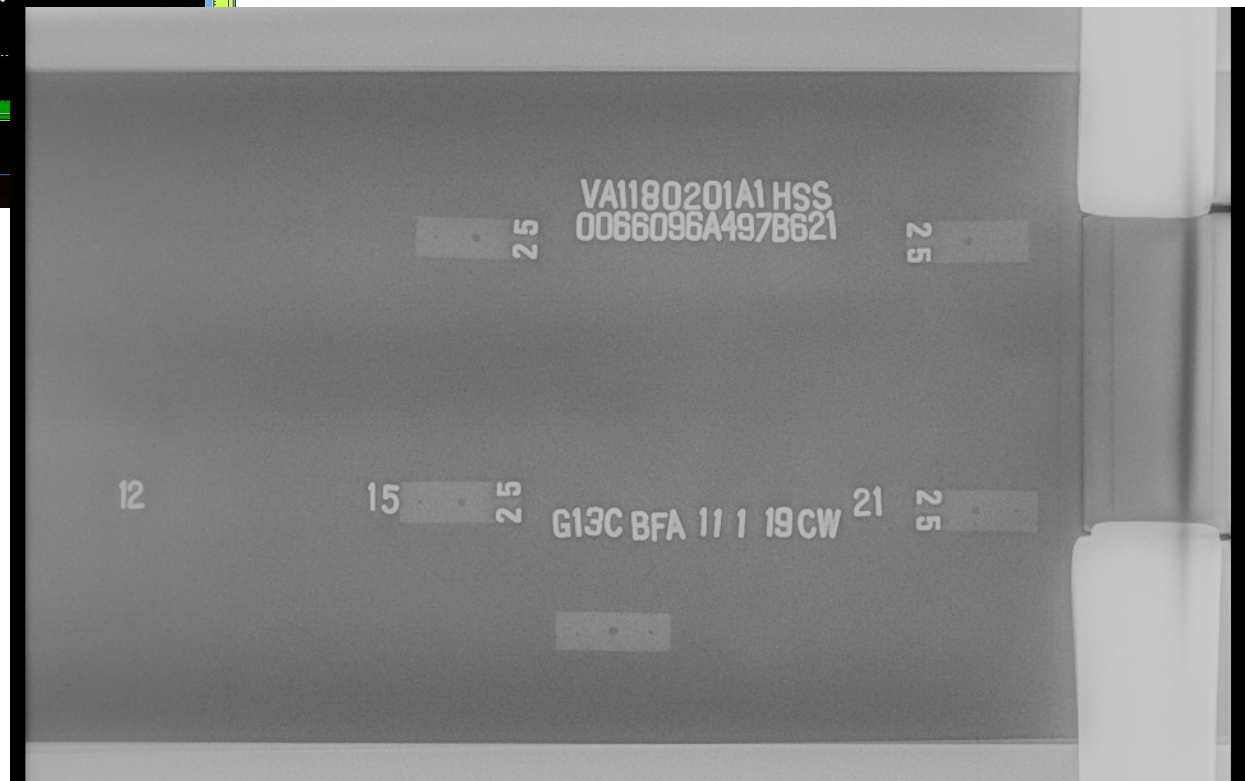
- RT result: 0.03”, acc
- PAUT result
  - Annex K: D, 13.0% (67.5 deg), acc
  - NCHRP: 20.6%, acc…?
- UT result: +7, (70 deg), rej

G13C BFA #3 (A1)





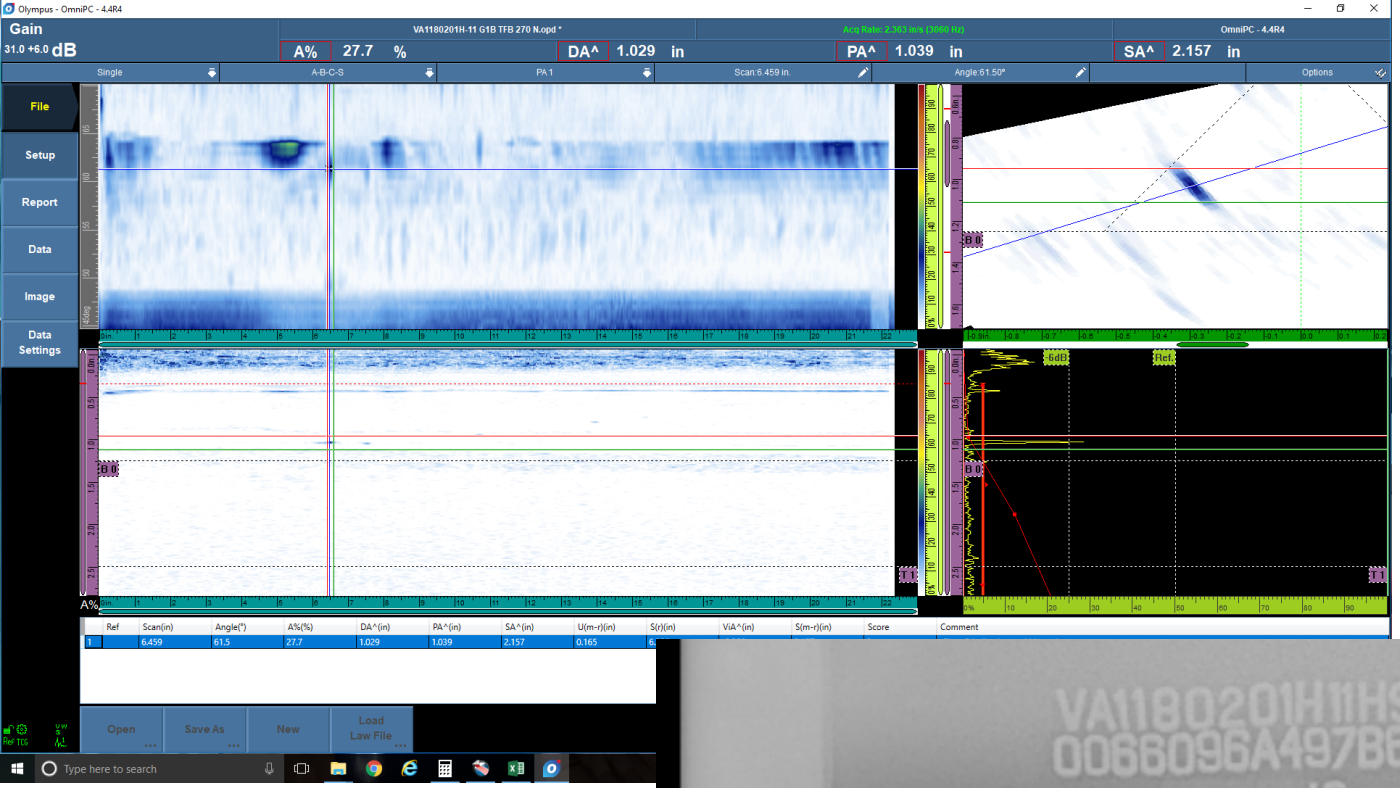
G13C BFA edge (non-encoded raster image)

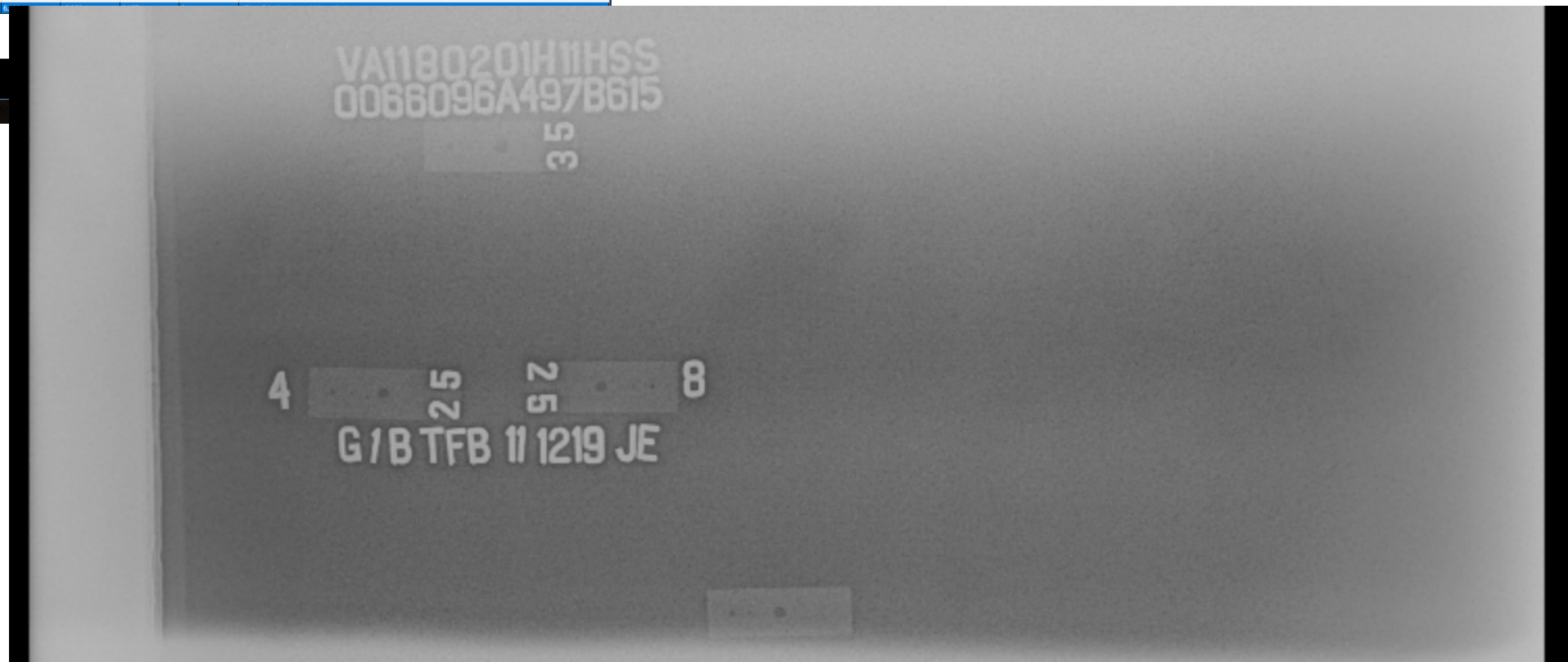


- RT result: acc
- PAUT result
  - Annex K: D13.3%, acc
  - NCHRP: 21%, raster
- UT result: not tested

G1B TFA (H11)

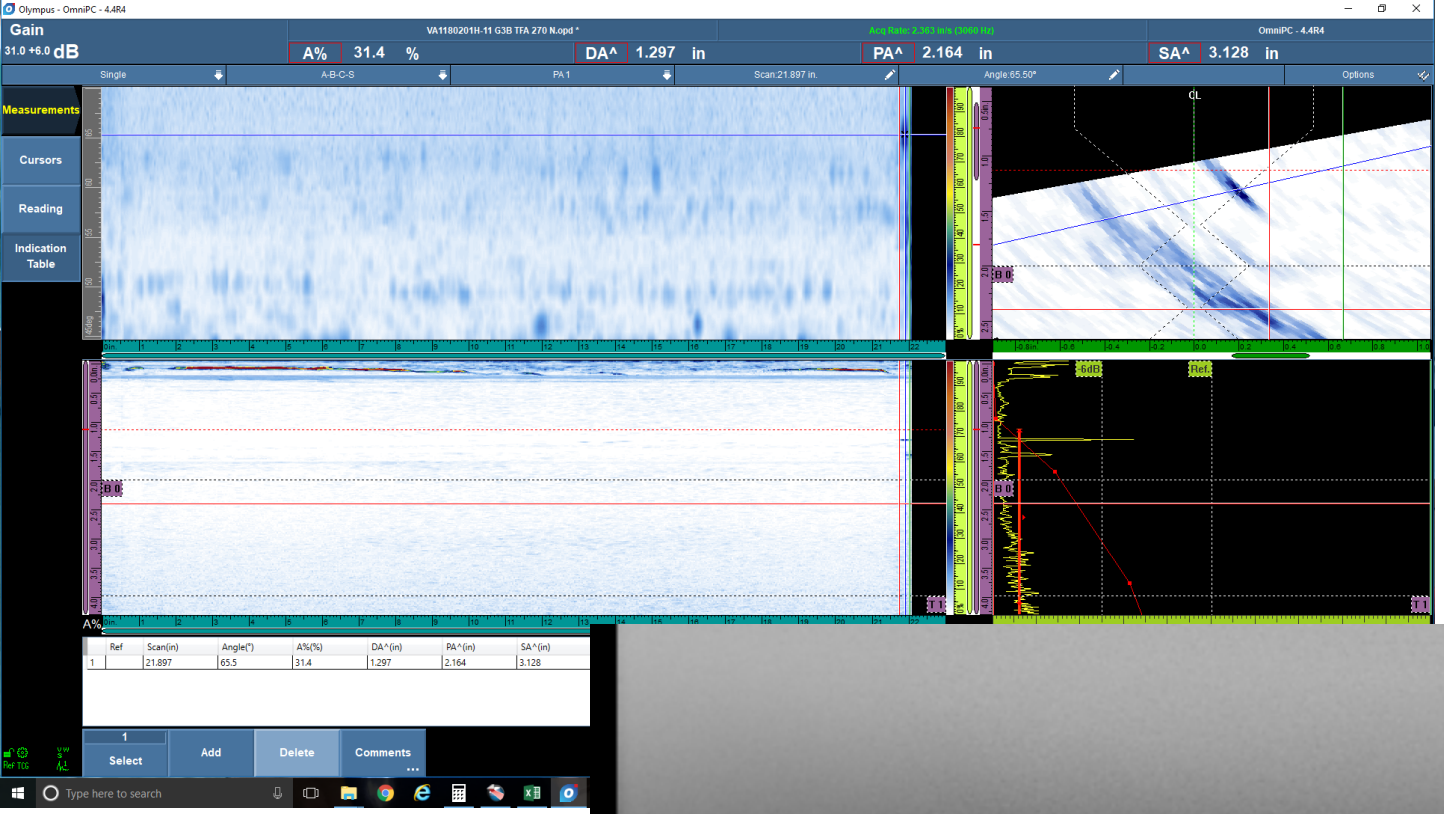
- RT result: not found
- PAUT result
  - Annex K: D, 14.2%, acc
  - NCHRP: 22.5%, raster
- UT result: not tested

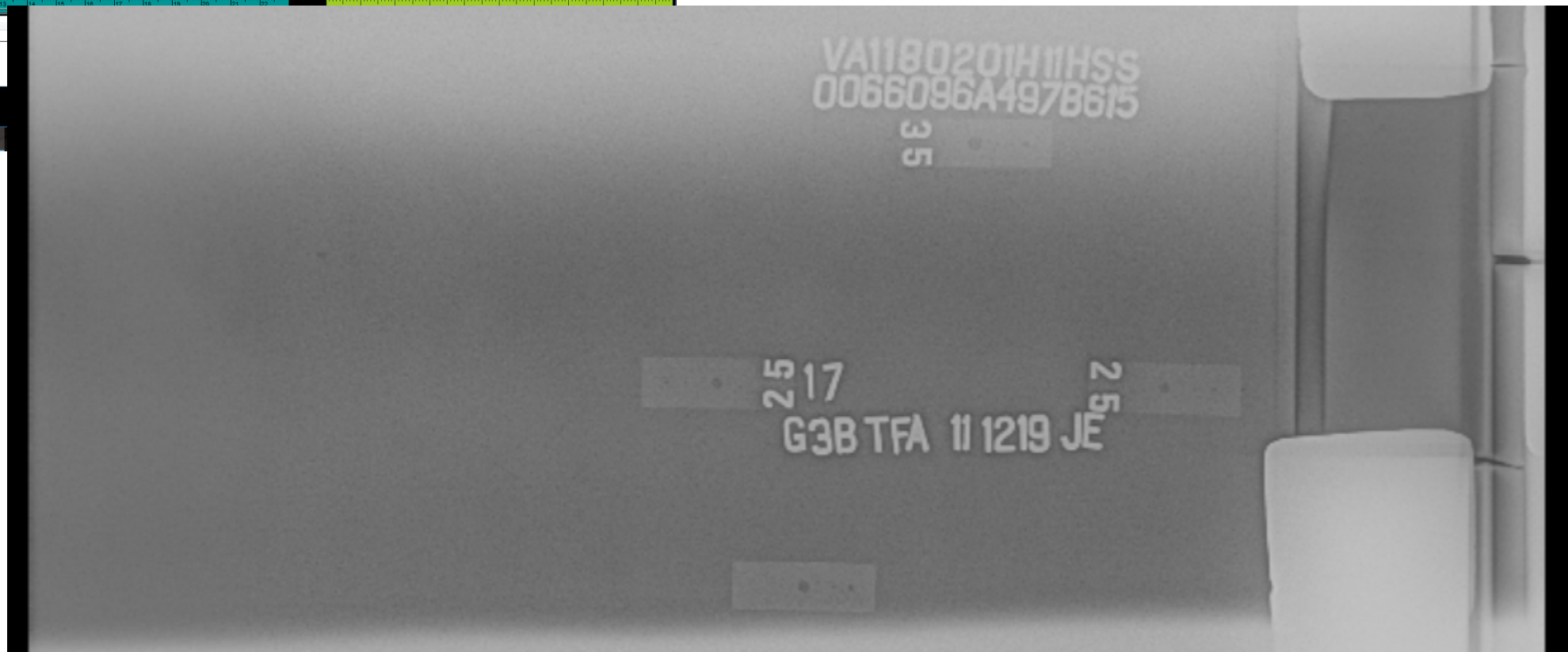




G1B TFB (H11)

- RT result: not found
- PAUT result
  - Annex K: D, 16.1%, acc
  - NCHRP: 25.4%, fix
- UT result: +18, acc





G3B TFA (H11)

G3B TFA

- conventional UT report for previous slide

Quality Control Ultrasonic Inspection Report

HIGH STEEL STRUCTURES

Job Number:	VA1180201H-11					Location:	North Bay								Report #							
Structure No.	0066-096A-497, B615					Date:	November 12, 2019								Weld Process:	SAW						
Joint Design:	B-L2c S					UT unit Serial #	180583103								Model #:	Epoch 650						
						Decibels					Inches											
Piece Mark	Drawing Number	Weld Number	Face	Indic. No.	Transducer Angle	Indic. Level A	Ref. Level B	Atten. Factor C	Indic. Rating D	Length of Sound Path	Depth from Face A	Length of Indication	X Distance	Y Distance	Thickness Inches	Accepted	Rejected	Repair #	Weld Stamp	Length or Quantity of Welds Tested and Comments		
G3B	1110	TFA	A		70	71.8	52.5	1.8	18	1.9"	.65"	.18	0	21.94	1.25	X				UT Edge of plate at PAUT reject area		

We, the undersigned, certify that the statements in this record are correct and that the welds were prepared and tested in accordance with the requirements of:

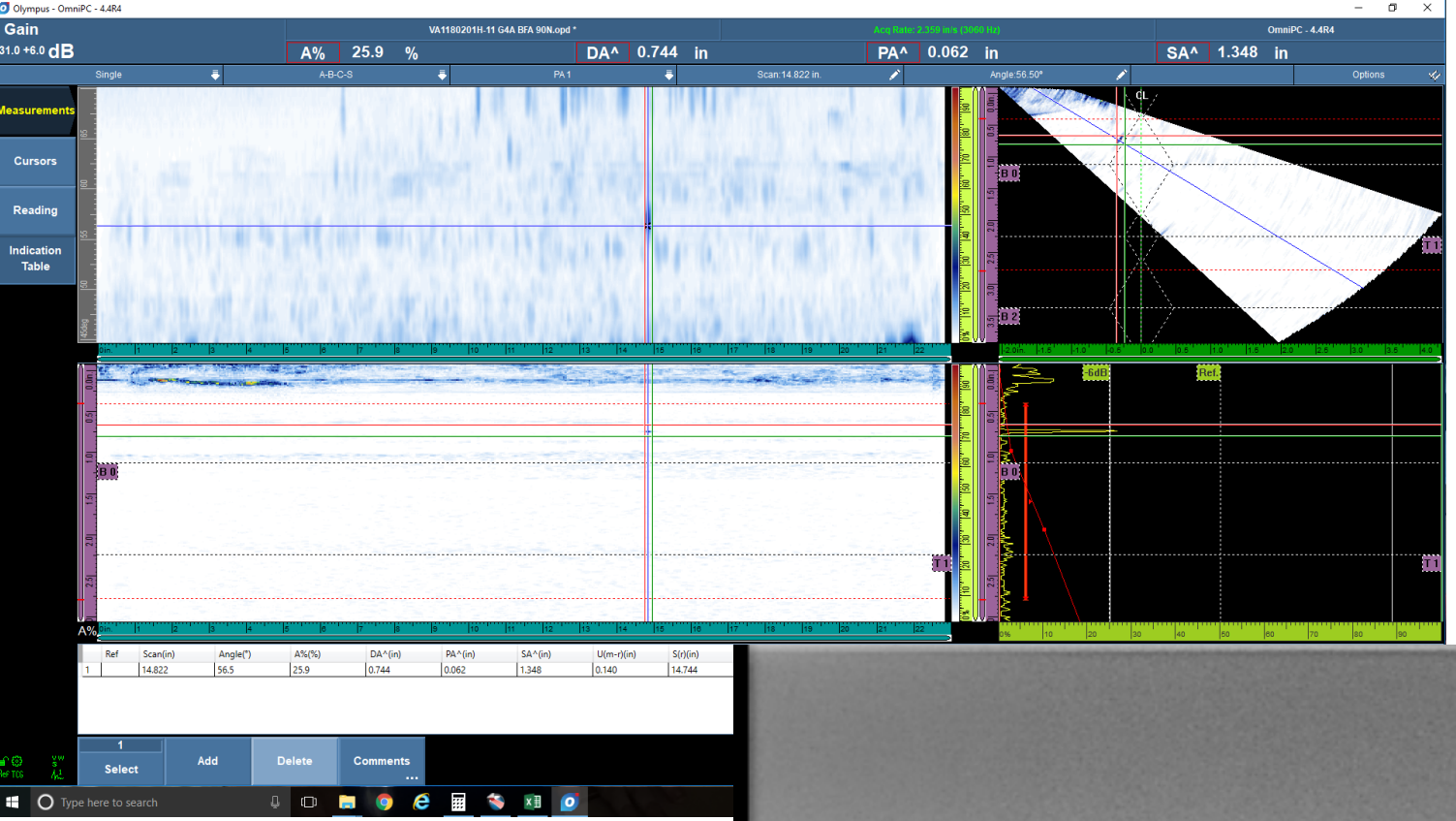
AWS D1.5 2015 Table 6.3

Technician: Curt Breneman Level: II

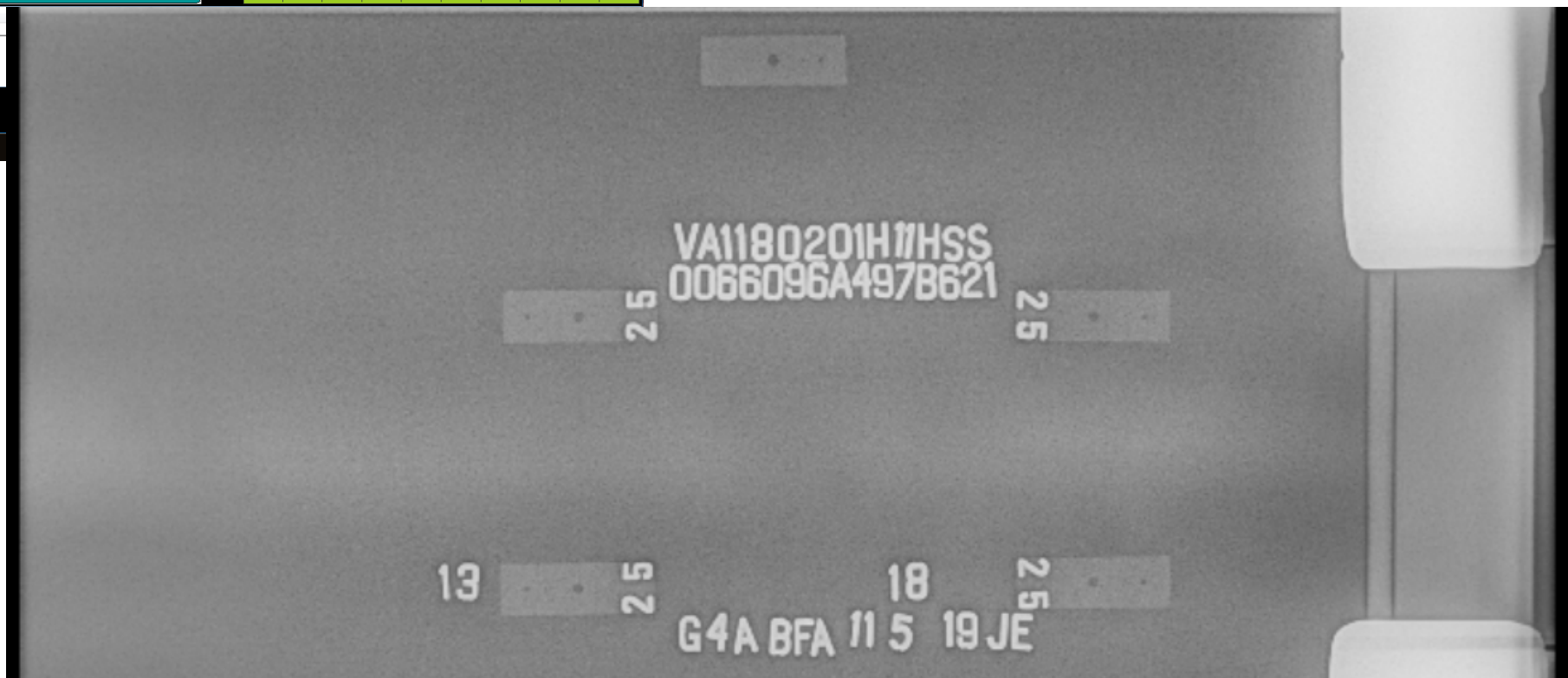
Witness:

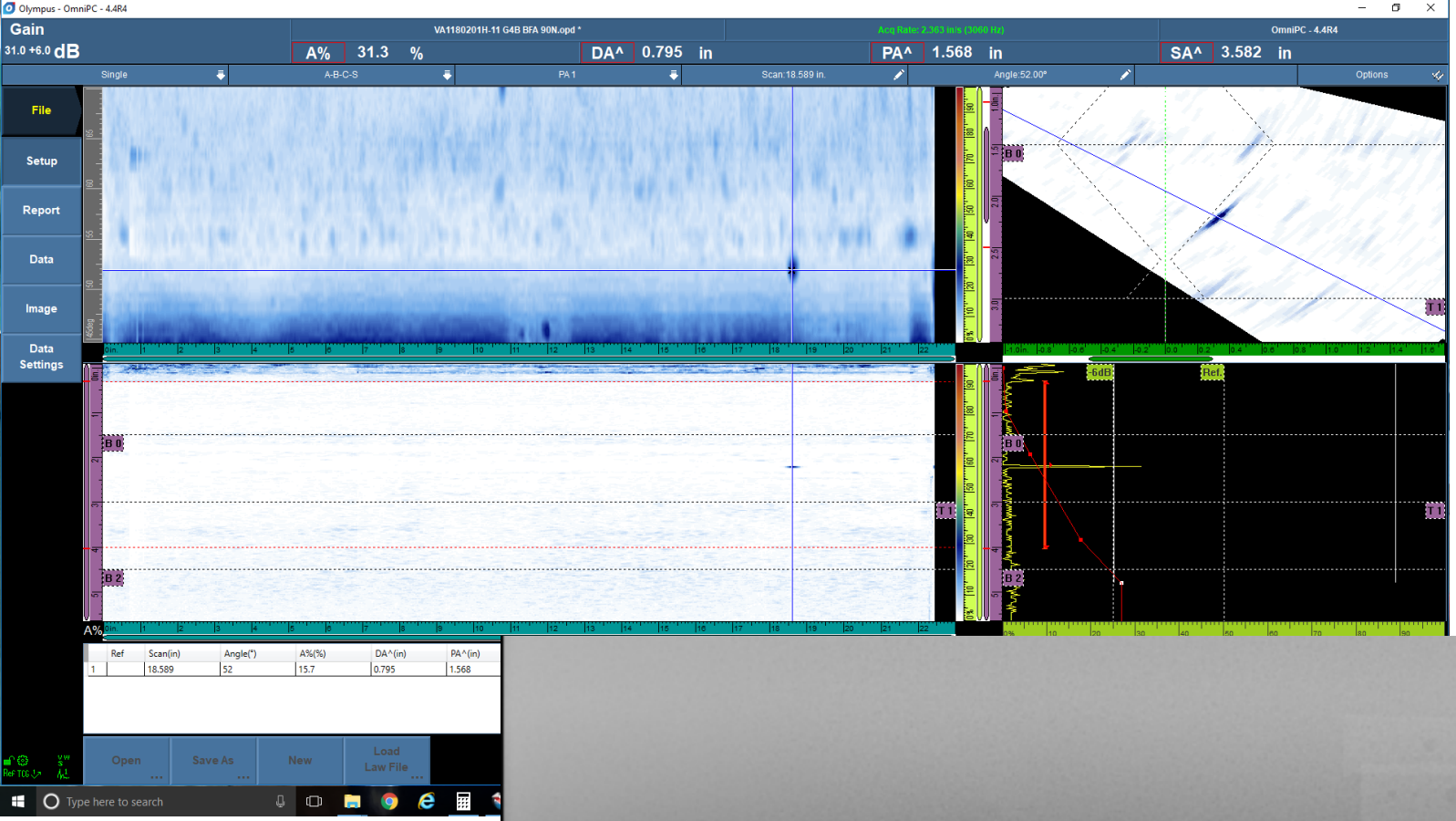
Revision Date: 04/07/09 @ 10:45 a.m. (Page 1 of 1) Hilfileserv1/Shops/Shop Forms/Quality/Ultra Insp.XLS

- RT result: not found
- PAUT result
  - Annex K: D, 13.3%, acc
  - NCHRP: 21.0%, raster
- UT result: not tested



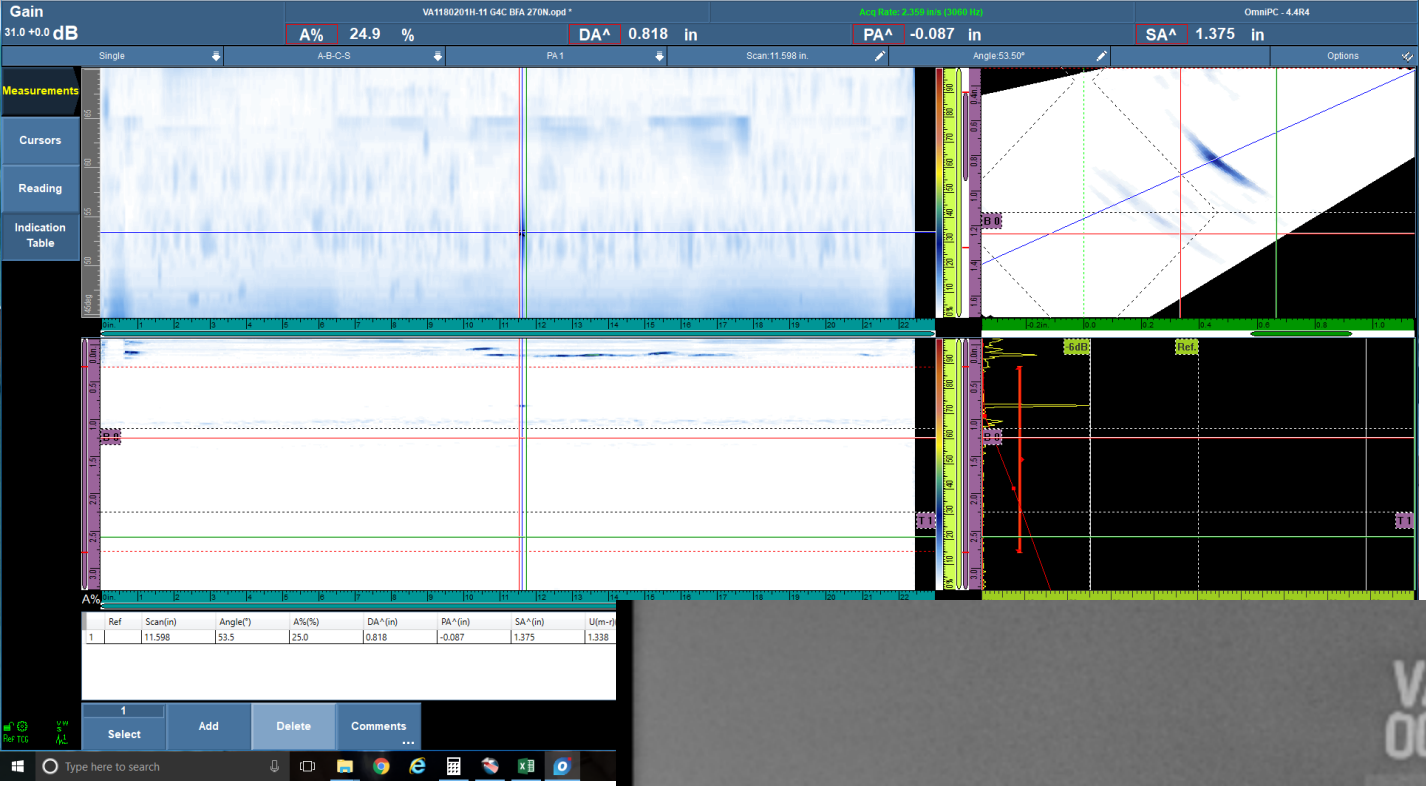
G4A BFA (H11)





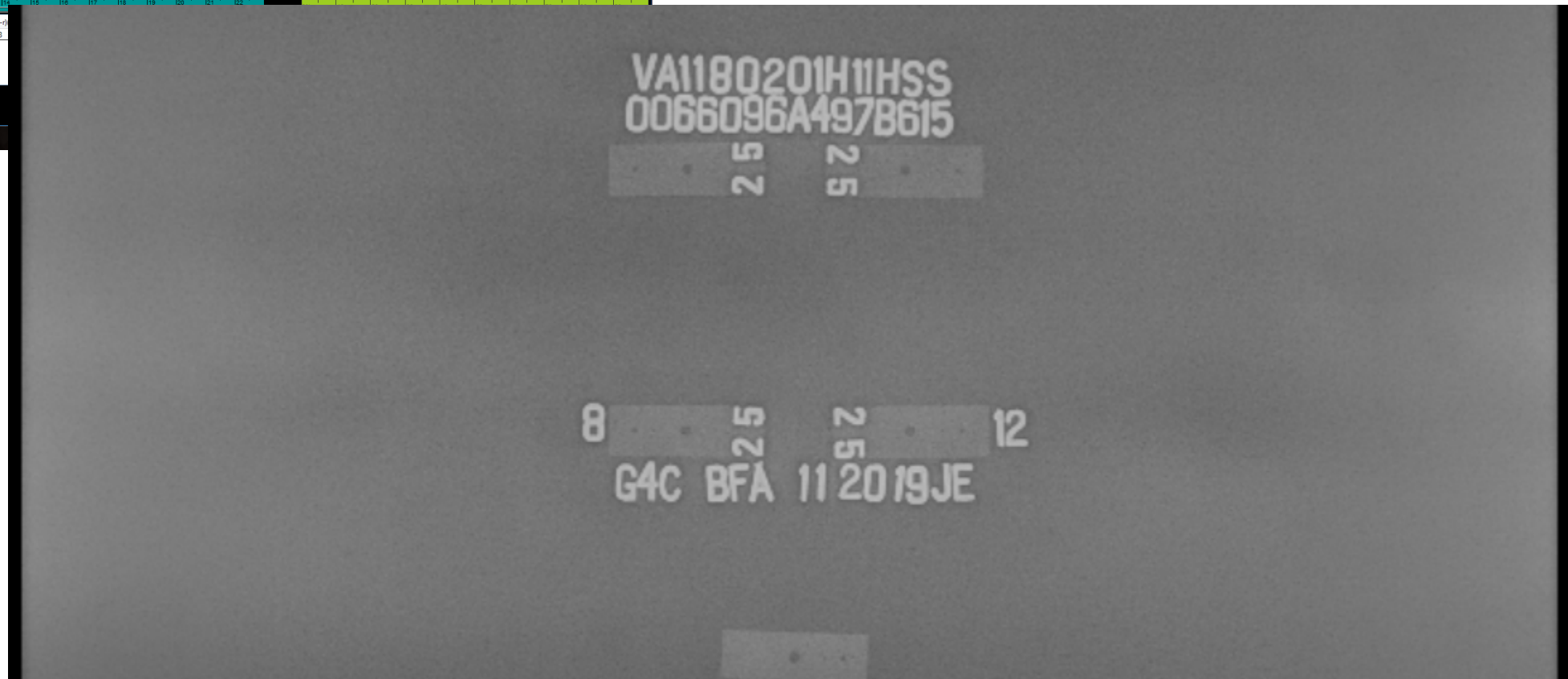
- RT result: not found
- PAUT result
  - Annex K: D, 15.7%, acc
  - NCHRP: 22.9%, raster; then 28.4% - fix
- UT result: not tested

G4B BFA (H11)

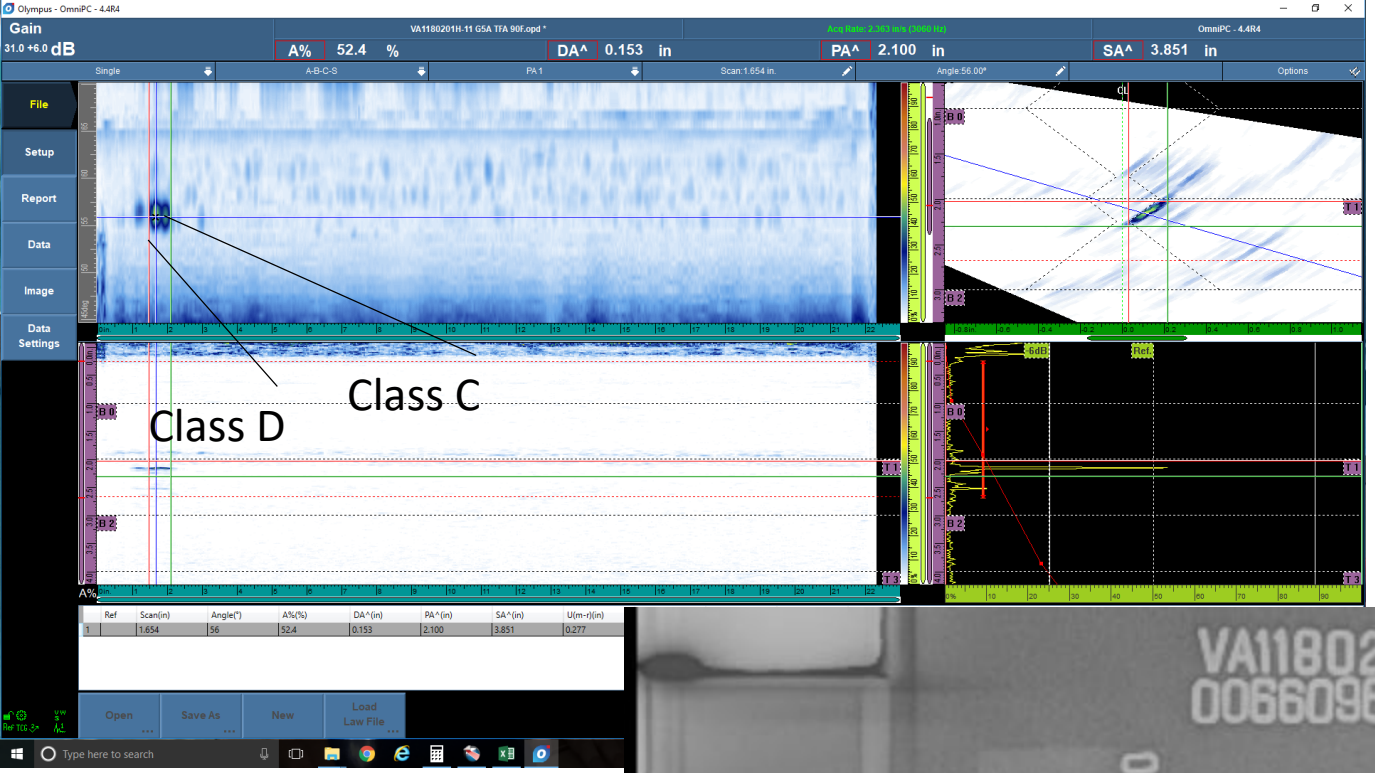


- RT result: not found
- PAUT result
  - Annex K: D, 24.9%, acc
  - NCHRP: 41.1%, fix
- UT result: not tested

G4C BFA (H11)



- RT result: 1.06 inches, fix
- PAUT result
  - Annex K: C, 26.6%, acc
  - NCHRP: 42.1%, fix
- UT result: +11 acc



G5A TFA (H11)

G5A

- conventional UT report for slide 37

HIGH STEEL STRUCTURES

Quality Control Phased Array Ultrasonic Inspection Report

Job Number:	VA1180201H-11	Location:		Report #	6
Structure No.	0066-096A-497, B615	Date:		Weld Process:	
Joint Design:	B-L2c S	UT unit Serial #	QC-015362	Model #:	OmniScan MX2

					dB					Inches/MM										
Piece Mark	Drawing Number	Scan/File Name	Face	Indic. No.	Standard Sensitivity Level	Minimum Scan Incident Angle	Maximum Scan Incident Angle	Detection Angle	Indication Classification	Depth from Face A	Length of Indication	Height of Indication	X Distance	Y Distance	Thickness	Accepted	Rejected	Repair #	Welder Stamp	Length or Quantity of Welds Tested and Comments
All Below		**Base Metal**	**A**																	**UT'd Adjacent to Weld**
G5A TFA			**A**		**56**			**70**	**+11**	**.32"**	**.625"**		**0.0"**	**1.4"**	**1.0"**	**X**				

We, the undersigned, certify that the statements in this record are correct and that the welds were prepared and tested in accordance with the requirements of: **AWS D1.5 Annex K** Table **K1 & K3**

Technician: **Steve Amspacher** Level: **II**

Witness:

Revision Date: 04/11/16 @ 3:45 p.m. (Page 1 of 1) Hiifileserv1/Shops/Shop Forms/Quality/Ultra Insp.XLS

High Steel Comparisons

- On two Virginia bridges, used PAUT for flange splices and one web splice
  - Performed RT on any indication above the disregard level (DRL, which is 6db below SSL), as scanned
  - Evaluated NCHRP need for rastering (anything above 10% full screen height, as evaluated)
  - Evaluated NCHRP need for repair
  - Looked at some joints with UT as well

Piece Mark Splice	Scan	Thickness	Length	Transition (Y/N)	PAUT			CONVENTIONAL	
					Annex K	NCHRP	NCHRP Raster	RT	UT
VA1180201A-1									
G8A WA	270F	.625"	.84"	N	C 26.6%REJ.	42.1%	R	REJ.	N/A
G8A WA	90F2	.625"	1.28"	N	C 37.1%REJ.	58.7%	R	REJ.	N/A
G8A WA	270F2	.625"	.24"	N	D 14.2%	23.0%	R	ACC.	N/A
G8B BFA	90N	2.0"	.197"	N	D 13.6%	22.0%	R	Not found	N/A
G8B TFA	270N	2.0"	.275"	N	D 15.8%	24.9%	R	Not found	N/A
G9B TFA	90F	2.0"	.5"	N	D 13.3%	21.0%	R	Not found	N/A
G11B TFA	270N	2.0"	.236"	N	D 18.6%	29.4%	R	Not found	N/A
G11B BFA	edge	2.0"	N/A	N	C 27.0%		*	Not found	Not found
G11C BFA	90N	1.25"	.196"	N	D 25.1%	39.6%	R	Not found	N/A
G11C TFA	90N	1.25"	.158"	N	D 13.3%	21.0%	R	Not found	N/A
G11C TFA	90N	1.25"	.197"	N	D 14.5%	23.0%	R	Acc.	N/A
G13A TFA	90F	1.5"	.158"	N	C 27.5%	43.5%	R	Not found	N/A
G13A TFA	270N	1.5"	.197"	N	D 17.0%	26.9%	R	Not found	N/A
G13A BFA	90N	1.5"	.276"	N	D 7.7%	12.2%	N/A	Acc.	Acc. +20
G13B BFA	90m	2.0"	.276"	N	C 34.9%	55.3%	R	Not found	Acc. +11
G13C BFA	edge	1.25"	edge	N	D 16.1%	24.9%	*	Not found	Acc. +19
G13C BFA	270N	1.25"	.237"	N	D 13.9%	22.0%	R	Not found	Not found
G13C BFA	270N	1.25"	.275"	N	D 15.8%	24.9%	R	Not found	Not found
G13C BFA	270N	1.25"	.197"	N	D 13.0% (67.5)	20.6%	R	.03" Acc	+7 Rej. (70)
G9C TFA	90N	1.25"	.196"	N	C 29.4%	46.5%	R	.05" Acc.	N/A
G9C BFA	90F	1.25"	.393"	N	D 14.5%	23.0%	R	Not found	N/A
G10C BFA	270N	1.25"	.197"	N	D 11.8%	18.6%	R	Not found	N/A
VA1180201H-11									
G1B TFA	90N	1.25-2	.196"	Y	D 13.3%	21.0%	R	.07" Acc	N/A
G1B TFB	270N	1.25-2	.197"	Y	D 14.2%	22.5%	R	Not found	N/A
G3B TFA	270N	1.25-2	.315"	Y	D 16.1%	25.4%	R	Not found	+18
G4A BFA	90N	1.125"	.196"	N	D 13.3%	21.0%	R	Not found	N/A
G4B BFA	90N	1.5-2	.315"	Y	D15.7%	22.9%	28.4%	Not found	N/A
G5A TFA	90F	1.0"	.630"	N	C 26.6% (56)	42.1%	R	1.0"	+11 (70) .63"
G4C BFA	90N	1.125"	.276"	N	D 23%	37.4%	39.9%	Not found	N/A
G4C BFA	270N	1.125"	.276	N	D 24.9%	41.1%	32.2%	Not found	N/A
						R = NCHRP Raster scan required			
						* = Found with raster scan of edge			
Reject			Accept					Not Found	

Testing Summary

- Joints scanned per Annex K: 71
- Joints with recordable indications: 19, or 27%

• Failed Annex K	2 joints, 3 repairs	3% (of total)
• Failed RT	2 joints, 3 repairs	3%
• Required NCHRP raster:	all	
• Failed NCHRP	11 joints, 13 repairs	15%

Summary

- PAUT is more sensitive than RT for detecting discontinuities or indications
  - PAUT Annex K gets many recordable indications that do not show up on x-ray – maybe 25%
  - All RT indications are found by PAUT
- Generally good agreement between Annex K and RT regarding acceptance
- Annex K compared to NCHRP
  - All Annex K indications require rastering
  - About half of Annex K indications fail NCHRP
- More comparisons planned

Florida Structural Steel Testing

- There were no recordable indications found by PAUT that would fail Annex K
- (6) 15” sections failed per 908 criteria utilizing PAUT
- 49% of the PAUT scans would require rastering per 908
- Traditional UT found no rejectable indications
- The 6 rejectable indications found utilizing PAUT and 908 criteria were Class D indications by traditional UT
- RT found no rejectable indications
- The 6 rejectable indications found by utilizing the 908 criteria were shown to be minor porosity on RT film
- Radiographic inspection showed non-rejectable minor porosity that wasn’t found by PAUT or traditional UT

Questions?