PNNL-SA-130000

Signal Dropout and Flaw Signal Persistence Assessments in CASS Materials

PNNL Status Update on CASS NDE Evaluations to Task Group CASS (TG-CASS)

October 30, 2017

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What is Signal Dropout?

Signal dropout (in this context) is defined as:

The amplitude dip of an ultrasonic end-of-block signal response below a specified amplitude threshold (in terms of signal-to-noise ratio – SNR) for the purposes of detection, as a function of circumferential spatial position and incident angle.

Why Evaluate Signal Dropout?

- **Motivation**: To address whether use of a discrete incident angle is viable for the effective examination of CASS materials, where microstructural variability is unpredictable, typical SNRs are low, and flaw detection/discrimination is challenging

- **Objective**: To better understand and quantify the prevalence and impact of signal dropout on the detection of the “end-of-block” geometry (essentially a 100% through-wall flaw) in CASS mockups, in terms of key inspection parameters

- **Key Inspection Parameters**: SNR, probe type/characteristics, frequency/wavelength, scan orientation to the end of block, and CASS material properties/dimensions

Grain Structure and Probe Frequency: PA-UT Sound Field Mapping in CASS

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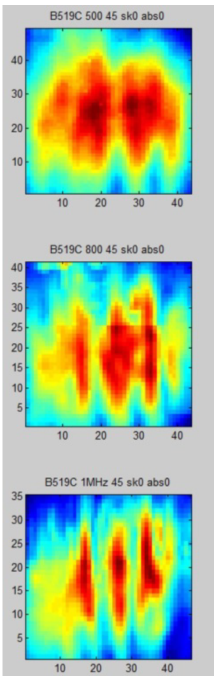
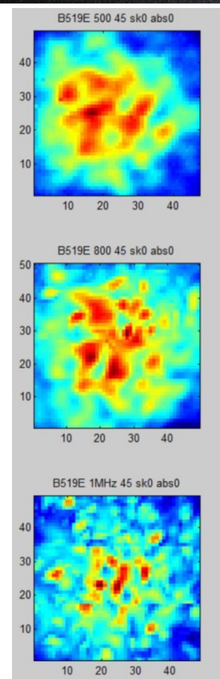
Columnar | **Equiaxed** | **Coarse-grained mix** | **Fine grained wrought SS**

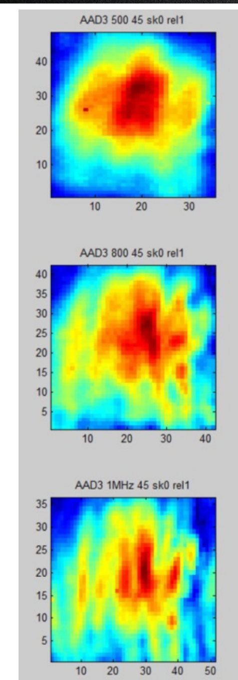


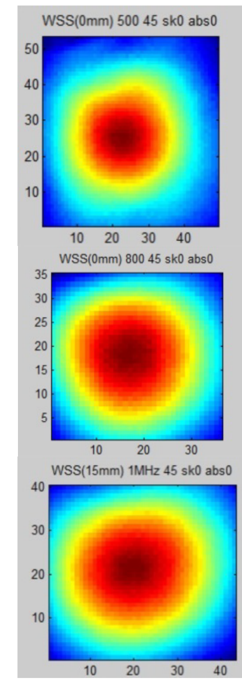
500 kHz

800 kHz

1.0 MHz



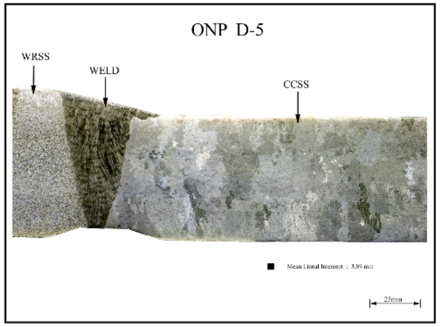


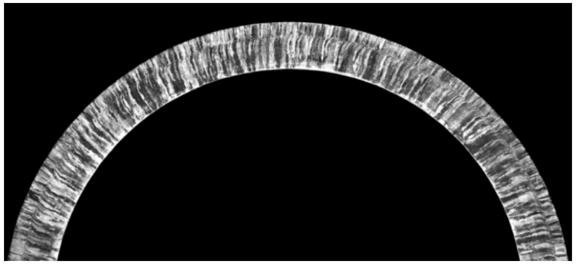


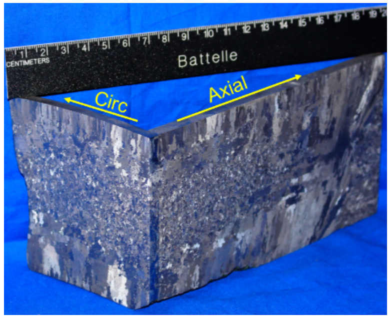
Phased Array Ultrasonic Sound Field Mapping in Cast Austenitic Stainless Steel (ML14155A165)

Methods

- Measured the amplitude of the signal response from the end-of-block on CASS specimens with a range of known grain structures
- CASS specimens evaluated
  - Small-grain equiaxed (Manoir) – 75 mm thick
  - Coarse-grain equiaxed (ONP-D-5) – 64 mm thick
  - Columnar (Westinghouse) – 64 mm thick
  - Mixed/banded (Manoir, 14C-146) – 85 mm thick
  - Wrought specimen, control – 64 mm thick
- Encoded phased array, TRL, TD focus at ID
  - 500 kHz, 10x5 elements, 64x34 mm aperture
  - 800 kHz, 10x5 elements, 43x21 mm aperture
  - 1.0 MHz, 10x5 elements, 40x20 mm aperture
- Angle range 20-70 deg., 5 deg. steps
- Raster scans
  - 2.0 mm index resolution
  - 0.5 mm scan resolution
- Scanned as much of the specimen as was accessible







Analysis

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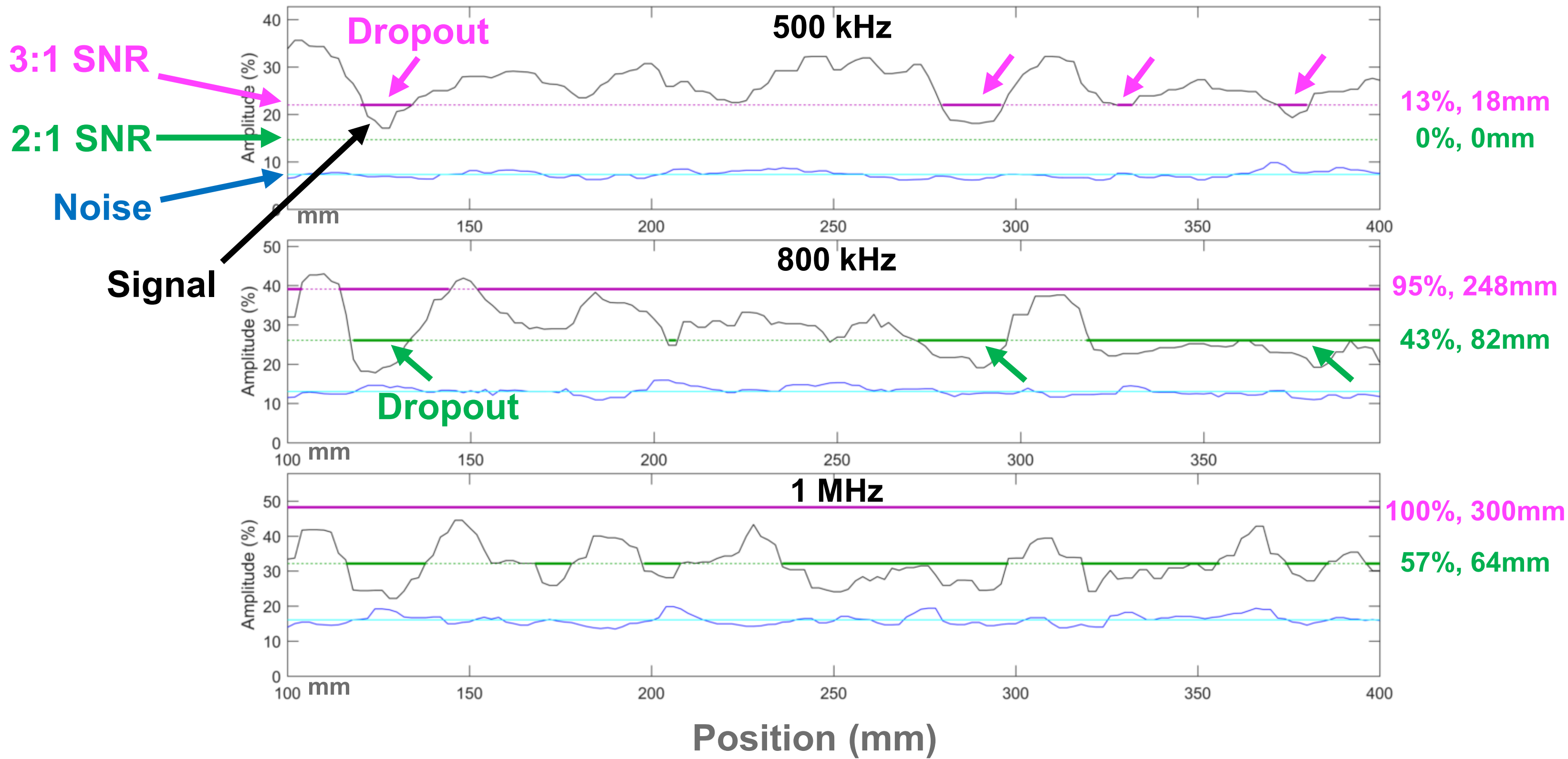
- Data exported from UltraVision. Fully automated analysis in MATLAB.
- Measured corner signal intensity and mean noise at same metal path for all frequencies and all angles
- Identified regions where signal dropped below 3:1 SNR and 2:1 SNR (noise increases with f)
- Calculated % dropout and longest continuous dropout



Data Example: Columnar

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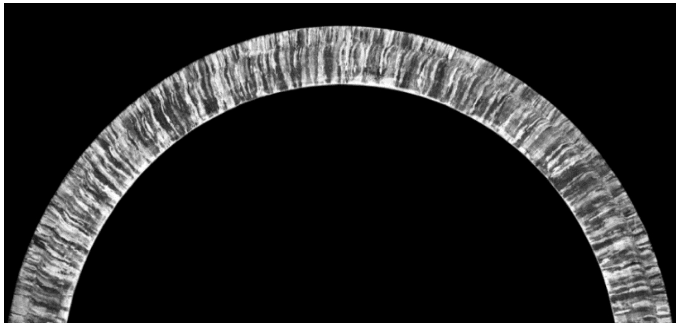
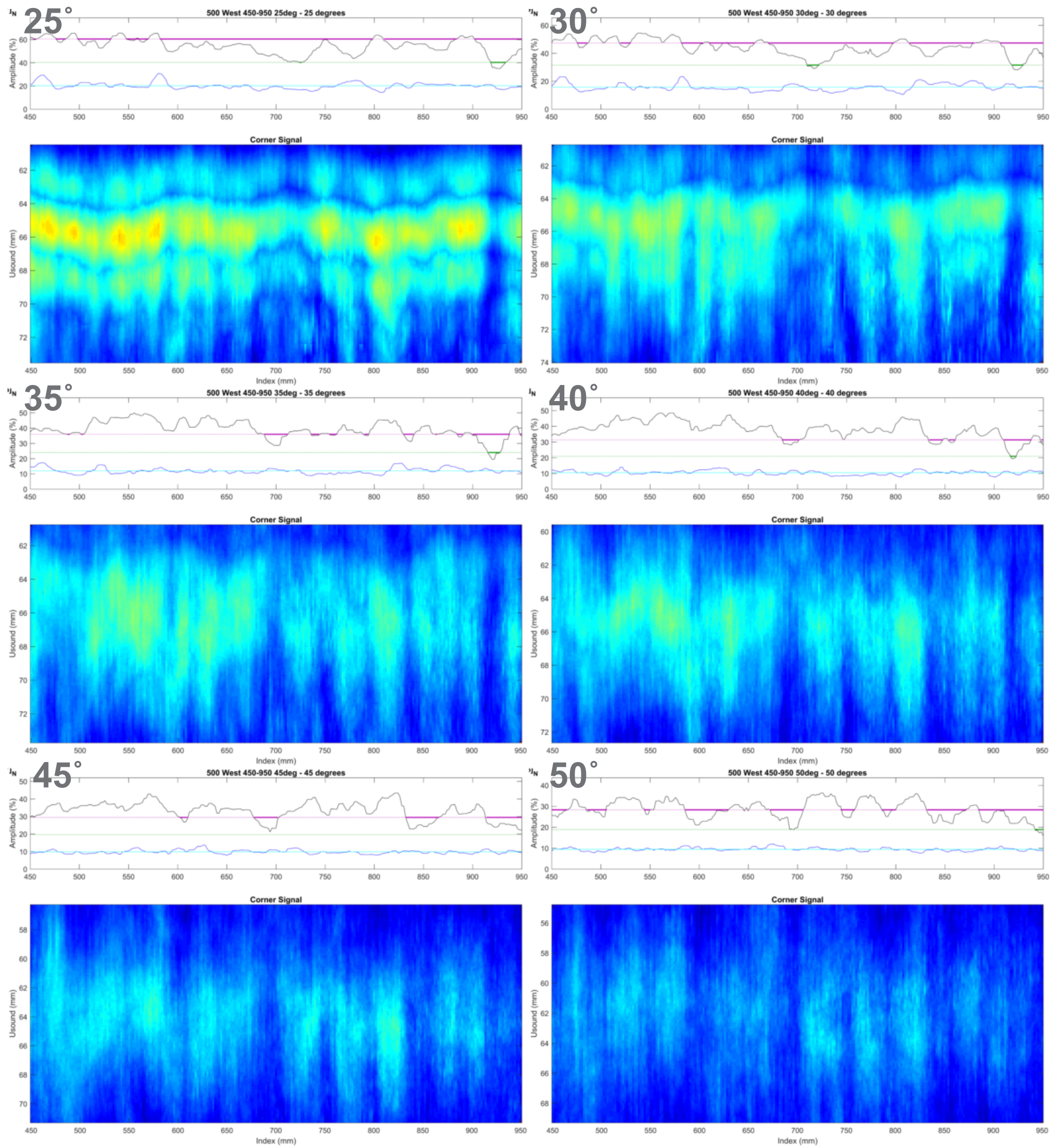


2:1 SNR at 500 kHz

Angle	% Dropout	Max Dropout
20	15	46
25	4	18
30	6	14
35	3	14
40	2	8
45	0	0
50	2	10
55	10	16
60	49	36
65	49	44

Percentage of scan range where signal dropped below threshold.

Maximum continuous dropout length (mm).



2:1 SNR Dropout Comparison at Different Frequencies

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- 500 kHz (top), 800 kHz (middle), and 1 MHz (bottom)

Small Grained Equiaxed

500 kHz, 2x SNR		
Angle	% Dropout	Max Dropout
20	0	0
25	0	0
30	0	0
35	0	0
40	0	0
45	0	0
50	0	0
55	0	0
60	35	88
65	–	–

800 kHz, 2x SNR		
Angle	% Dropout	Max Dropout
20	0	0
25	0	0
30	0	0
35	0	0
40	0	0
45	0	0
50	0	0
55	11	26
60	35	46
65	–	–

1 MHz, 2x SNR		
Angle	% Dropout	Max Dropout
20	0	0
25	0	0
30	0	0
35	0	0
40	0	0
45	2	8
50	19	26
55	49	60
60	73	76
65	–	–

Coarse Grained Equiaxed

500 kHz, 2x SNR		
Angle	% Dropout	Max Dropout
20	96	170
25	87	160
30	50	64
35	29	50
40	6	12
45	11	16
50	26	32
55	86	82
60	–	–
65	–	–

800 kHz, 2x SNR		
Angle	% Dropout	Max Dropout
20	100	200
25	98	166
30	91	128
35	68	90
40	56	48
45	38	32
50	65	30
55	–	–
60	–	–
65	–	–

1 MHz, 2x SNR		
Angle	% Dropout	Max Dropout
20	98	162
25	100	200
30	85	122
35	68	58
40	59	52
45	71	48
50	83	84
55	–	–
60	–	–
65	–	–

Columnar

500 kHz, 2x SNR		
Angle	% Dropout	Max Dropout
20	15	46
25	4	18
30	6	14
35	3	14
40	2	8
45	0	0
50	2	10
55	10	16
60	49	36
65	49	44

800 kHz, 2x SNR		
Angle	% Dropout	Max Dropout
20	88	200
25	43	52
30	20	38
35	8	16
40	4	12
45	6	12
50	31	36
55	74	74
60	98	264
65	–	–

1 MHz, 2x SNR		
Angle	% Dropout	Max Dropout
20	89	92
25	55	44
30	21	38
35	8	16
40	13	16
45	21	28
50	55	42
55	95	148
60	–	–
65	–	–

Mixed/Banded

500 kHz, 2x SNR		
Angle	% Dropout	Max Dropout
20	0	0
25	0	0
30	0	0
35	0	0
40	0	0
45	0	0
50	17	14
55	37	22
60	36	24
65	–	–

800 kHz, 2x SNR		
Angle	% Dropout	Max Dropout
20	0	0
25	0	0
30	0	0
35	10	10
40	43	82
45	48	84
50	67	84
55	90	98
60	–	–
65	–	–

1 MHz, 2x SNR		
Angle	% Dropout	Max Dropout
20	6	8
25	25	20
30	46	42
35	47	46
40	57	64
45	83	68
50	95	156
55	99	250
60	–	–
65	–	–

Wrought

500 kHz, 2x SNR		
Angle	% Dropout	Max Dropout
20	0	0
25	0	0
30	0	0
35	0	0
40	0	0
45	0	0
50	0	0
55	0	0
60	0	0
65	0	0

800 kHz, 2x SNR		
Angle	% Dropout	Max Dropout
20	0	0
25	0	0
30	0	0
35	0	0
40	0	0
45	0	0
50	0	0
55	0	0
60	0	0
65	0	0

1 MHz, 2x SNR		
Angle	% Dropout	Max Dropout
20	0	0
25	0	0
30	0	0
35	0	0
40	0	0
45	0	0
50	0	0
55	0	0
60	0	0
65	0	0

CASS Corner Dropout Summary

- The window of least affected angles appears to be approximately 20-55 degrees for a planar, 100% through-wall, end-of-block reflector
  - The range of least affected angles was not consistent between 2:1 and 3:1 SNR
  - Optimum angular increment for scanning yet to be determined
- Range of least affected angles was unpredictable
  - Grain structure
  - Probe frequency
- Dropout varied considerably from specimen to specimen and within individual specimens
- Amount and locations of dropout were unpredictable

CASS Corner Dropout Summary

- The 500 kHz data consistently showed:
  - Least overall dropout
  - Shortest dropout lengths
  - Fewest affected angles
  - Lowest mean noise level
- Coarse-grain equiaxed and columnar-grained microstructures appear to exhibit the highest dropout
- Results represent signal dropout for a best-case scenario: 100% through-wall planar reflector and only 2:1 SNR
  - Dropout from actual flaws is anticipated to be considerably more significant
- Low frequency (500 kHz) phased array recommended for effective and reliable flaw detection in thick-walled CASS

What is Flaw Signal Persistence?

Flaw signal persistence (in this context) is defined as:

The time-duration that an ultrasonic flaw signal response remains above a specified amplitude threshold (in terms of signal-to-noise ratio – SNR) for the purposes of detection, as a function of scan speed.

Why Evaluate Flaw Persistence?

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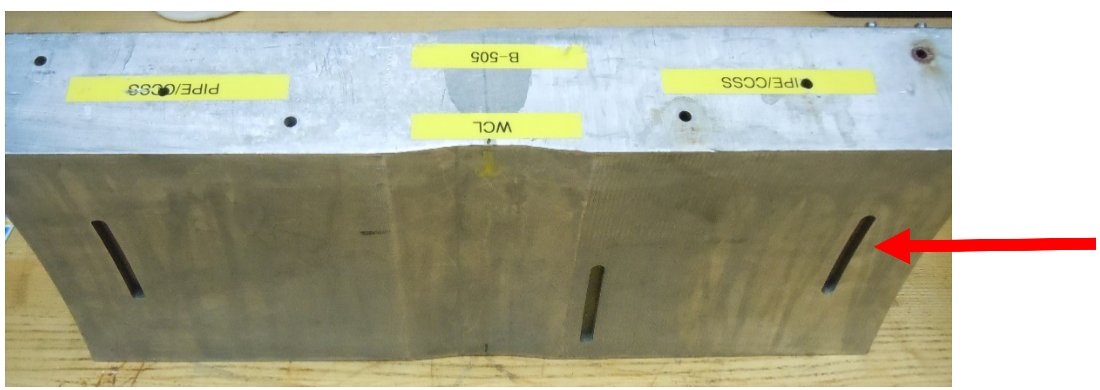
- **Motivation**: To address whether non-encoded, real-time, conventional examination approaches are viable for CASS materials, where typical SNRs are low and flaw detection/discrimination is challenging
- **Objective**: To better understand and quantify the impact of flaw persistence on flaw detection in CASS materials, in terms of inspection parameters
- **Inspection Parameters**: **Scan speed, SNR,** probe type/characteristics, frequency/wavelength, scan orientation relative to the flaw orientation, CASS material properties, and flaw type/size/morphology

How "Conventional" is Defined Here

- Use of single- or dual-element, pulse-echo or transmit-receive transducer configurations operating at frequencies at or above 1.0 MHz.
- Ultrasonic sound fields having a "dead zone" in the near field with more linear beam characteristics in the far field
  - Reduction of sound field intensity
  - Beam divergence
- Typically employ only a single fixed angle for each transducer configuration
- May or may not be spatially encoded
- Scanning may be done manually or by using automated fixtures

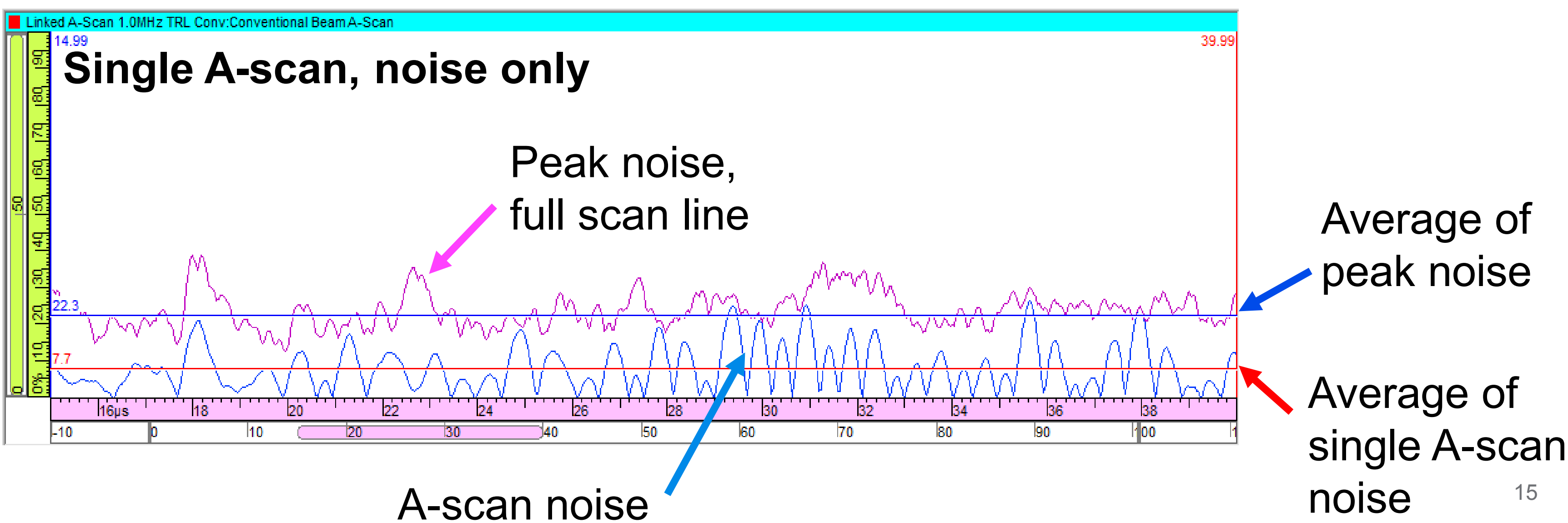
Data Acquisition

- Conventional dual probe used for manual inspections in the field
  - 1.0 MHz nominal frequency (0.98 MHz center frequency, 49.95% BW at -6 dB)
  - 0.75 x 1.0 in. (19.05 x 25.4 mm) element dimensions
  - Dual-element, 45˚ longitudinal (pitch-catch configuration)
  - Designed for 2.0 in. (50.8 mm) crossover depth point in steel (zone focus)
- Data were collected using automated, encoded scanning
  - 0.6 in./sec (15.2 mm/sec)
  - Scan resolution 0.02 x 0.04 in. (0.5 x 1.0 mm)
- Specimen details
  - Small-to-medium size columnar grained structure (equiaxed on opposite side of weld)
  - 2.35 in. (59.7 mm) wall thickness
  - 10% deep, 0.25 in. wide (6.33 mm) notch (red arrow)



Data Analysis

- Noise measurement for CASS varies significantly due to grain structure
  - Specimen corner amplitude set to approximately 80% FSH
  - A-scan average noise at same metal path was about 8% (red horizontal line) – typical noise spikes were 3x this level
  - Average peak noise across a full scan line was about 22% (blue horizontal line)
  - The average of the peak noise was used as the noise threshold



Data Acquisition and Assessment Details

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- Three slices were taken through the notch signal representing three different peak signal levels.
- The duration of signal persistence above the noise level in these slices was calculated for two different scan rates:
  - 1 in./sec and 2 in./sec

C-scan of Encoded Data

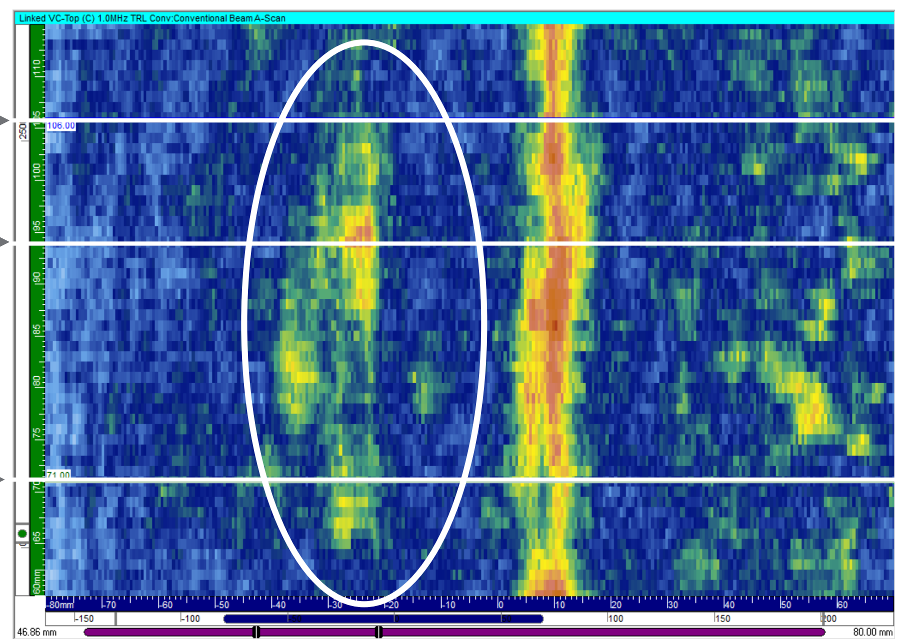
Notch

End of Block

1.89 SNR

3.26 SNR

2.12 SNR



Signal Persistence (at 2 in./s)

<u>Machined Reflector:</u> 0.25 in. wide, 10% through-wall notch in CASS mockup with small-grained columnar microstructure

Signal Persistence (at 1 in./s)

<u>Machined Reflector:</u> 0.25 in. wide, 10% through-wall notch in CASS mockup with small-grained columnar microstructure

CASS Signal Persistence Summary

- The detection of a large, machined reflector represents a best-case-scenario for detection as opposed to actual crack detection

- Signal persistence for peak observed signal (3.26 SNR):
  - 0.24 sec at 2 in./sec
  - 0.47 sec at 1 in./sec

- Signal persistence for nominal observed signal (2.12 SNR):
  - 0.08 sec at 2 in./sec
  - 0.16 sec at 1 in./sec

- The use of conventional, non-encoded, real-time techniques is not expected to be effective or reliable in CASS components with low SNR

CASS Signal Persistence Summary

- Detection is very challenging or impossible when signal dropped below 2:1 SNR level, regardless of scan speed

- Detection in CASS using non-encoded, conventional, real-time methods is not feasible due to short signal persistence in the presence of high noise levels
  - The notch was readily detected using encoded data

- The data suggest a minimum 3:1 SNR and encoded scanning are necessary for effective and reliable CASS examinations