

Detecting and Sizing Defects in Railroad Track Using the Ultrasonic and Induction Test Methods

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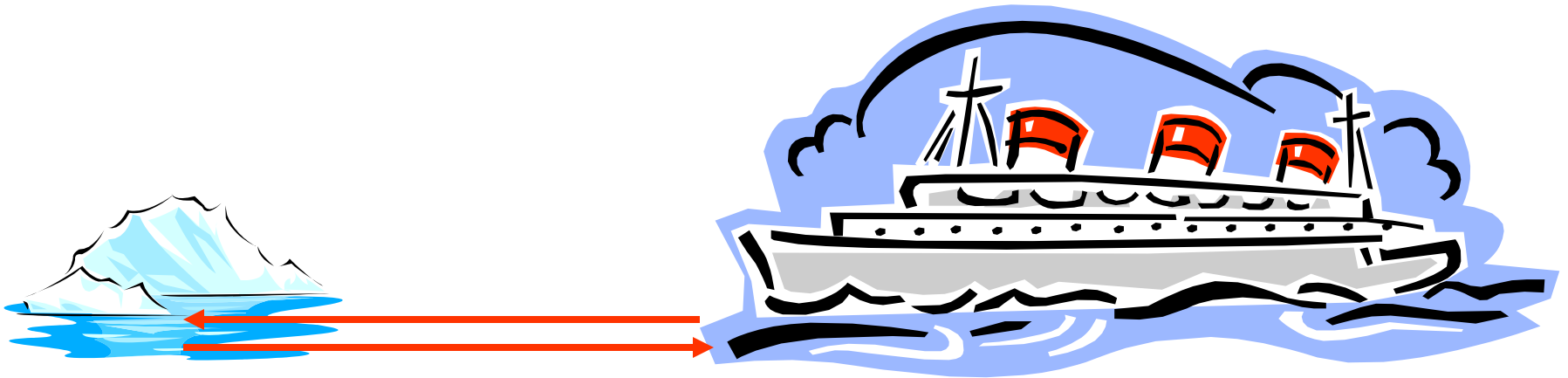
Testing with Sound

- Ultrasonic testing works similar to the way sonar finds icebergs.



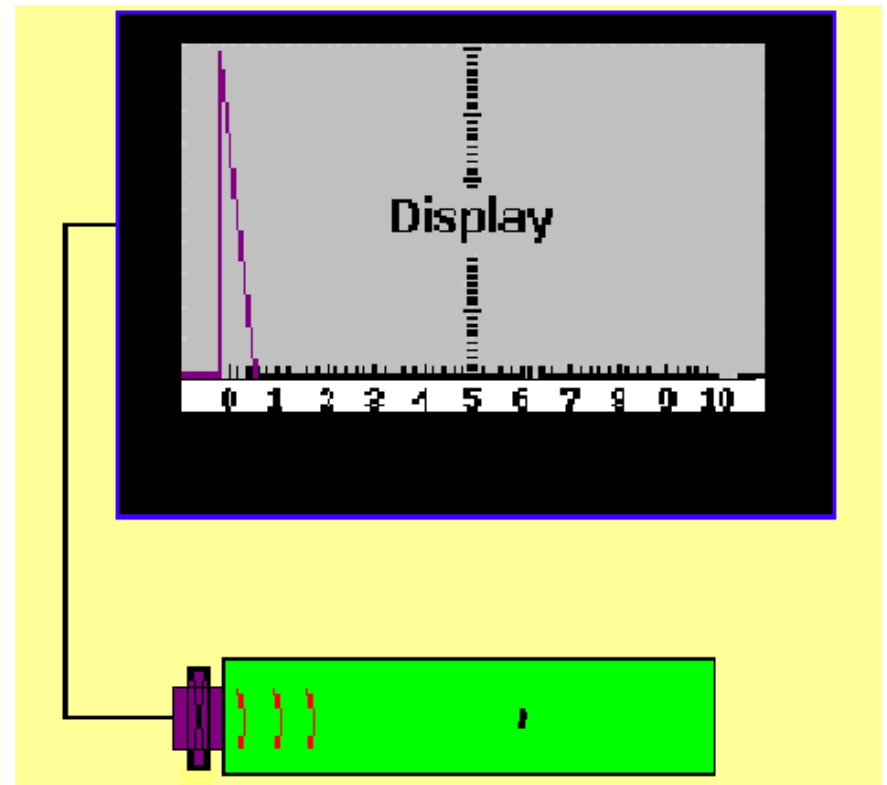
Testing with Sound

- A ship sends a beam of sound (sonar) into the water. The sound travels through the water, strikes the iceberg, reflects from it, and brings an echo from the iceberg back to the ship.



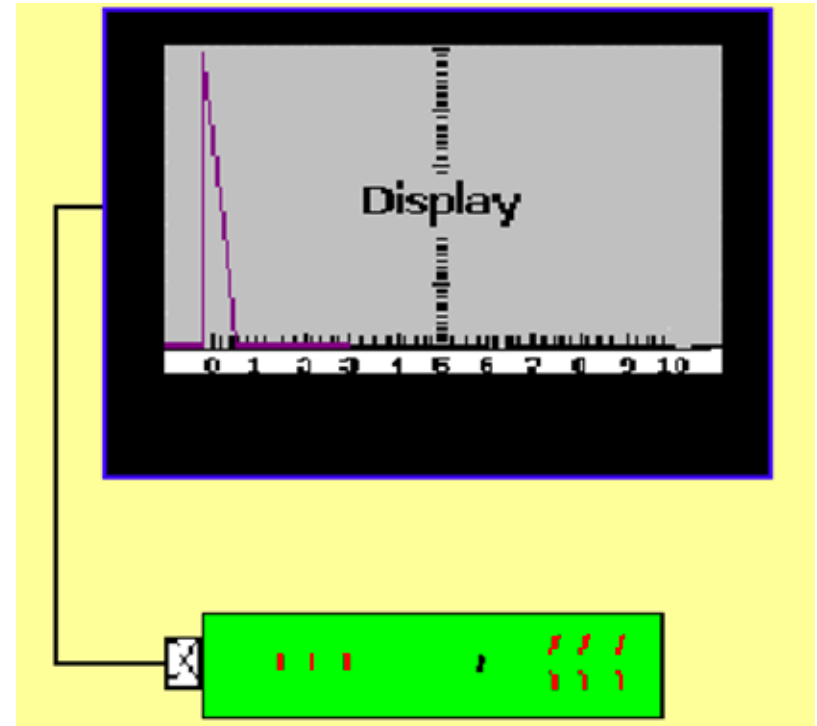
Ultrasonic Testing

- The test instrument or system sends a voltage pulse to a search unit
 - which converts the voltage into sound waves that enter the test object



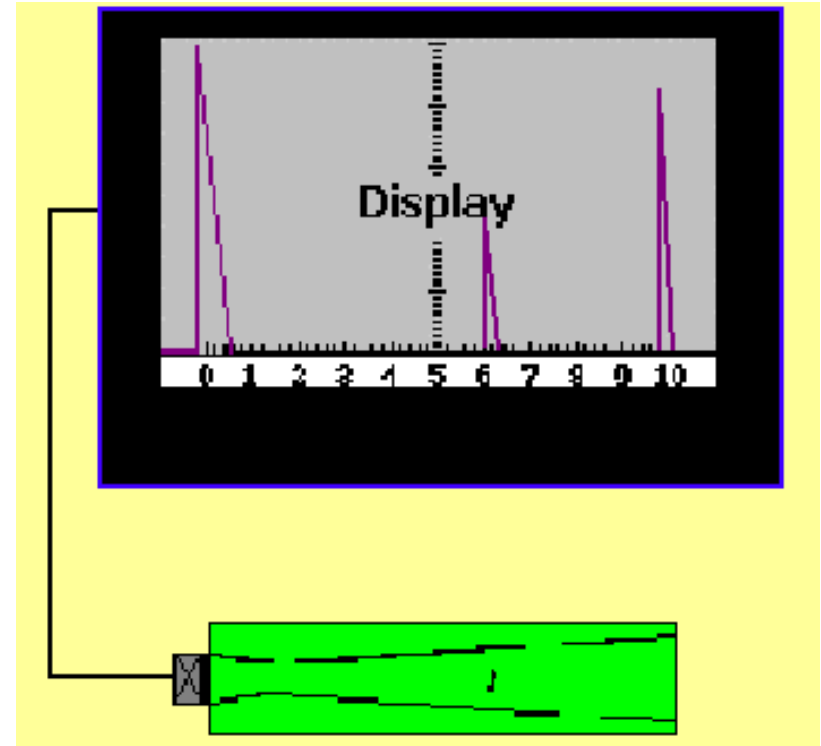
Ultrasonic Testing

- The sound travels through the test object, reflecting from any surfaces in its path, such as:
 - defect
 - rear surface



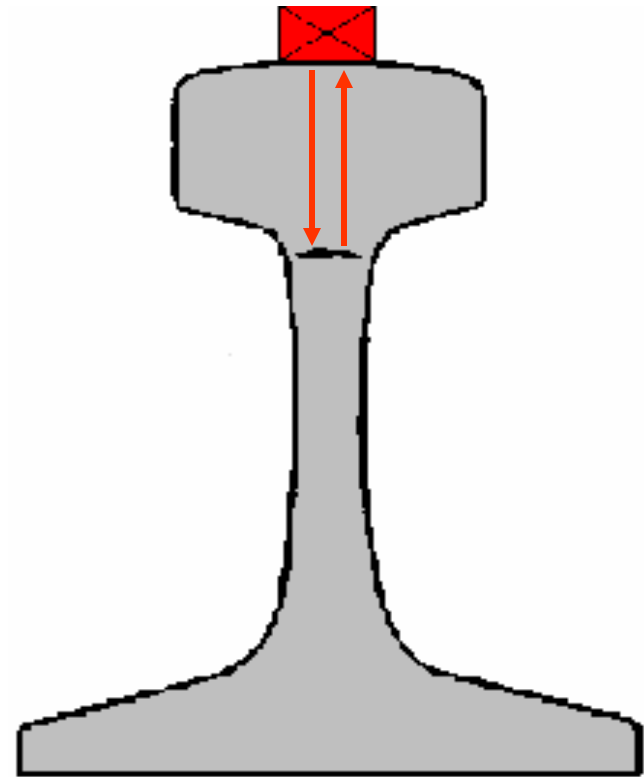
Ultrasonic Testing

- When ultrasound strikes perpendicular to a reflector:
 - It retraces its path back to the ultrasonic search unit,
 - The search unit converts the echoes into electrical signals that appears on display



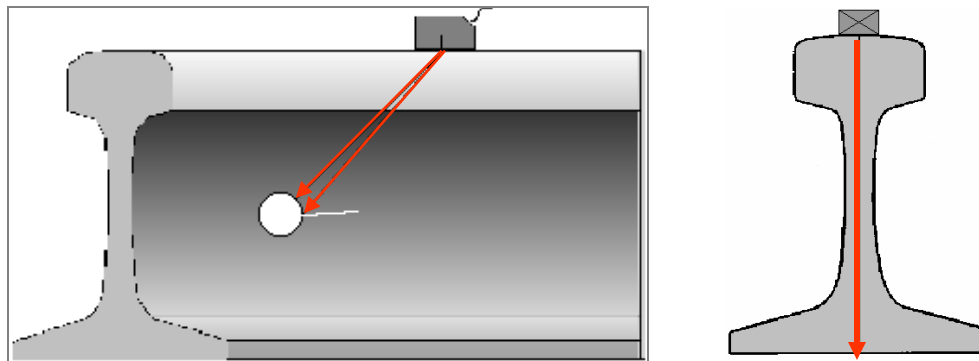
Rail Testing

- Ultrasonic Testing
 - Sends high frequency sound waves into a steel rail and receives echoes back from that rail
 - to obtain information about the internal condition of the rail



Rail Testing

- Sound traveling through a steel rail will reflect when it strikes a defect or the bottom of the rail.



Rail Testing

- Rail testing is typically done in two steps:
 - Initial automated inspection using test vehicle
 - Follow-up by verification with ultrasonic hand testing.



Test Vehicles

- The test vehicles can be:
 - Railbound vehicles
 - Hi-Rail vehicles



Test Vehicles

- Railbounds are typically one-car, self-propelled vehicles with complete crew living facilities
 - Simpler designs also used



Test Vehicles

- Hi-Rail vehicles:
 - Can be driven to a railroad crossing
 - Positioned over tracks
 - Then lower flanged railcar-type (hi-rail) wheels onto tracks.
 - Quickly removed for redeployment elsewhere



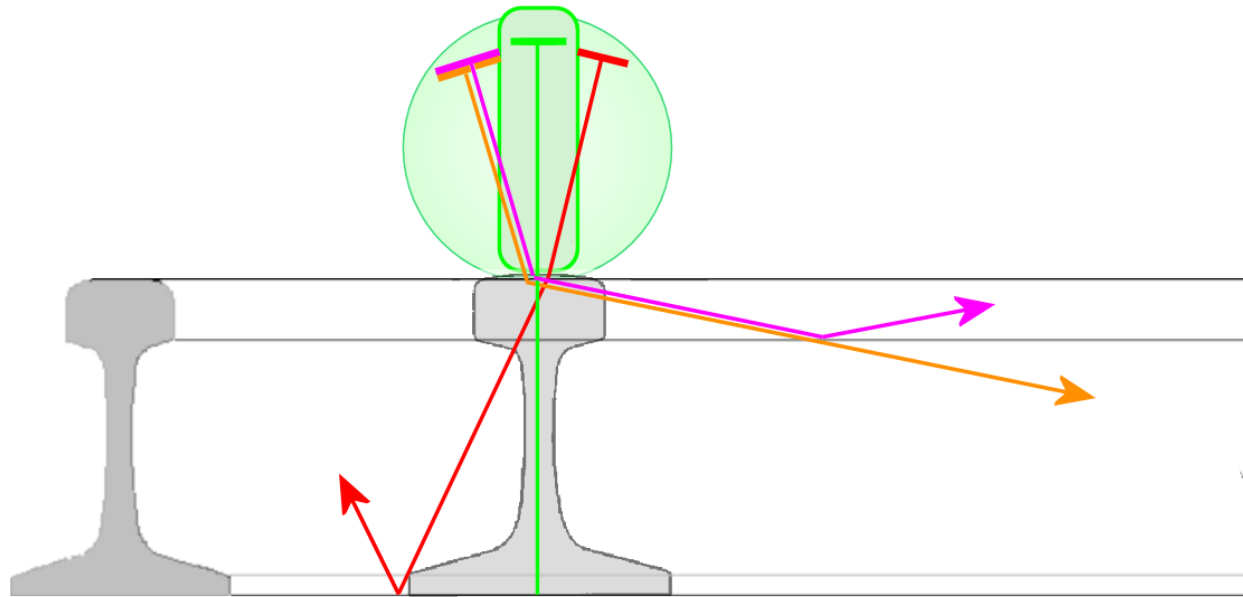
Test Vehicles

- Pedestrian Vehicles
 - Available for testing one or both tracks
 - Recent designs provide displays and test data similar to rail car systems



Test Vehicles

- Test Vehicles perform initial detection of indications
 - Using sound beams that originate from fixed points



Hand Testing

- When a possible defect is detected:
 - Test operator follows up with hand testing for verification



Rail Defects & Transducer Configurations



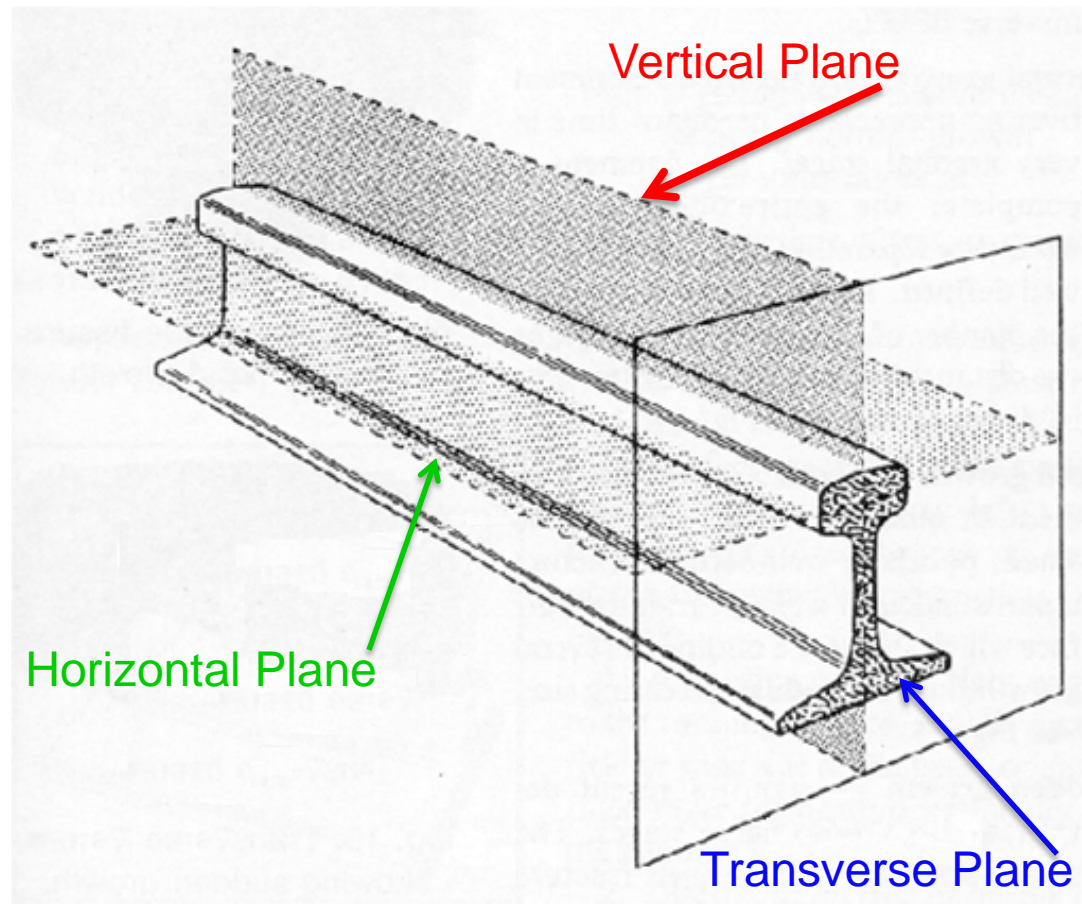
Rail Defects & Transducer Configurations

- For testing purposes, rail defects will be categorized by position and orientation in the rail.
 - Because position and orientation determine the path that ultrasonic and induction test energy must follow
 - Ideally the energy should strike perpendicular to the broad face of the defect



Rail Defects & Transducer Configurations

- Defect categories:
 - Transverse Plane Defects
 - Horizontal Plane Defects
 - Vertical Plane Defects
 - Bolt Hole Defects (horiz.- vert.- oblique)



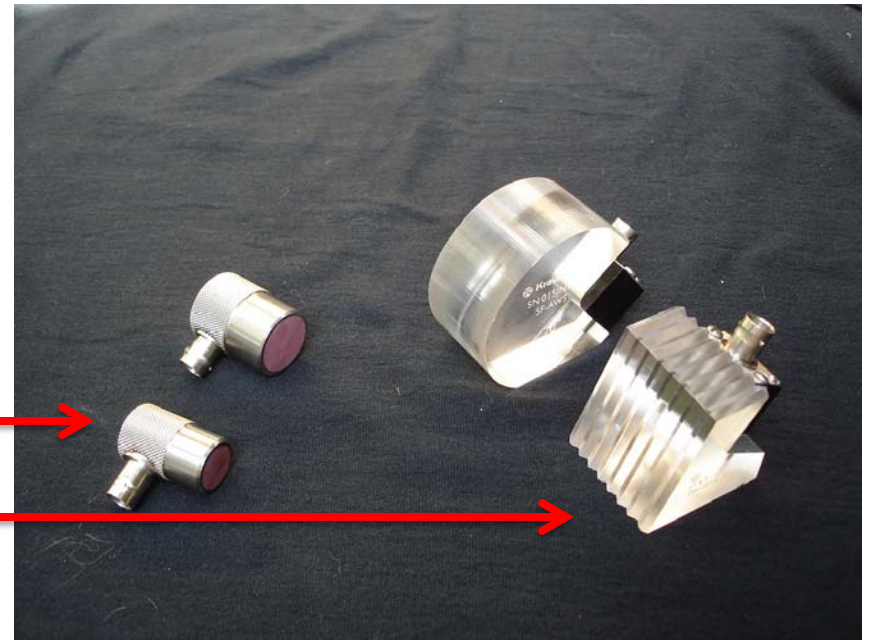
Rail Defects & Transducer Configurations

- Sound is introduced into rails using search units containing piezoelectric transducers – crystals that convert voltage sent from test instruments into sound pulses
- Because of all these defects' different orientations and locations in rail, variety of transducers required to detect them.



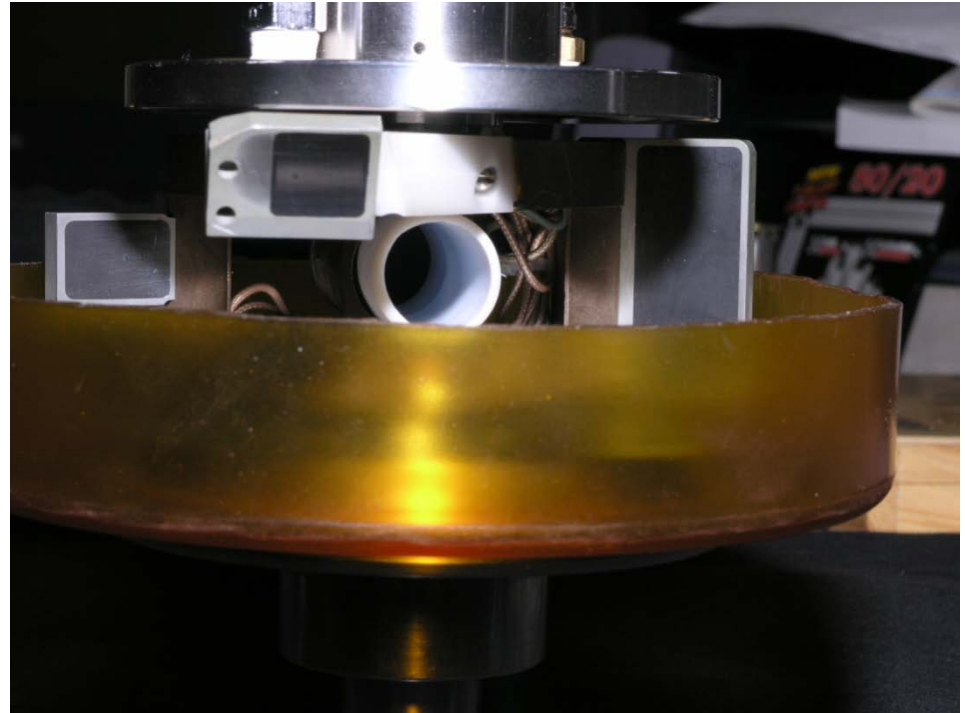
Rail Defects & Transducer Configurations

- Search units for hand testing
 - Zero Degree (straight beam)
 - Angle Beam



Rail Defects & Transducer Configurations

- Rail Cars & Pedestrian use multiple crystal configurations:
 - Wheel transducers
 - also called roller search units (RSUs)
 - transducers are contained inside liquid-filled tires

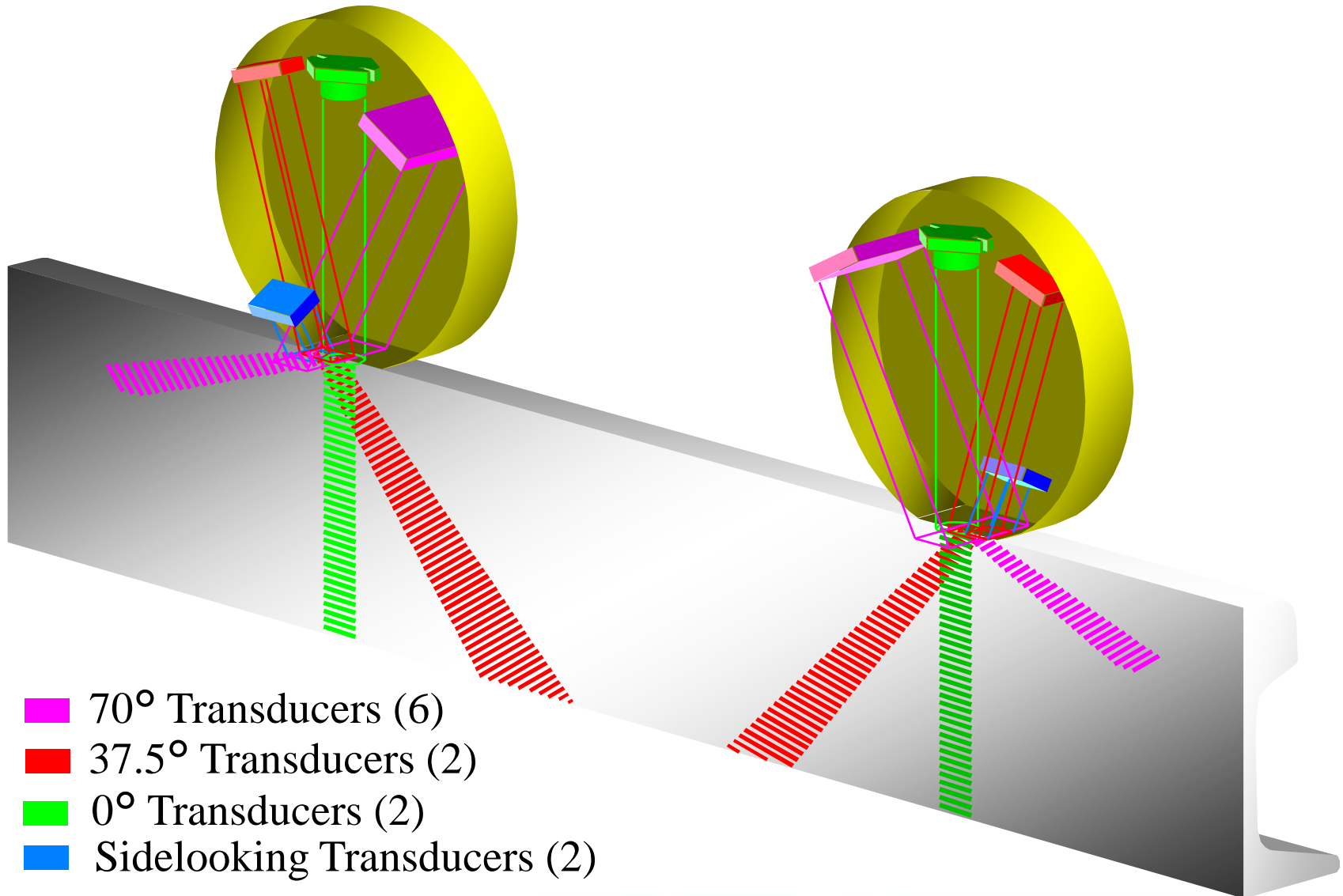


Rail Defects & Transducer Configurations

- One arrangement:
 - 12 transducers assembled into 2 RSUs
 - facing in opposite directions to accommodate defect orientation.



Rail Defects & Transducer Configurations



Rail Defects & Transducer Configurations

- 0^0 transducers detect horizontal plane defects (horizontal split head defects, head & web separation, split web)
- In addition, 0^0 verifies test integrity by monitoring the rail bottom (back reflection) echo



Rail Defects & Transducer Configurations

- ***Horizontal Plane Defects***
 - Horizontal Split Head



Defects & Transducer Configurations

Horizontal Plane Defects

Head and Web Separation



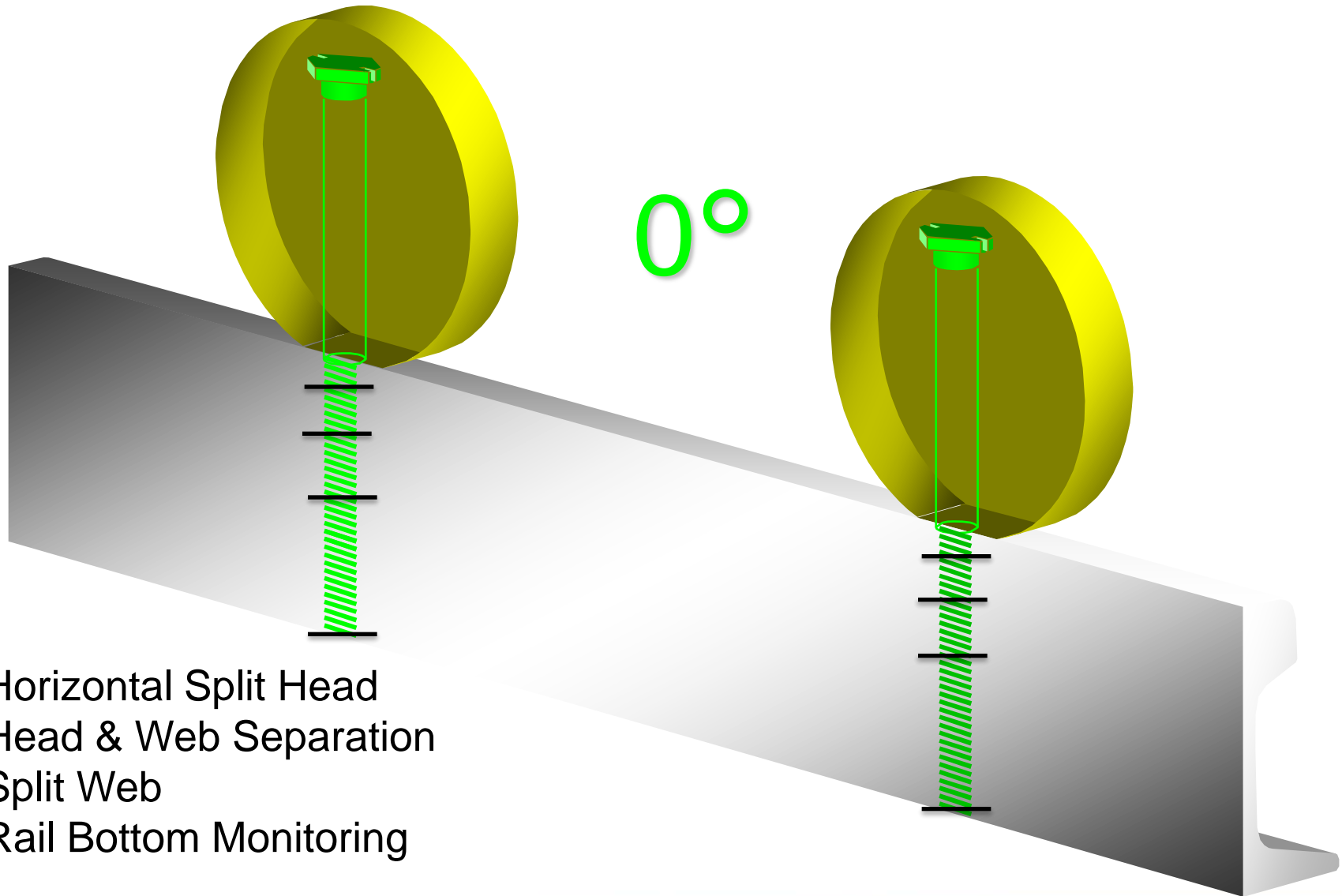
Rail Defects & Transducer Configurations

Horizontal Plane Defects

Split Web



Rail Defects & Transducer Configurations



Rail Defects & Transducer Configurations

- 37.5° transducers intended to inspect web for
 - bolt hole cracks
 - split webs
 - weld defects.



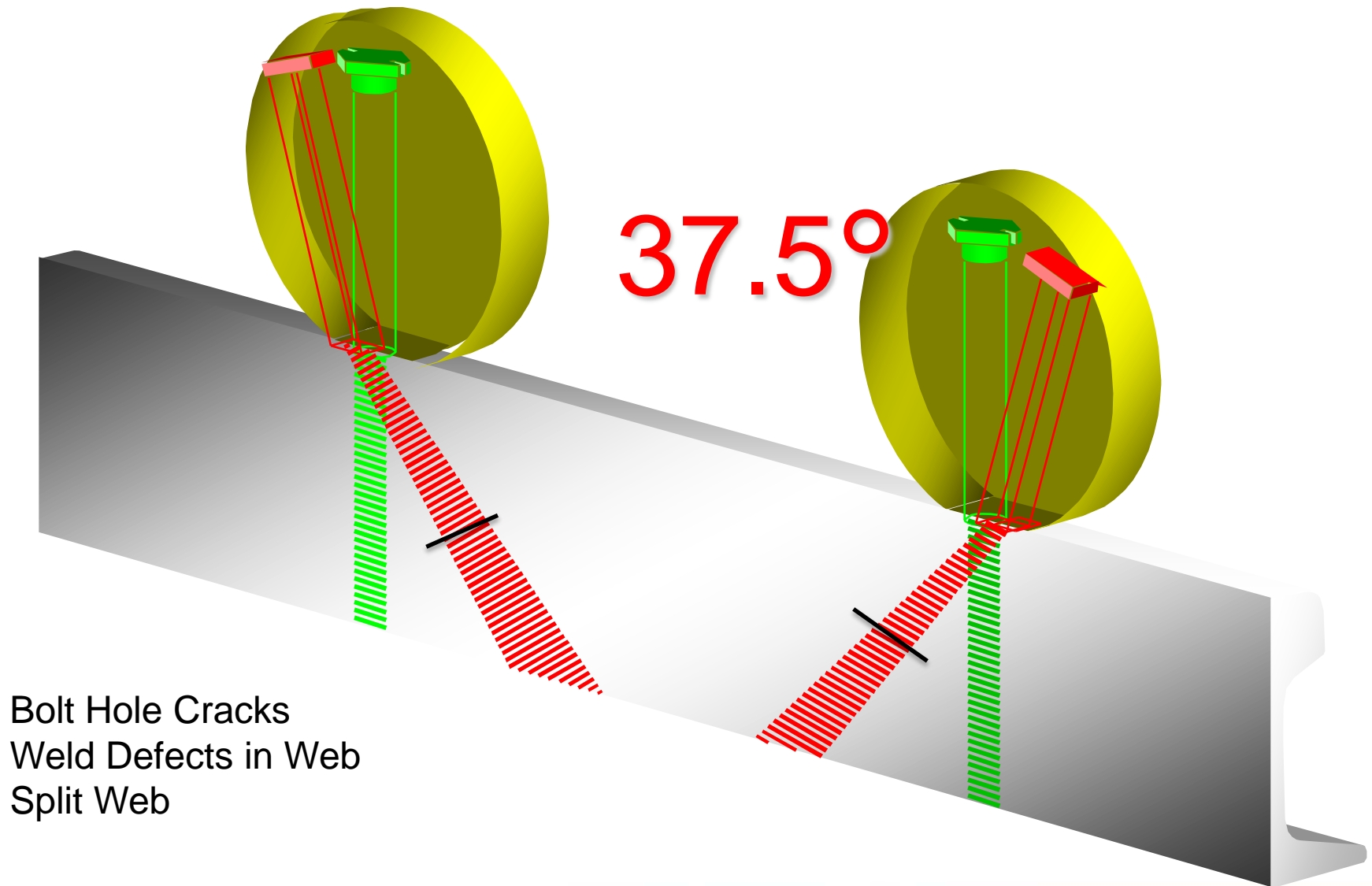
Rail Defects & Transducer Configurations

Joint Defects

Bolt Hole Crack



Rail Defects & Transducer Configurations

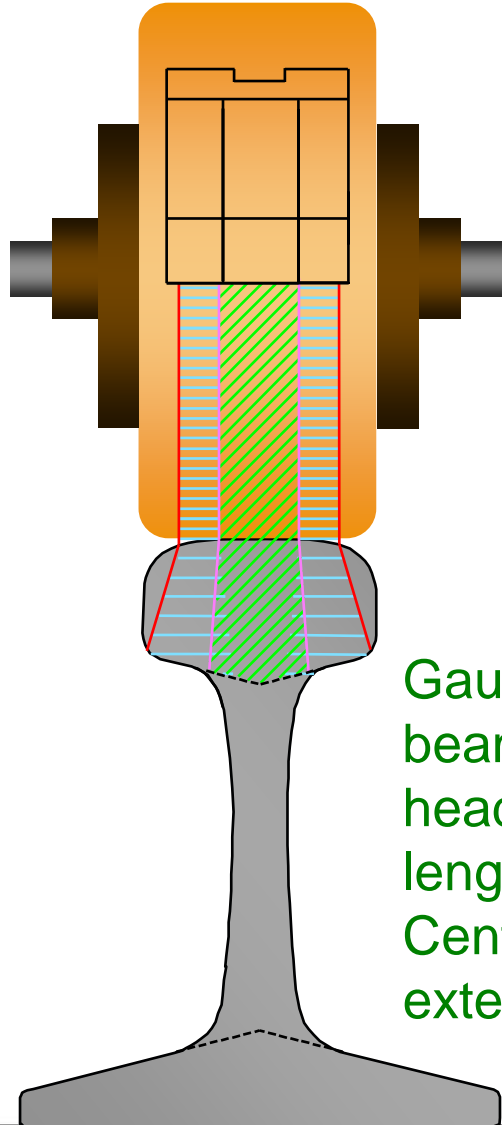


Rail Defects & Transducer Configurations

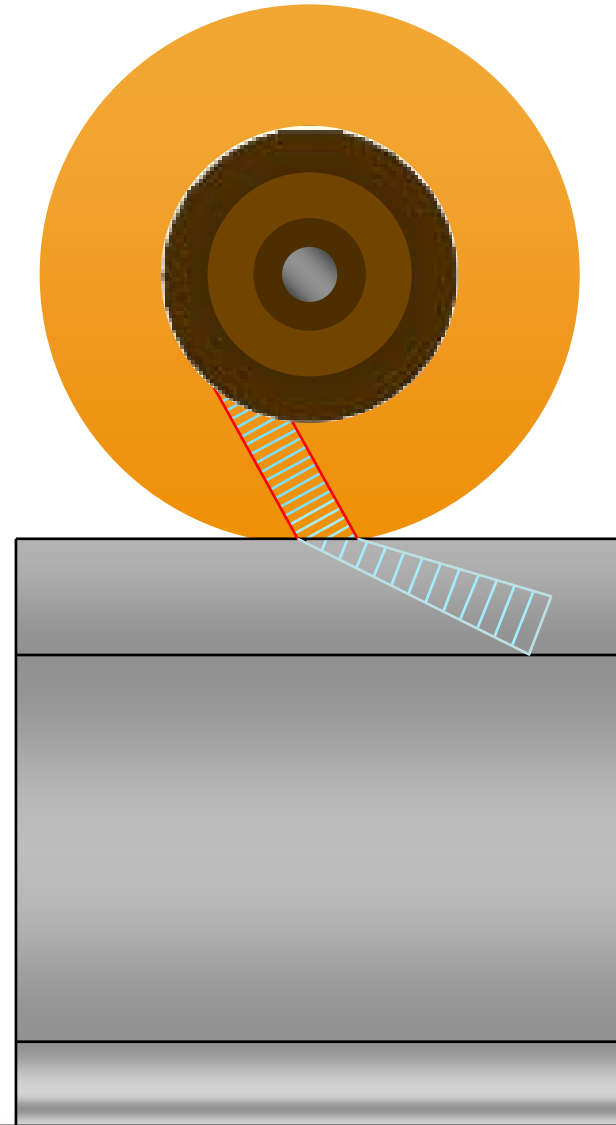
- 70° transducers (One each for gauge, center, field portions of rail head) detect:
 - Transverse defects in rail head
 - Weld defects in the head



70° Transducer 3 Element Array



Gauge and field
beams remain in
head, skipping along
length of rail
Center beam
extends into web



Rail Defects & Transducer Configurations

Transverse Plane Defects

Transverse Fissure



Rail Defects & Transducer Configurations

Transverse Plane Defects



Detail Fracture
from Shelling



Detail Fracture
from Head Check



Reverse Detail
Fracture



Rail Defects & Transducer Configurations

Transverse Plane Defects

Compound Fracture



Rail Defects & Transducer Configurations

Transverse Plane Defects

Engine Burn Fracture



Rail Defects & Transducer Configurations

Transverse Plane Defects

Welded Burn Fracture



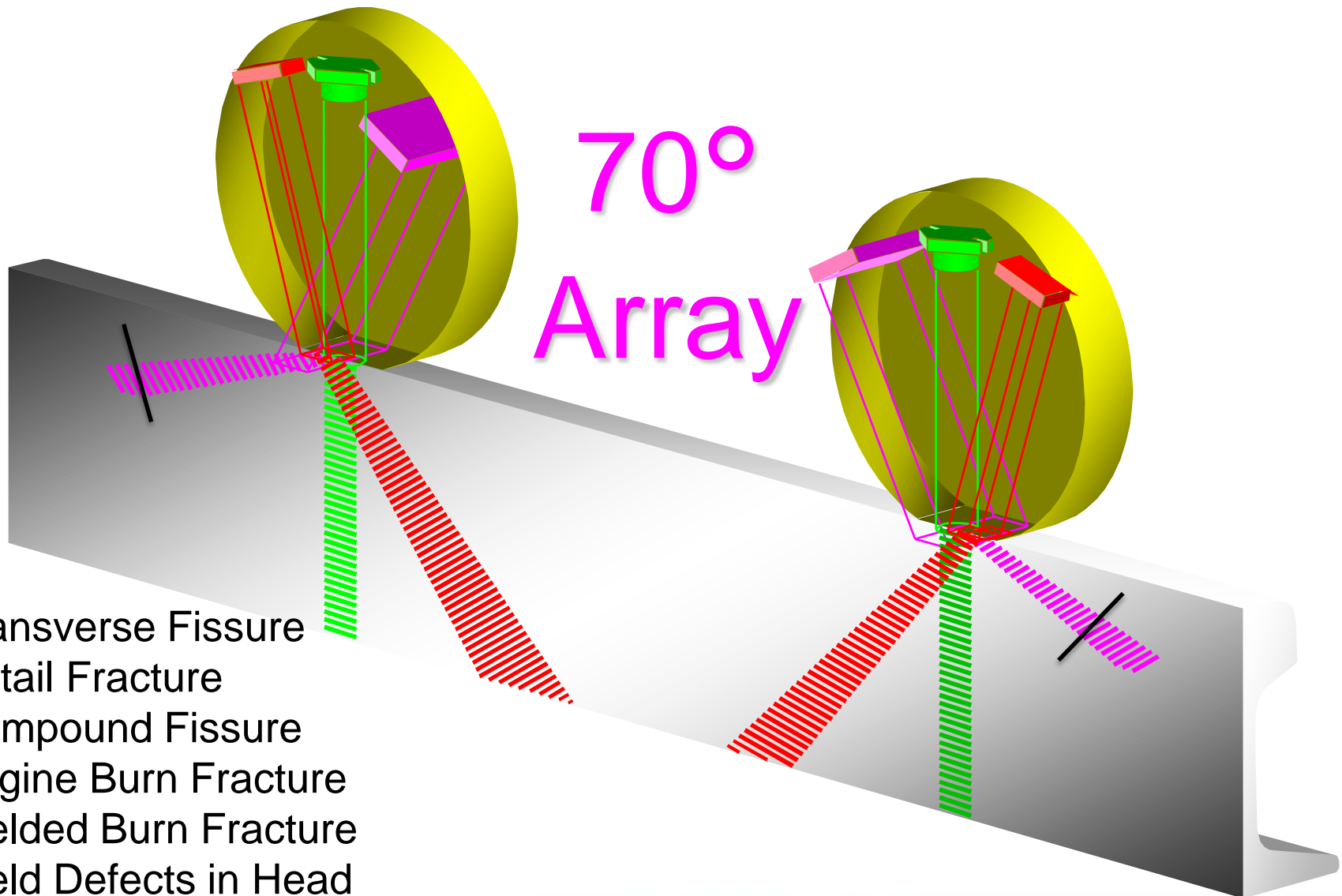
Rail Defects & Transducer Configurations

Transverse Plane Defects

Weld Defects



Rail Defects & Transducer Configurations



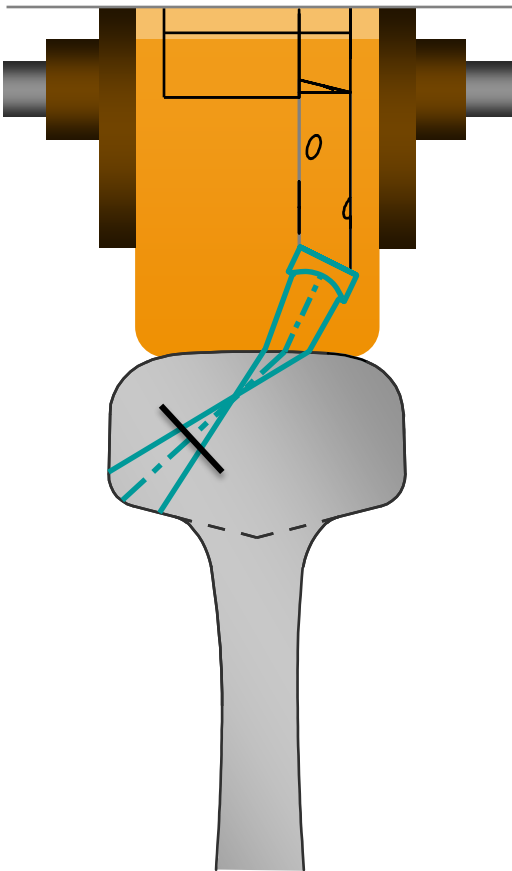
Rail Defects & Transducer Configurations

- Side-looking transducers direct beams diagonally across head to intercept vertical split heads and shear breaks.



Rail Defects & Transducer Configurations

Vertical Plane Defects



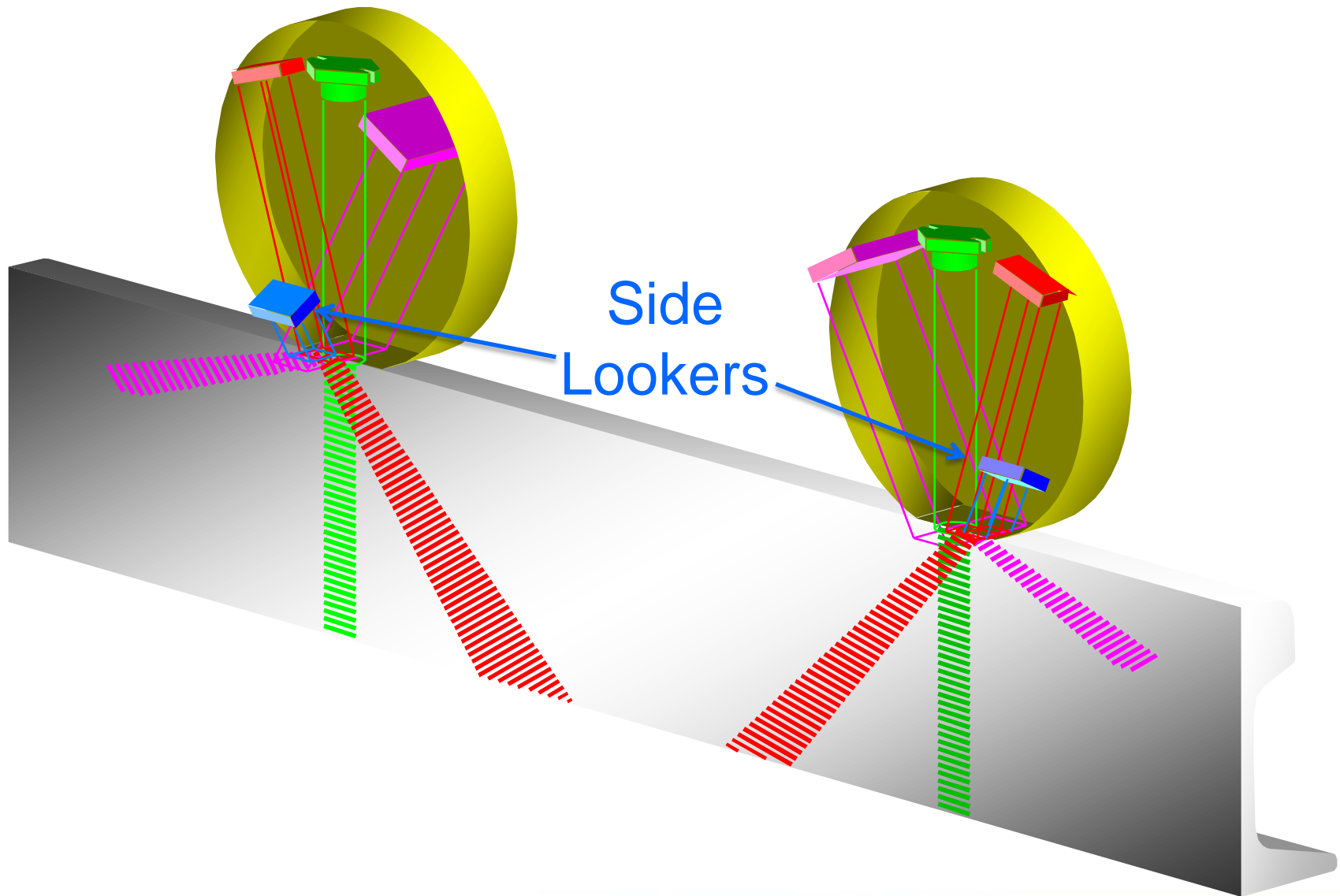
Vertical Split Head



Shear Break

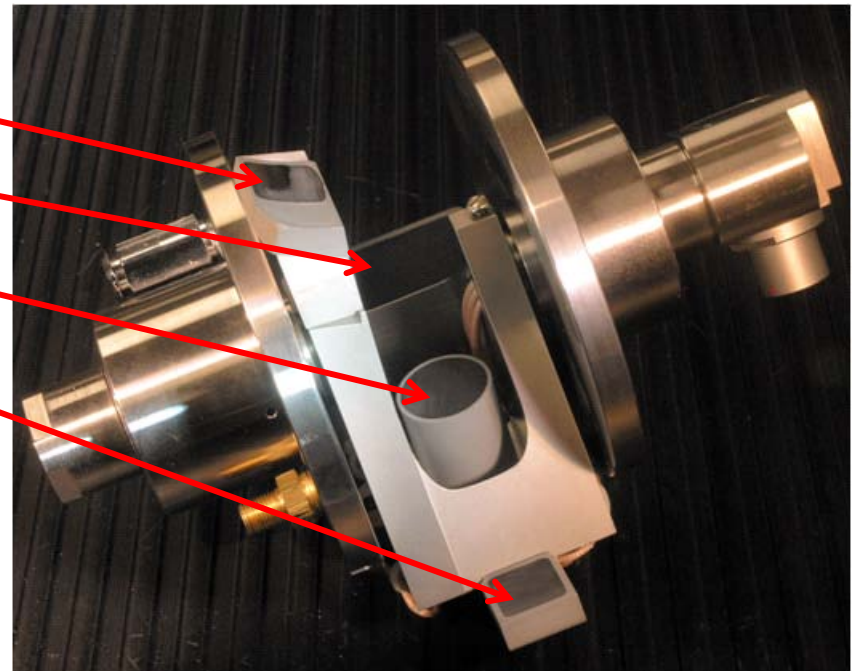


Rail Defects & Transducer Configurations



Rail Defects & Transducer Configurations

- The hardware
 - One side-looker
 - Three 70 degrees
 - One zero degree
 - One 37.5 degree



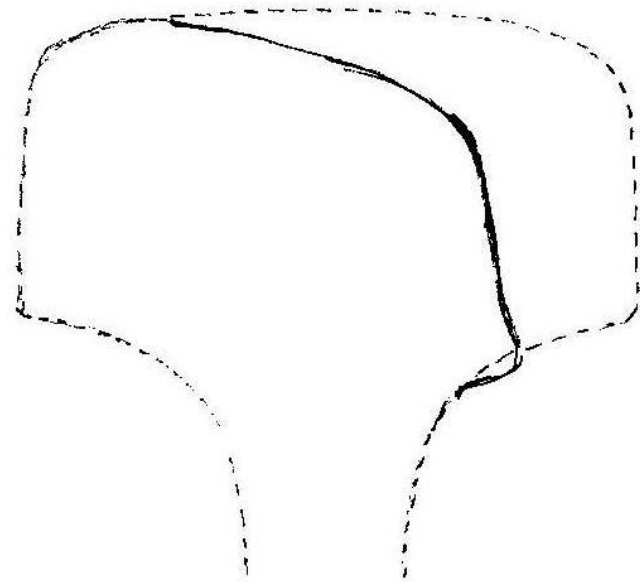
Rail Defects & Transducer Configurations

- 12 transducer arrangement works well if:
 - rail profile has not become distorted from excessive wear
 - there are no obstructions preventing the various sound beams from properly entering the rail



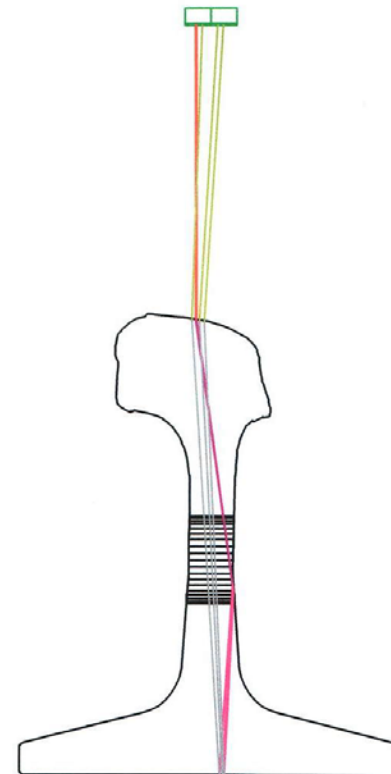
Rail Defects & Transducer Configurations

- Problem:
 - Friction between wheel flange and gauge side of head can distort head profile
 - alters effective incident angles of sound beams approaching rail



Rail Defects & Transducer Configurations

- Result:
 - sound beams entering rail deflect away from intended paths
 - degrades test integrity



Rail Defects & Transducer Configurations

- Additional disturbances are caused by various types of surface blemishes and condition called shelling
 - Shelling is horizontal separation close to test surface on gage side
 - Not normally rejectable, shelling interrupts sound path of 70° angle beams from intercepting detail fractures.



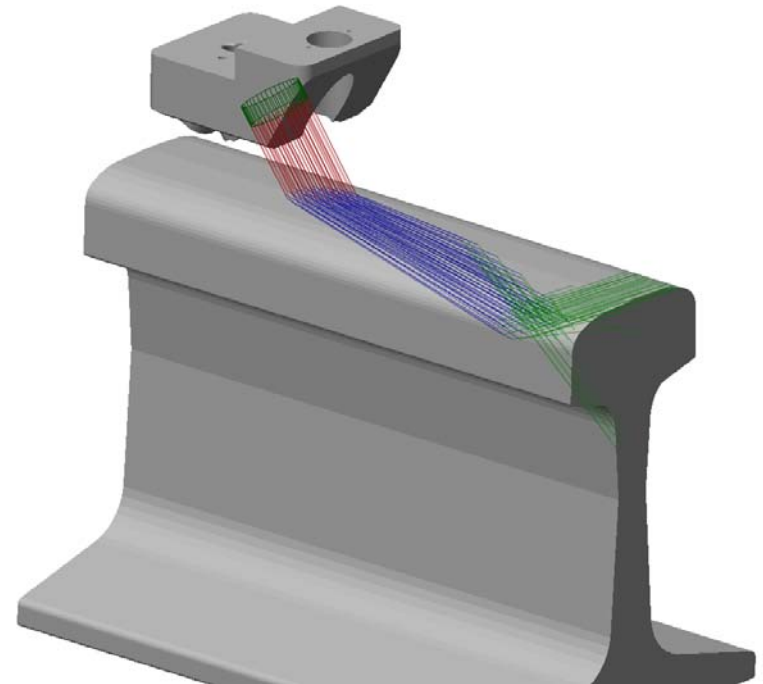
Rail Defects & Transducer Configurations

- These problems can be addressed with 3rd RSU, containing
 - Pair of 70° s
 - Single 0°



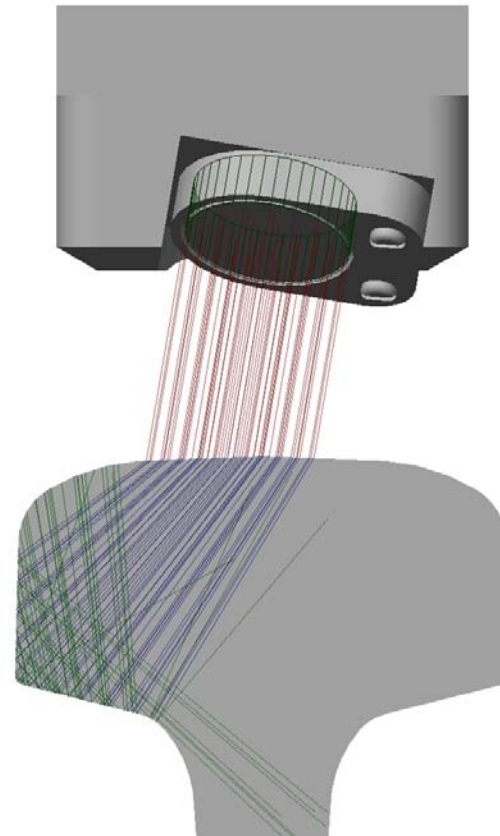
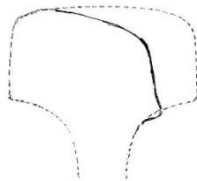
Rail Defects & Transducer Configurations

- In contrast to main 70^0 beams these 70^0 s
 - Enter the railhead at its center
 - Are skewed toward gauge side.



Rail Defects & Transducer Configurations

- Additional trajectory can direct sound toward detail fractures under shells
 - Also useful for improving sound directivity where railhead is so worn and distorted that sound beam can no longer achieve desired refracted angle



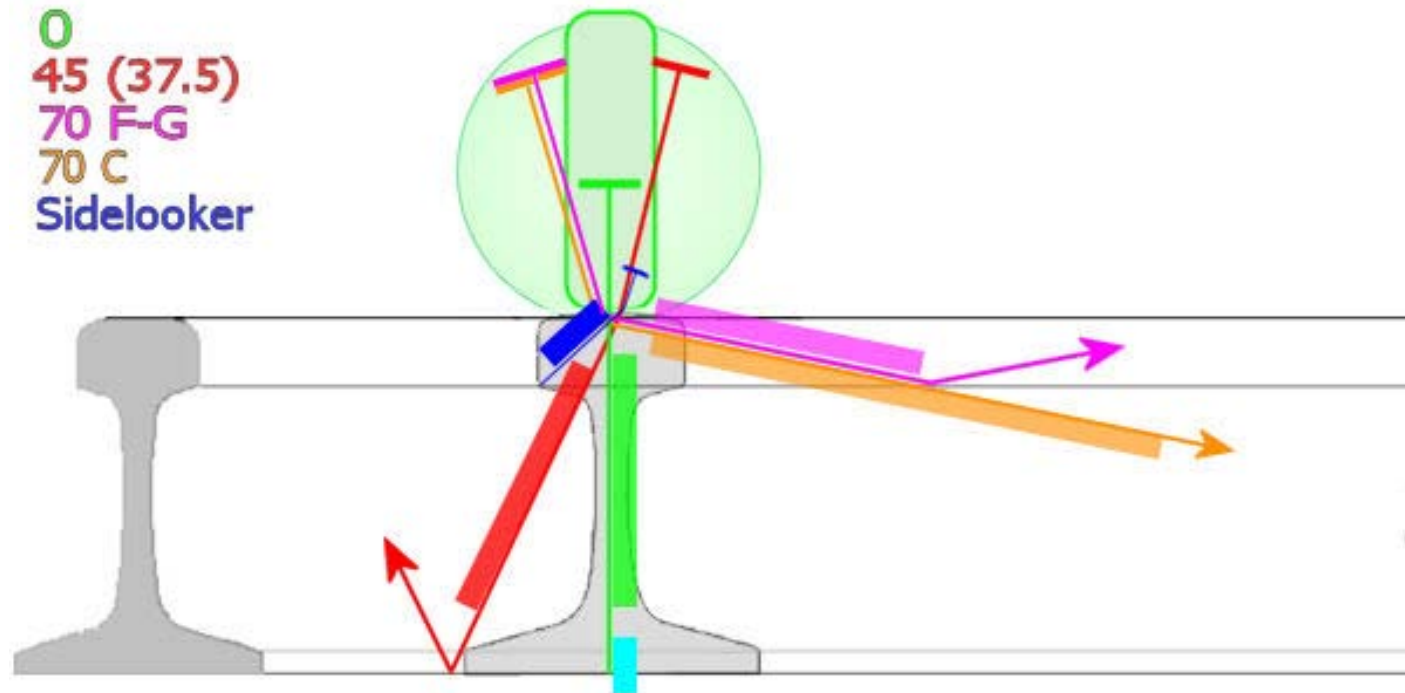
Rail Defects & Transducer Configurations

- Configuration has now become:
 - 3 RSUs with 15 transducers emitting ultrasound into the confined space of each rail
 - requires precise management in order to produce well organized readout.



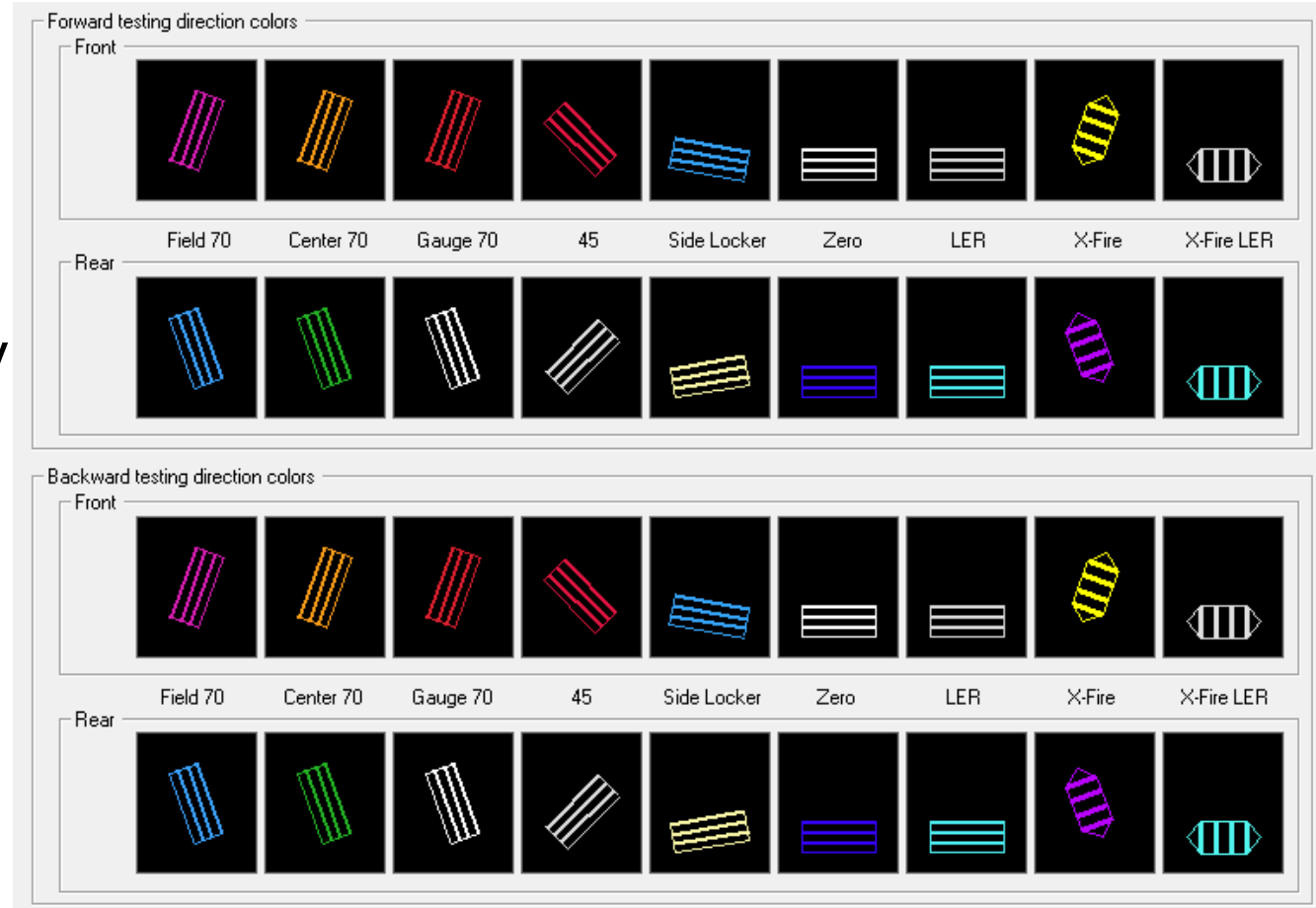
Rail Defects & Transducer Configurations

Challenge is met with a system of gates that select the desired segment from each transducer's sound path for display



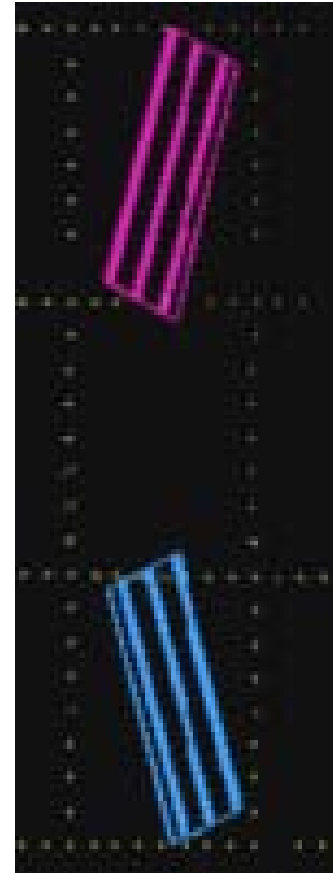
Rail Defects & Transducer Configurations

Symbols that are color-coded and angled identify which transducer(s) received indications



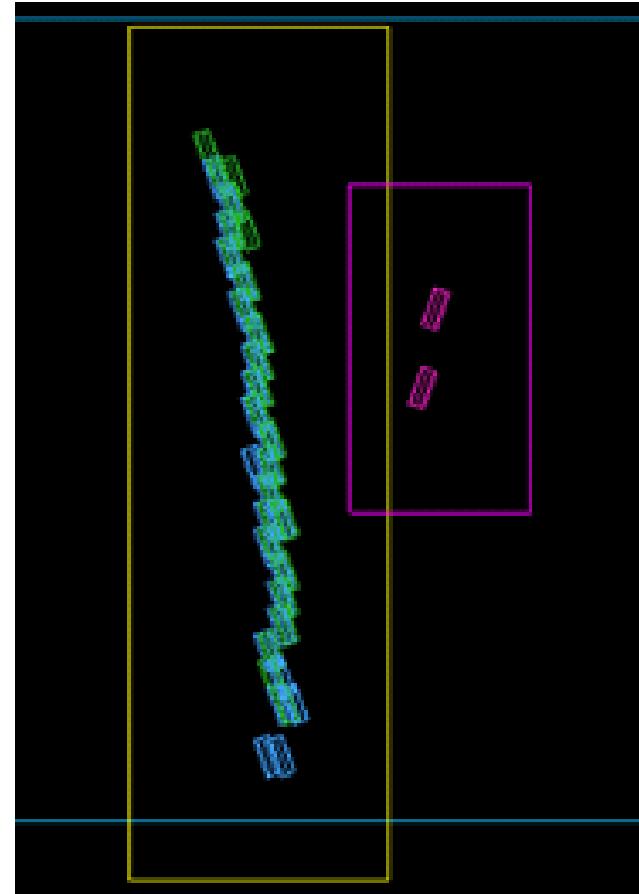
Rail Defects & Transducer Configurations

- Openings in marks enable individual identification of separate marks which are overlaid.



Rail Defects & Transducer Configurations

- Each “hit” on a given transducer places corresponding mark on the display.

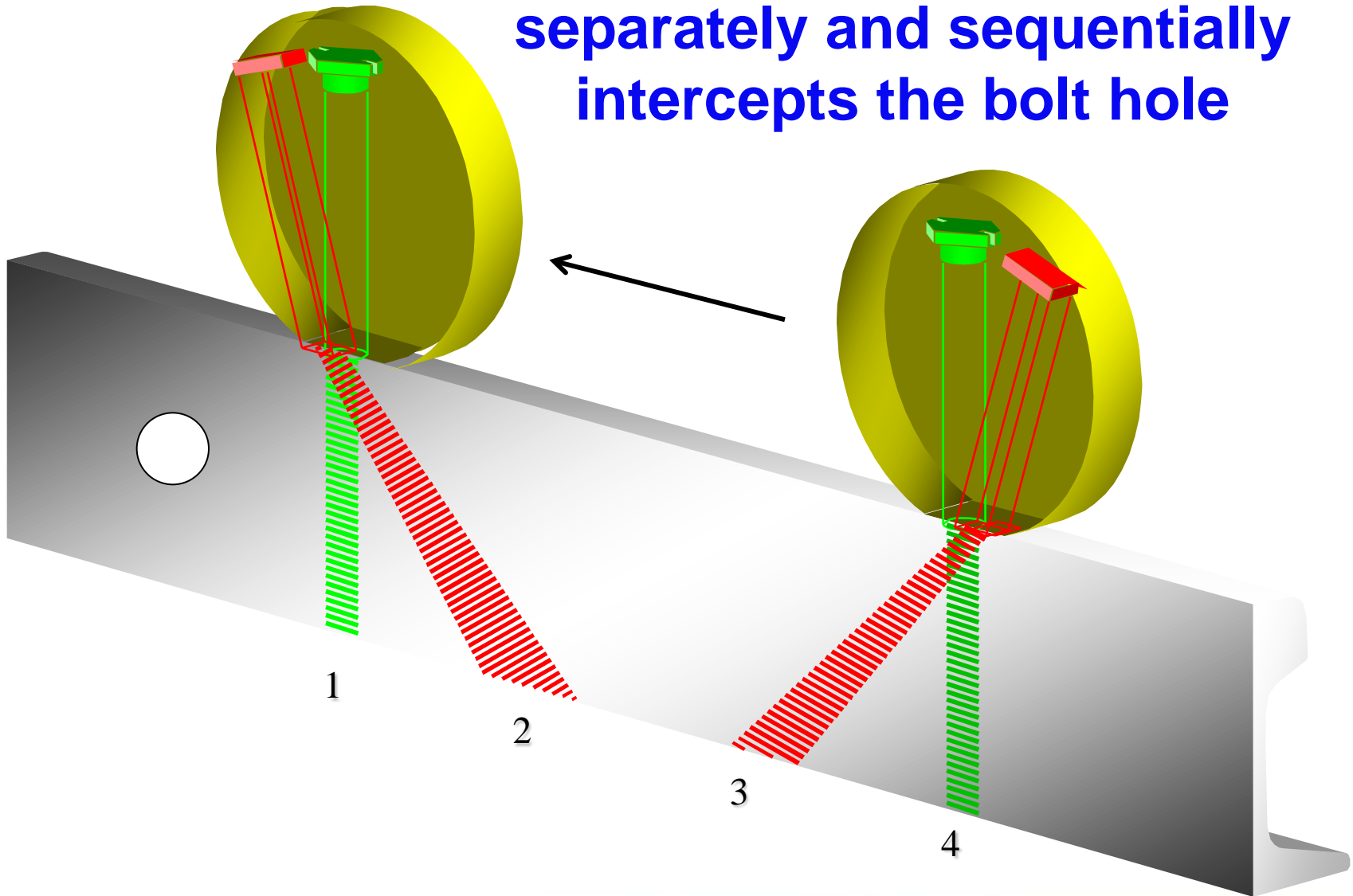


Rail Defects & Transducer Configurations

- Also needed is means of arranging the indications so that they appear in their correct positions on the display
 - For example, a bolt hole will return echoes from each of two 0^0 and two 37.5^0 transducers.

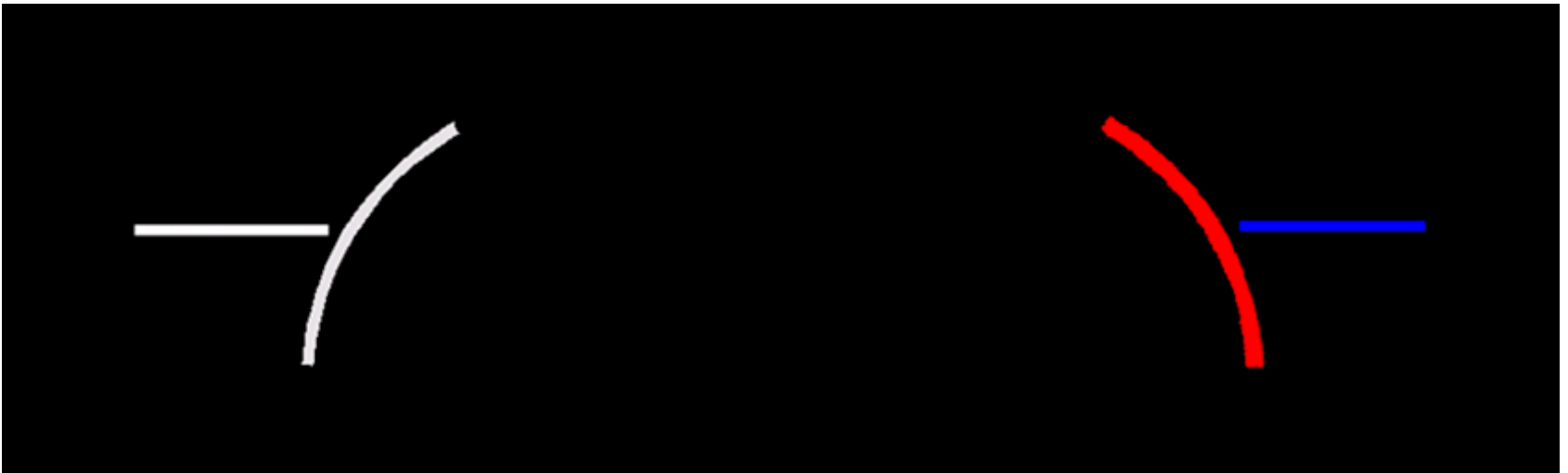


**Beam from each transducer
separately and sequentially
intercepts the bolt hole**



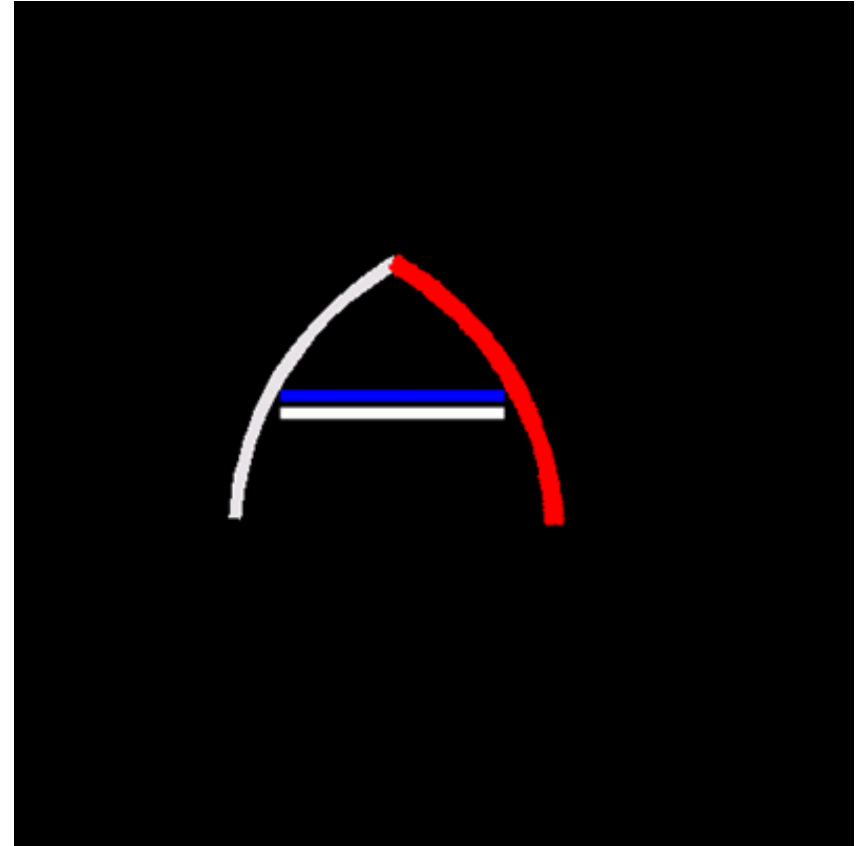
Rail Defects & Transducer Configurations

- And will display indications at separate points on the display rather than closely connected.



Rail Defects & Transducer Configurations

- Intervention by “spatial transformation” software solves problem
 - Takes slice of data from all transducers every $1/32$ ”
 - Applies trig to all angle beam sound paths
 - Stores in triple matrix
 - Transfers to B-Scan display when all transducers have gathered data from a given rail location

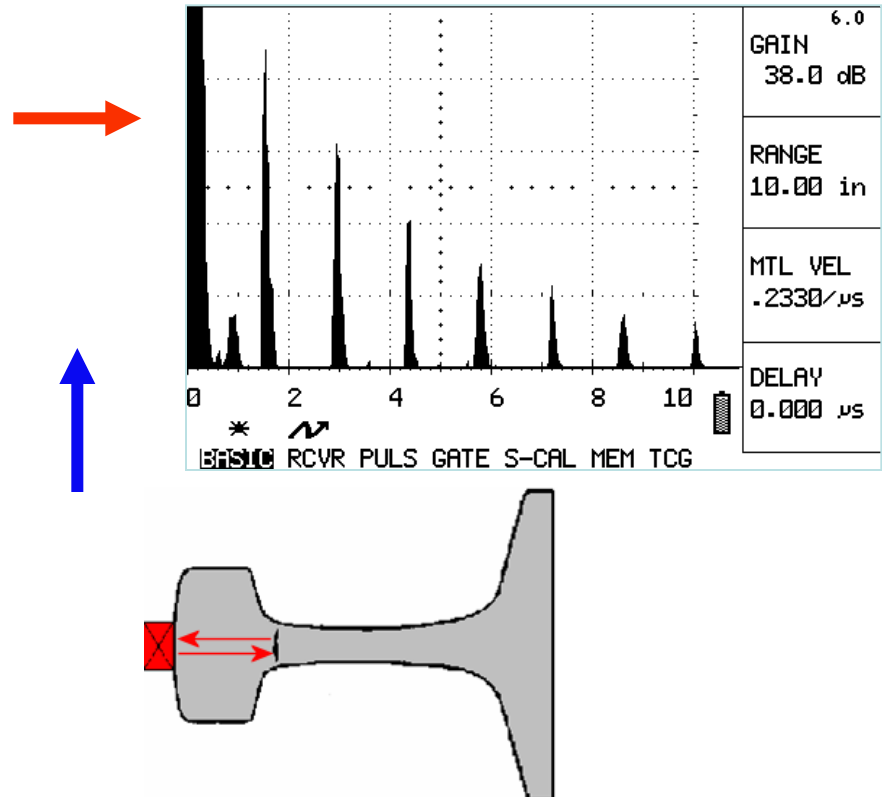


Signal Interpretation



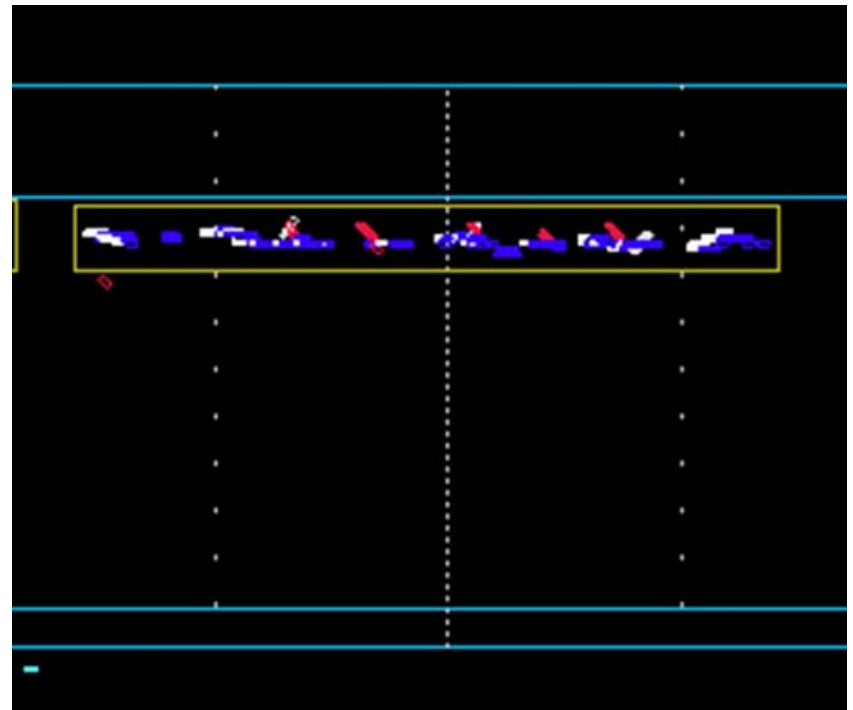
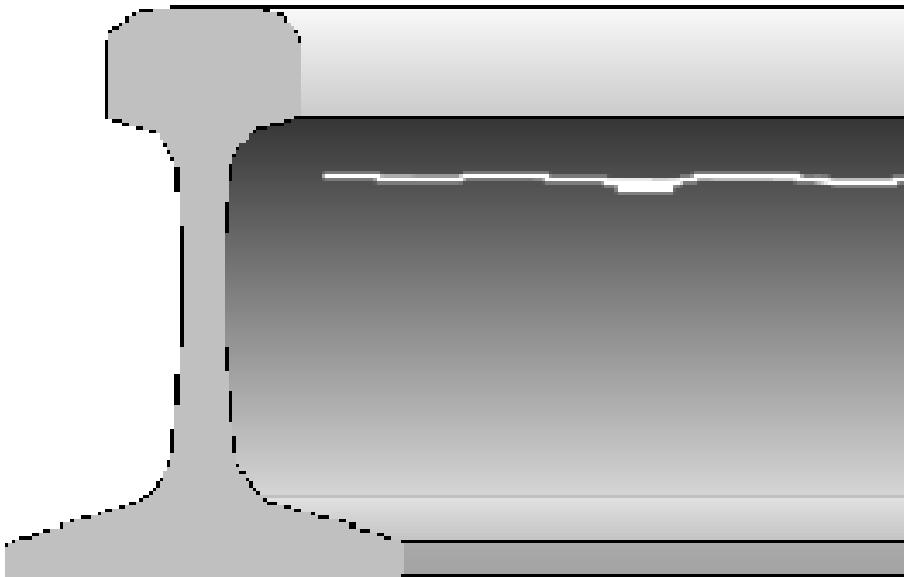
Displays: A-Scan

- Horizontal scale
 - Shows time for sound to travel
 - to determine distance to reflectors
- Vertical scale
 - Shows amplitude of received echoes
 - to help determine the size of reflectors such as rail defects



Displays: B-Scan

- Pictorial & Intuitive – graphic image of rail



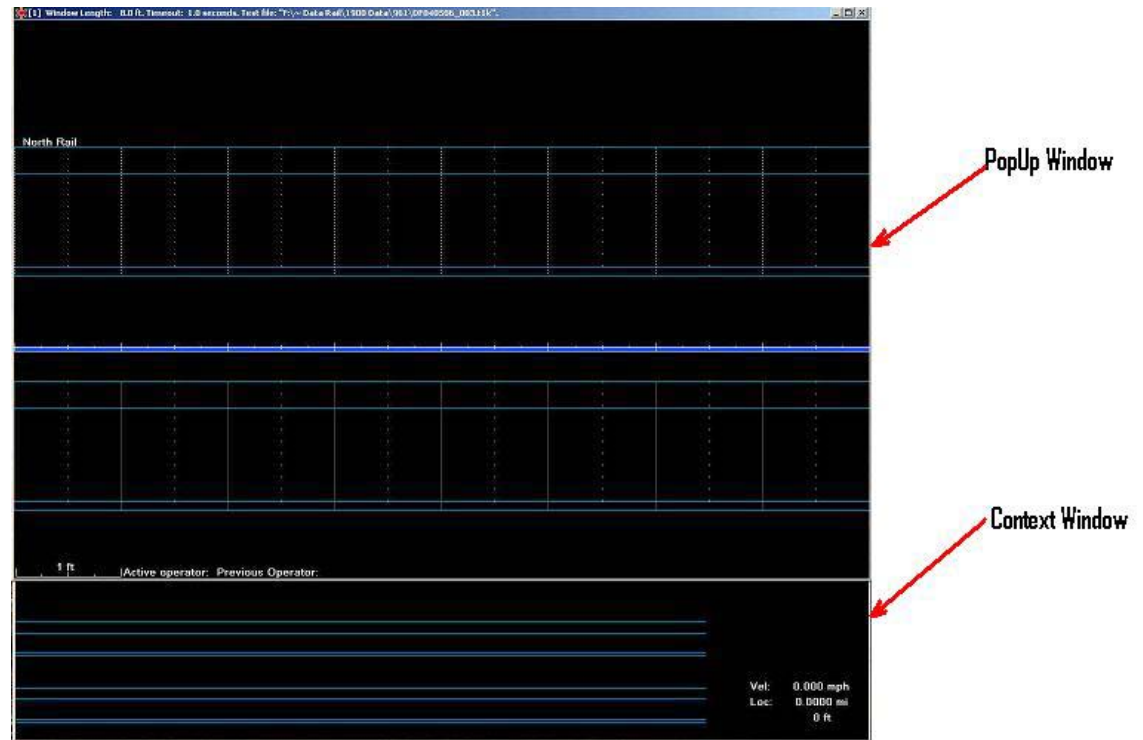
Signal Interpretation

- Various B-Scan schemes are in use
- One system employs two window display, as follows



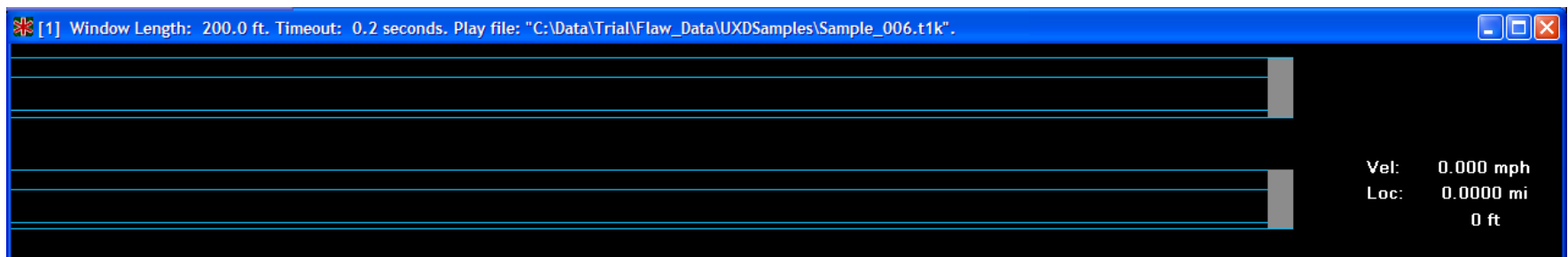
Signal Interpretation

- A smaller *context* window on the bottom and a larger *popup* window on top



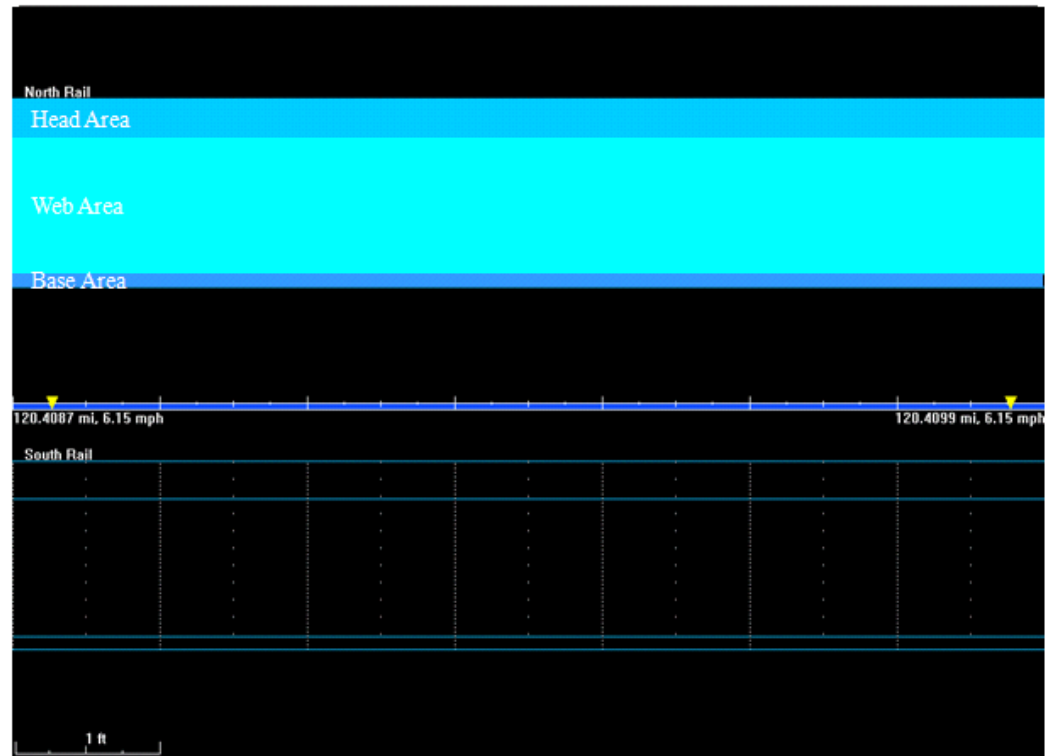
Signal Interpretation

- The context window shows the running progress of the test along the rails, displaying indications for all received echoes, with a cursor showing the position of information captured in the popup window.



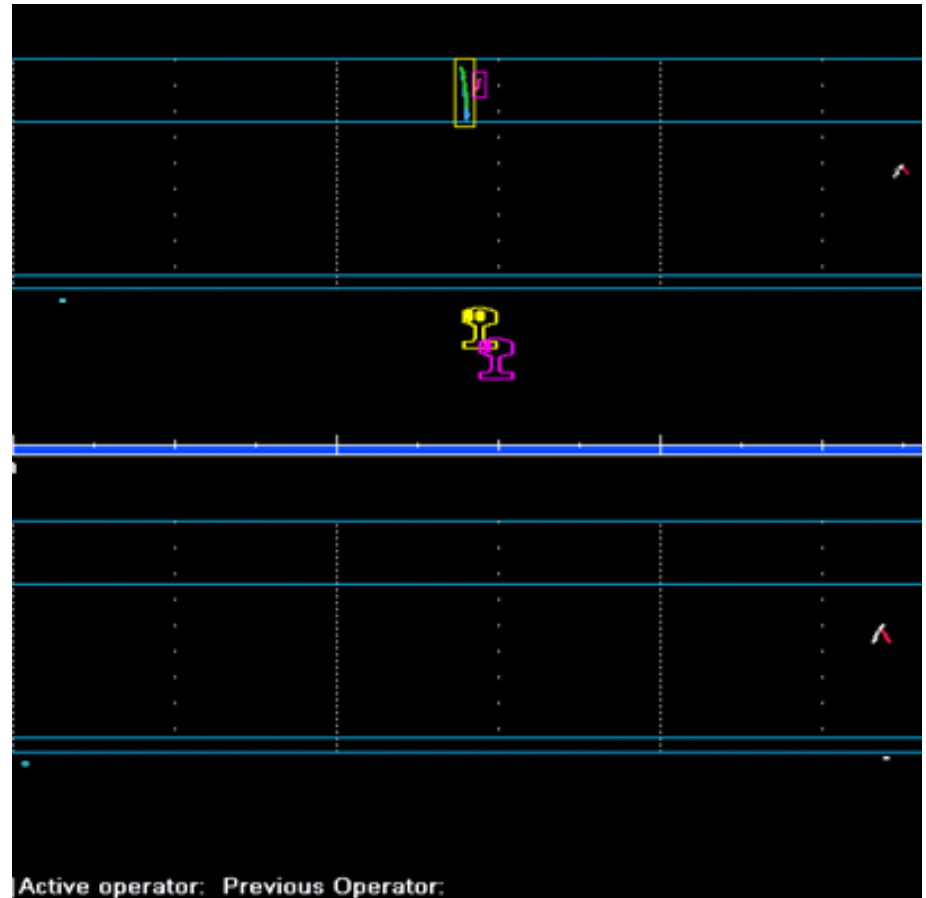
Signal Interpretation

- In the popup window, the left rail is shown on top, the right rail on the bottom.
- Horizontal lines are positioned to represent the head, web, and base portions of the rail
 - enabling test operators to imagine that they are looking into the rail.



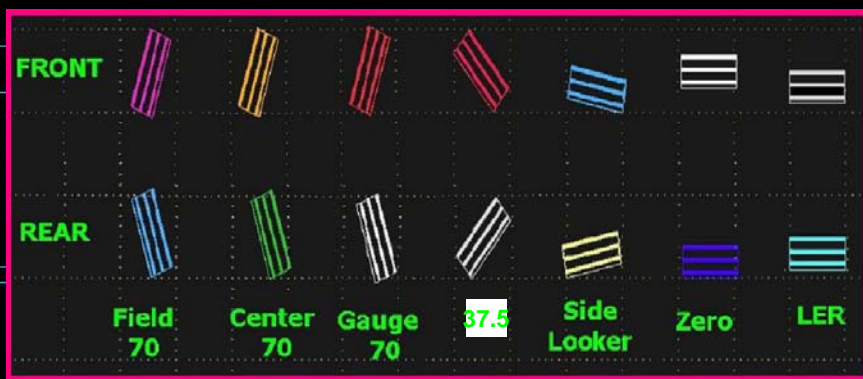
Signal Interpretation

- The popup window employs “recognition” software
 - only shows rail segments that the system recognizes as being of interest to operator.
 - boxes appear around most significant indications
 - icons suggesting causes of those indications appear below.





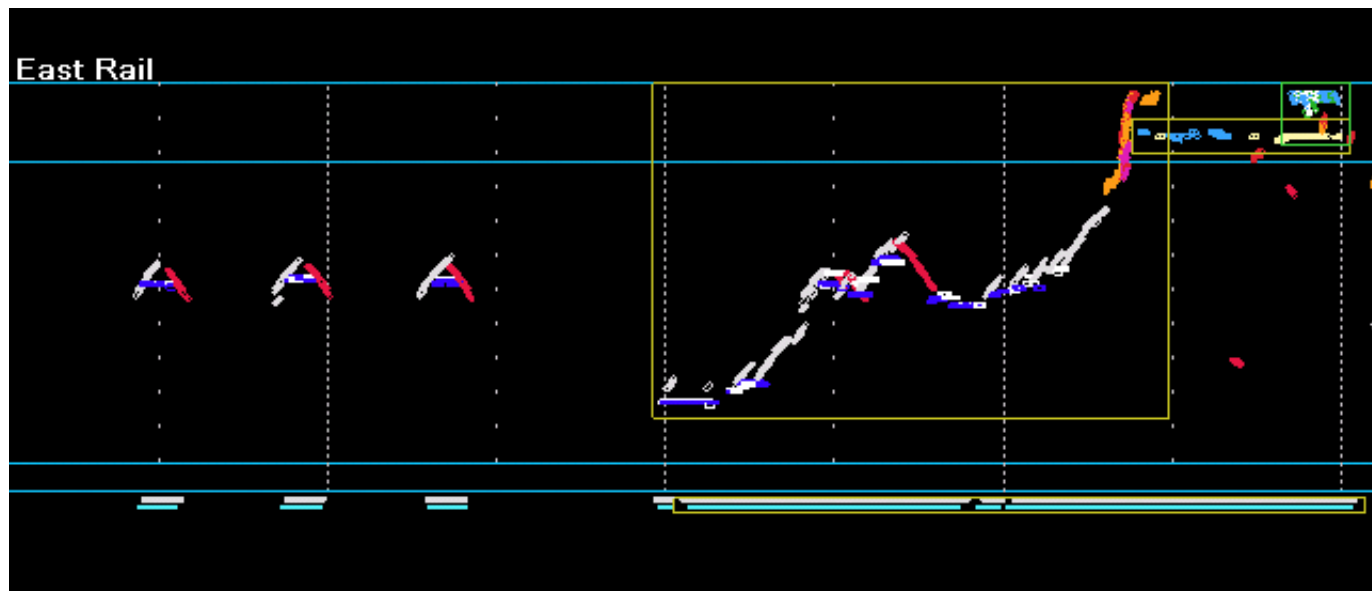
Fencelet Channel Map



Analyzing Signals

Bolt Hole Cracking

- A-shaped indications: reflections from bolt holes received by 0° and 37.5°
- Gray and cyan lines below the base: “loss of bottom” signals,
- Note the boxed areas, suggesting defects



Analyzing Signals

Carom Shot

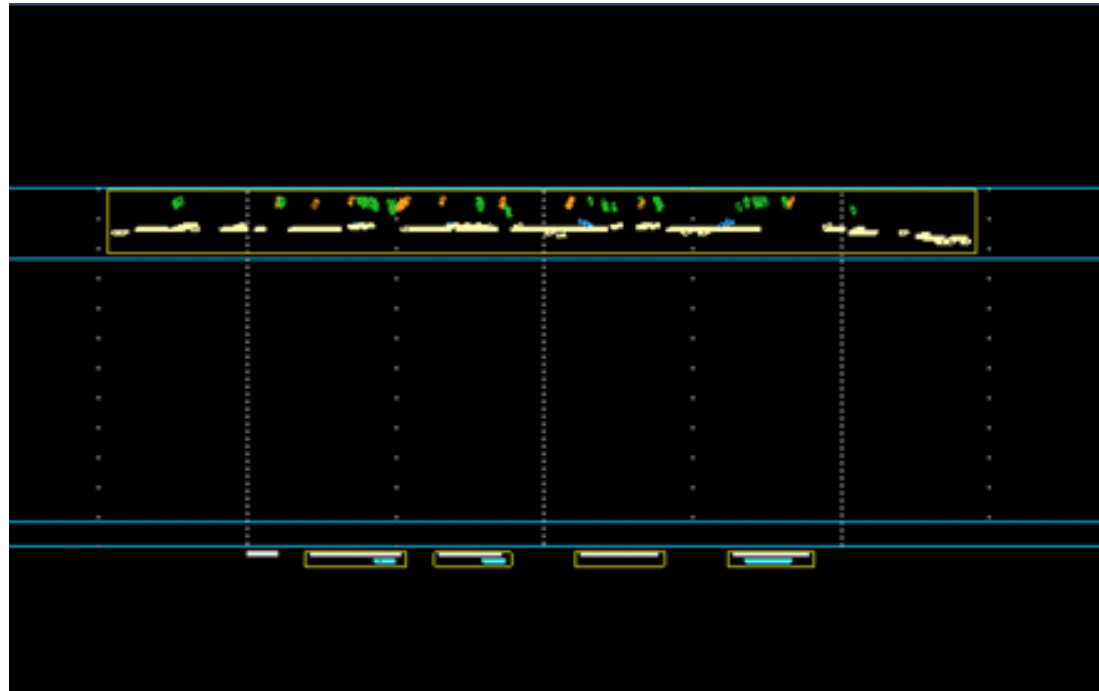
- Sound reflects off the rail end & displays on the other side of the joint



Analyzing Signals

Vertical Split Head

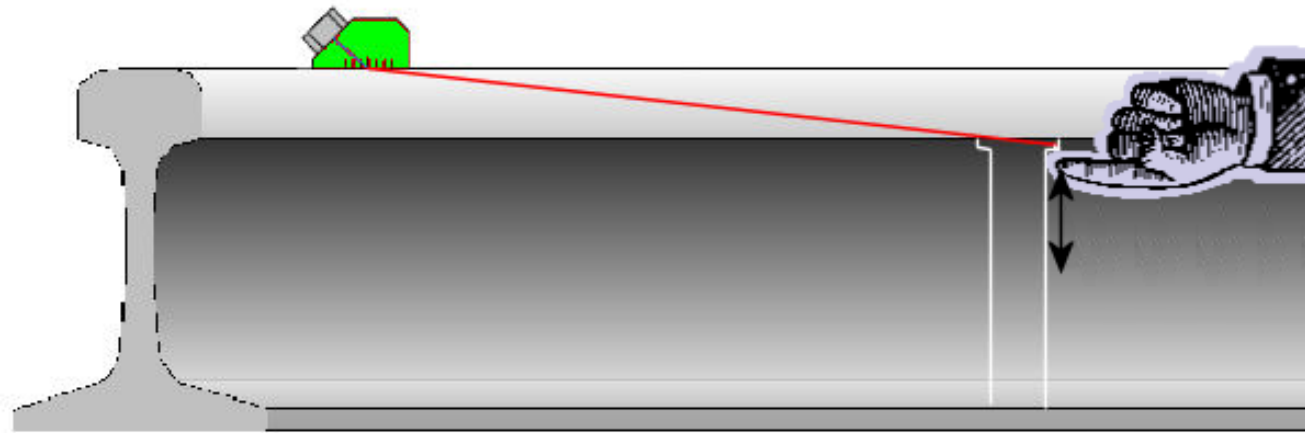
- VSH can return signals from multiple channels



Analyzing Signals

Weld Contour vs. Defect

- Weld Crown vs. Actual Weld Defect
 - Finger Damp
 - Measure Distance
 - Observe Signal Dynamics



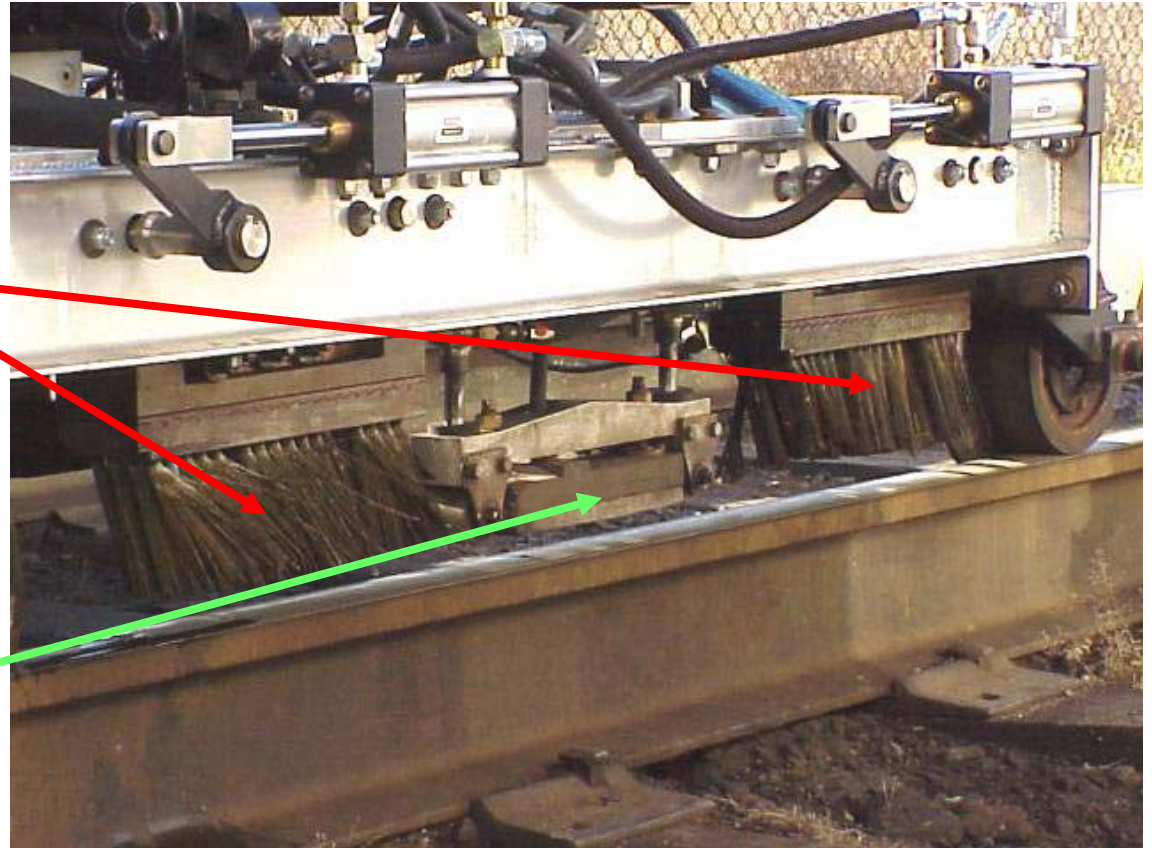
Induction Testing



Induction Testing

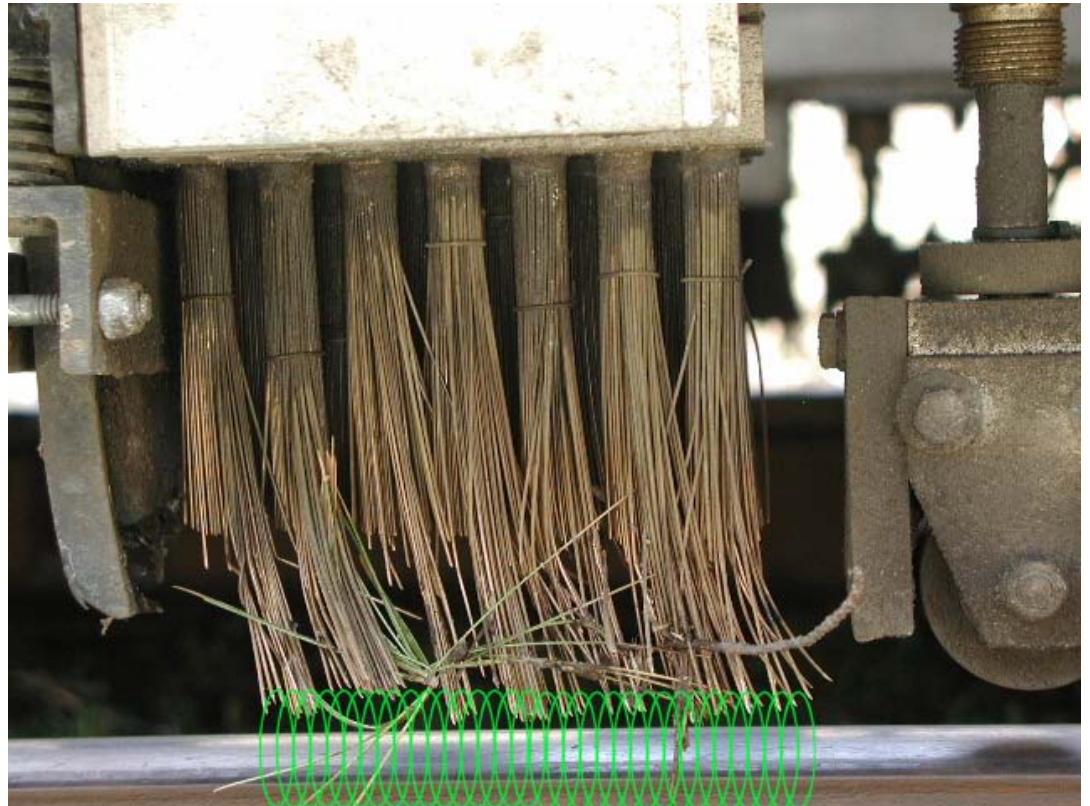
- Beryllium-Copper Brushes

- Sensing Coils



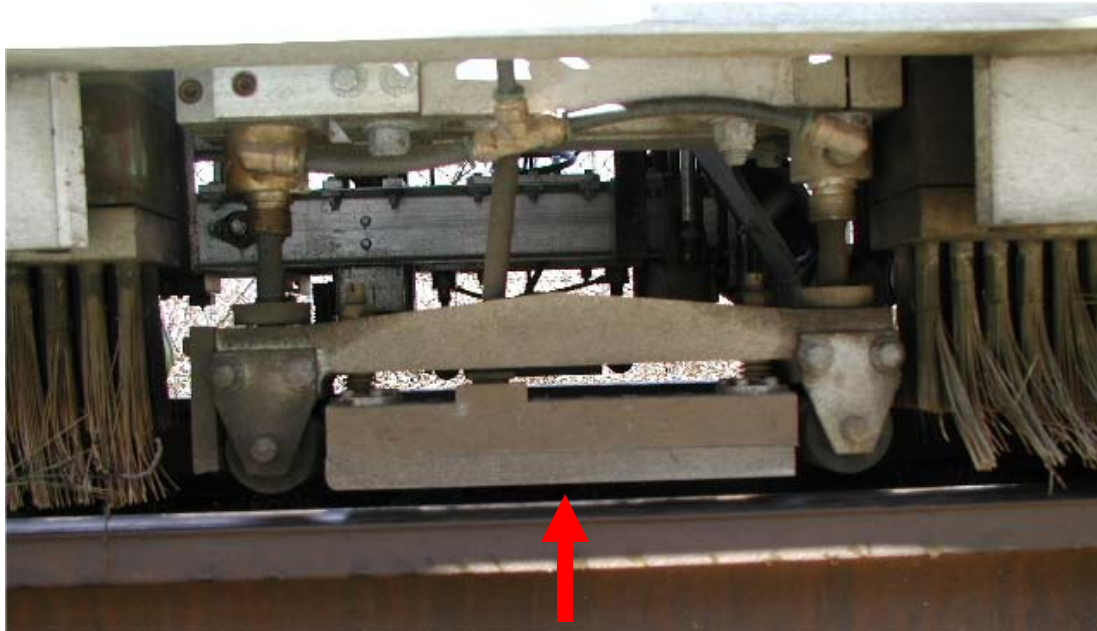
Induction Testing

- Metal brushes apply DC voltage to the rail
 - Causing current to flow through the rail
 - causing a magnetic field to surround the rail



Induction Testing

- Sensing coils travel through the flux field as the rail car moves



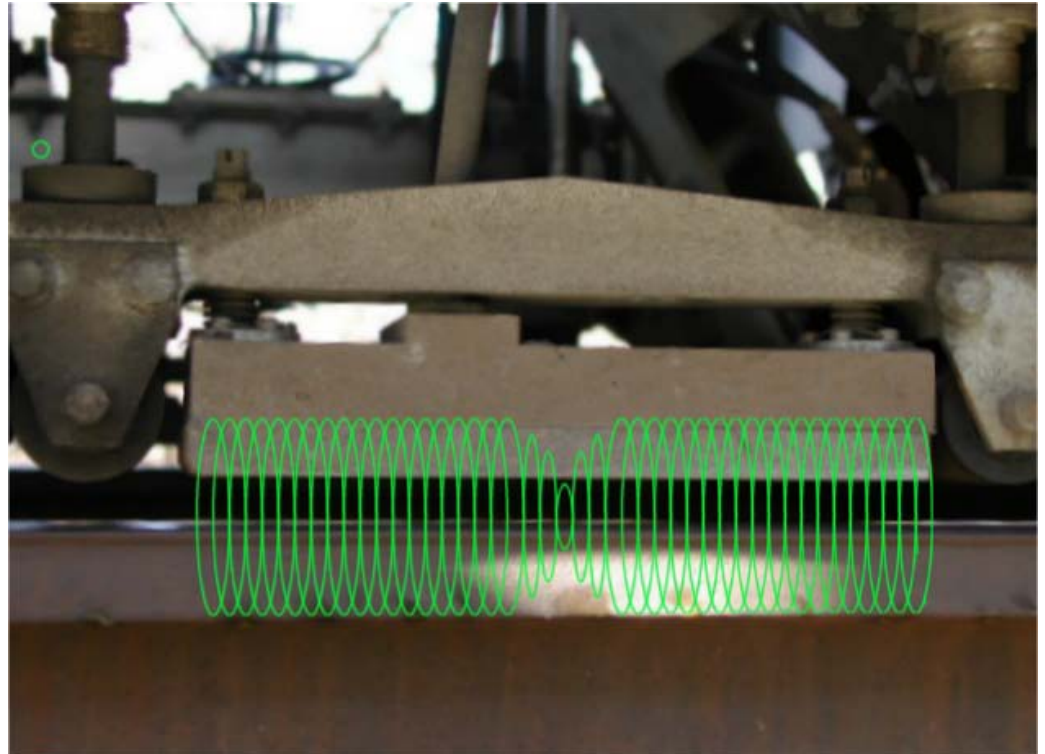
Induction Testing

- Defects reduce current flow, thereby varying the flux field surrounding the rail



Induction Testing

- Voltages are induced in the sensing coils proportional to variation of the inducing flux, causing indications on the display



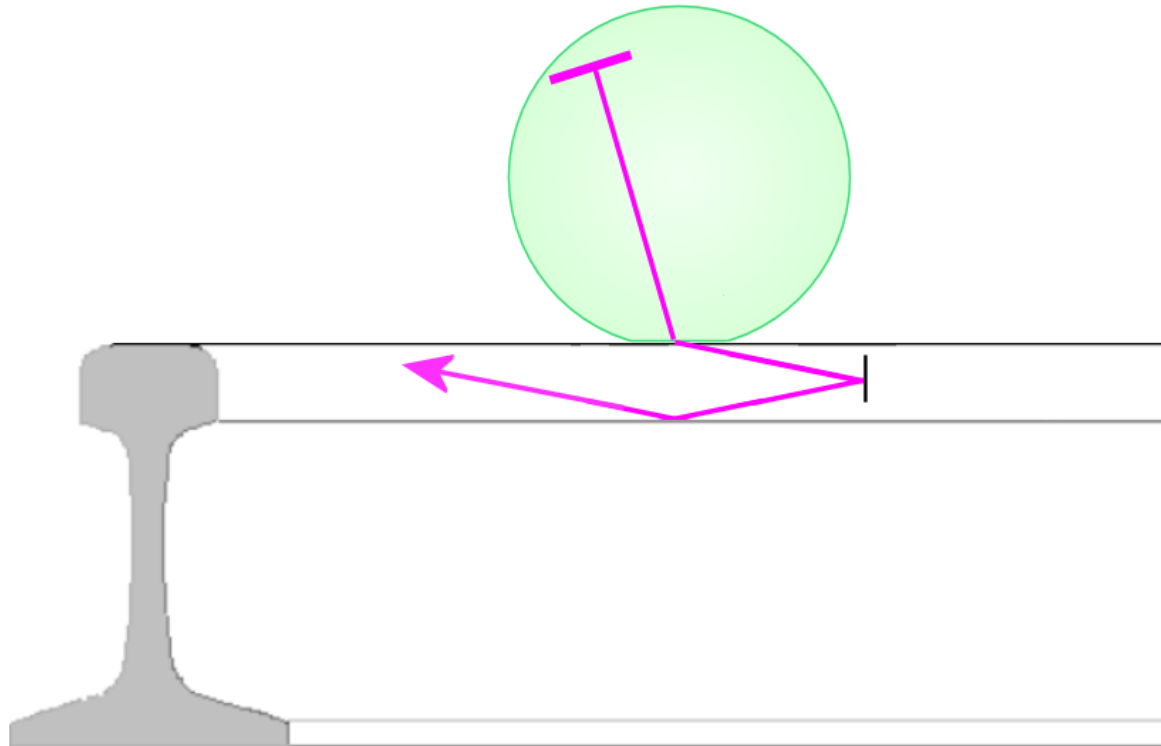
Induction Complements Ultrasonics



Induction Complements Ultrasonics

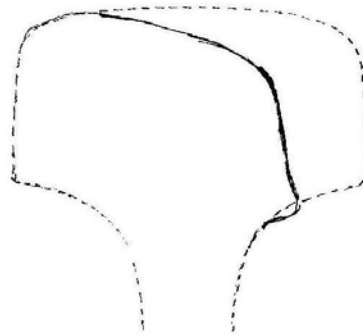
- Induction tolerates variation in defect orientation

- Particularly important in the detection of transverse fissures in the head



Induction Complements Ultrasonics

- Induction tolerates head shape changes



- Ultrasonic beams refract at the rail surface
 - So beam geometries in the rail change with head shape



Induction Complements Ultrasonics

- Shells don't stop current from detecting transverse defects



- They can block ultrasound from reaching transverse defects



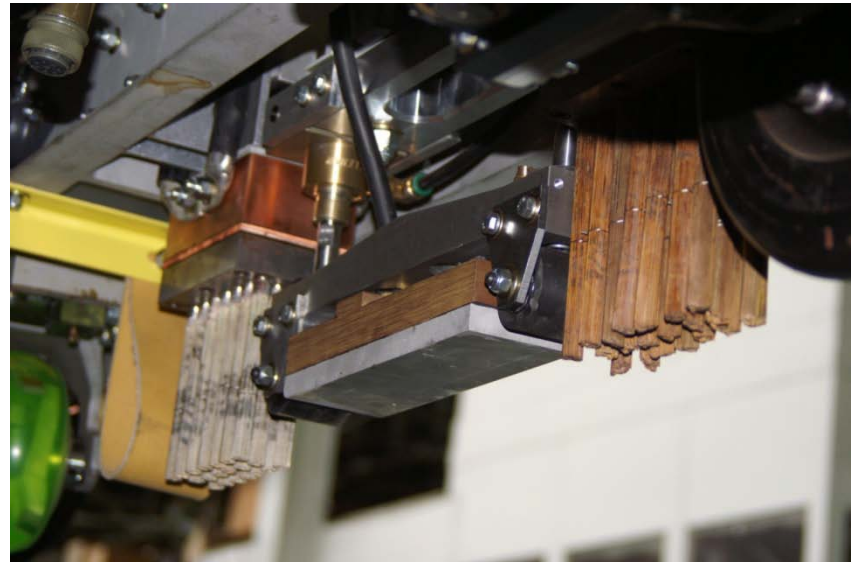
Induction Complements Ultrasonics

- Vertical split heads are sometimes more detectable with induction than with ultrasound
 - when there are coupling and directionality problems
- Small variations in the lateral path of VSH defects produce major flux changes, with proportionally detectable signals



Induction Complements Ultrasonics

- Induction is less susceptible to surface debris
 - Induction brushes can scrape through most surface debris (leaves, grass, dirt, etc.)
 - Surface debris does not prevent the flux field from being sensed



Induction Complements Ultrasonics

- Induction requires no couplant
- Ultrasonic search units require a couplant between the transducer and the rail surface to conduct sound into the rail



Induction Limitations

- Induction tests only the rail head
 - Flux variations from web and base defects are too weak to be detected



Induction Limitations

– Induction is ineffective in the joint area

- Angle bars, bolt holes, rail ends, and bond wires affect the current flow in joint areas
 - causing large distortions in the magnetic field
 - » effectively blanking out the induction system



Induction Limitations

- Induction has lower sensitivity to centrally located transverse defects
 - Magnetic flux does not leak efficiently from small fissures located in the center of the rail head



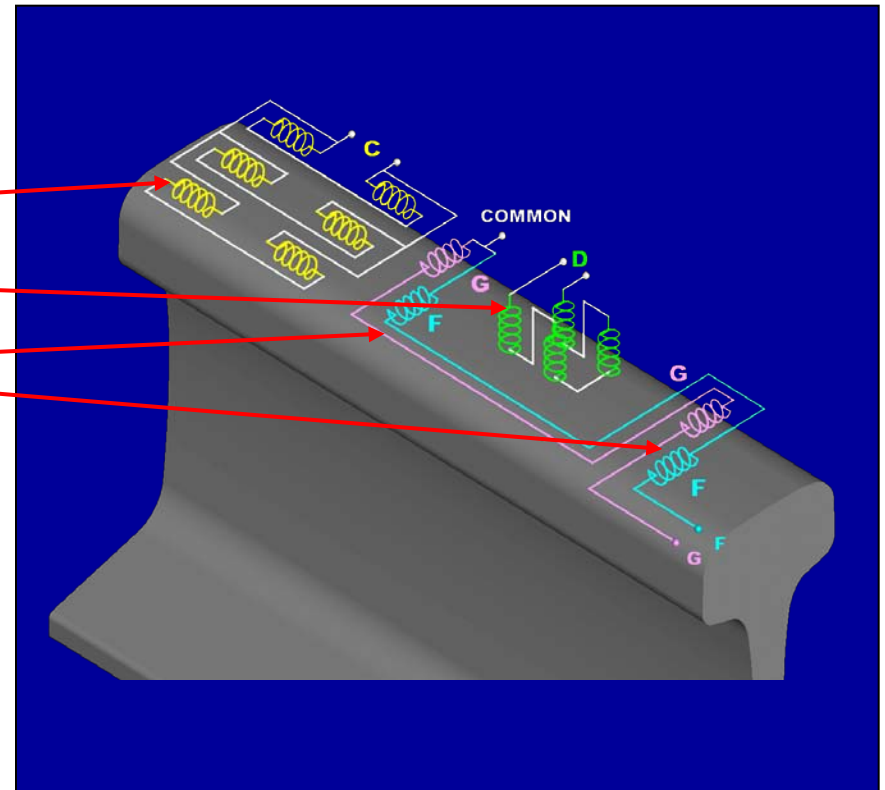
Induction Complements Ultrasonics

- In effect, induction and ultrasonic testing play off against each other's strengths and limitations
 - Producing powerful detection capability



Signal Interpretation

- There are 3 Induction Channels
 - C-Channel
 - D-Channel
 - F&G-Channel
- One channel each for the X, Y, & Z axis
- Each channel is color-coded on the display



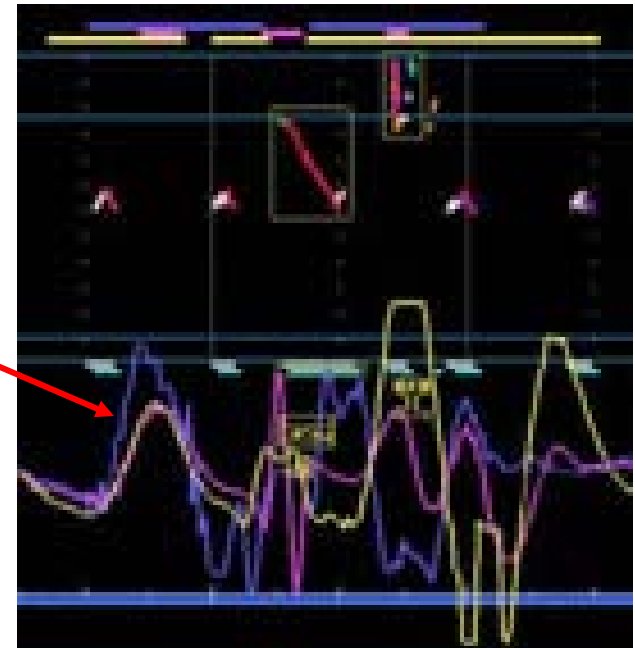
Induction Signals

- Like ultrasonics induction displays data in two forms:
 - Analog
 - Digital



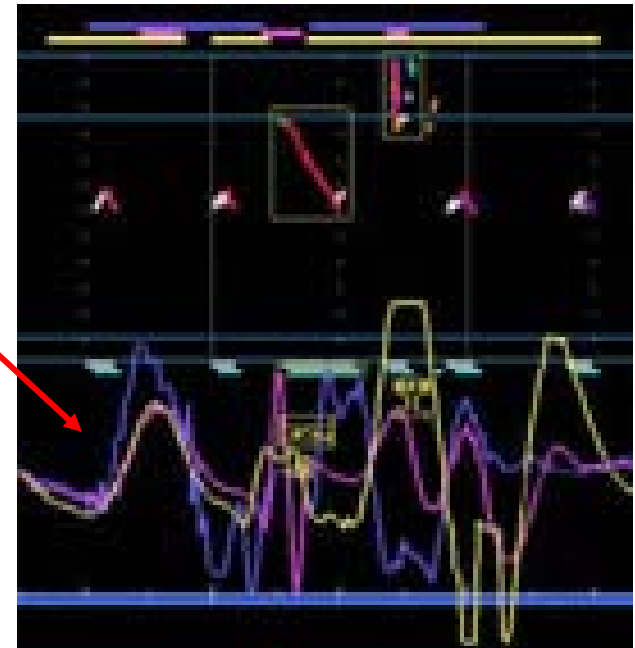
Induction Signals

- Analog Induction is like A-Scan Ultrasonics
 - It's constantly indicating



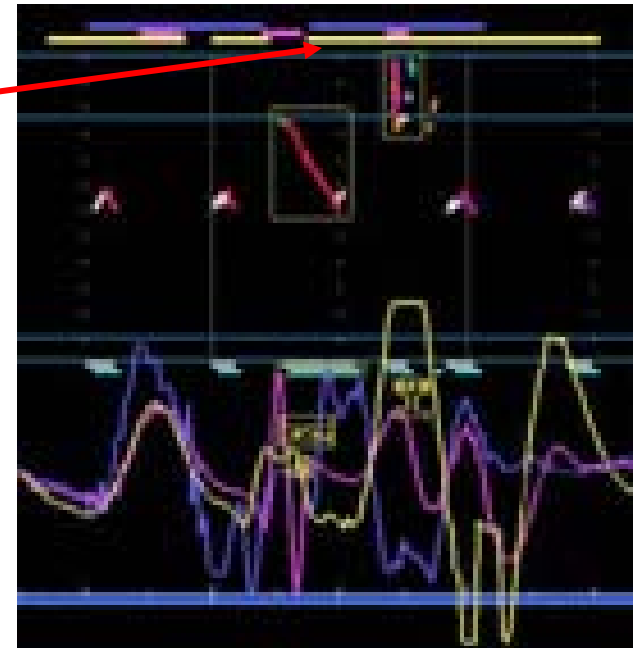
Induction Signals

- Analog induction can display in three colors
 - D Channel: **Purple**
 - C Channel: **Yellow**
 - F&G Channel: **Blue**



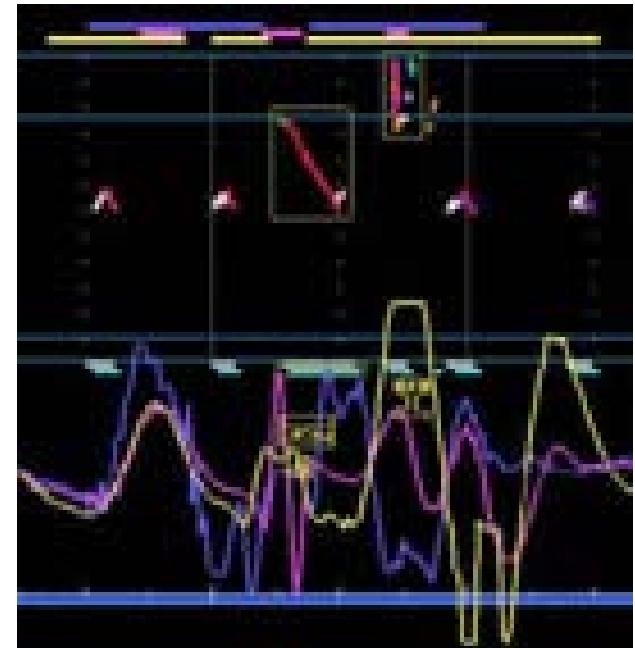
Induction Signals

- Digital Induction is like B-Scan Ultrasonics
 - indicates only selected information



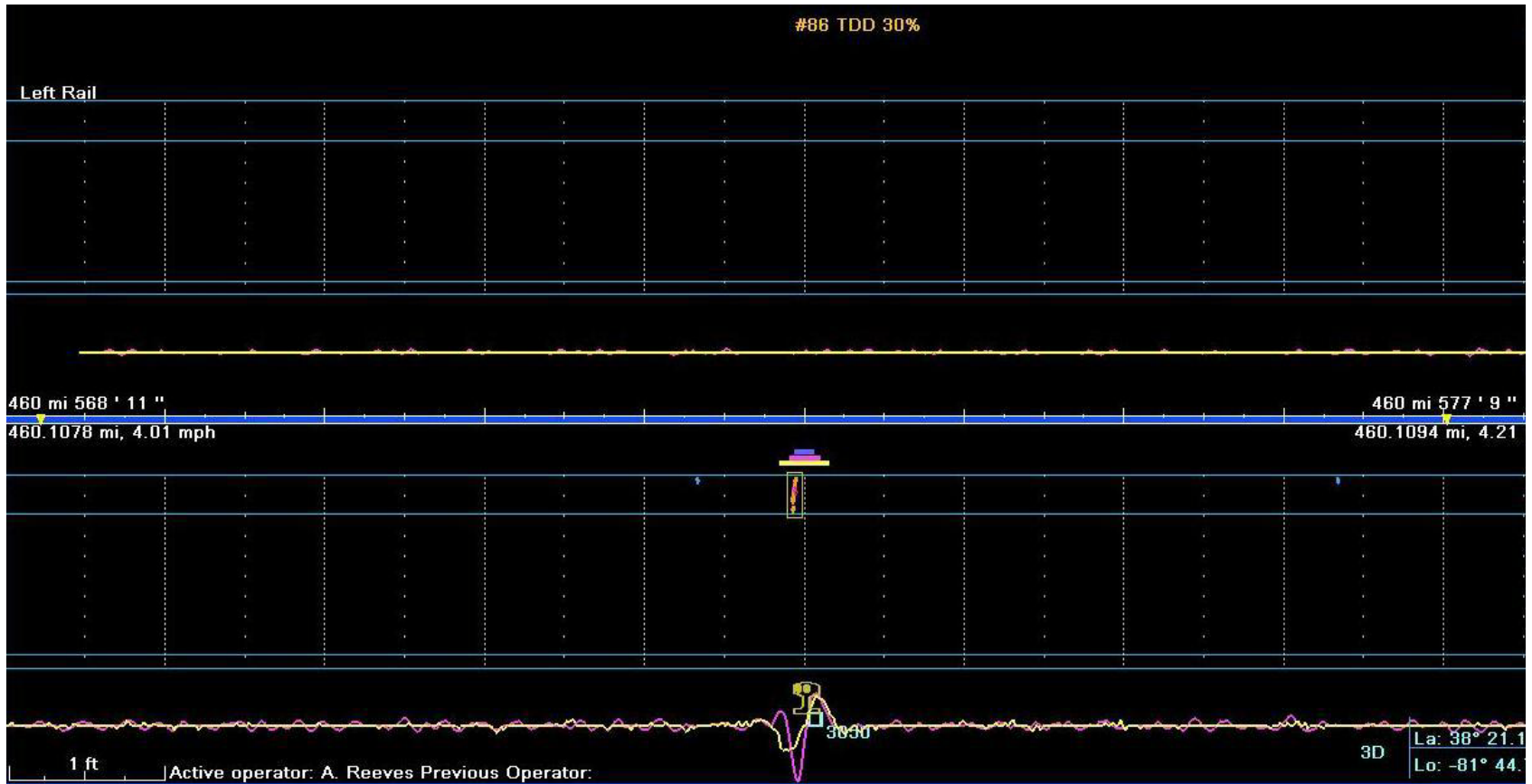
Induction Signals

- Digital induction displays in four colors:
 - D Channel: Purple
 - C Channel
 - (Sensitive): Yellow
 - (Insensitive): Green
 - F&G Channel: Blue



Induction Signals

TD: Ultrasonics/Induction



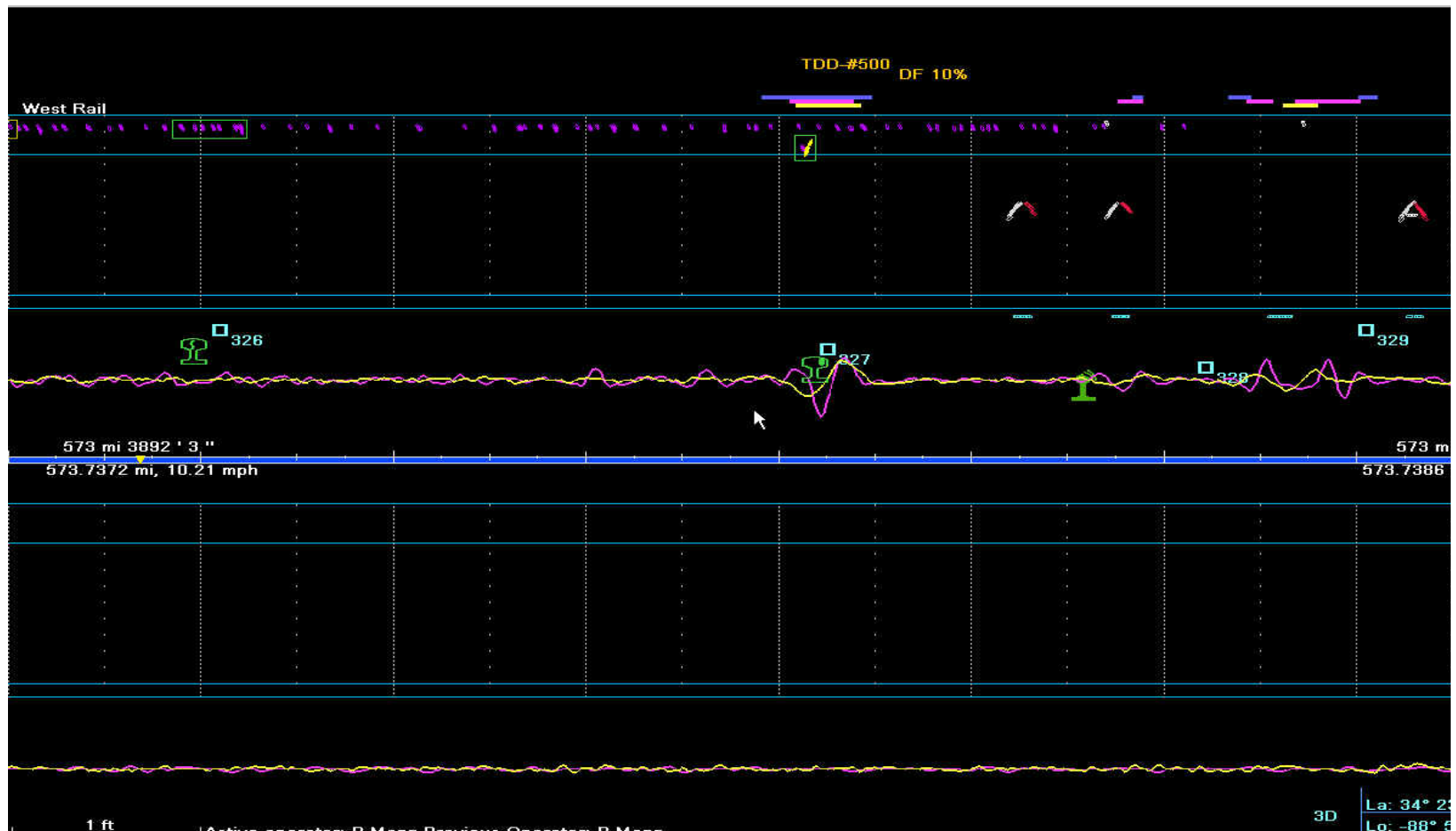
Induction Signals

TD: Induction Only



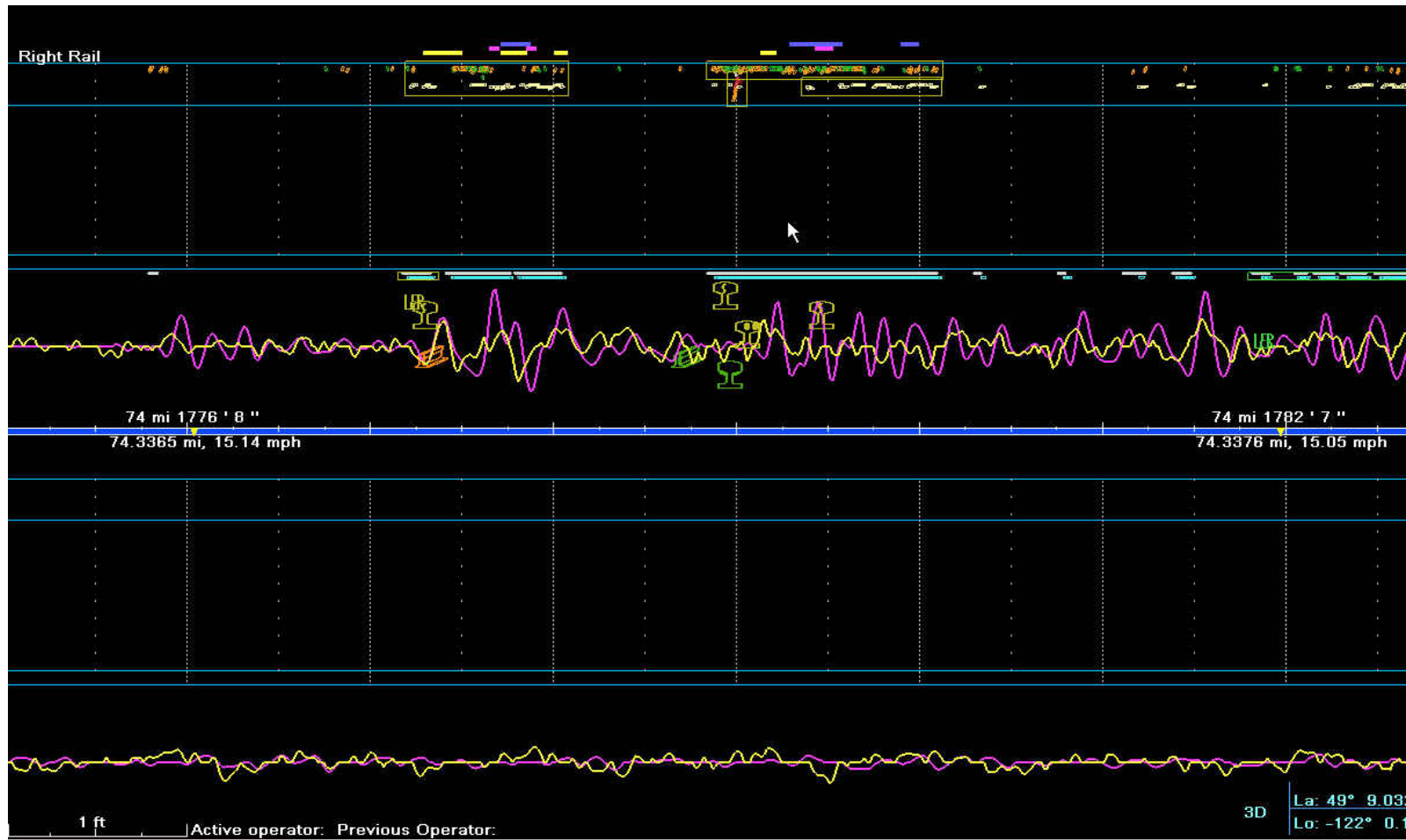
Induction Signals

Detail Fracture: X-Fire & Induction



Induction Signals

VSH: Ultrasonics/Induction



End of Presentation

