

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

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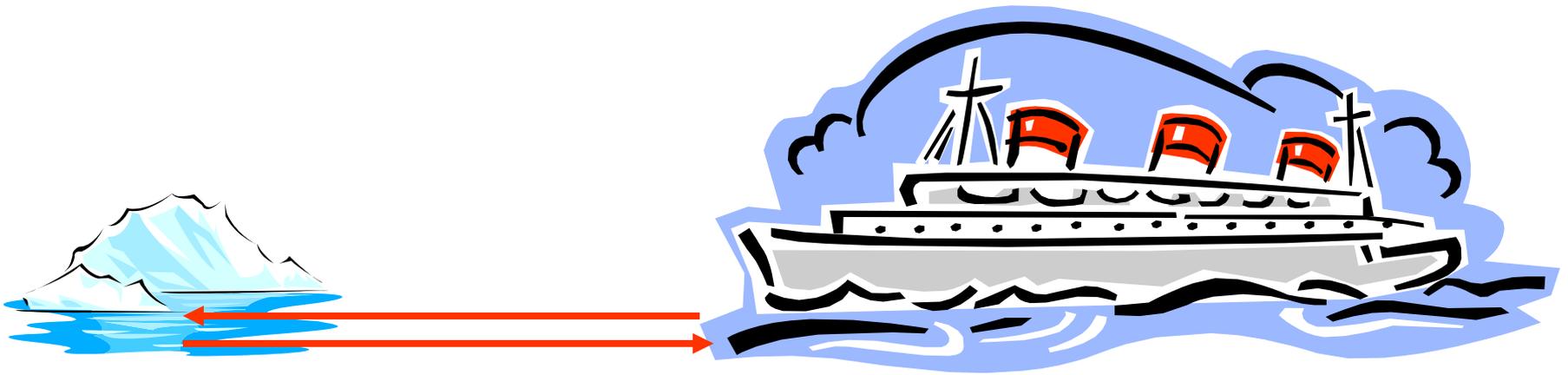
# Testing with Sound

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



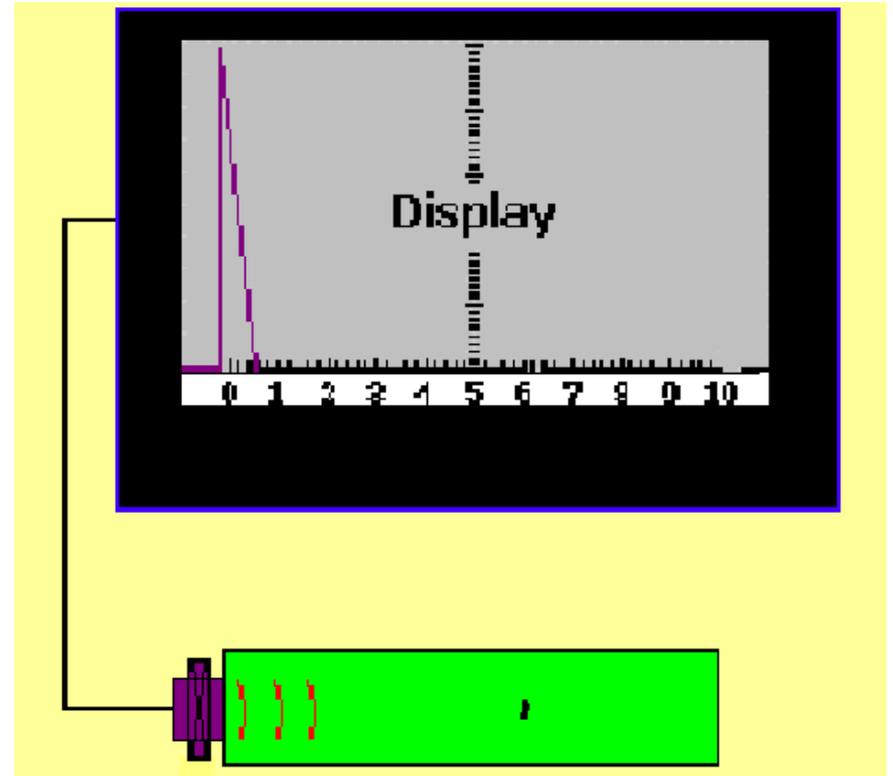
# Testing with Sound

- 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.



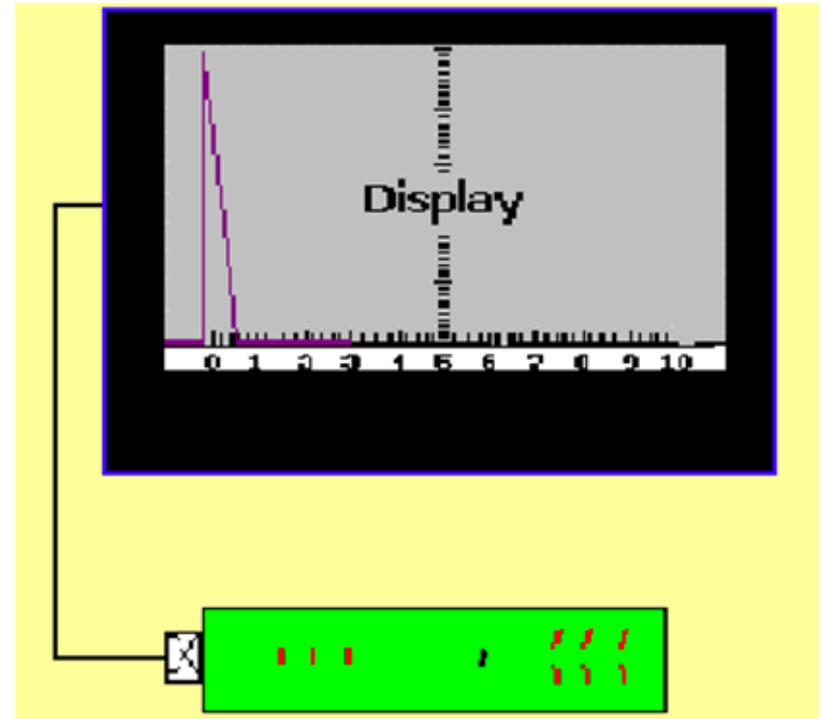
# Ultrasonic Testing

- 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



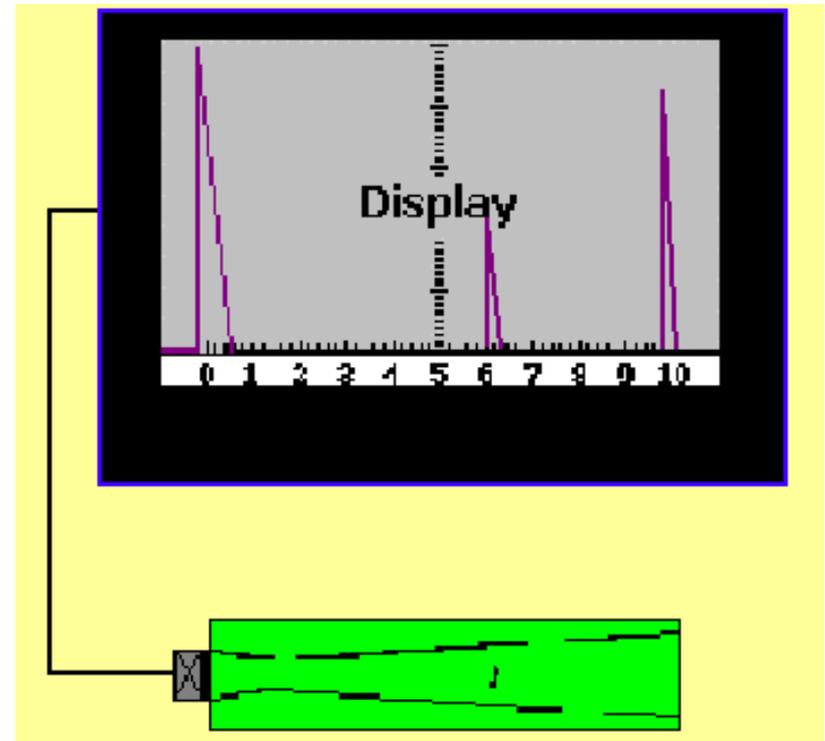
# Ultrasonic Testing

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



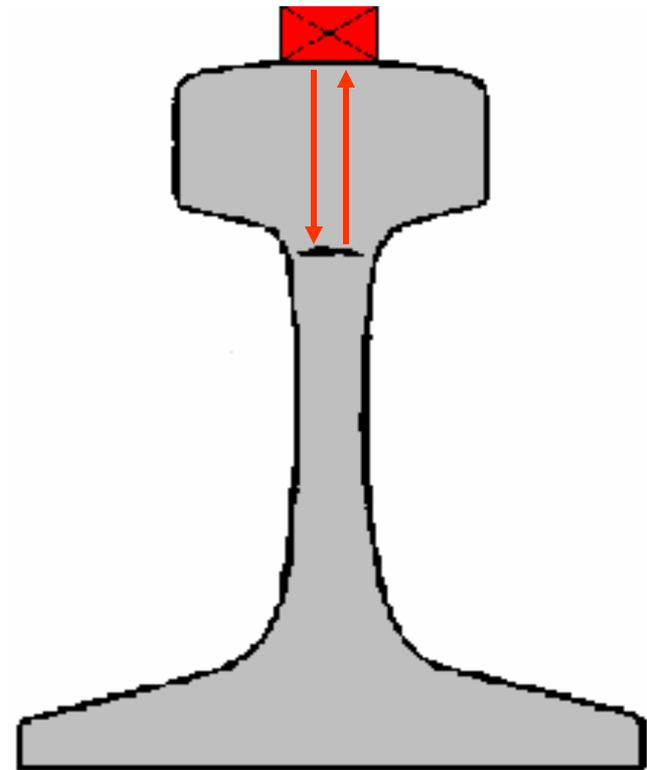
# Ultrasonic Testing

- 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



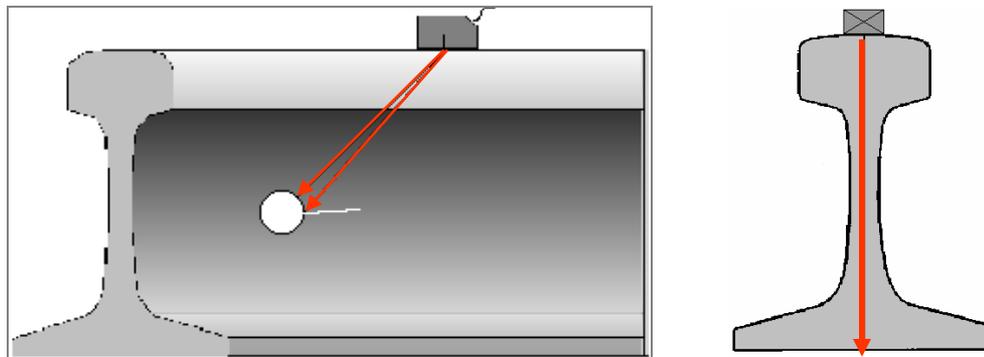
# Rail Testing

- 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



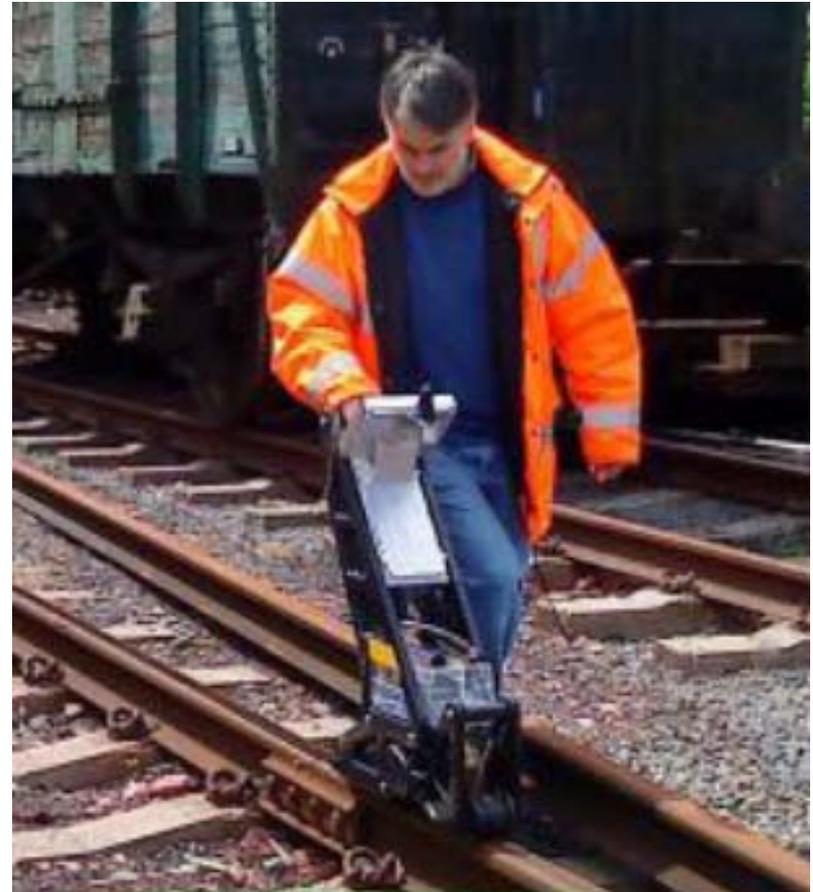
# Test Vehicles

- 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



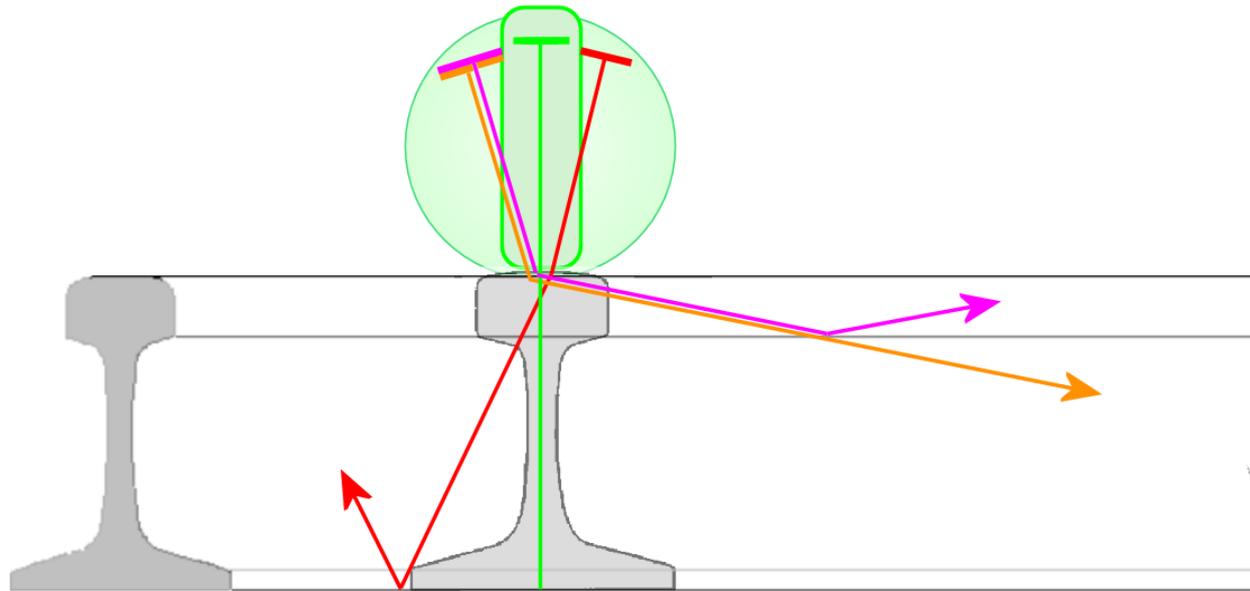
# Test Vehicles

- 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



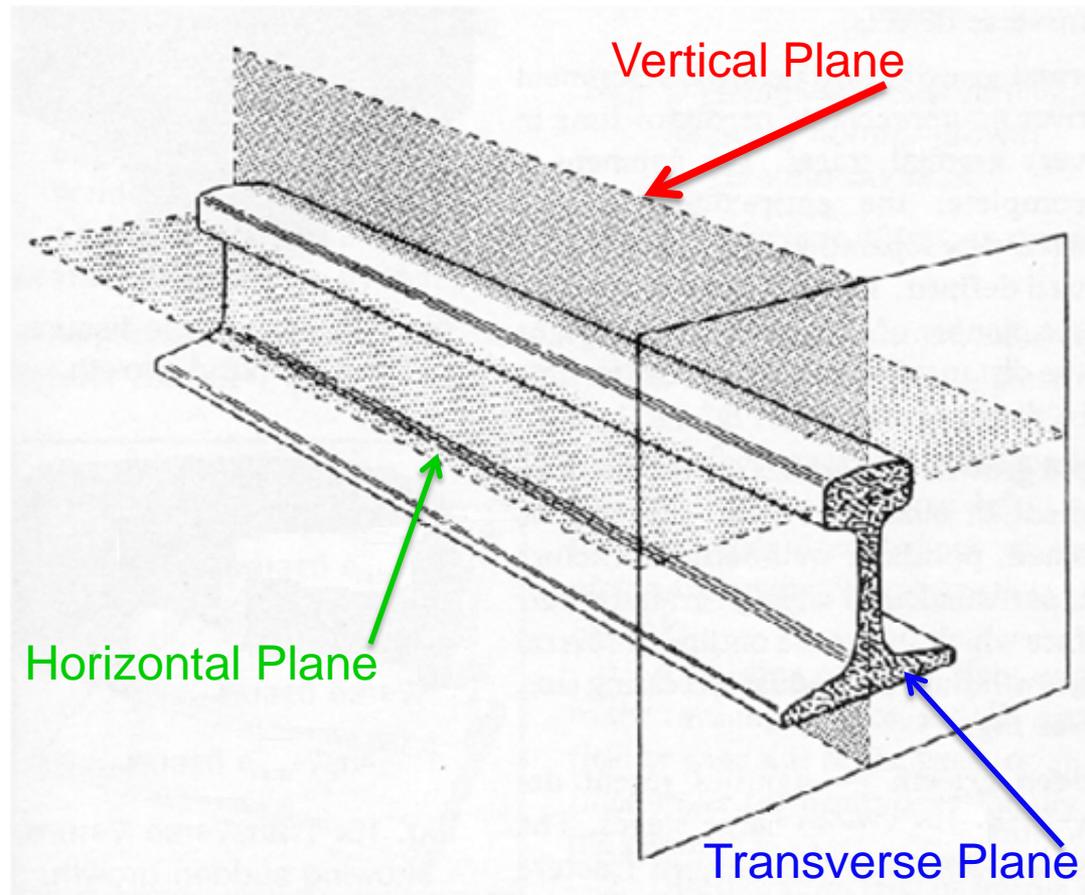
# Rail Defects & Transducer Configurations

- 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)



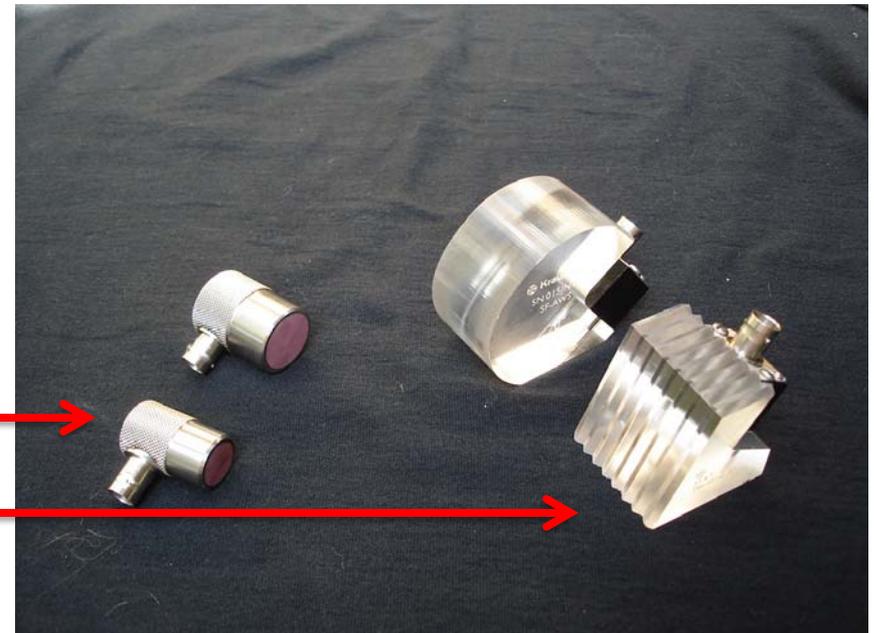
# Rail Defects & Transducer Configurations

- 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.



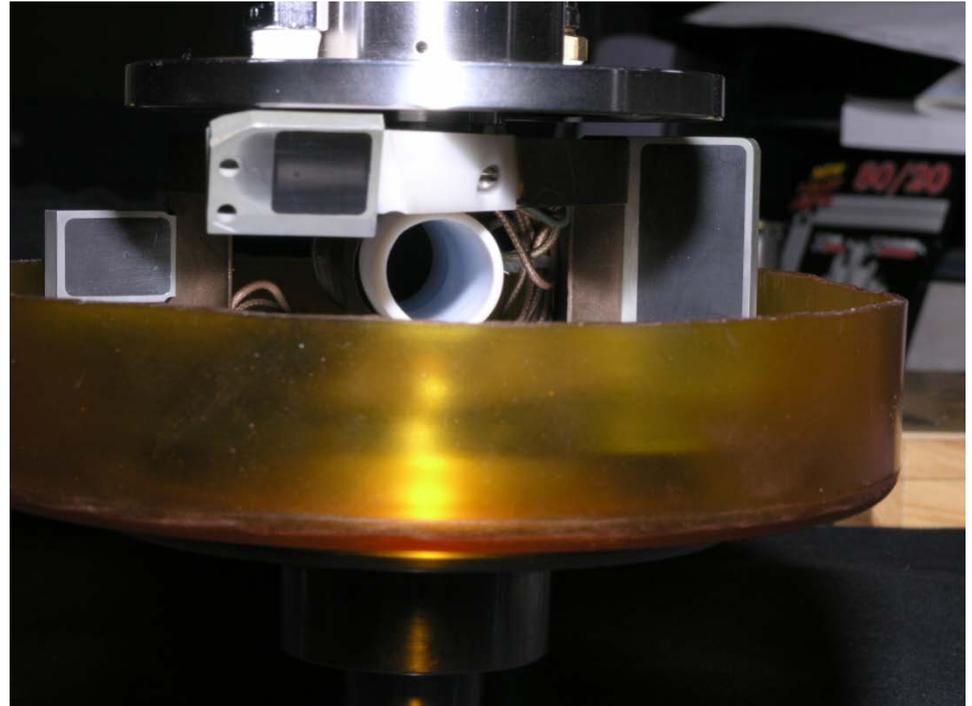
# Rail Defects & Transducer Configurations

- 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

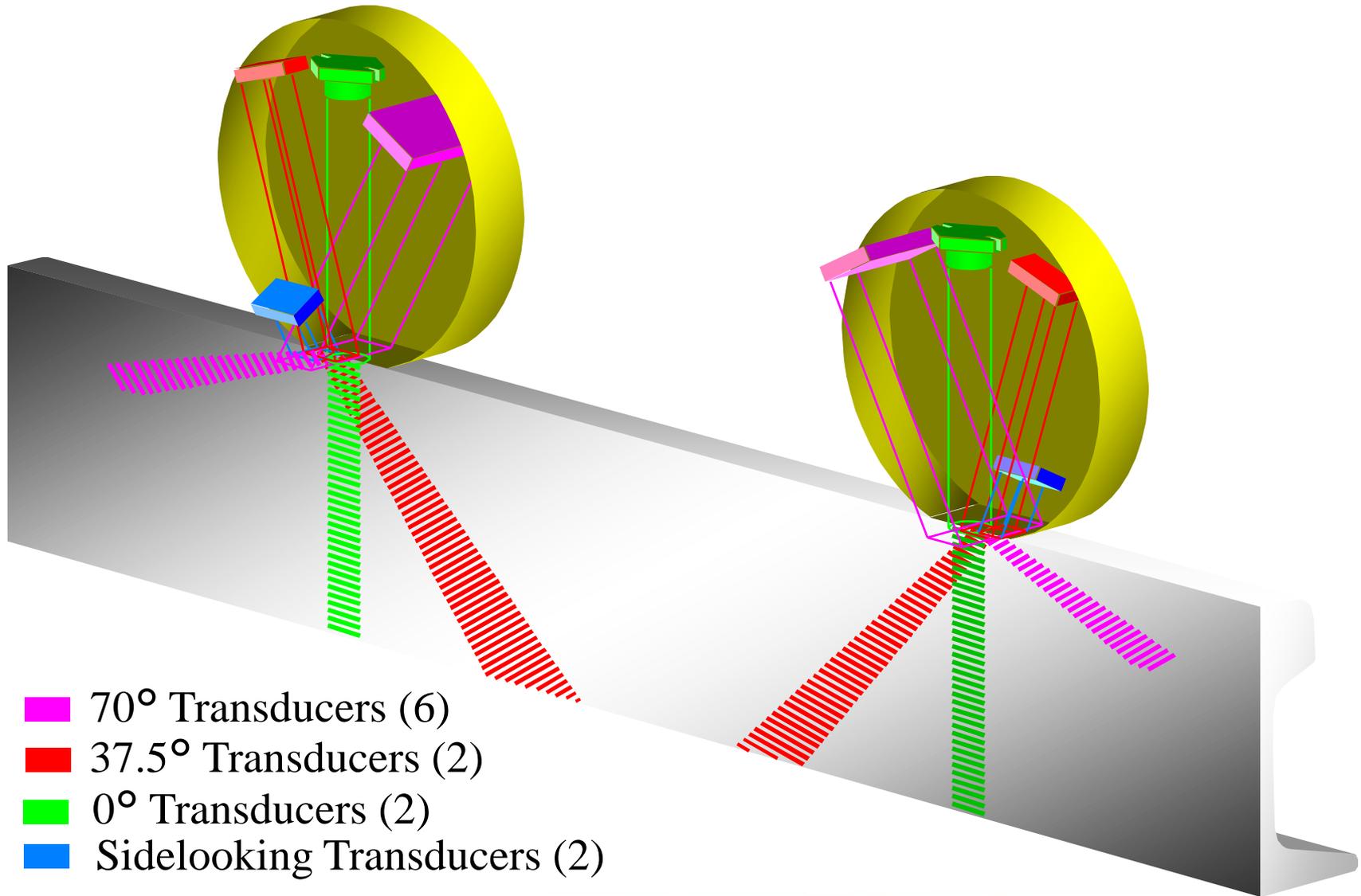


# Rail Defects & Transducer Configurations

- 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



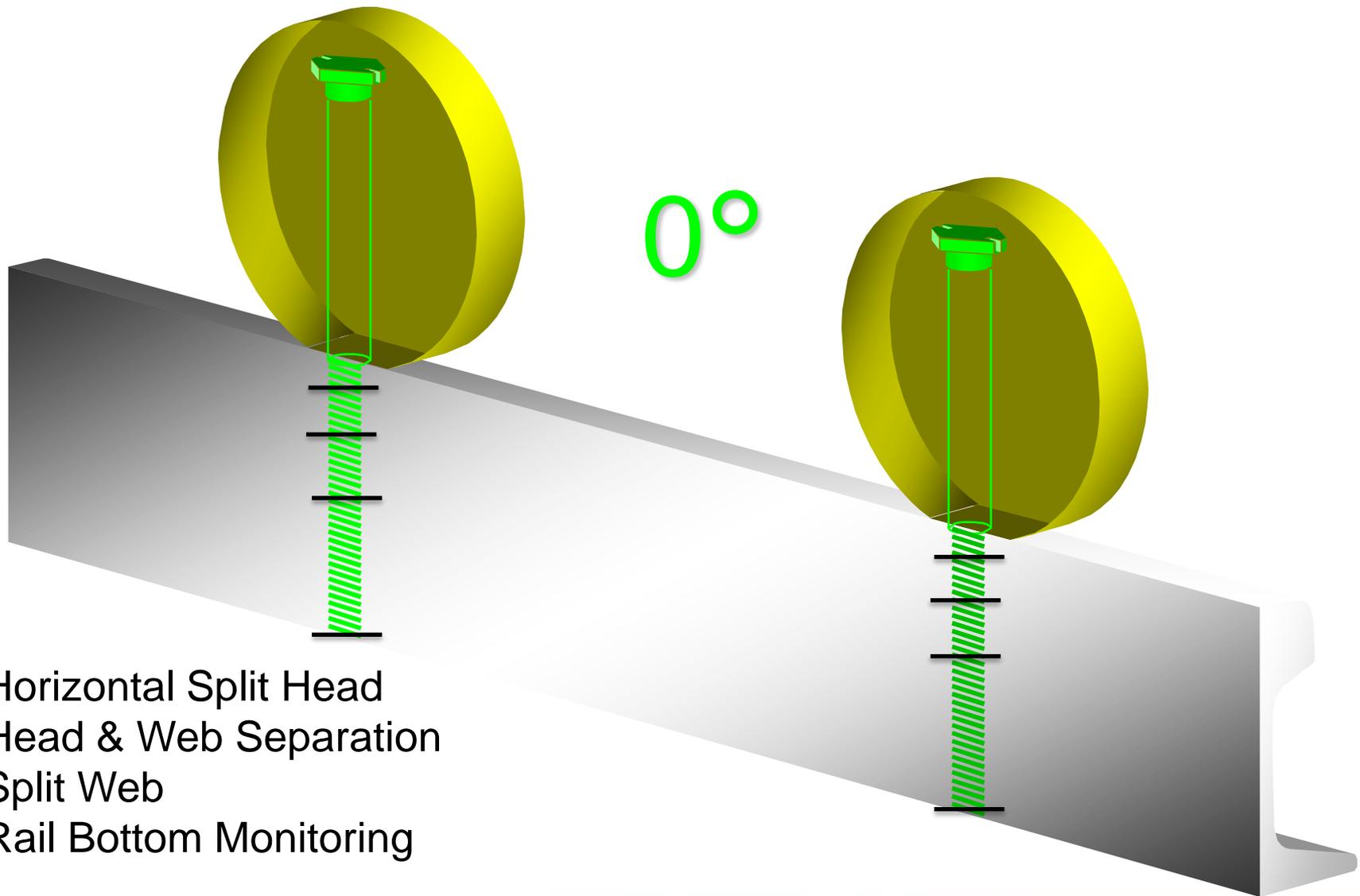
# Rail Defects & Transducer Configurations

## *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.



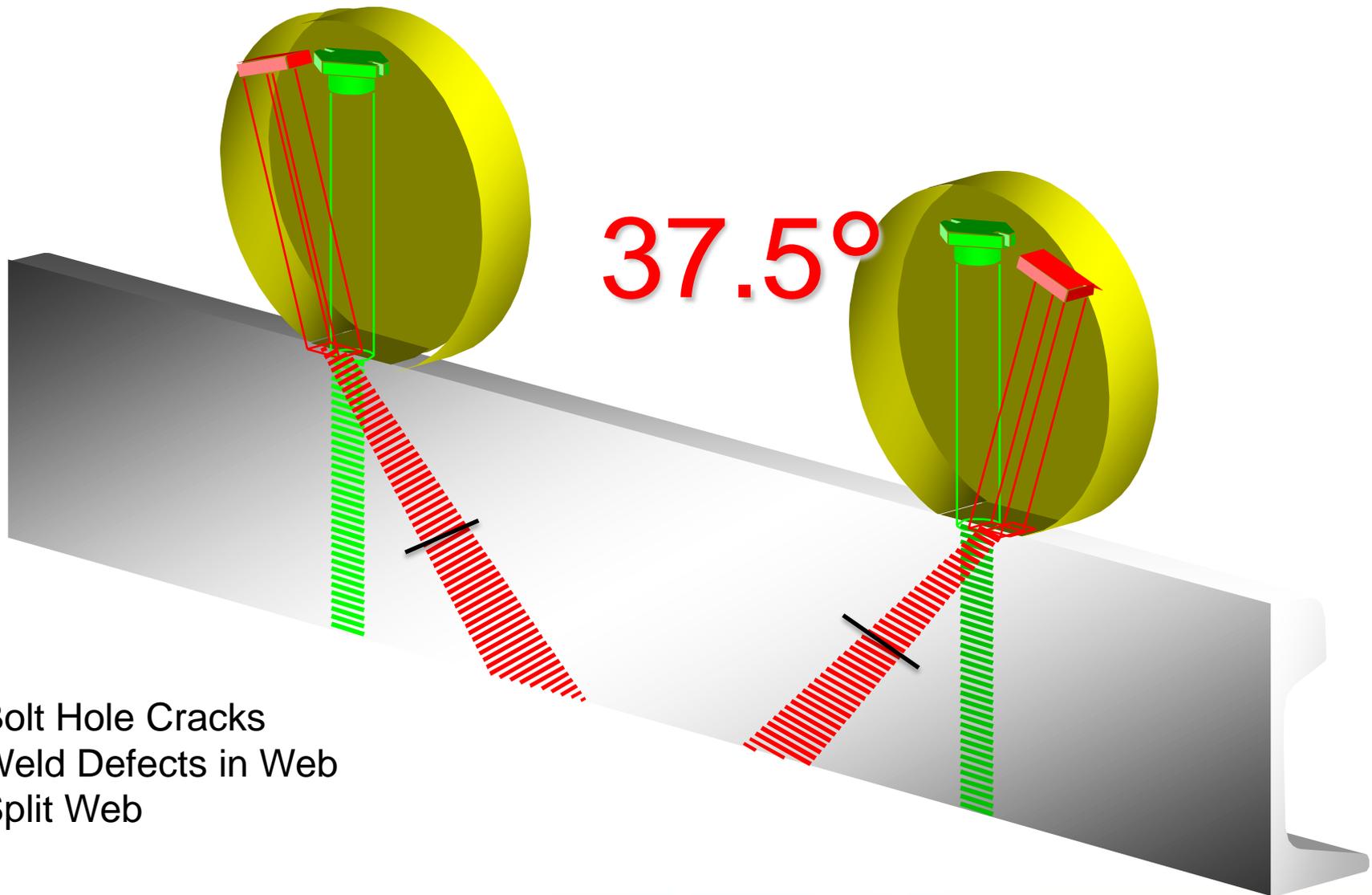
# Rail Defects & Transducer Configurations

## Joint Defects

Bolt Hole Crack



# Rail Defects & Transducer Configurations

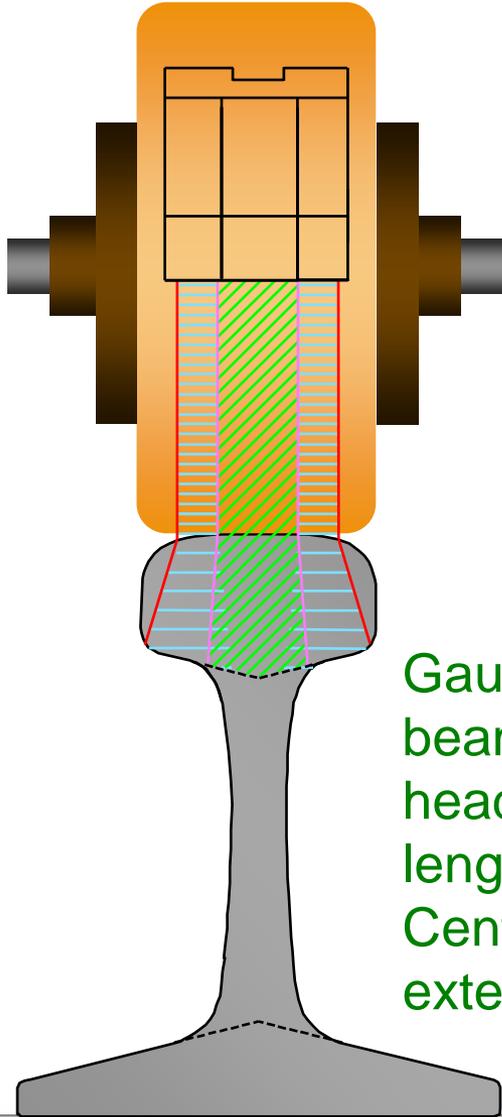


# Rail Defects & Transducer Configurations

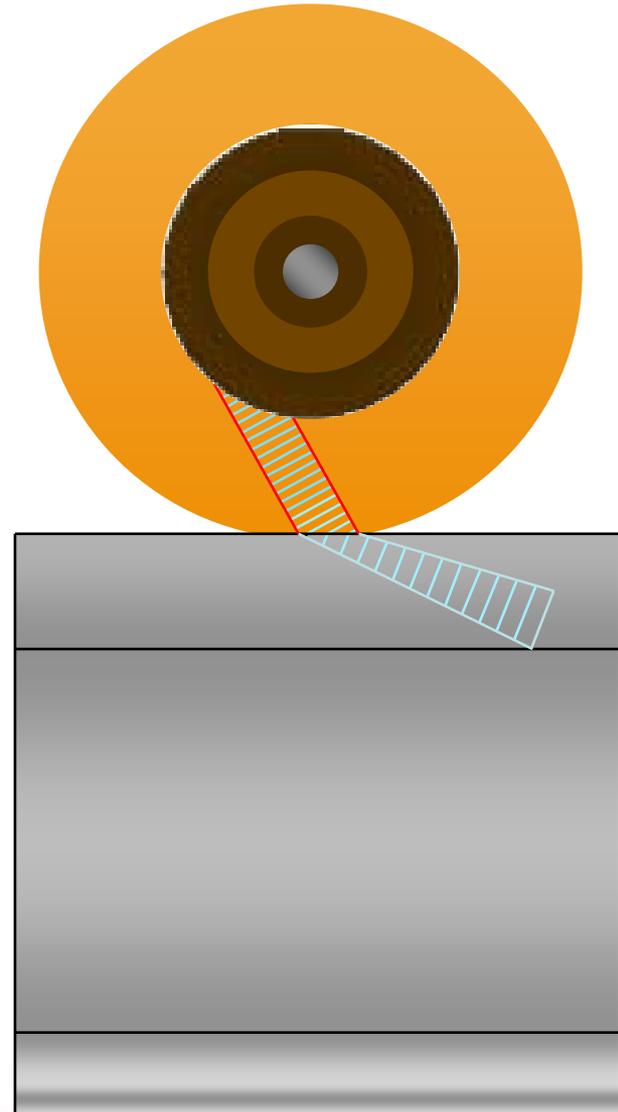
- 70° transducers (One each for gauge, center, field portions of rail head) detect:
  - Transverse defects in rail head
  - Weld defects in the head



# 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



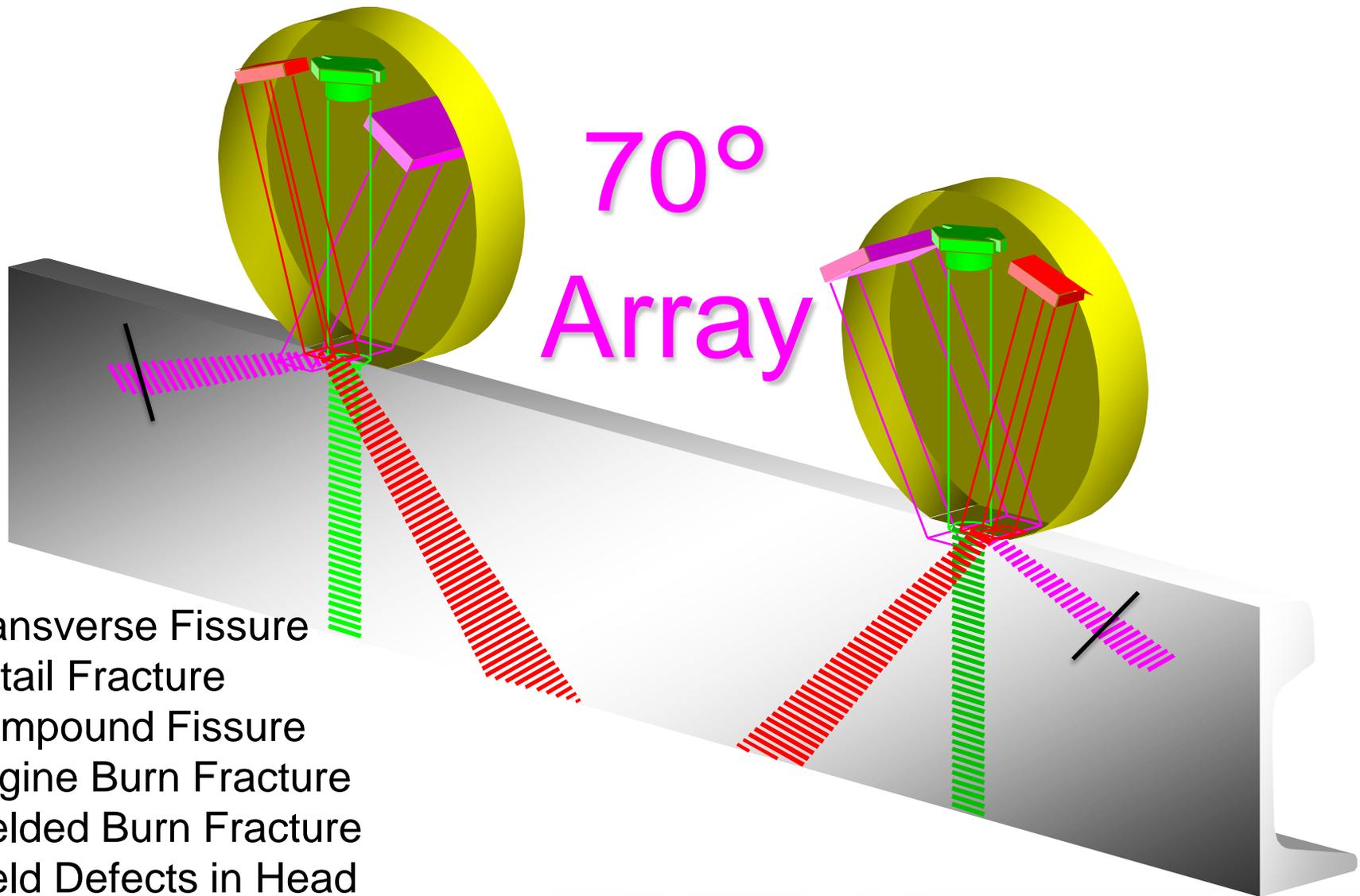
# Rail Defects & Transducer Configurations

## *Transverse Plane Defects*

Weld Defects



# Rail Defects & Transducer Configurations



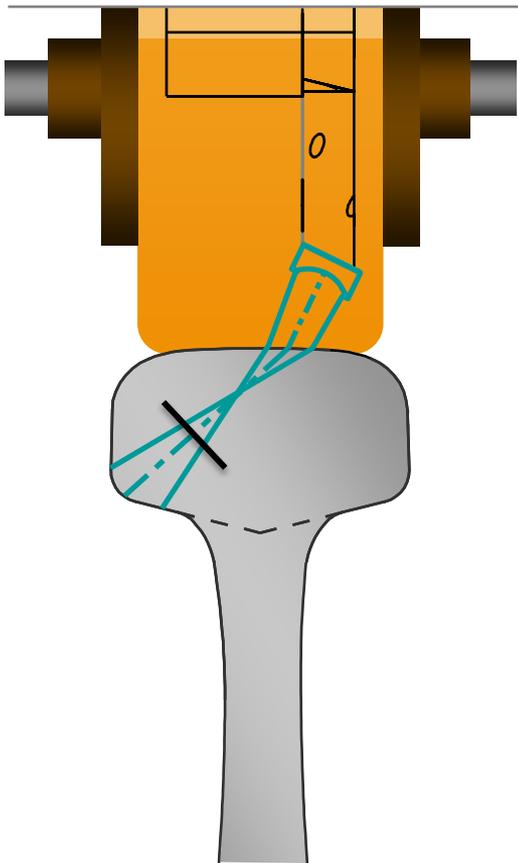
# Rail Defects & Transducer Configurations

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



# Rail Defects & Transducer Configurations

## *Vertical Plane Defects*



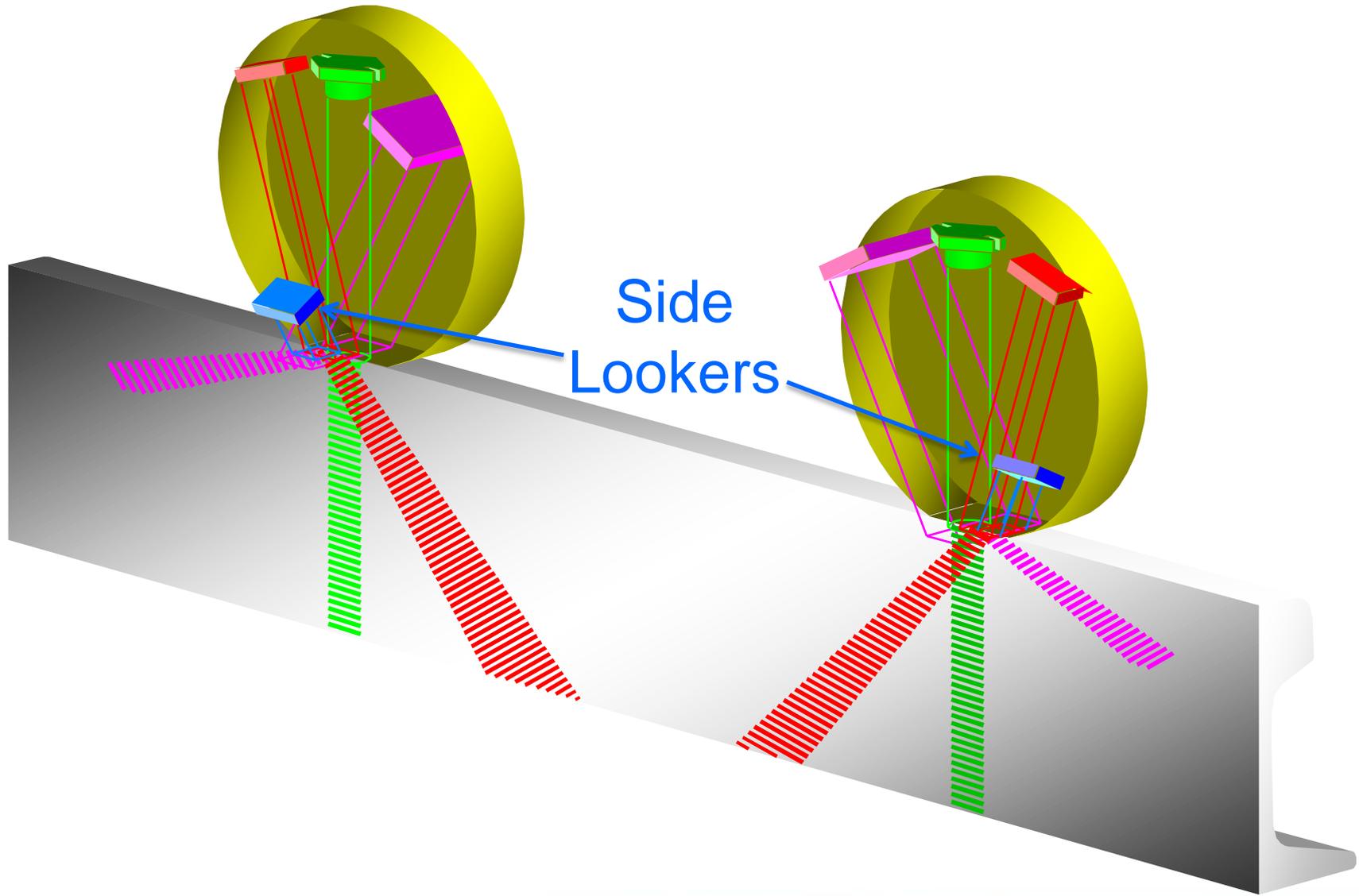
Vertical Split Head



Shear Break

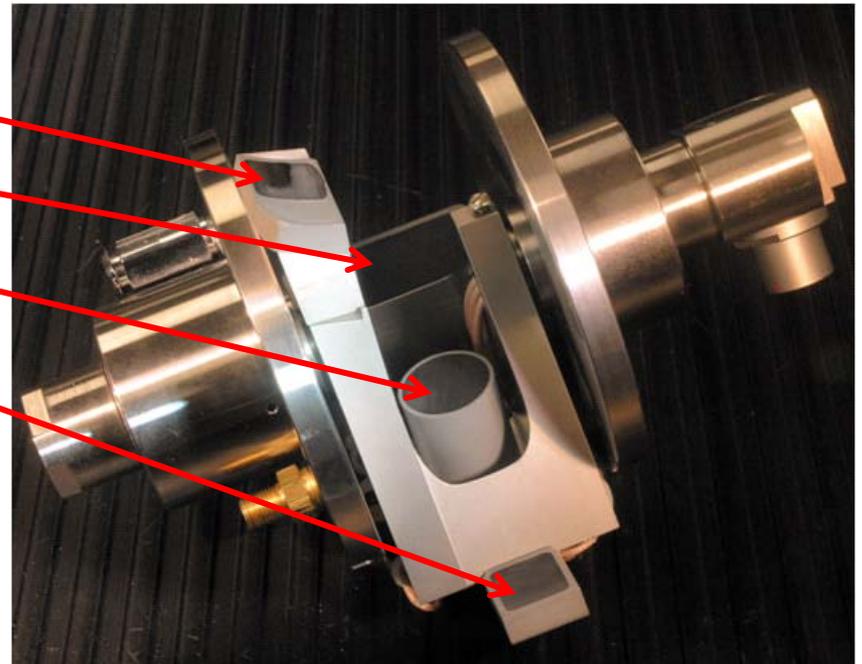


# Rail Defects & Transducer Configurations



# Rail Defects & Transducer Configurations

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



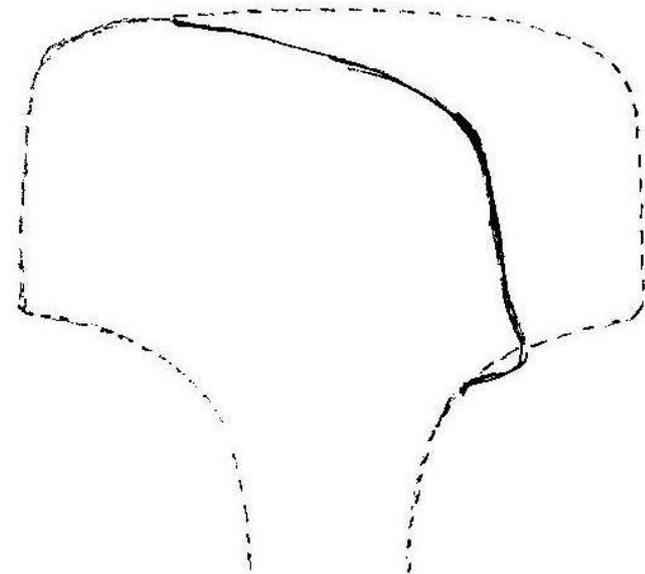
# Rail Defects & Transducer Configurations

- 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



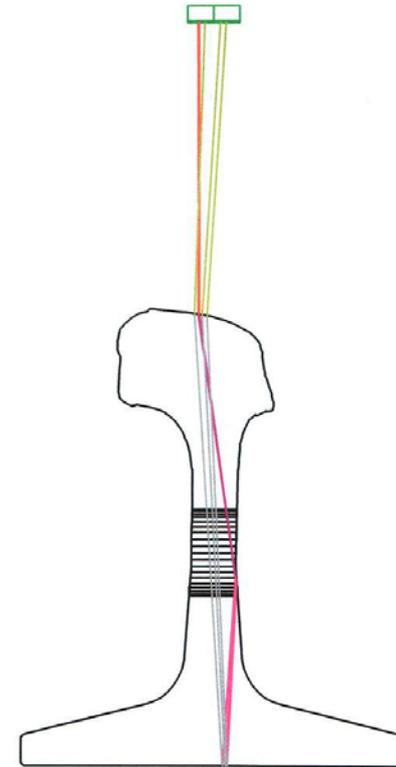
# Rail Defects & Transducer Configurations

- 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



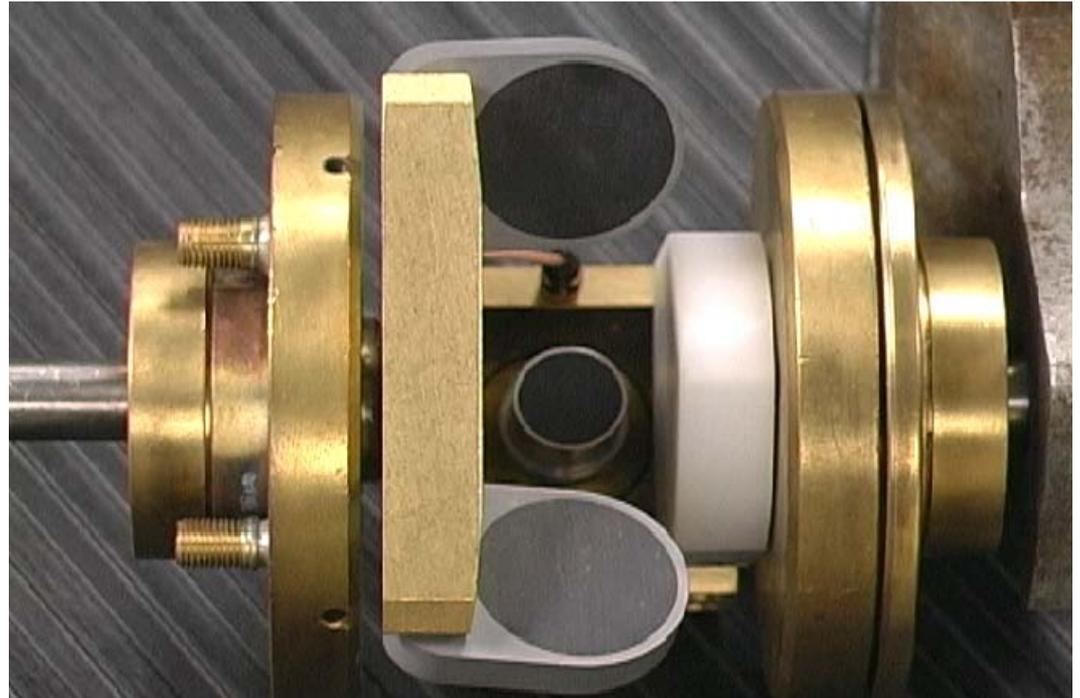
# Rail Defects & Transducer Configurations

- 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  $70^{\circ}$  angle beams from intercepting detail fractures.



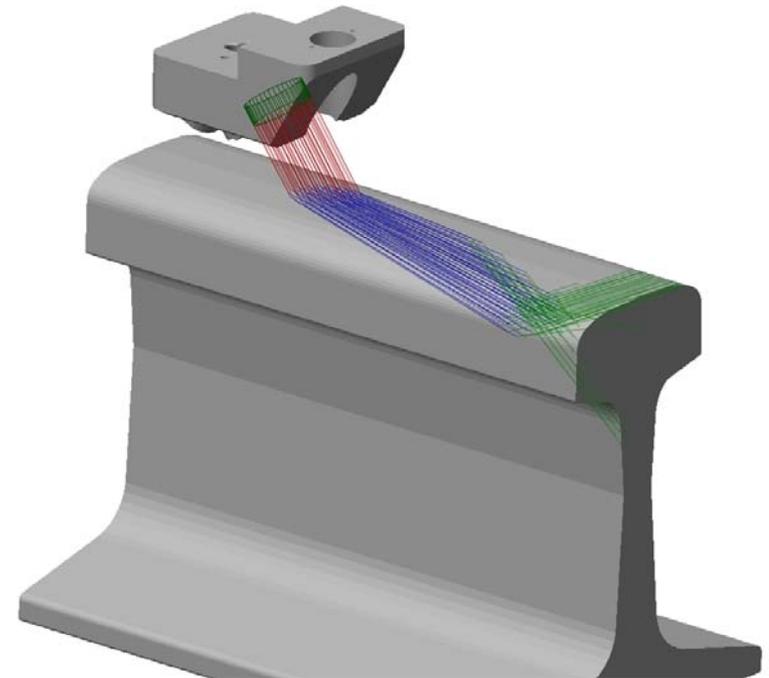
# Rail Defects & Transducer Configurations

- These problems can be addressed with 3rd RSU, containing
  - Pair of  $70^{\circ}$ s
  - Single  $0^{\circ}$



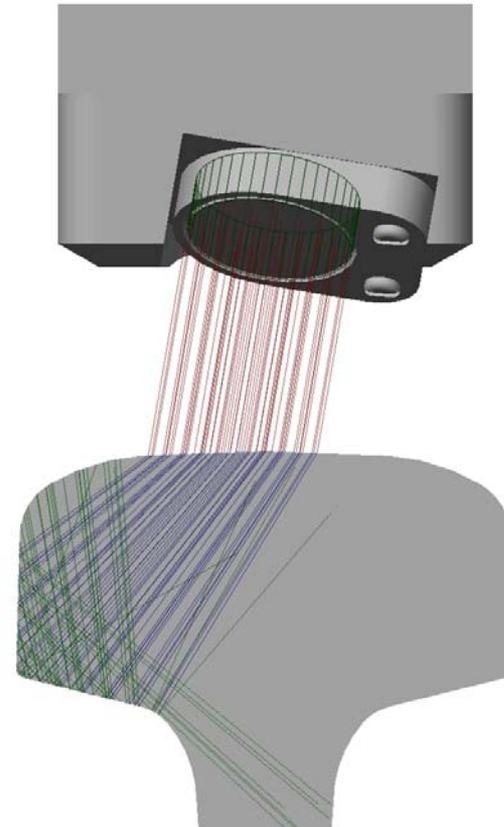
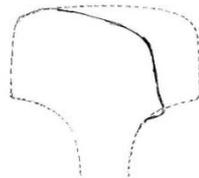
# Rail Defects & Transducer Configurations

- In contrast to main  $70^{\circ}$  beams these  $70^{\circ}$ 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 has become so worn and distorted that sound beam can no longer achieve desired refracted angle



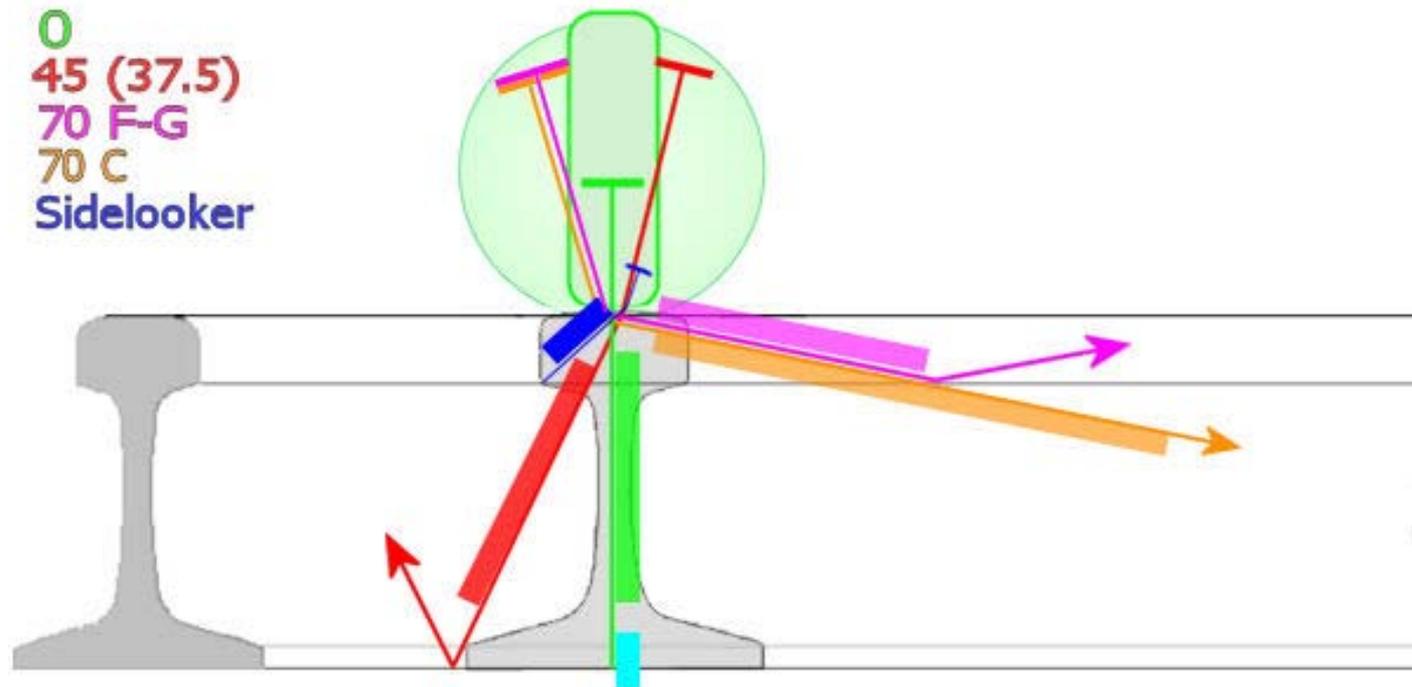
# Rail Defects & Transducer Configurations

- 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.



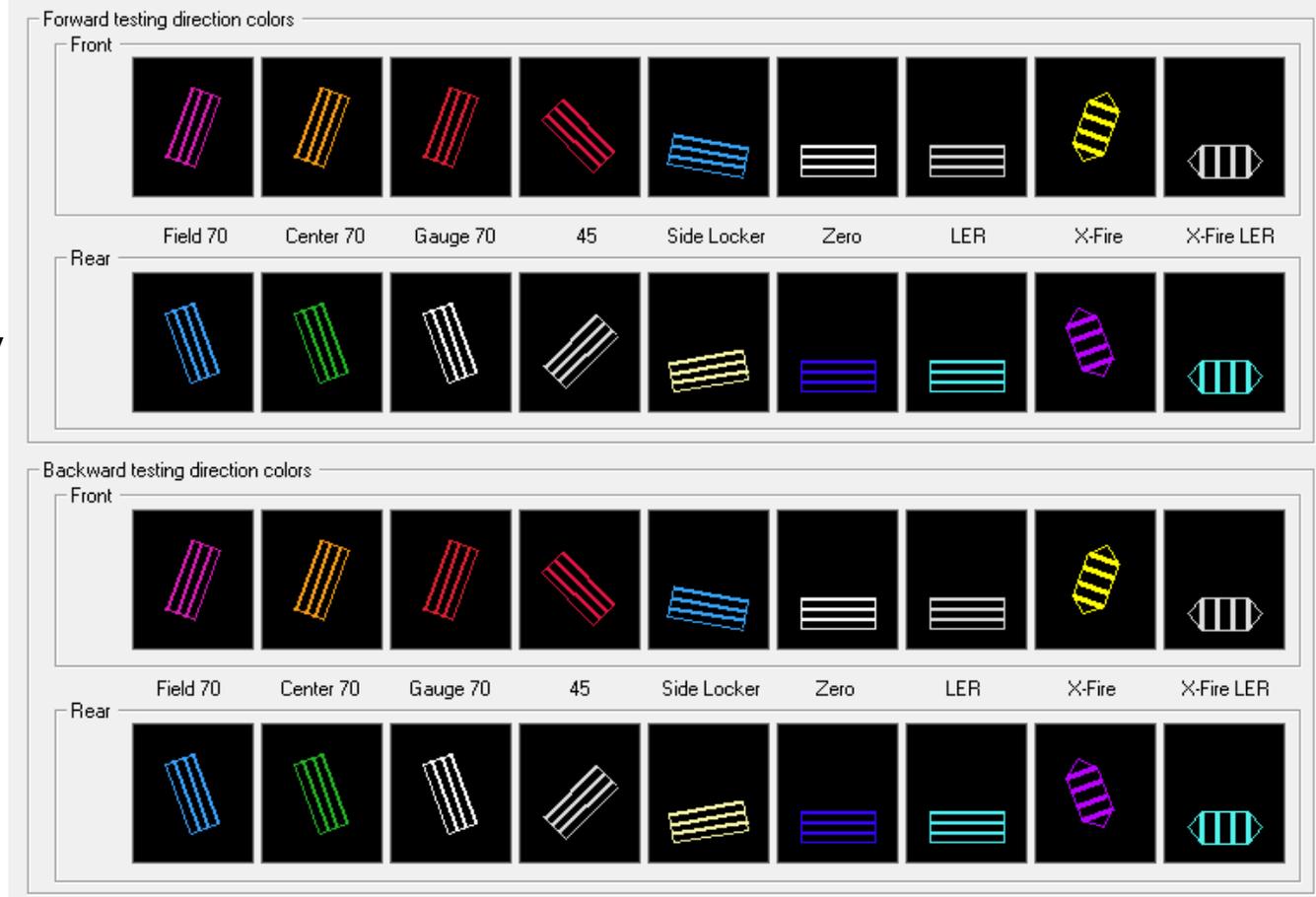
# Rail Defects & Transducer Configurations

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



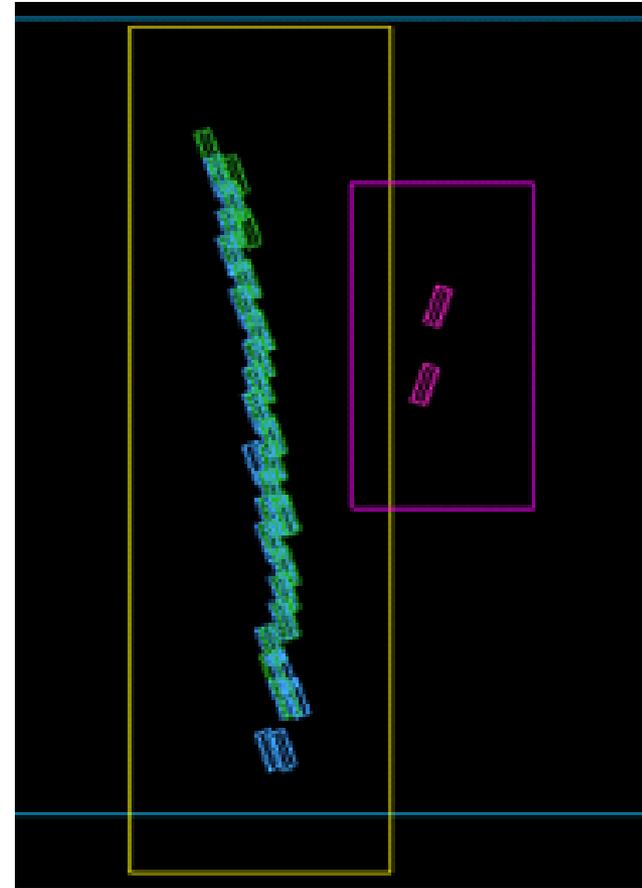
# Rail Defects & Transducer Configurations

- 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.

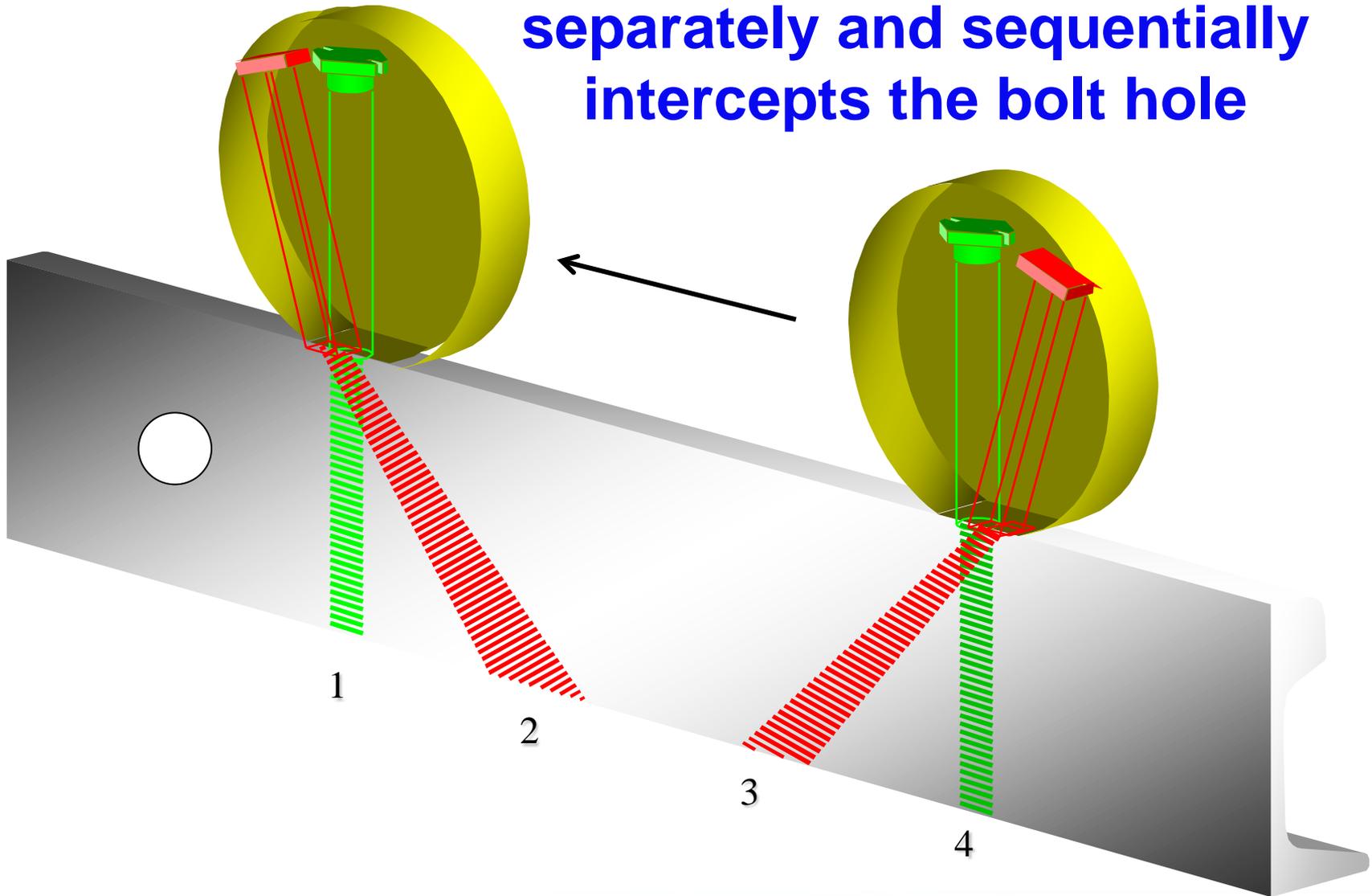


# Rail Defects & Transducer Configurations

- 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  $0^{\circ}$  and two  $37.5^{\circ}$  transducers.

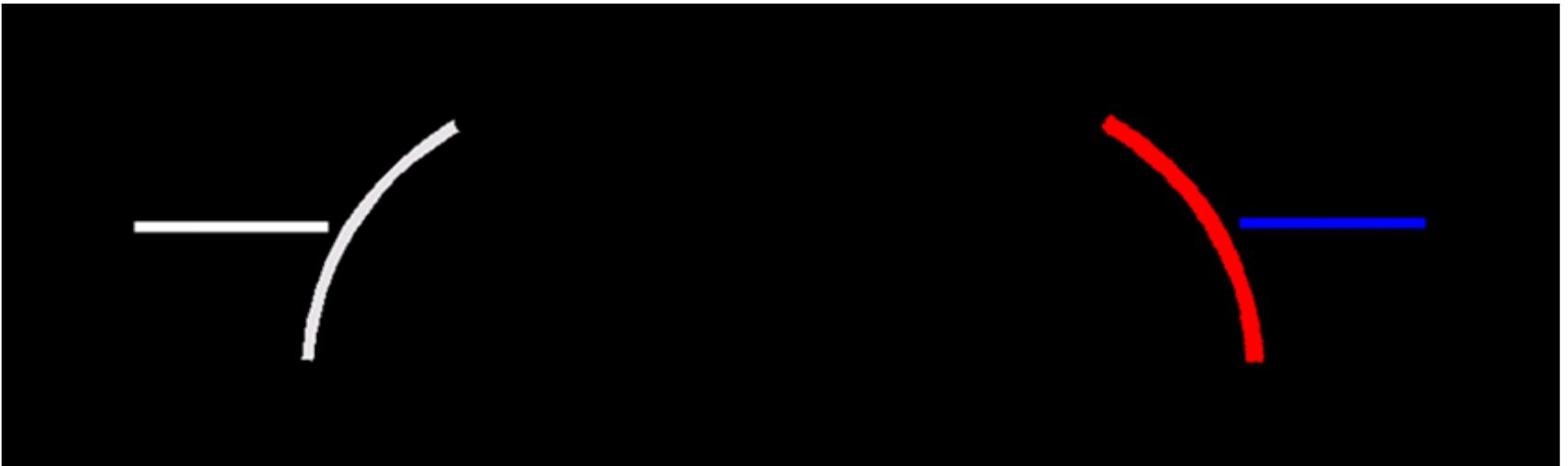


**Beam from each transducer separately and sequentially intercepts the bolt hole**



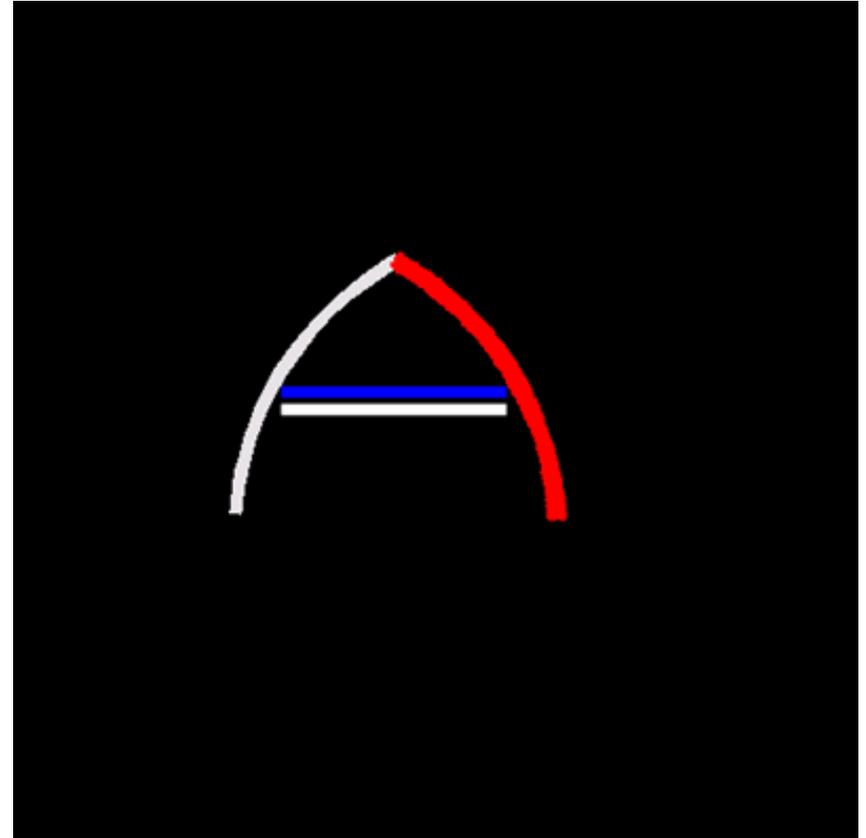
# Rail Defects & Transducer Configurations

- 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

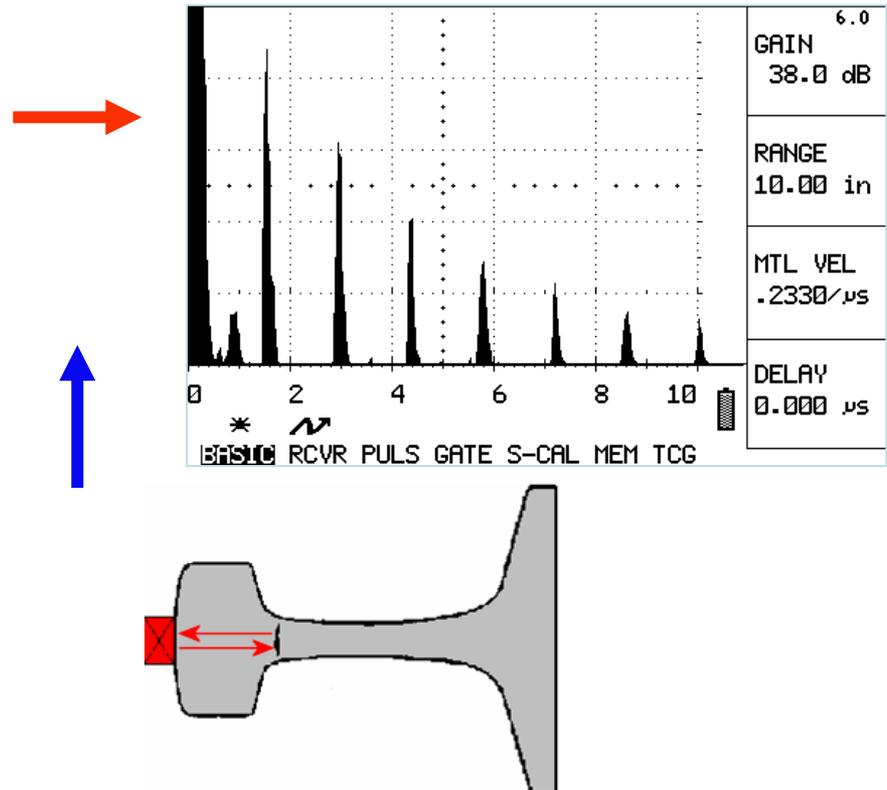


# Signal Interpretation



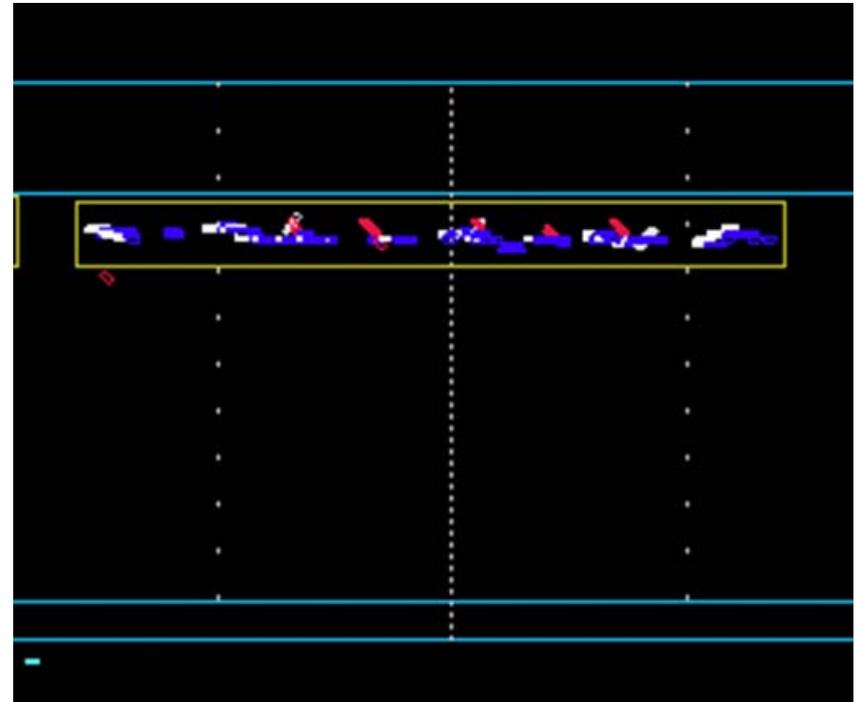
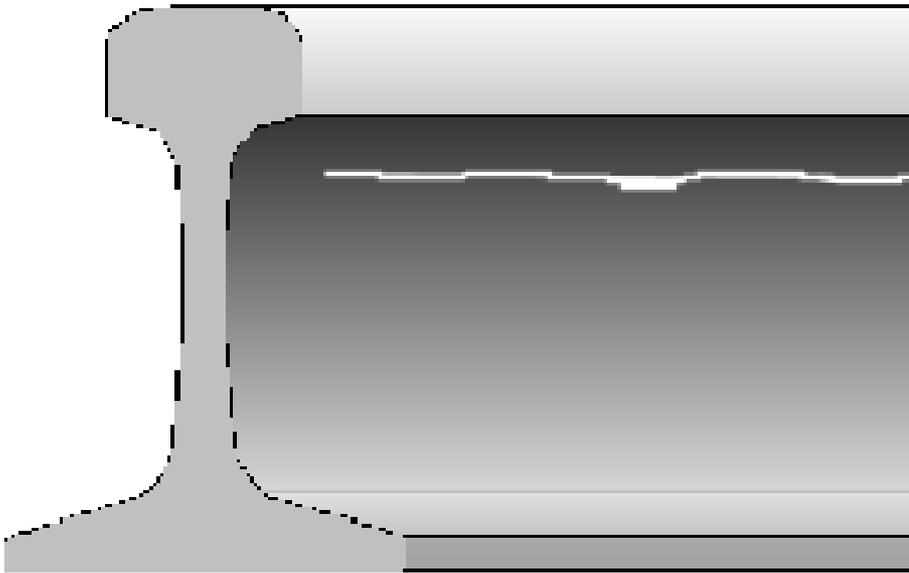
# Displays: A-Scan

- 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



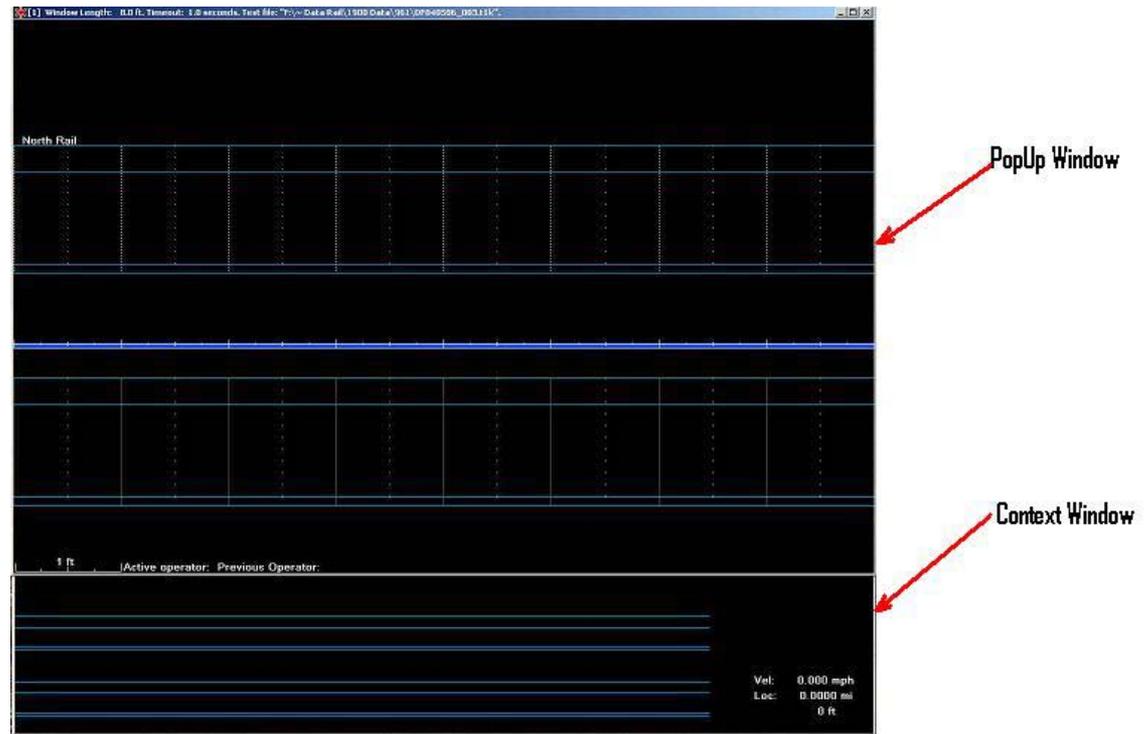
# Signal Interpretation

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



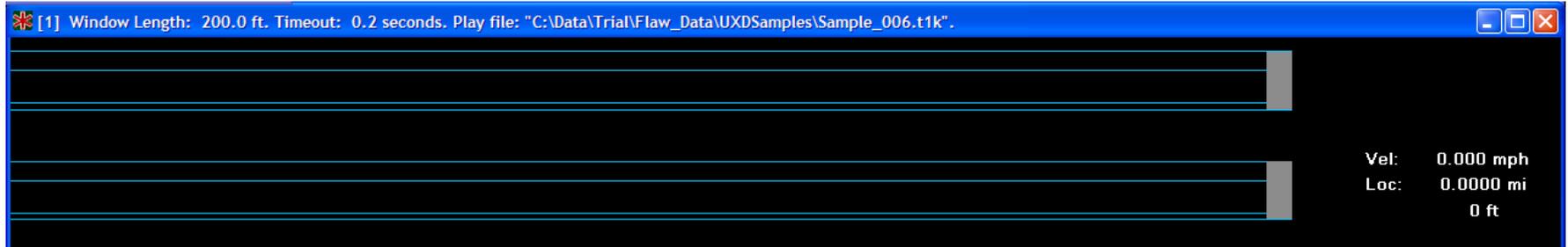
# Signal Interpretation

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



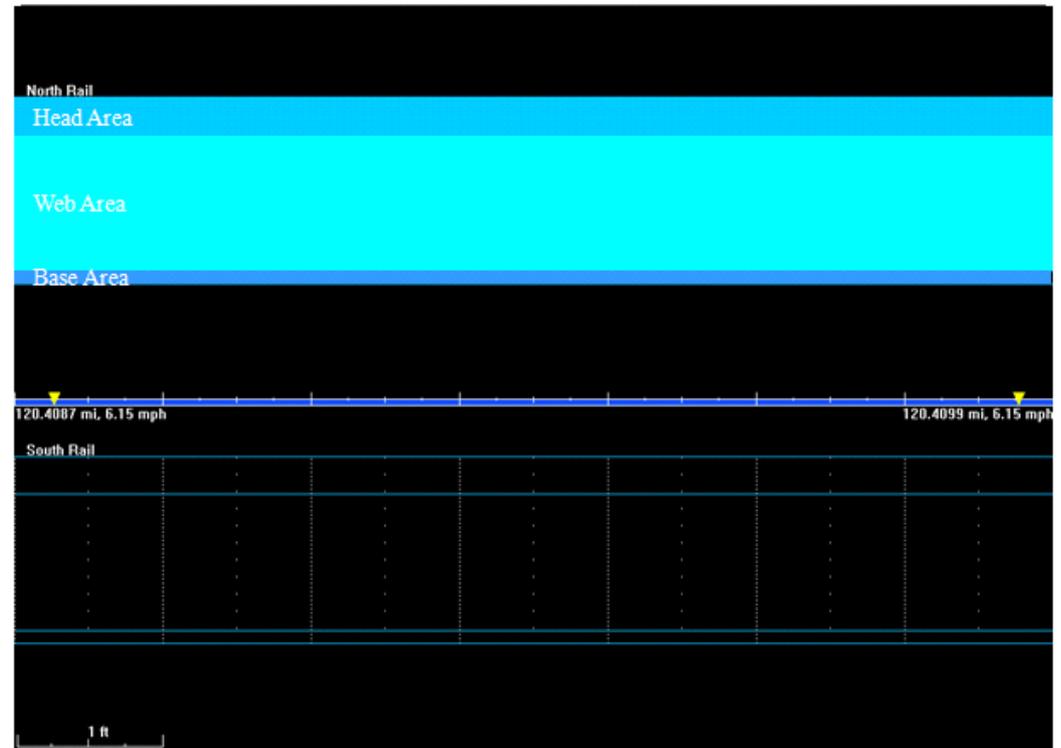
# Signal Interpretation

- 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.



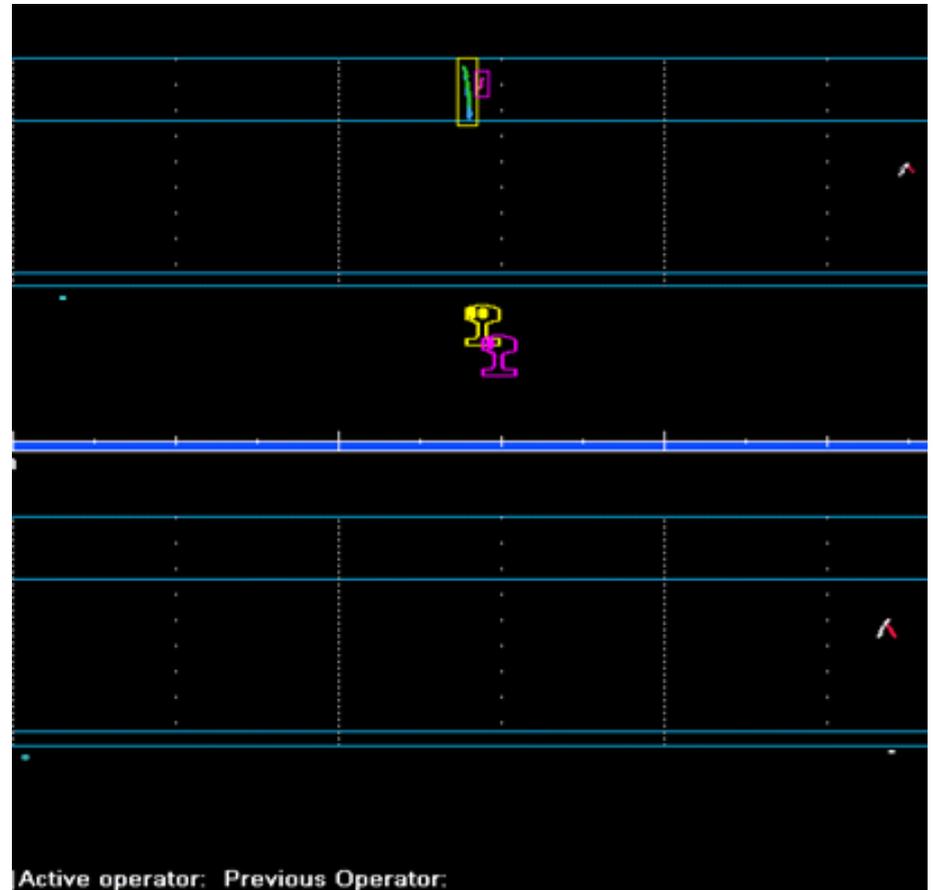
# Signal Interpretation

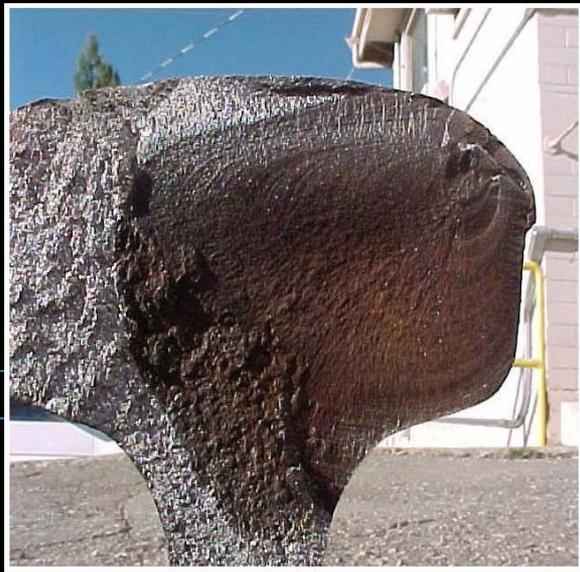
- In the popup window, the left rail is shown on top, the right rail on the bottom.
- Horizontal lines are positioned to represent the head, web, and base portions of the rail
  - enabling test operators to imagine that they are looking into the rail.



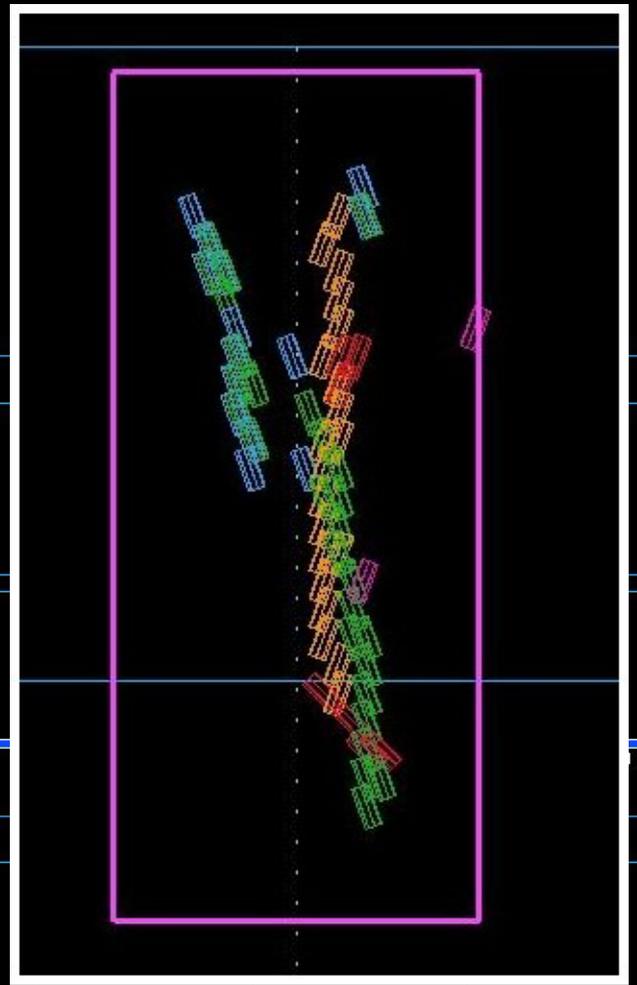
# Signal Interpretation

- 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.



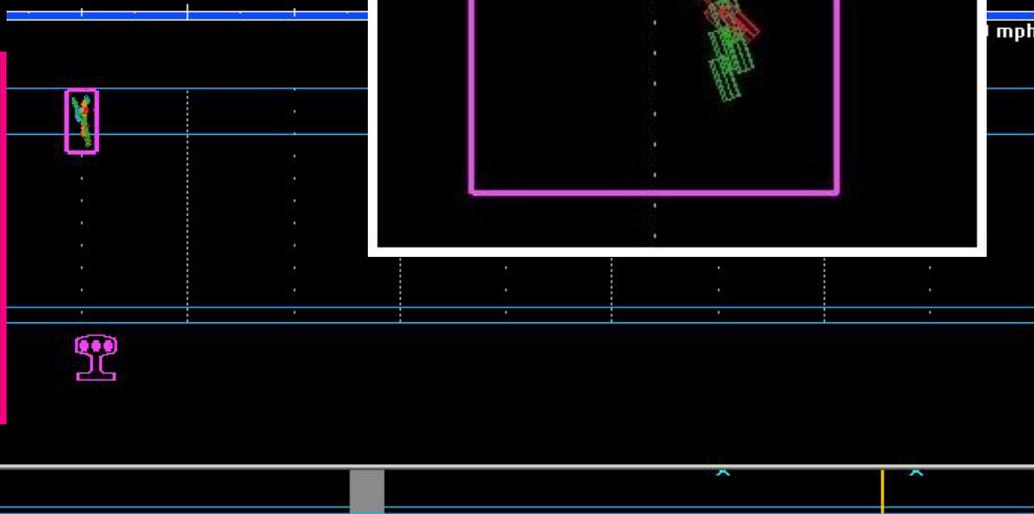


# Analyzing Signals



## Fencelet Channel Map

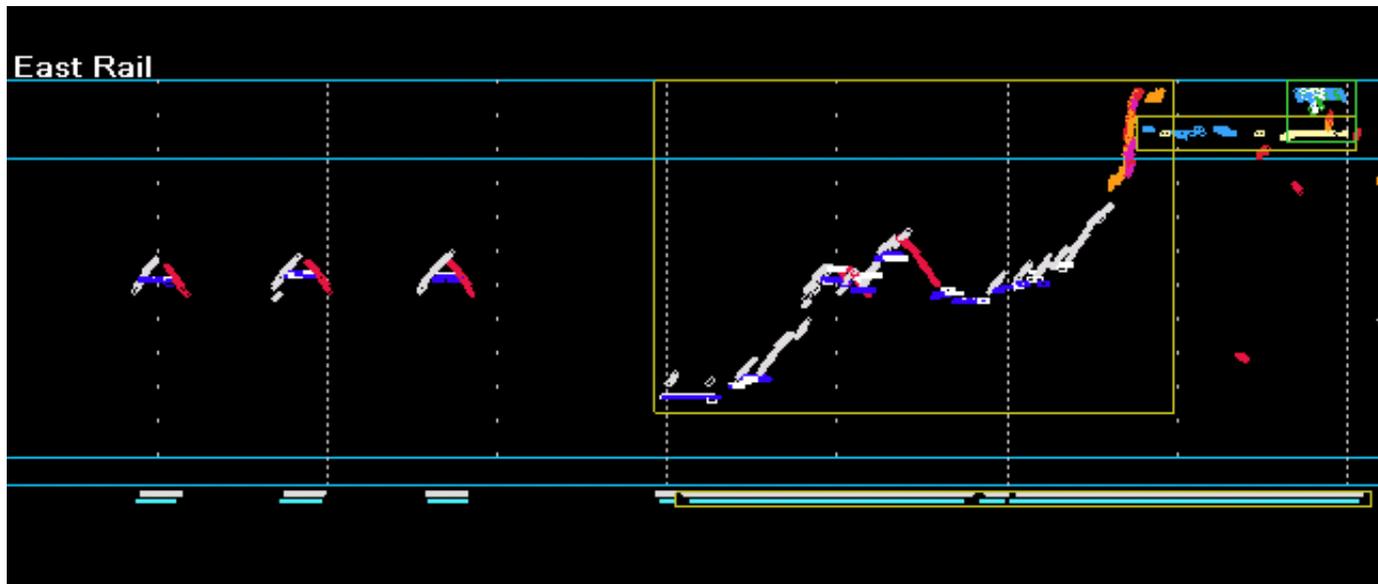
<b>FRONT</b>							
<b>REAR</b>							
	<b>Field 70</b>	<b>Center 70</b>	<b>Gauge 70</b>	<b>37.5</b>	<b>Side Looker</b>	<b>Zero</b>	<b>LER</b>



# Analyzing Signals

## Bolt Hole Cracking

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



# Analyzing Signals

## Carom Shot

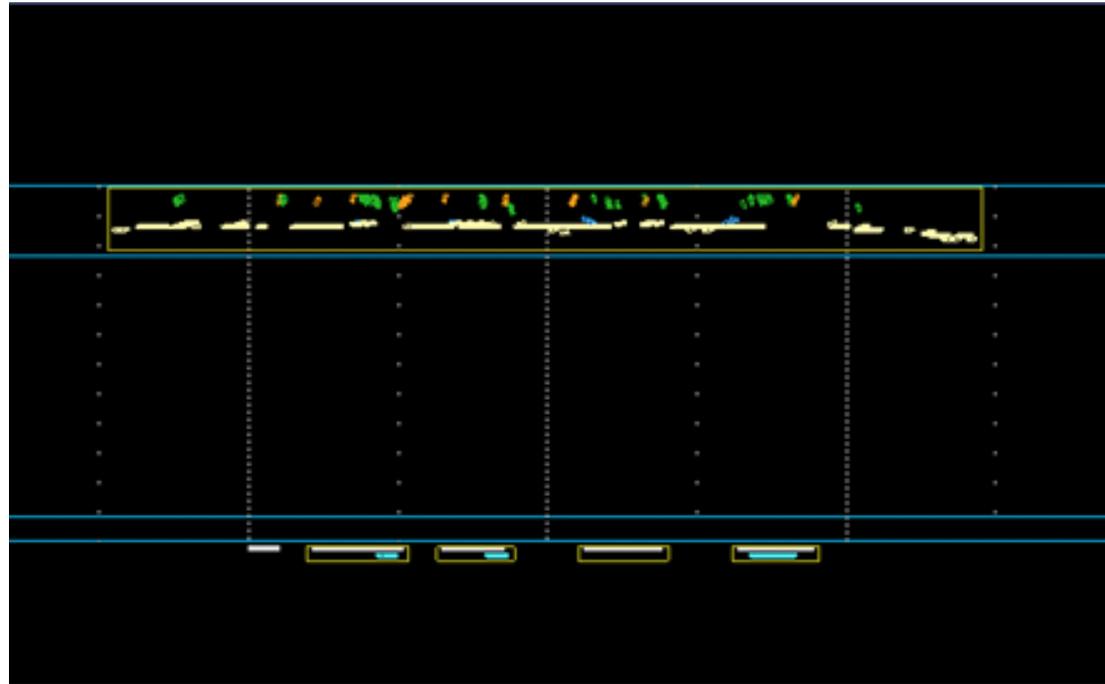
- Sound reflects off the rail end & displays on the other side of the joint



# Analyzing Signals

## Vertical Split Head

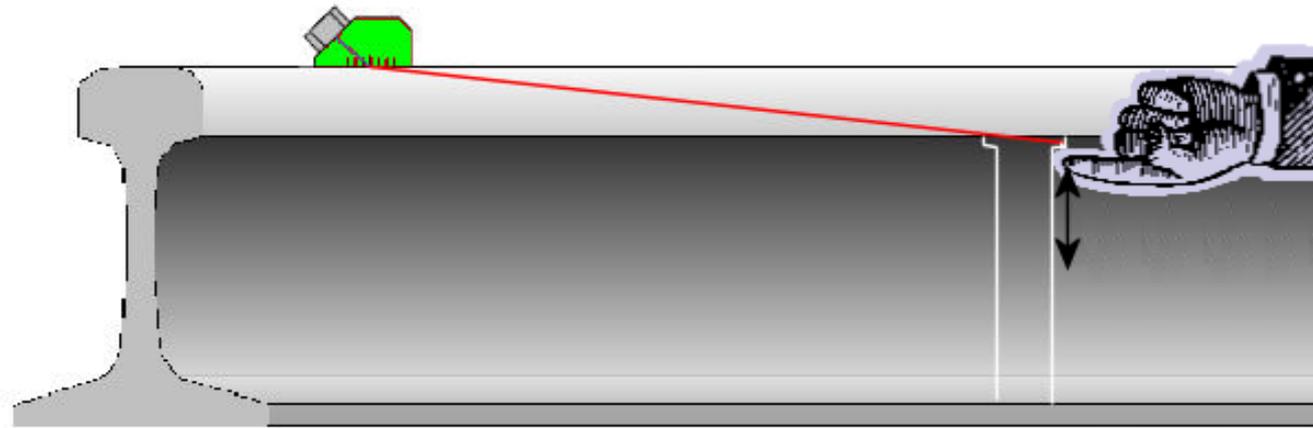
- VSH can return signals from multiple channels



# Analyzing Signals

## Weld Contour vs. Defect

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



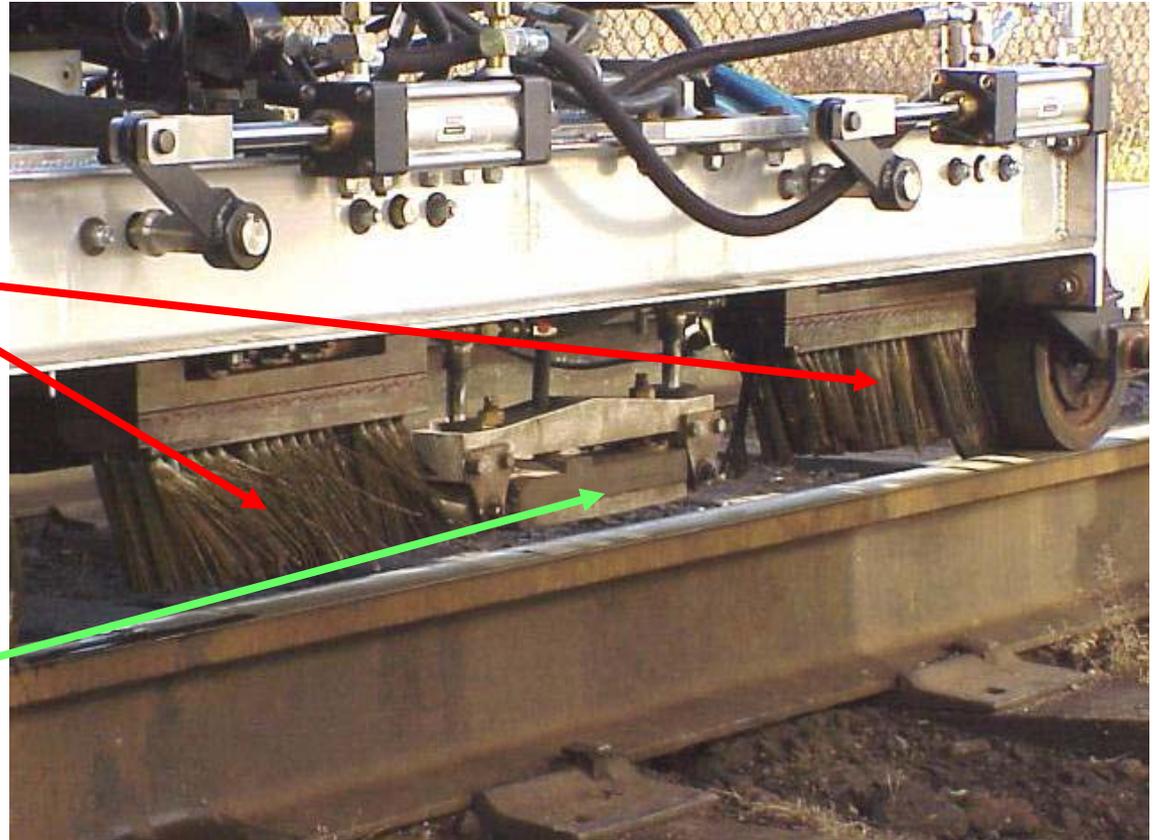
# Induction Testing



# Induction Testing

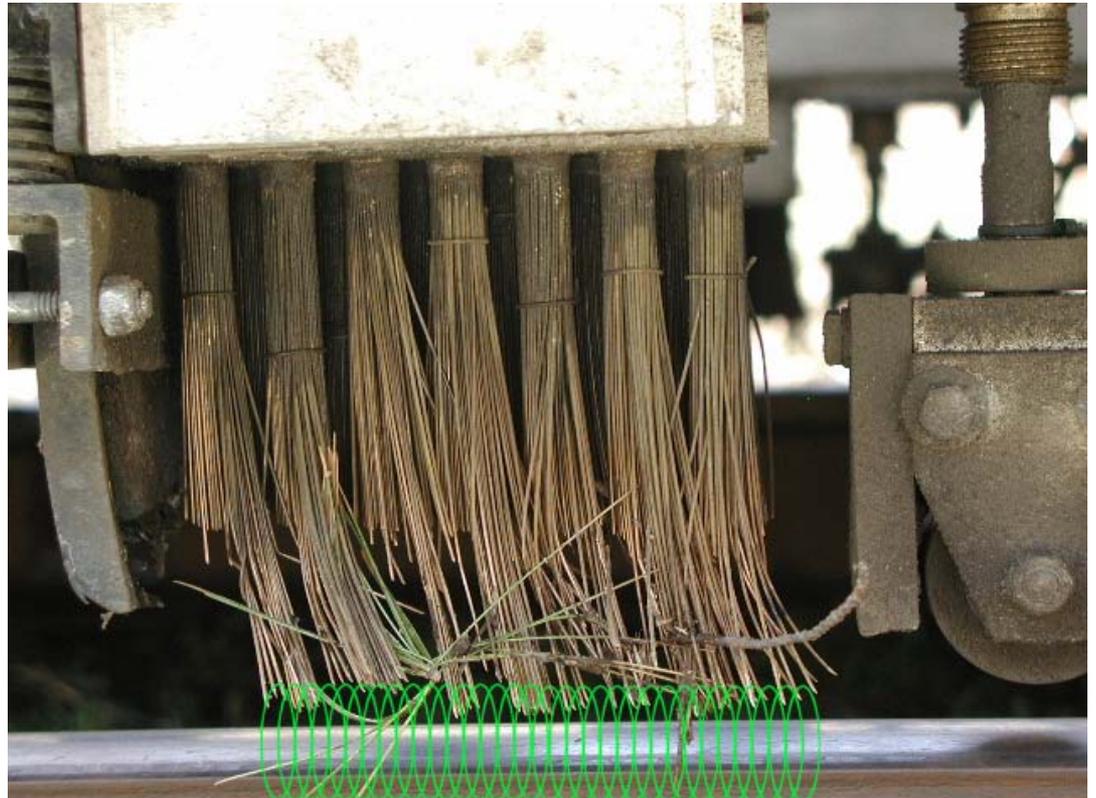
- Beryllium-Copper Brushes

- Sensing Coils



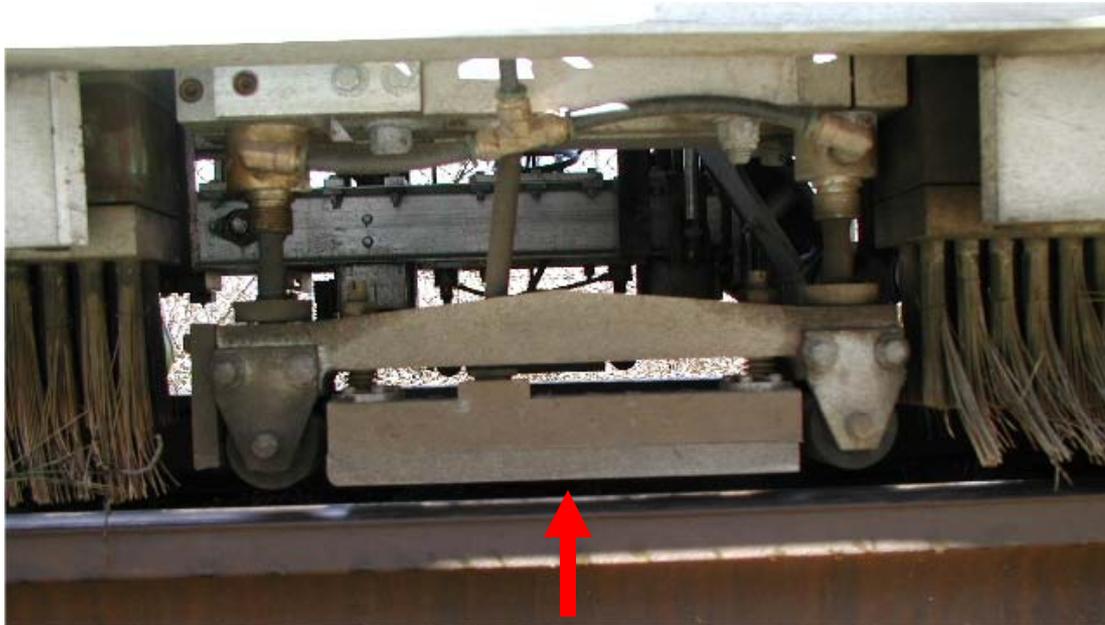
# Induction Testing

- 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



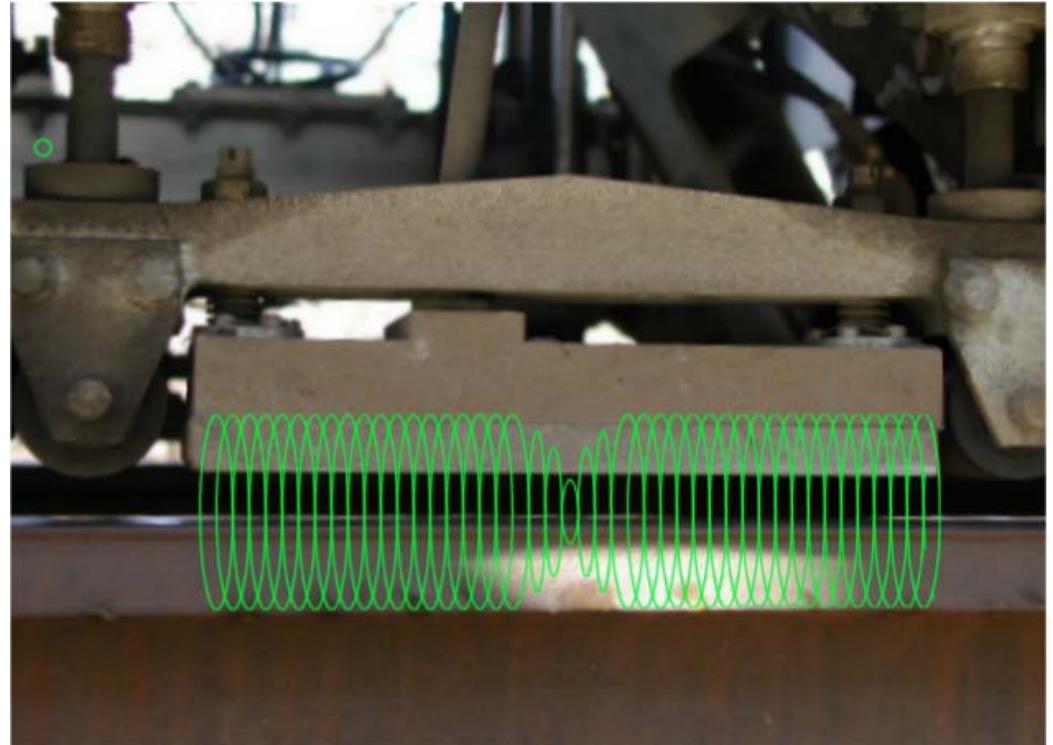
# Induction Testing

- 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



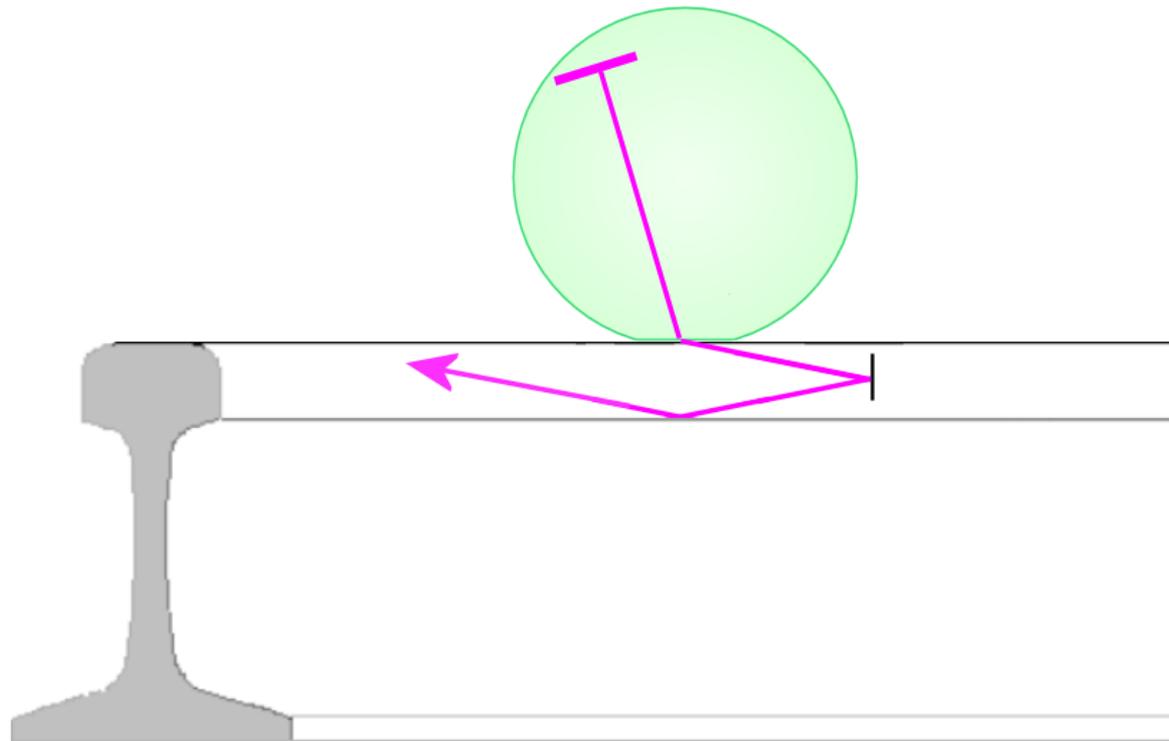
# Induction Complements Ultrasonics



# Induction Complements Ultrasonics

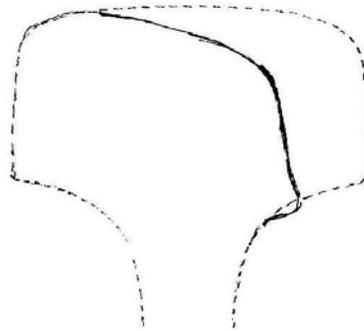
- Induction tolerates variation in defect orientation

- 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



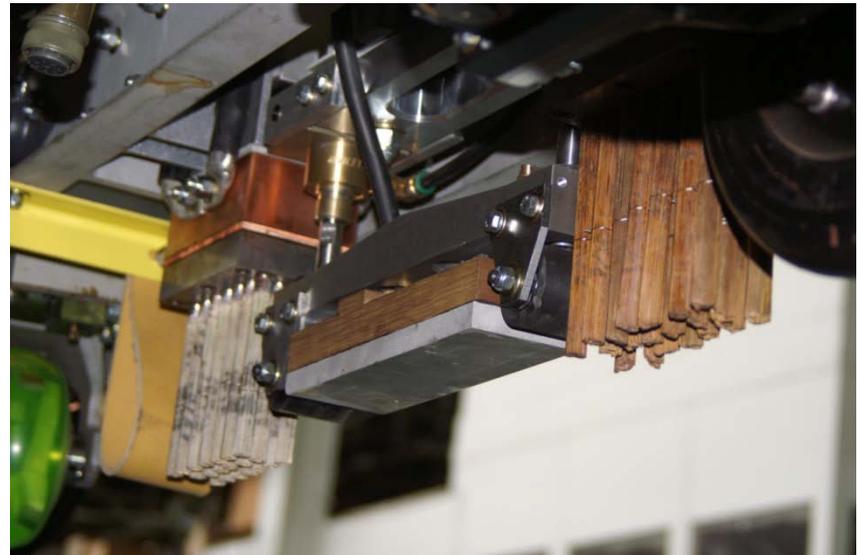
# Induction Complements Ultrasonics

- 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



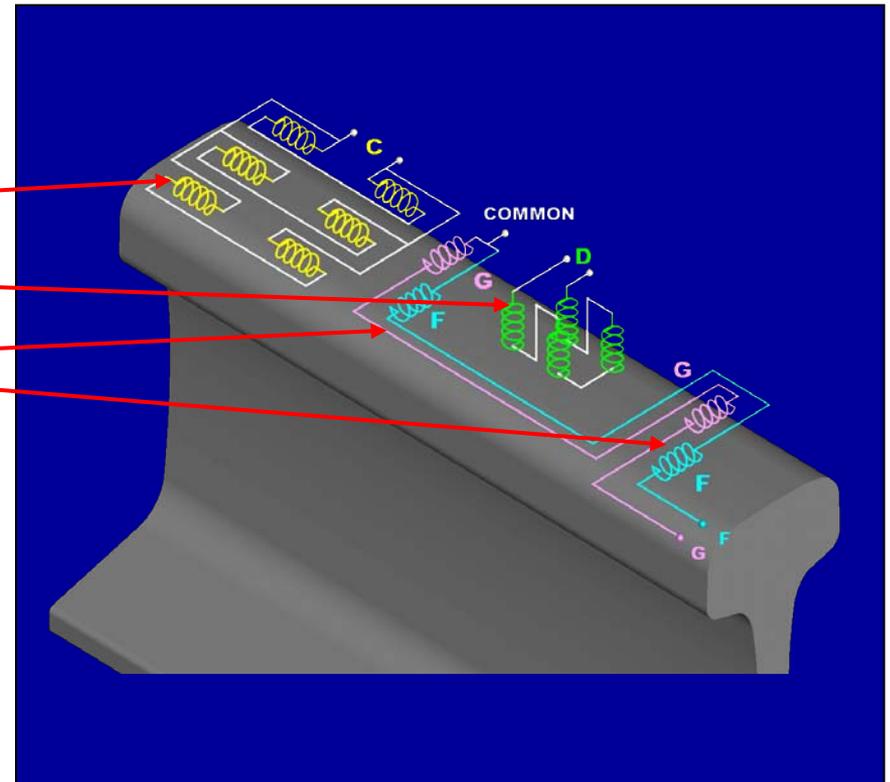
# Induction Complements Ultrasonics

- 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



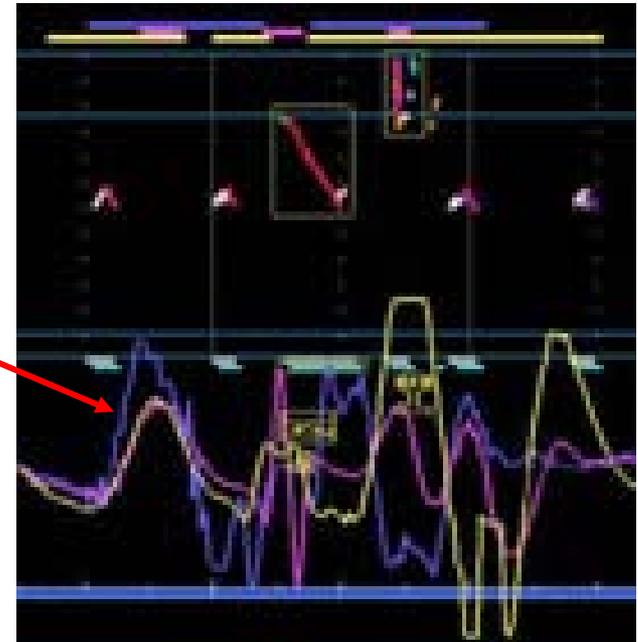
# Induction Signals

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



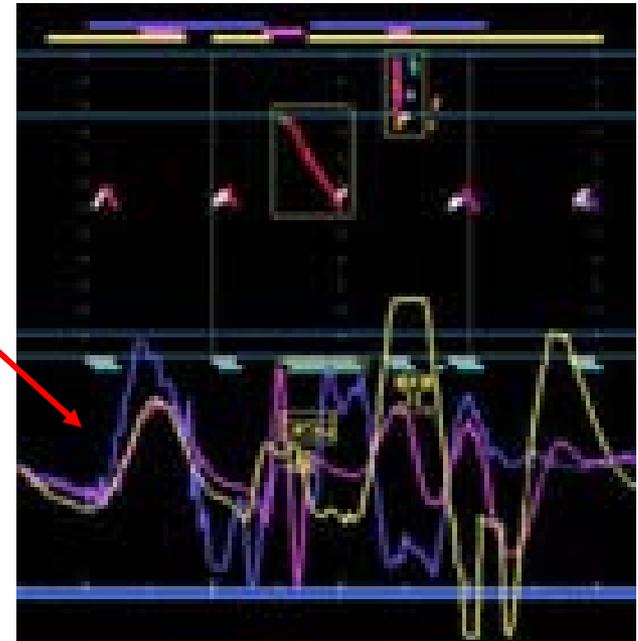
# Induction Signals

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



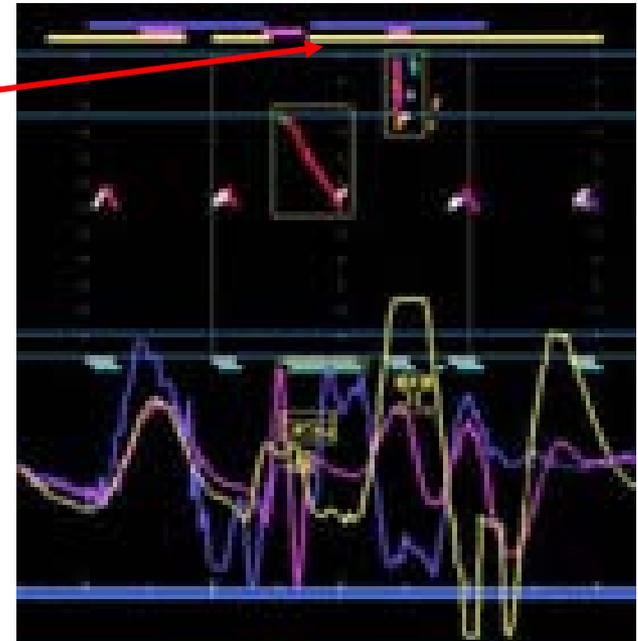
# Induction Signals

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



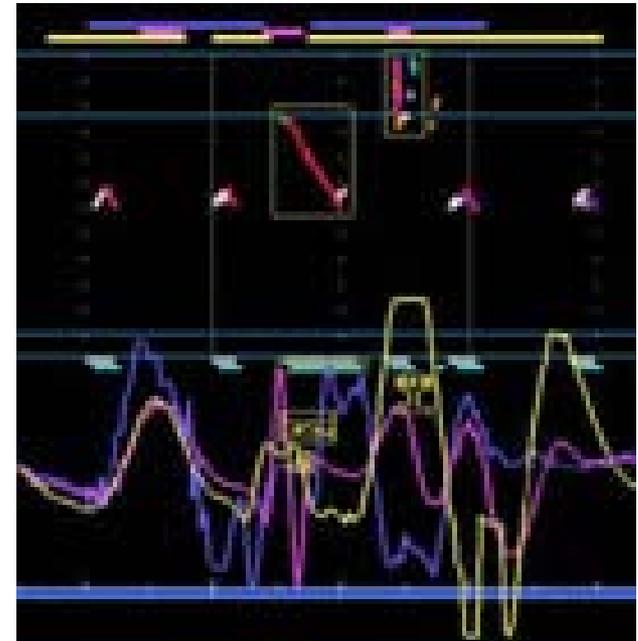
# Induction Signals

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



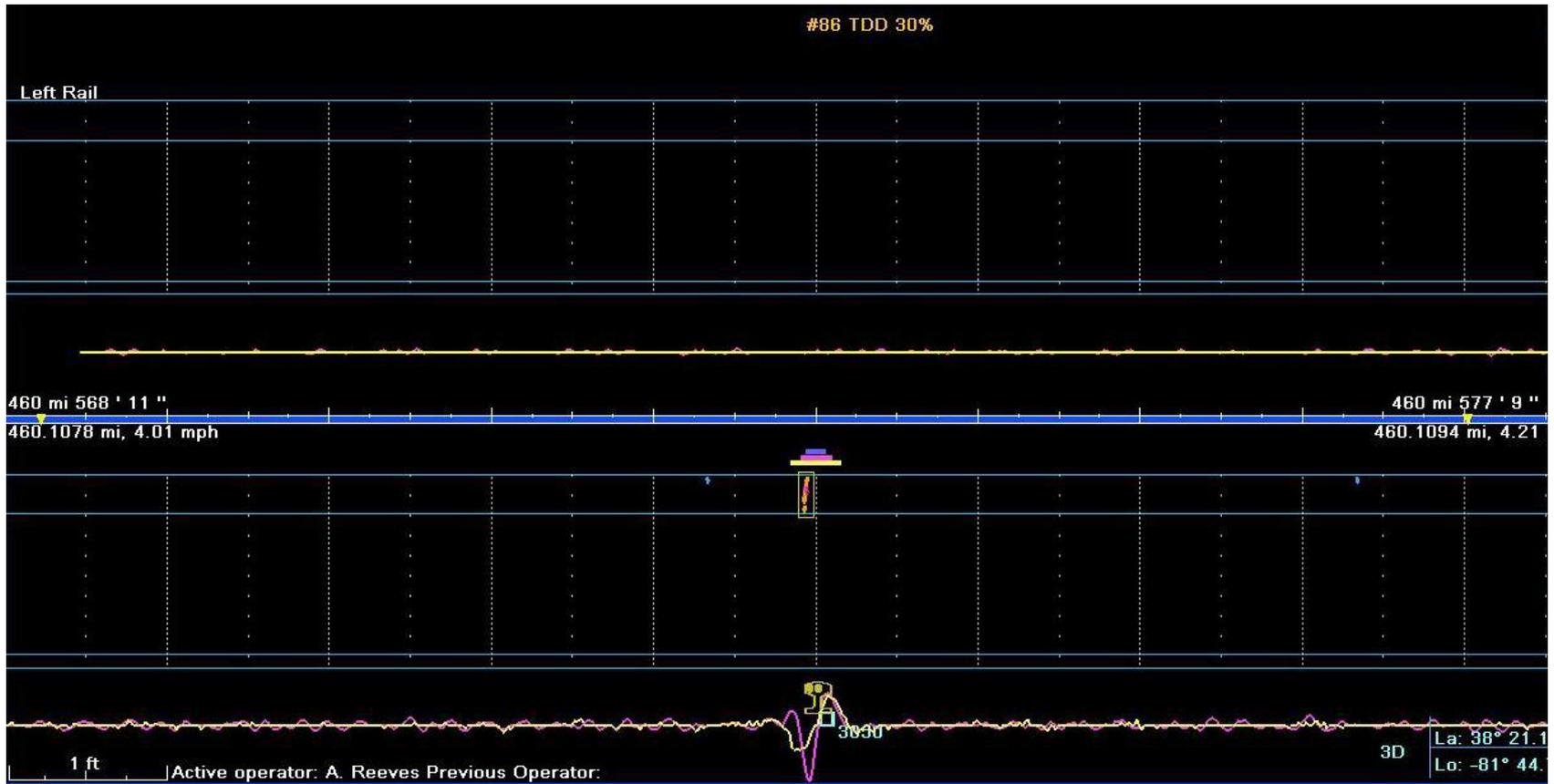
# Induction Signals

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



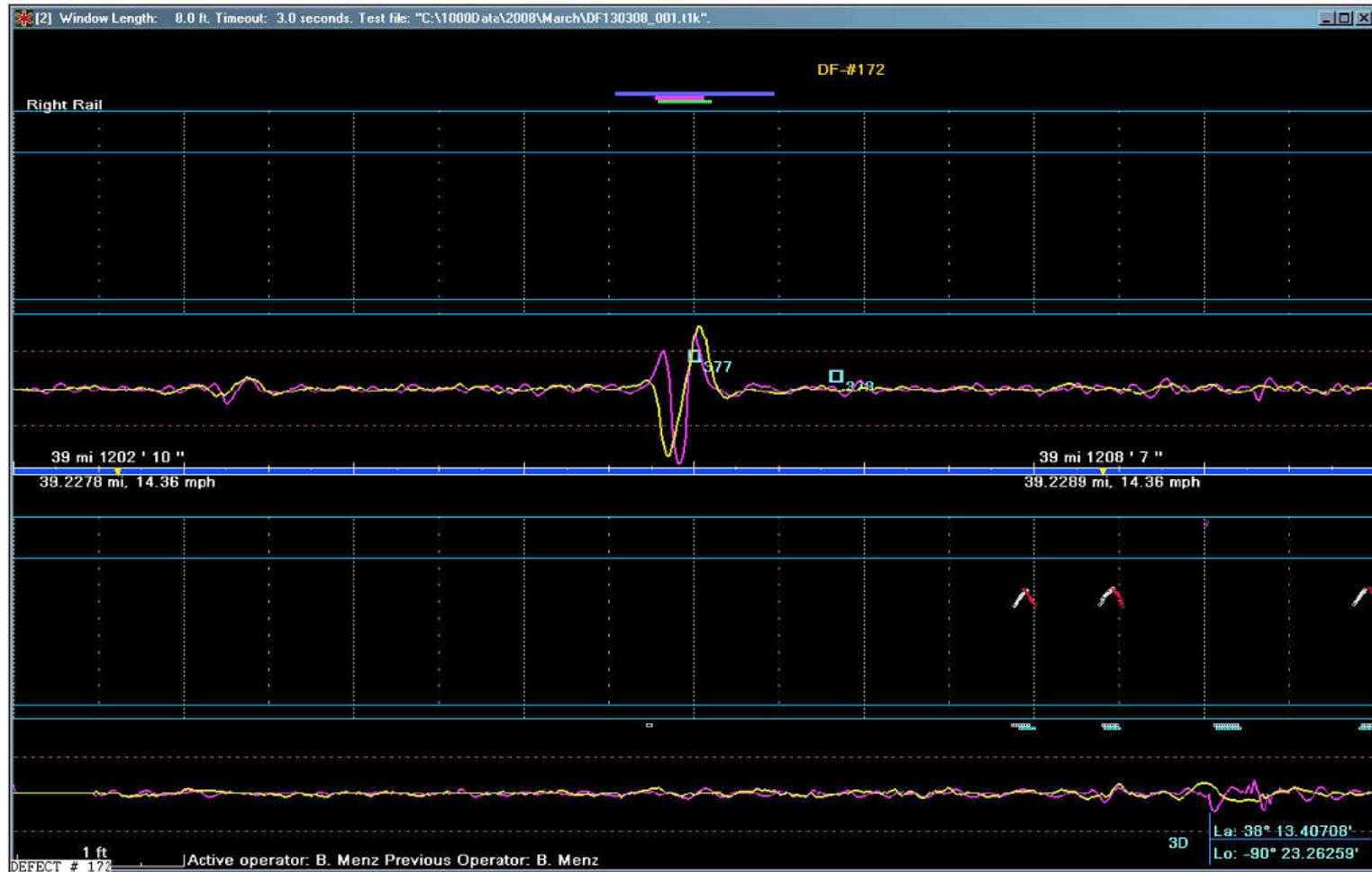
# Induction Signals

TD: Ultrasonics/Induction



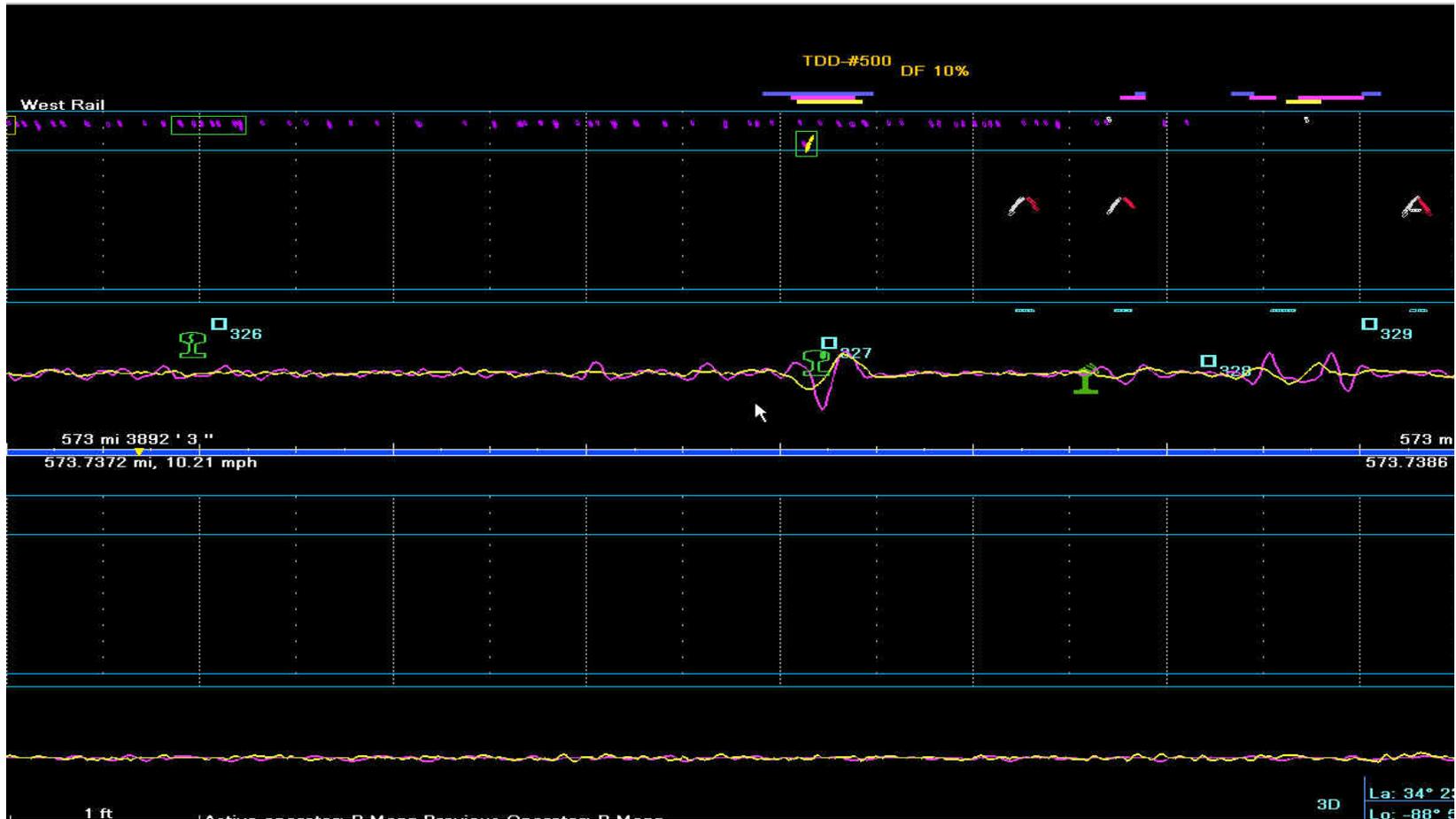
# Induction Signals

TD: Induction Only



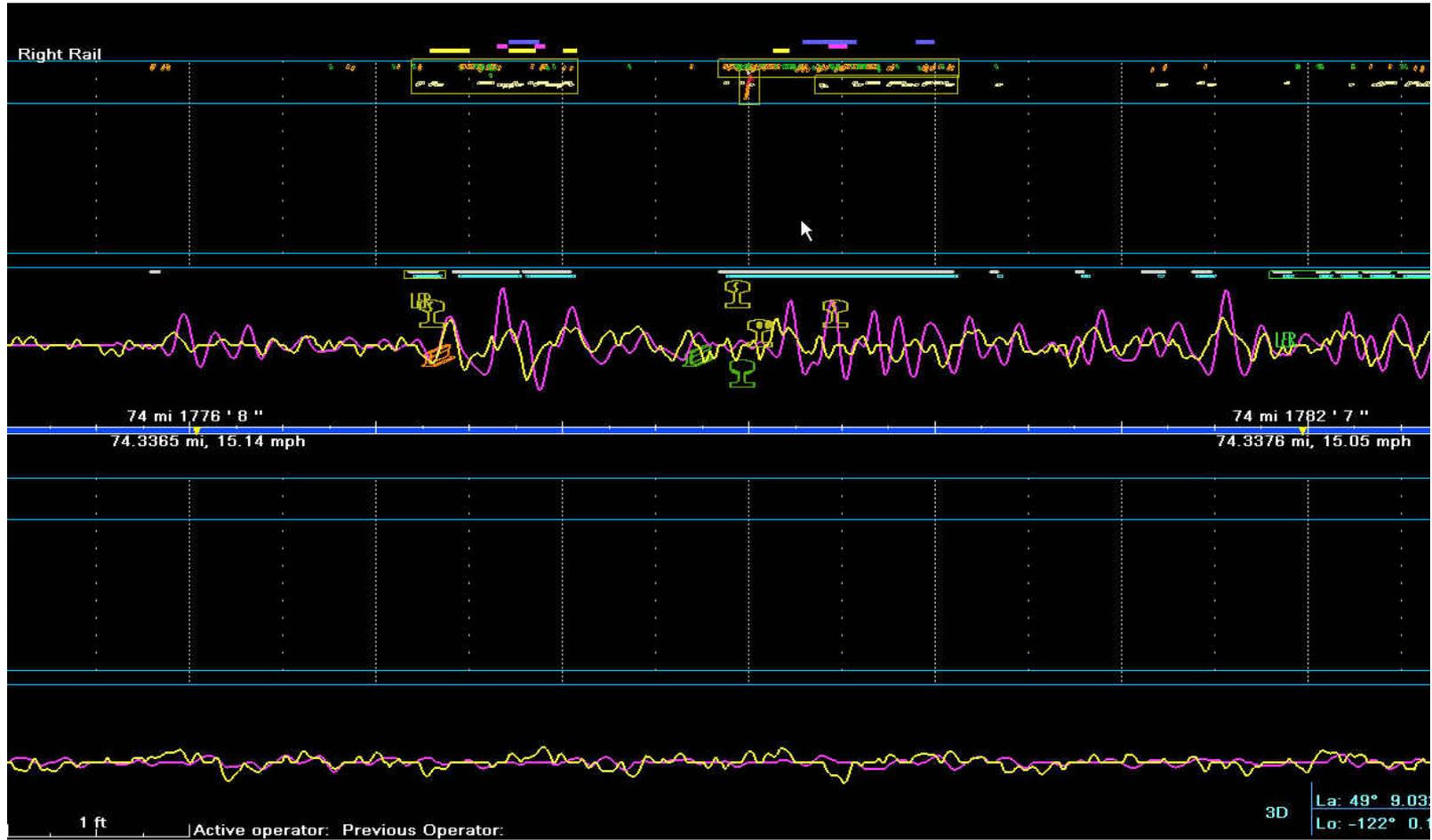
# Induction Signals

## Detail Fracture: X-Fire & Induction



# Induction Signals

VSH: Ultrasonics/Induction



*End of Presentation*

