EMW-C and EMW-I
NDT for Annulus and Internal Pipe Inspection

WaveTrue Science + Technologies
504 El Paraiso Rd NE
Albuquerque, NM 87113

CEO – Ron Floit
President – John DeWees

(888) 711-2532/ (212) 625-6622
www.wavetrue.com

Background

WHO Are We?

- WaveTrue was formed through the acquisition of Profile Technologies business and associated patents for hardware and software in November 2013.
- Profile Technologies registered as a public company in 1996 and was actively involved in the development of industry-leading technologies to identify corrosion and other anomalies within metallic pipelines.
- Acquisition was the result of two proven, successful entrepreneurs making key investments to continue the advancement of these innovative technologies.

Background
WHAT Do We Do?

- Provide metallic pipeline inspection services to locate corrosion and other anomalies
  - Cased: above ground and buried
  - Thermally insulated
  - 1/8” diameter to 48+” diameter capabilities
  - Up to 150 meters in length (~500’)
- Pipeline Applications
  - Oil & natural gas (transmission or distribution)
  - Power plants
  - Storage facilities
  - Propane / LNG facilities
  - Refineries
  - Chemical plants

WaveTrue
SCIENCE + TECHNOLOGIES

Background
Clients Served

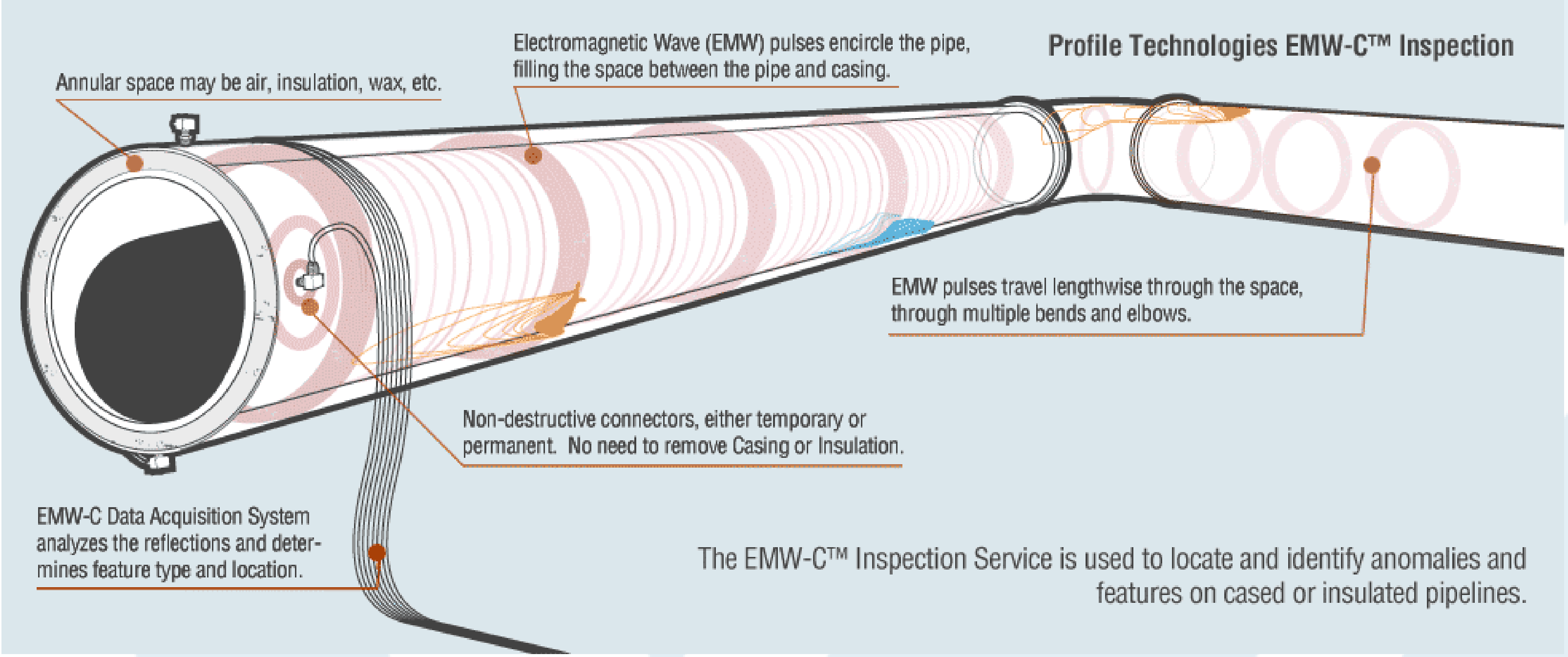
Technology Involved

EMW-C™

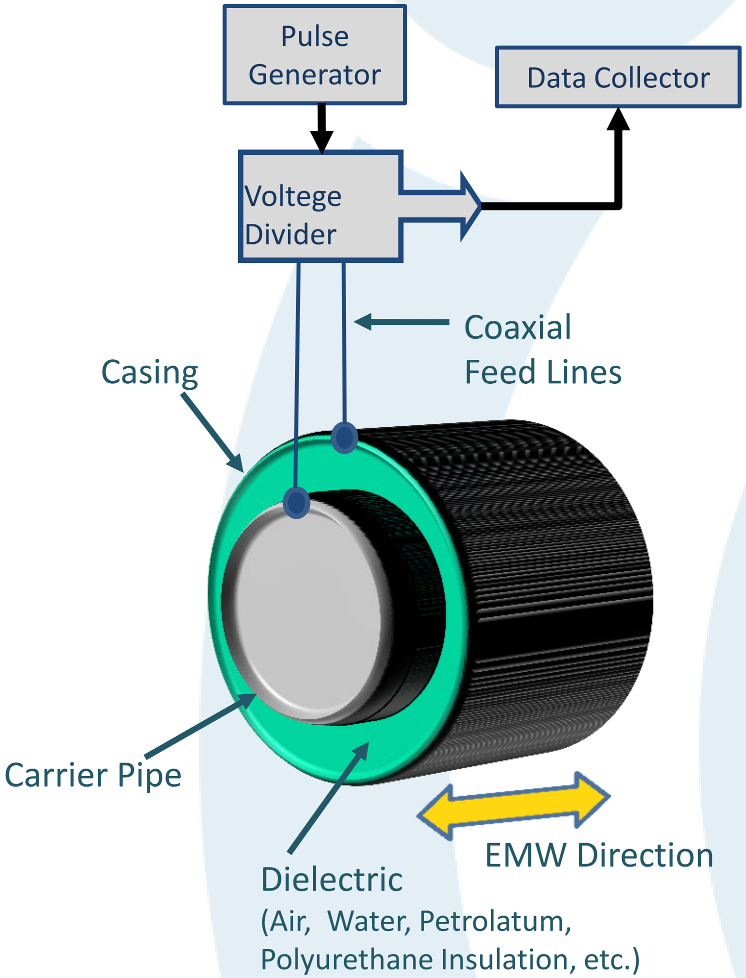
EMW-I™

EMW-C™

- WaveTrue develops pipeline inspection tools that utilize electromagnetic waves (EMW) to interrogate the pipe system.
- Our patented technology, ***EMW-C™***, was developed 15 years ago and is used to inspect cased and insulated pipe for CUI and other anomalies.
- These are long-range methods allowing for inspection of long segments (up to 150 meters) in both directions from a single location.



EMW-C™ Basic Setup



- Connection is made to the carrier and casing (or jacket) using coaxial connectors and cables.
- A pulse generator creates electromagnetic waves (EMW) in the annulus (dielectric).
- The casing and carrier pipe guide the waves, which travel through the annulus and through the dielectric material(s) in the space between.
- Similar to RADAR, the waves are reflected back to the equipment from material changes in the annulus.
- Changes in dielectric material (rust, water, spacers, wax) are seen as variations of amplitude and polarity of reflections.
- Lengthwise distance to reflectors (anomalies) are determined by time of return.

EMW-C™

- ***EMW-C™ is the only*** long range electromagnetic wave (EMW) inspection system for pipelines:
  - Designed for cased and thermally insulated pipe
  - Designed as a long term permanent solution to analyze and monitor both filled and unfilled casings
  - Designed to provide necessary information for a cased pipe ECDA program
    - Baseline conditions
    - Short / electrolytic couple
    - Fill volume analysis
    - End seal condition
    - Documented monitoring to identify changing conditions
- With the use of above ground permanent connectors, future excavations can be eliminated.

PHMSA Casing Guidelines
Casing Monitoring

- In November 2010, PHMSA published Guidelines for Integrity Assessment of Cased Pipe in Gas Transmission Pipelines.
- The guidelines suggest **casing monitoring** as “other assessment activities” to satisfy the requirements of NACE ECDA RP0502.
- Under Section 3.2.2:

“The other assessment activities (such as monitoring casing integrity) supplement the indirect inspection tool data with additional data which is indicative of the effectiveness of engineered systems (such as casings, end seals, and wax fill) in preventing corrosion and protecting carrier pipe integrity.”

Casing Monitoring Requirements

- Under D.1.2 Guidance for Filled Casings Free of Metallic Shorts and Electrolytic Contacts…

> *"To ensure the continued effectiveness of the casing and fill material at preventing external corrosion:*
> *•The fill material must remain in place and continue to encapsulate the carrier pipe.*
> *•The level of fill material in the annulus of a casing must be monitored to ensure that the annulus remains effectively filled. Field verification of fill material effectiveness must include verification of casing integrity to assure that fill material is not lost through corroded or damaged casing.*
> *•Electrical isolation of the casing from the carrier pipe must also be monitored."*

Long range EMW can verify that the wax remains in place through above ground monitoring and identification of new voids or water incursion.

Similarly, the level of fill material can be monitored and verified versus original baseline data.

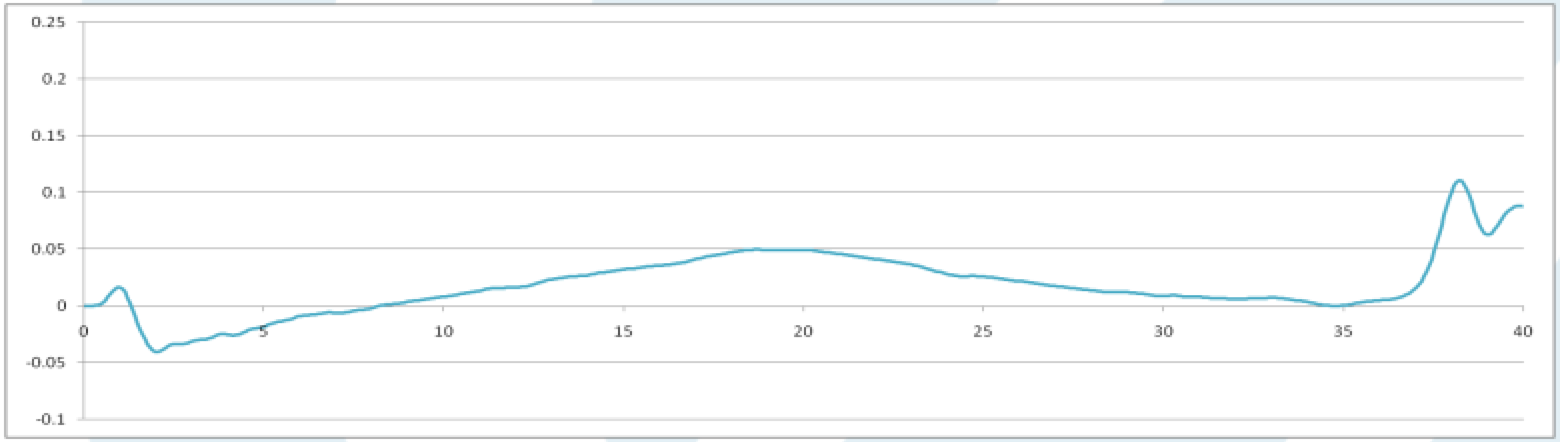
Electrical isolation is monitored by long range EMW by identification of metallic shorts and electrolytic coupling.

Other Assessment Activities – Casing Monitoring

- Under D.1.1.3 Casing Fill Procedure…

  "Once the fill material level has stabilized, the total volume of fill material pumped into the casing and vents must be compared to the calculated volume. The difference in fill volume should be within 10% of expected."

Long-range EMW can determine the volume of wax fill immediately after filling to determine if this requirement has been satisfied. WaveTrue can also determine locations along the casing where fill problems may occur.



Casing Monitoring Requirements

- Under D.1.2.5 Periodic Monitoring…

After the integrity assessment of the carrier pipe and casing has been completed, the operator must periodically monitor casing integrity as described below:
•Structural integrity of the casing and end seals (i.e., that the casing pipe and end seals are not leaking) must be monitored.
•Fill quantity and fill level must be monitored (i.e., that fill material is not leaking out or melting).
•Electrical isolation of the casing from the carrier pipe must also be monitored. The electrical isolation condition of the casing pipe to the carrier pipe must be in the clear or isolated condition. Testing techniques commonly utilized include Panhandle Eastern "B", Internal Resistance, DCVG, ACVG, Current Attenuation, etc.

Long range EMW can verify that the end seals are not leaking through monitoring of the entire annulus for (air) voids, and water incursion.

Similarly, the level of fill material can be monitored and verified versus original baseline data.

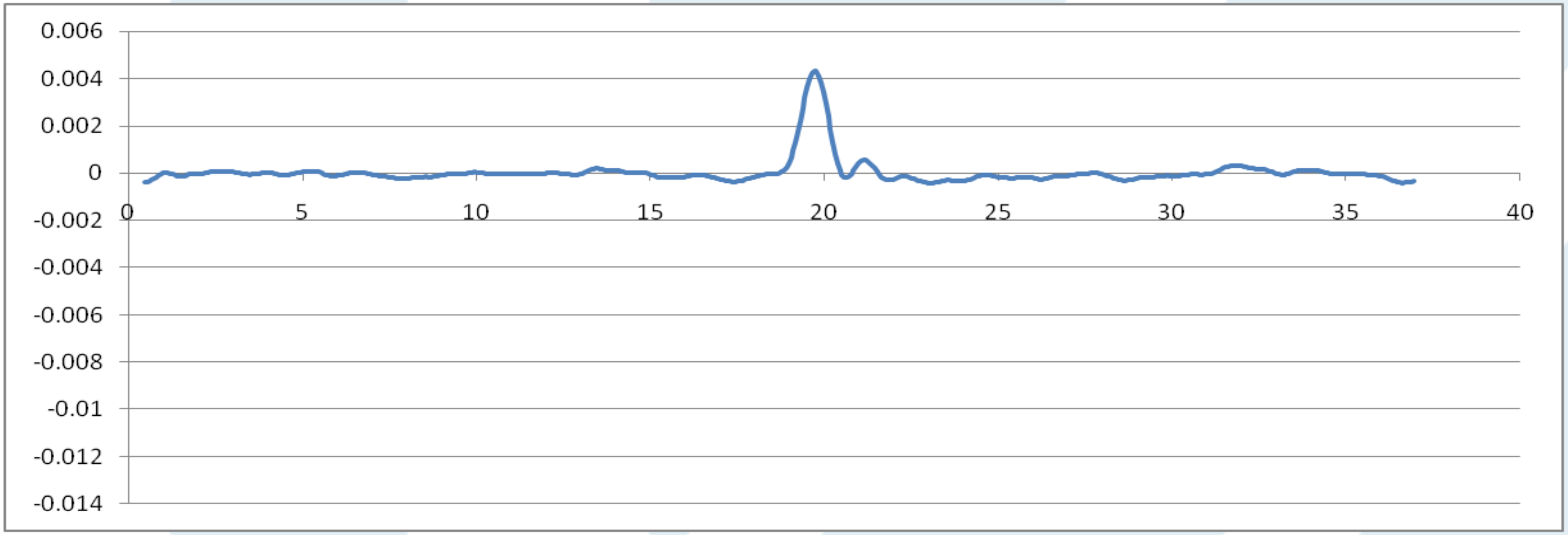
Electrical isolation is monitored by long range EMW by identification of metallic shorts and electrolytic coupling.

Casing Monitoring Requirements

- Under D.1.2.5 Periodic Monitoring…

  Documentation of these quarterly, annual or periodic tests for isolation between the carrier and casing pipe and fill level stability is required. The information must be used in the next reassessment as described in Section 3.

Long-range EMW provides documentation of each inspection with graphical representation of the full length of each casing. Consecutive inspections are compared to determine and isolate changes.



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Casing Monitoring Requirements

- Section D of the guidelines also provides monitoring requirements for unfilled casings

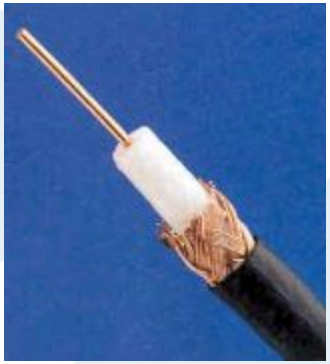
D.2.1 Guidance for Monitoring Unfilled Casings Free of Metallic Shorts and Electrolytic Contacts

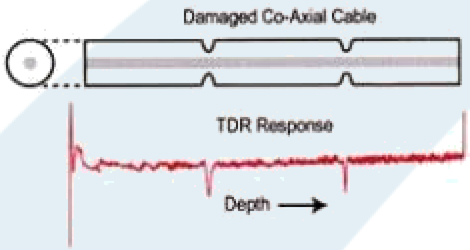
After the integrity assessment of the carrier pipe and casing has been completed, the operator must periodically monitor casing integrity as described below.
•Structural integrity of the casing and end seals (i.e., that the casing pipe and end seals are not leaking) must be monitored.
•Electrical isolation of the casing from the carrier pipe must also be monitored. The electrical isolation condition of the casing pipe to the carrier pipe must be in the clear or isolated condition. Testing techniques commonly utilized include Panhandle Eastern "B", Internal Resistance, DCVG, ACVG, Current Attenuation, etc.

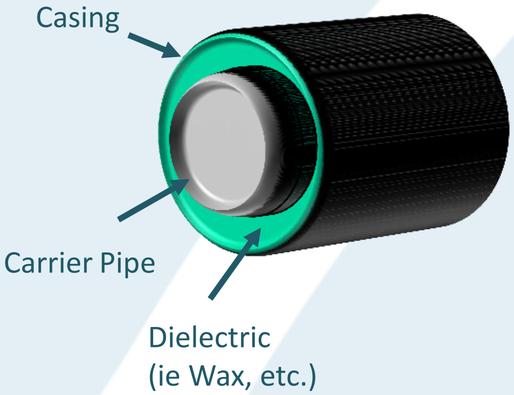
Just as with filled casings, long-range EMW can be used to perform the same monitoring as required by Section D.2.1 for unfilled casings.

Adaptation Monitoring of DIELECTRIC FILL

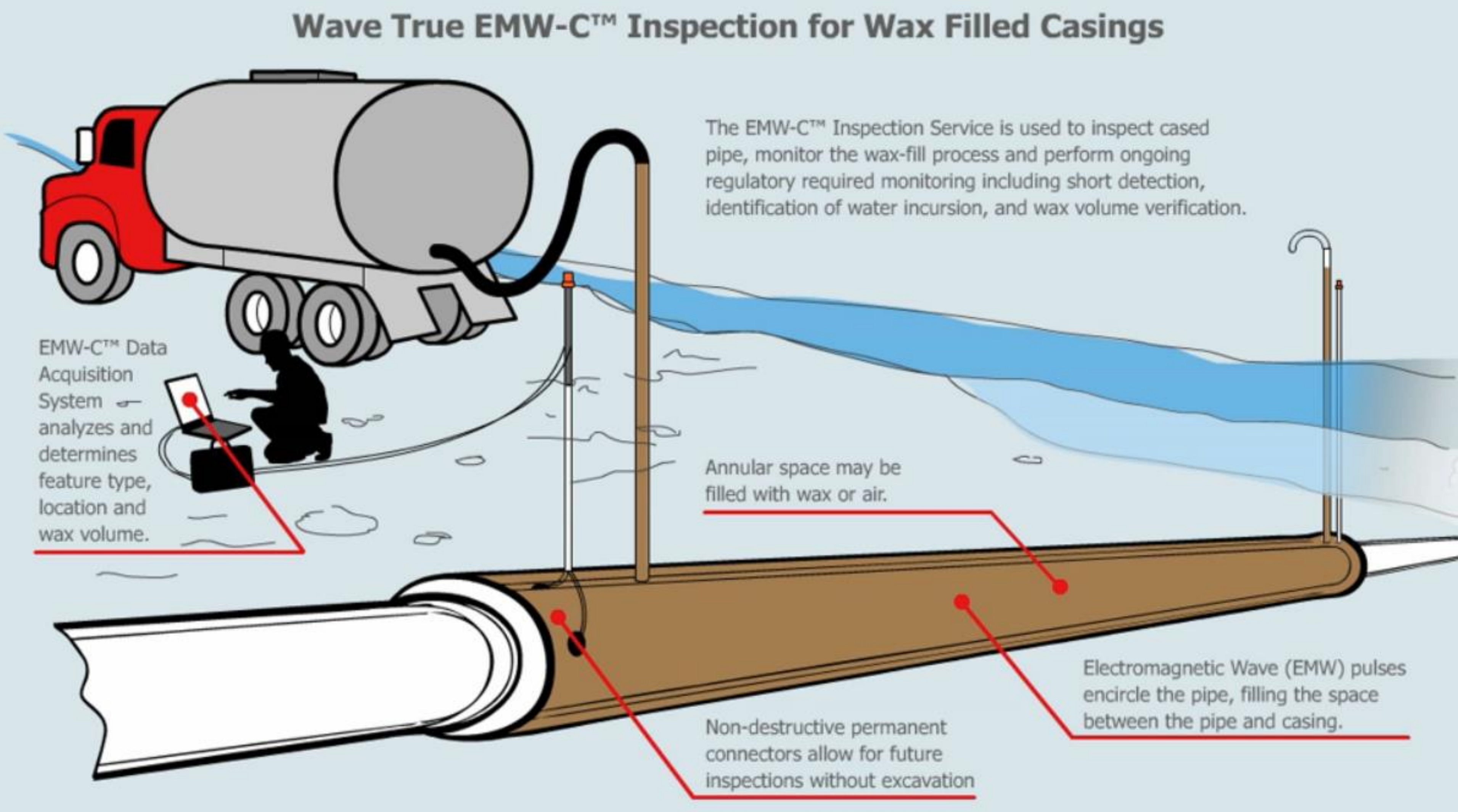
- A newly developed application of the ***EMW-C™*** allows the inspection and monitoring of wax filled casings through use of Time-Domain Reflectometry (TDR).
  - Is a commonly used technique to determine the characteristics of coaxial electrical lines.
  - Analyzes the dielectric filler between the center and outer conductor.
  - Identifies reflections that occur from changes in impedance along the structure caused by change in material or defects such as voids in the dielectric or shorts between conductors.
  - Capabilities include:
    - Volumetric monitoring of the annulus
    - Wax fill levels
    - Voids
    - Water in wax







Wax-Filled Casing Monitoring



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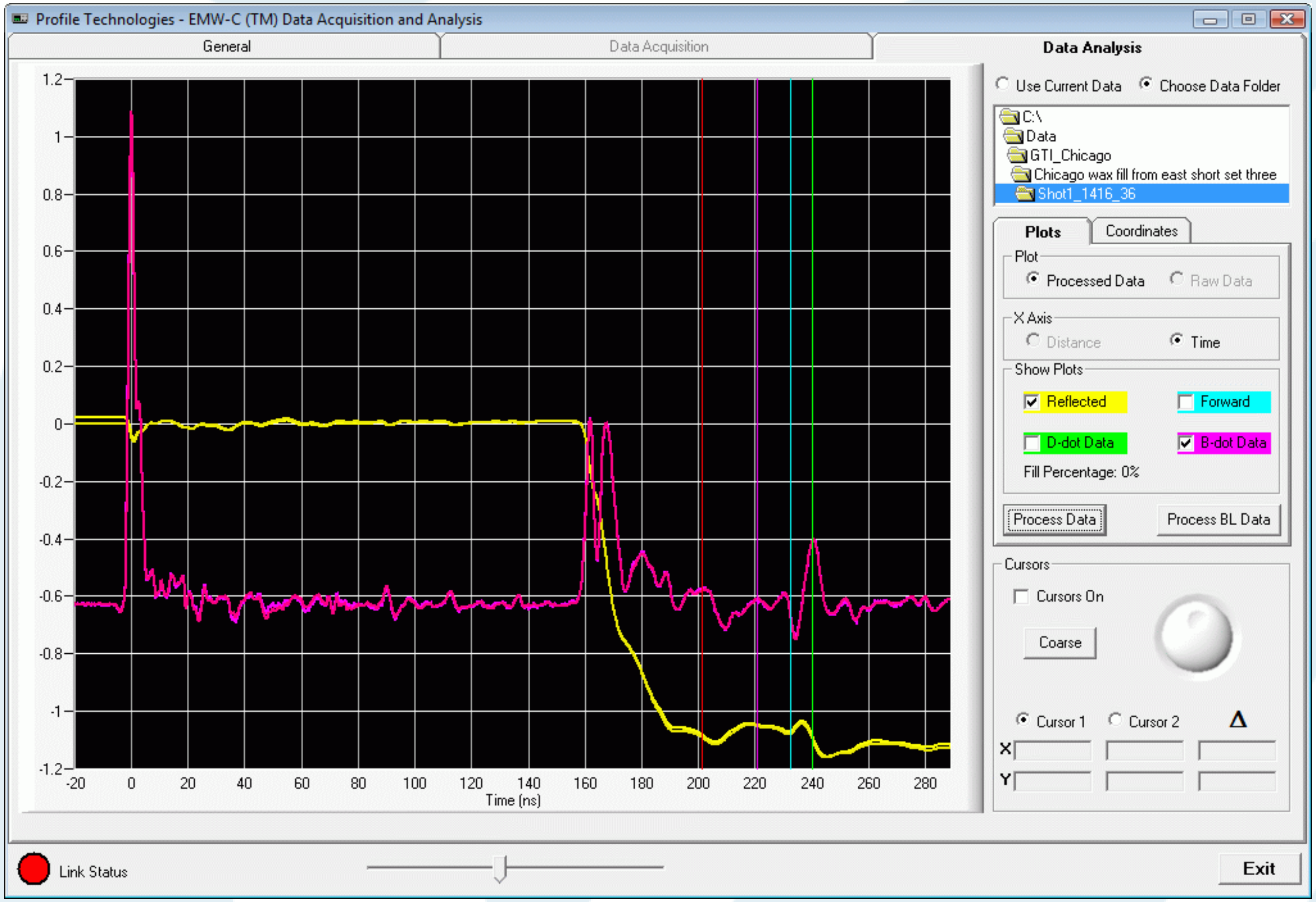
Monitoring During Wax Fill



Long-Range EMW Capabilities for Dielectric Monitoring

- Pre-Fill Analysis
  - Identifies existing conditions in casing (location of spacers, water, shorts, corrosion product)
  - Provides a baseline for post-fill comparison
  - Confirms casing length for accurate fill volume

- Real Time Analysis During Fill
  - Identifies possible fill problems such as boot leak, pipe/spacer movement, air / water voids
  - Tracks % full by volume in real-time

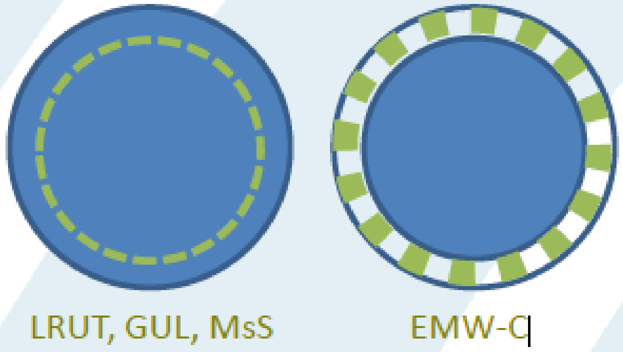
- Post-Fill Analysis
  - Confirms complete fill versus original (empty) baseline
  - Provides static full-length 'image' record of baseline following successful fill

- Periodic Monitoring to Detect Changes Over Time
  - Uses permanent above-grade connections in test station
  - Compares periodic measurements versus baseline for changes including loss of wax, water incursion, shorts, and corrosion growth

Comparison of Guided Wave Inspection Methods

Method	Wave Type	Wave Source	Waveguide
LRUT, GUL	Mechanical - Acoustic	Piezoelectric Transducers	Pipe cross-section
MsS	Mechanical - Acoustic	Magnetostrictive Sensors	Pipe cross-section
EMW-C™	Electromagnetic	Pulse Transmitter / Coaxial Connectors	Annular space between pipe and casing

Cross – Sectional view of pipe and casing. The dashed sections show the waveguide and "inspection area" for each method.



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Field Condition Cased Pipe	Type/Location	Guided Wave Technologies	WaveTrue EMW-C
Short condition	Direct	NA	Yes / location
	Electrolytic	NA	Yes / location
Corrosion	Pipe	Yes	Corrosion products / location in annulus
	Annulus	NA	Corrosion products / location in annulus
Water	Annulus	NA	Yes / location
Spacers	Annulus	NA	Yes / location
Wax fill corrosion inhibition		Voids readings	Monitors fill
			Provides above ground monitoring
Pipe wall thickness/		Yes	NA

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EMW-C Applications for ECDA

- For Pre-Assessment -
  - Collect otherwise "unknown" data about casing construction
    - Are Seals working as expected or allowing earth/water inside?
    - Are there shorts, if so how far in?
    - Are there spacers / are they where expected?

- For Indirect Inspection -
  - Identify locations of possible corrosion / water / shorts – Corrosion Likelihood
  - Can work with other GWUT tools as two complimentary tools
    - Where EMW identifies corrosion product or water does GWUT find metal loss?
    - Where EMW identifies as short does GWUT show an indication?

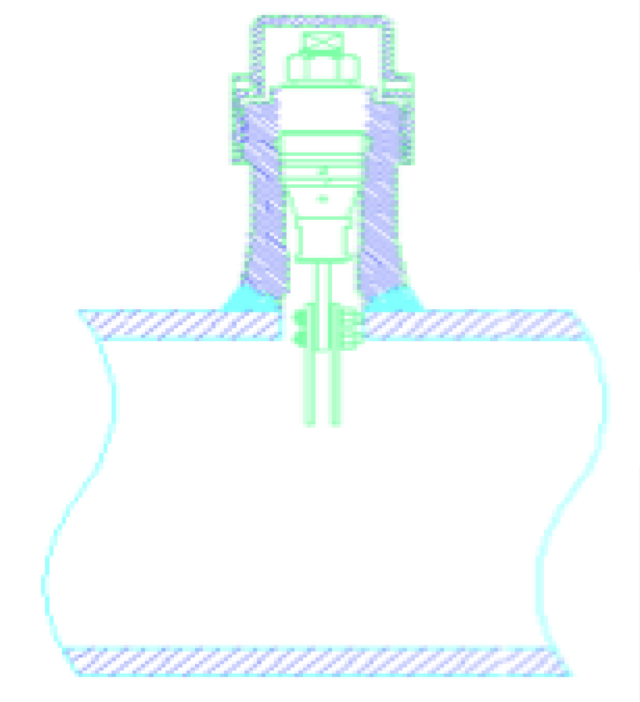
Summary of Casing Monitoring with Long-Range EMW

- Using existing capabilities of long-range EMW-C, the entire volume of dielectric material in the annulus can be monitored for:
  - Proper / complete fill (volumetric analysis)
  - Maintained fill levels versus original baseline
  - Changes such as air voids, water incursion, shorts, and corrosion growth
- Original baseline serves as test record ‘image’ of proper fill (following prescribed fill procedures).
- Once installed, all monitoring can be conducted at above-ground test stations.
- Process allows for comparison versus baseline data.

EMW-I™

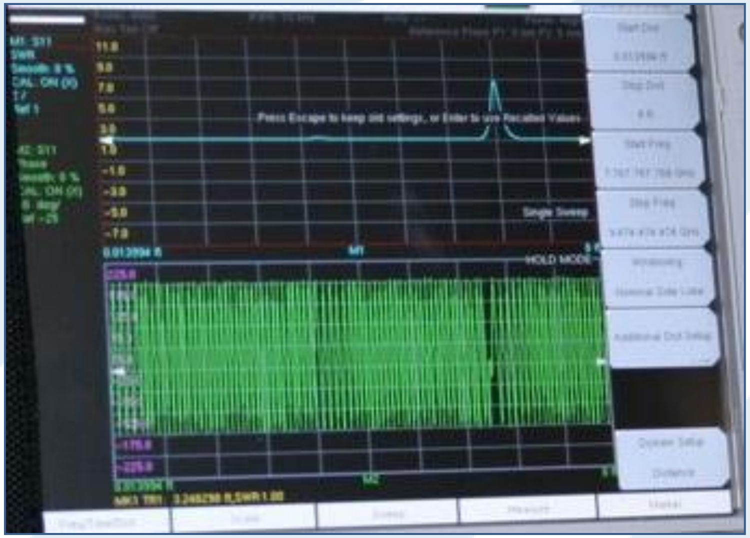
Over the past several years, the EMW technology has expanded from an external only inspection method to allow for internal inspection. With the ***EMW-I™***, electromagnetic waves are injected into the pipe or tube and 'fill' the internal space, producing an interrogation of the entire volume.

- The waves travel through the materials in the space (gas, oil, water, scale, corrosion product, sludge, etc).
- The materials are considered dielectrics to the waves. Part of the wave continues through and another part is reflected back.
- Each dielectric material has a permittivity constant associated with it which changes the impedance of the EMW as it passes through it.
- By analyzing the impedance changes and reflected waves, and comparing them to a signature, materials and their location within the casing can be identified.



EMW-I™ Combines Distance, Phase, and Dielectric Analysis

- By using the rich amount of data provided by EMW reflections, ***EMW-I™*** can interpret various characteristics of features inside the pipe.
  - Lengthwise distance and feature length is determined by analysis of time for reflected signals to return.
- By analyzing the impedance of the response, the material makeup of the feature can be inferred (differentiate corrosion from water from scale).
- Through phase interpretation, ***EMW-I™*** is capable of identifying volumetric differences of features. This lends itself to differentiation of voids (i.e. pits) versus the presence of materials (i.e. scale).



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EMW-I™ Applications

- Long-range detection of internal anomalies and corrosion indicators:
  - Corrosion product and internal pits
  - Location of cracks
  - Location of water holdup
  - Identification of scale or paraffin build-up
  - Locating blockages and causes of flow reduction
  - Monitoring for upsets in product flow (ie. slugs)
- Characterization of the magnitude of the anomaly based on data and equivalency models
- Continuous or periodic monitoring to detect changes over time
  - Permanent connectors may be installed.

EMW-I™
Other Uses / Key Points

In addition to detection of sludge build-up, ***EMW-I™*** can be used:

- To detect and locate anomalies such as wall loss and cracks. (Cracks significantly disrupt the currents that drive the modes and usually present a large reflection.)
- As a process monitoring system. (In this application, real time monitoring can be used to observe slugs of varying density flowing through the pipeline, e.g. a water slug in a steam pipeline.)

Key points for ***EMW-I™*** are:

- A defect or anomaly can be detected even if it is much smaller than the resolution.
- Bends do not pose a problem unless the bend radius is less than about 1.5x the ID of the pipe.
- The TE or TM modes launched down the pipe can propagate past an insulating flange. Although the insulating flange will give a response, information can be obtained past it.

Summary of Internal Inspection with EMW-I™

- Using ***EMW-I™***, the internal surface and area of a pipe or tube **can** be inspected at long range for various features including:
  - Pits, corrosion product, and cracks
  - Water holdup, scale, sludge, paraffin, and other blockages
  - Monitoring of upsets, slugs
- The technology can be applied with access to pipe or tube end or via access port such as high-pressure gland.
- May be used for spot inspection or online real-time monitoring.

- New Casing Installations / EMW-C
  - Provide QC of vendor installing wax product.
  - Establish a known baseline of the corrosion environment of the casing for future monitoring.
  - Install above-ground permanent connectors for “hassle-free” future monitoring.
- Existing Casing Regulatory Monitoring / EMW-C
  - Evaluate the environment within the casing.
    - Liquids
    - Shorts
    - Sag
  - In combination with wax fill, satisfy PHMSA for direct short management.
  - Identify anomalies.
- Identification of Moisture in Insulated Piping / EMW-C
  - Storage fields, propane, LNG
- Identification of Liquids Within Piping / EMW-I
  - Often an operational issue

WHY use us?

- STABLE TECHNOLOGY
- COST
  - Typically 1/3 cost of traditional guided wave installations
- FLEXIBILITY
  - Ability to install test leads and remotely monitor for any future environmental changes (changes to baseline)
  - Complimentary to Guided Wave in many applications
- BUSINESS MODEL

Thank You!

For more information, please contact:

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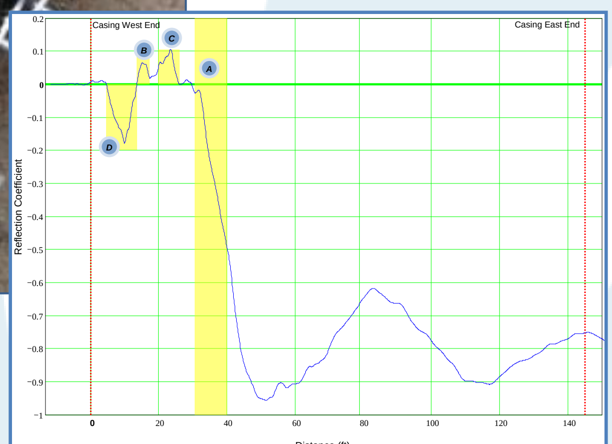
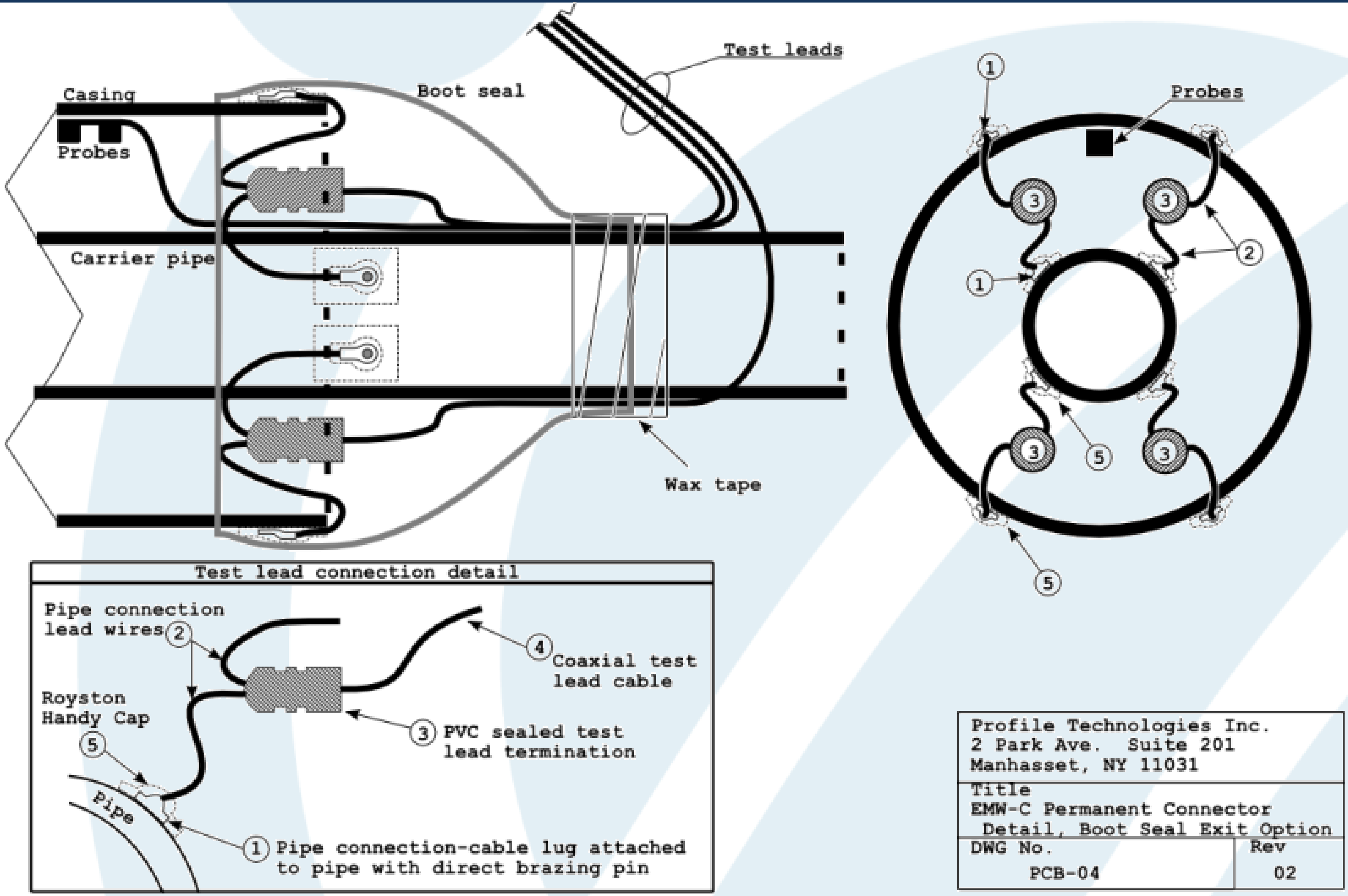


Appendix I -- EMW-C™

Pictures & Data Examples

Long Range EMW
Permanent Connectors for Above Ground Measurements



Long Range EMW Permanent Connectors for Above Ground Measurements

- The permanent connectors use typical CP style (pin brazed) connections at end of casing.
- Cables are routed outside the boot, gland seal, vent pipe, or one of several options to above ground test stations.
- Periodic measurements may be taken from above ground test stations. No additional excavations are needed.
- Data collected above ground is easily compared to the original baseline data to identify changes from the original fill.

Long Range EMW
Permanent Connectors for Above Ground Measurements

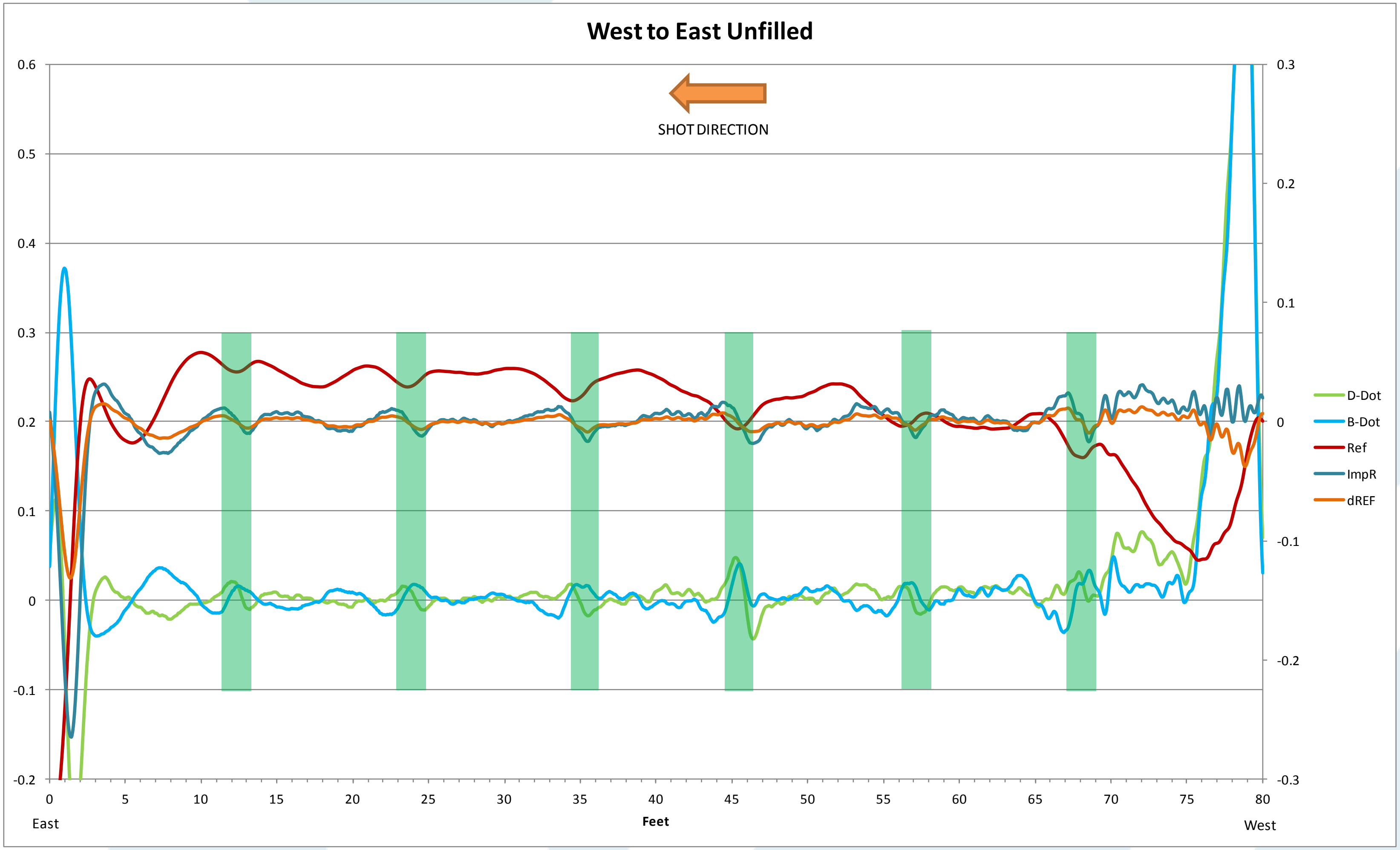


8” Casing – 38 Feet Long / 4” Pipe

- A pipeline / casing with the following specifications:
  - 38 foot carbon steel, 8” dia. casing
  - 40 foot carbon steel, 4” dia. carrier pipe
  - 2” upper and lower vent pipe
  - 4 PE spacers
  - Boot seals
  - Trenton FC #1 fill
  - Casing windows allowed visual inspection

Feature	Distance from Upper Vent End	Distance from Bottom Vent End
Pipe end	0	38 ft
Vent	16 in	36 ft 8 in
Spacer	3 ft	35 ft
6" access window	8 ft	30 ft
Spacer	14 ft	24 ft
6" access window	20 ft	18 ft
Spacer	26 ft	12 ft
6" access window	32 ft	6 ft
Spacer	34 ft	4 ft
Vent	36 ft 8 in	16 in
Pipe end	38 ft	0

Field Shot of 80 Foot 4"/8" Casing

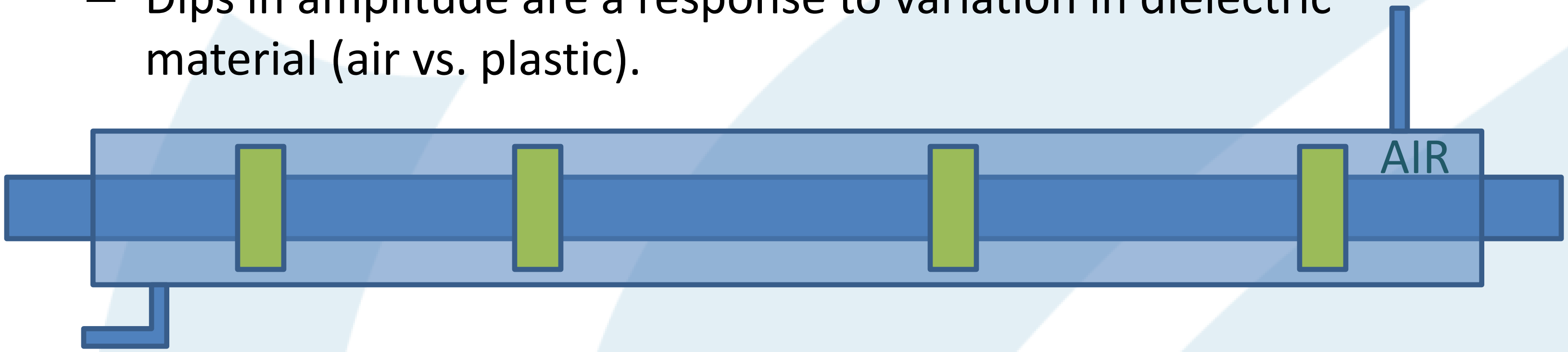


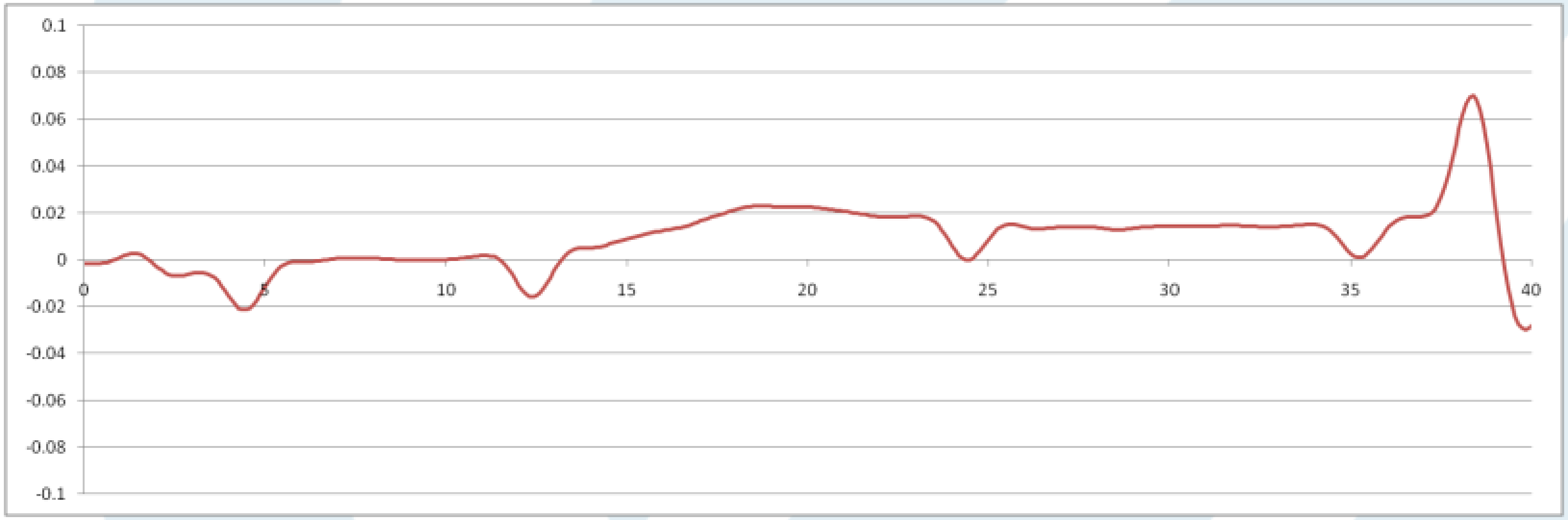
= Spacer

BASELINE (Unfilled) Shot
8″ Casing – 38 Feet Long / 4″ Pipe

4 Plastic Spacers Clearly Identified in Data of Air Filled Casing

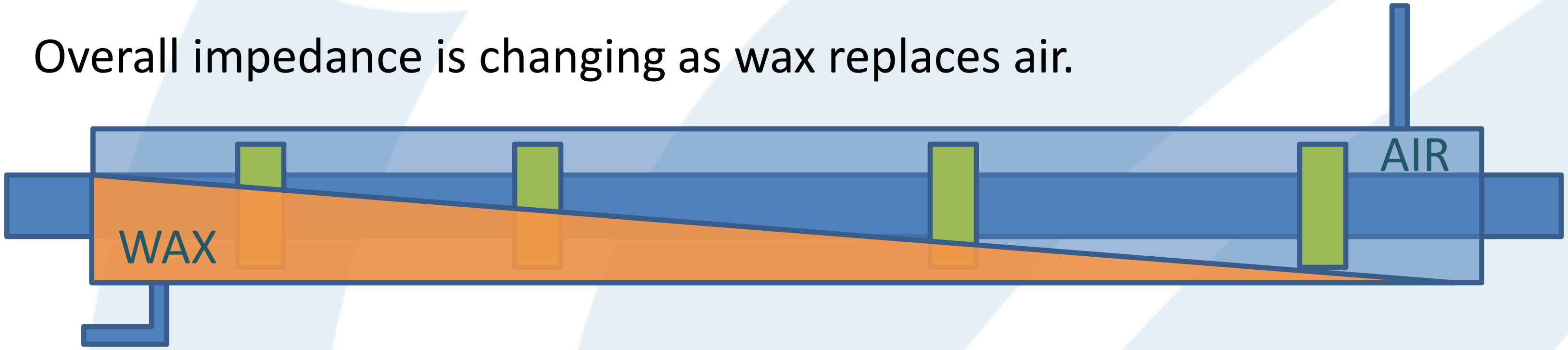
- Dips in amplitude are a response to variation in dielectric material (air vs. plastic).

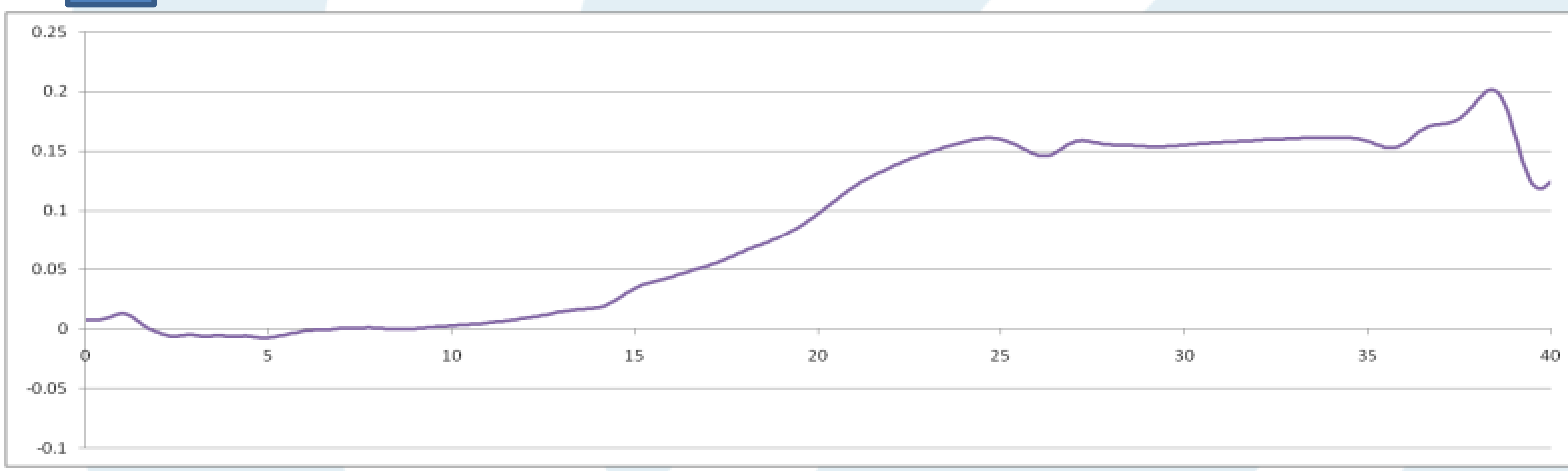




Partial Fill Realtime Shot 8″ Casing – 38 Feet Long / 4″ Pipe

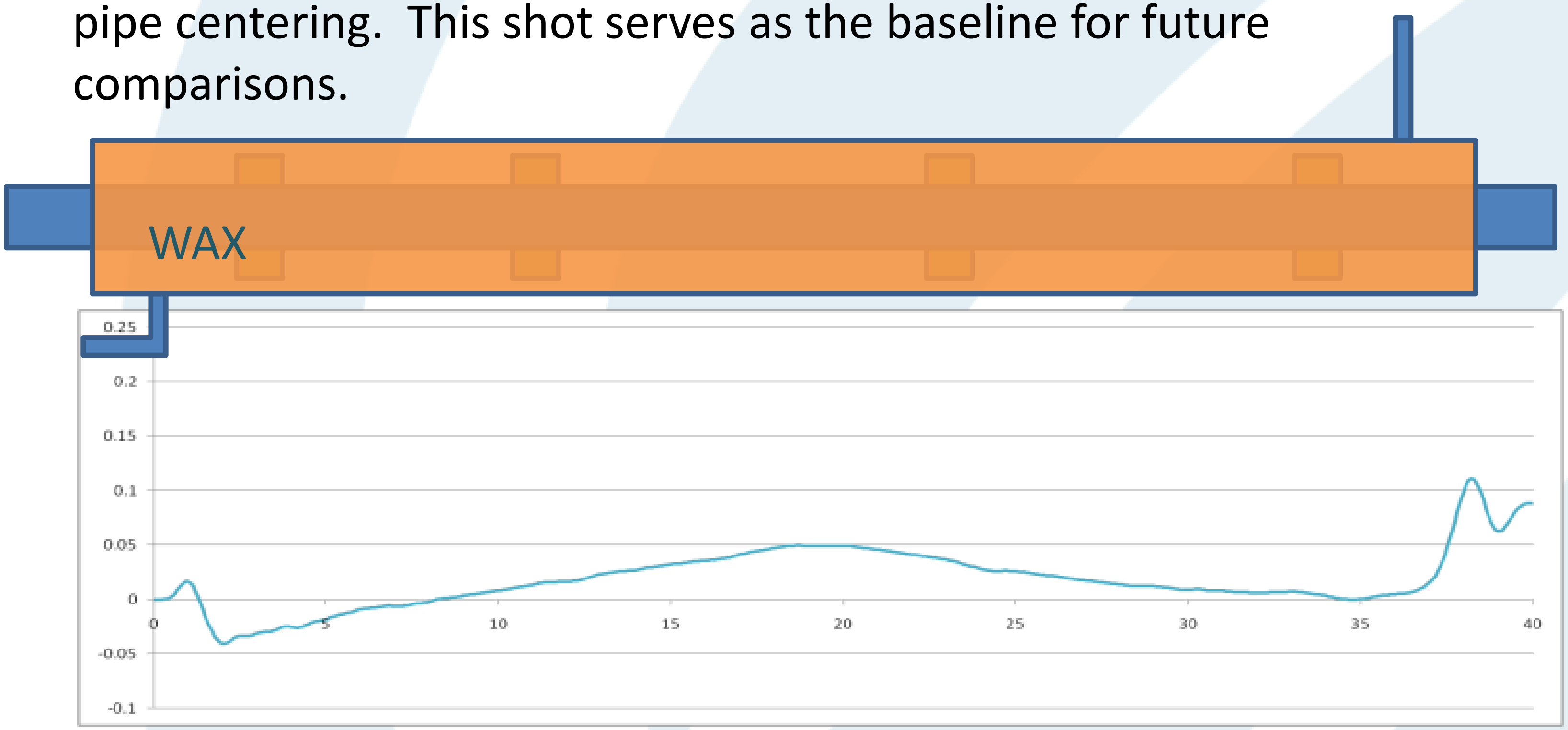
- Wax partially fills annulus during fill process.
- Plastic spacers start to 'fade' as wax (of similar dielectric value) fills the annulus.
- Overall impedance is changing as wax replaces air.





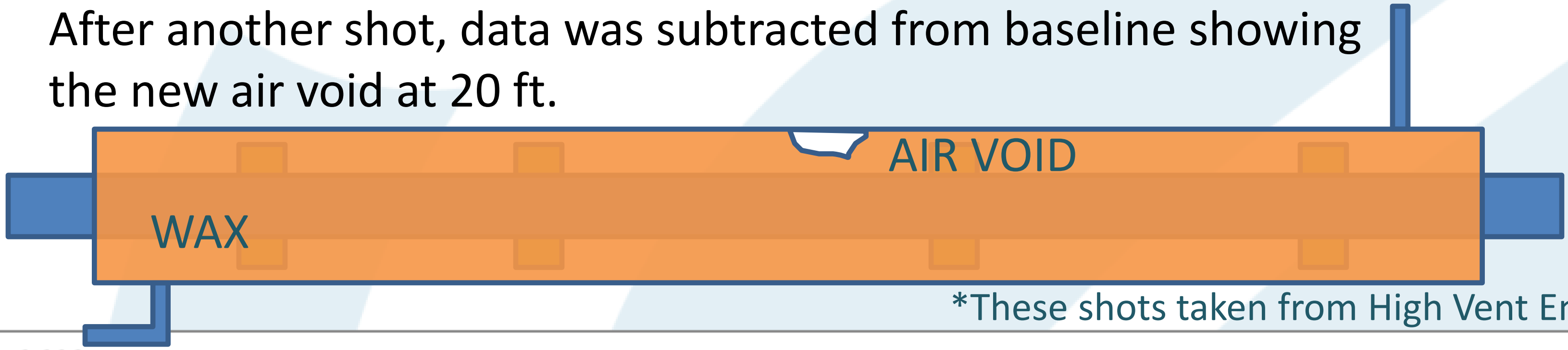
Final (Wax Filled) Shot
8″ Casing – 38 Feet Long / 4″ Pipe

- Plastic spacers faded (as expected).
- Expect to see a generally flat line response (typical for totally filled, homogenous annulus).
- This data curves slightly upward, as did the original pre-fill shot, due to pipe centering. This shot serves as the baseline for future comparisons.

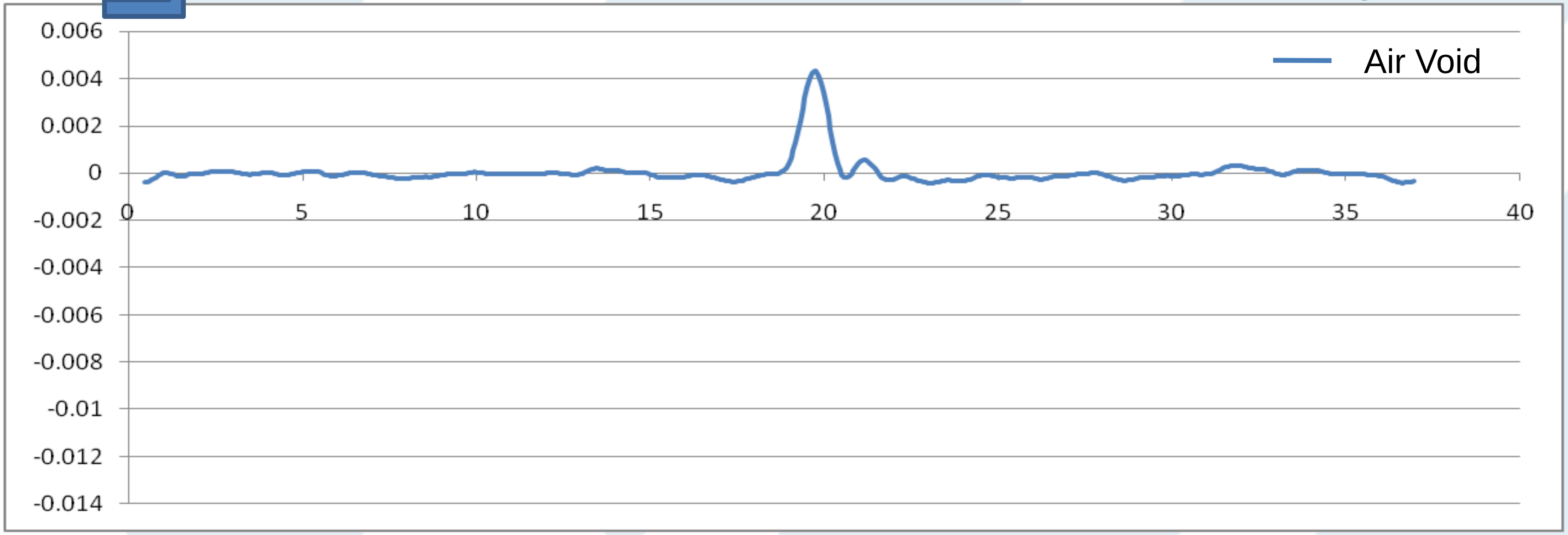


Post-Fill Shot with Air Void Added
8″ Casing – 38 Feet Long / 4″ Pipe

- An air void was created in the wax through an access window at 20 ft by removing 12 oz of wax.
- After another shot, data was subtracted from baseline showing the new air void at 20 ft.

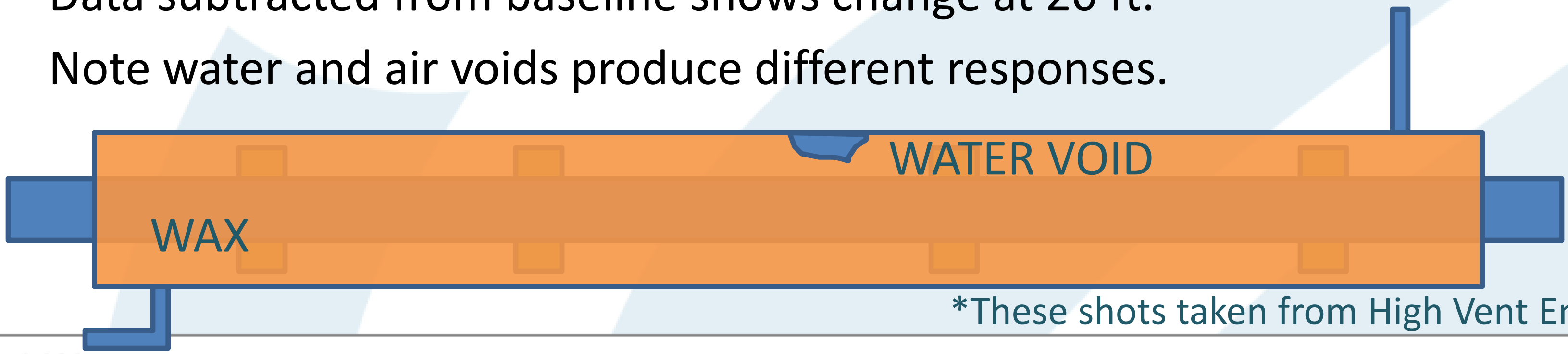


*These shots taken from High Vent End.



Post-Fill Shot with Water Void Added
8″ Casing – 38 Feet Long / 4″ Pipe

- Water (12 oz.) was then added to the void for a second shot.
- Data subtracted from baseline shows change at 20 ft.
- Note water and air voids produce different responses.



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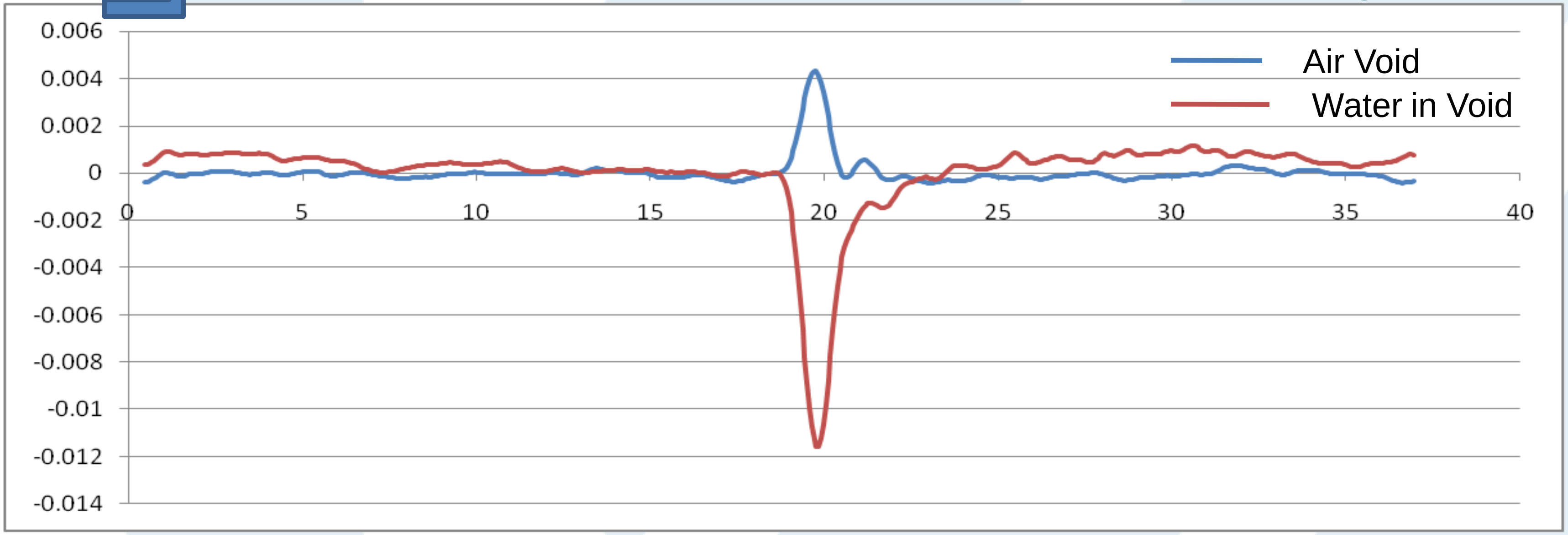
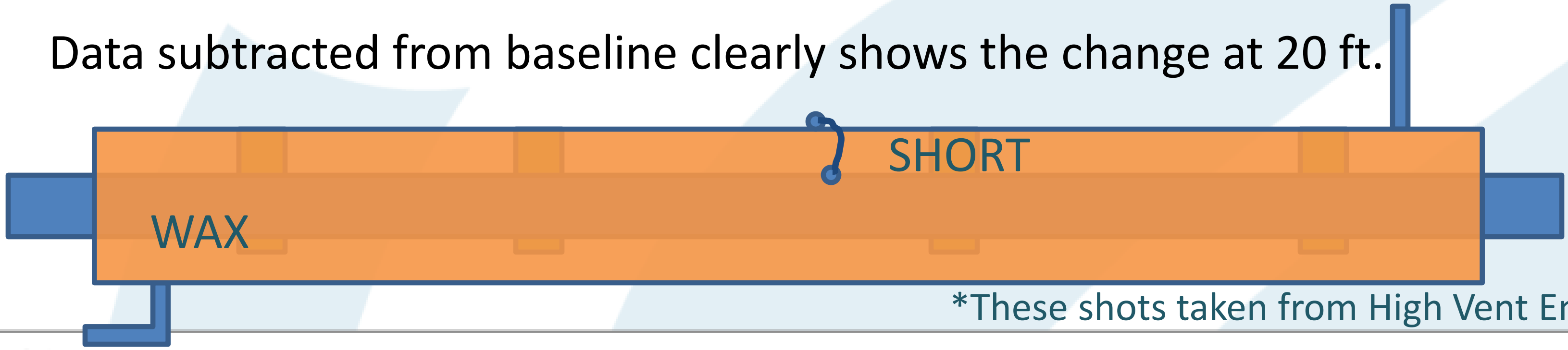


Post-Fill Shot with Short Added
8″ Casing – 38 Feet Long / 4″ Pipe

- An electrical short was created between casing and pipe at 20 ft. for third shot.
- Data subtracted from baseline clearly shows the change at 20 ft.



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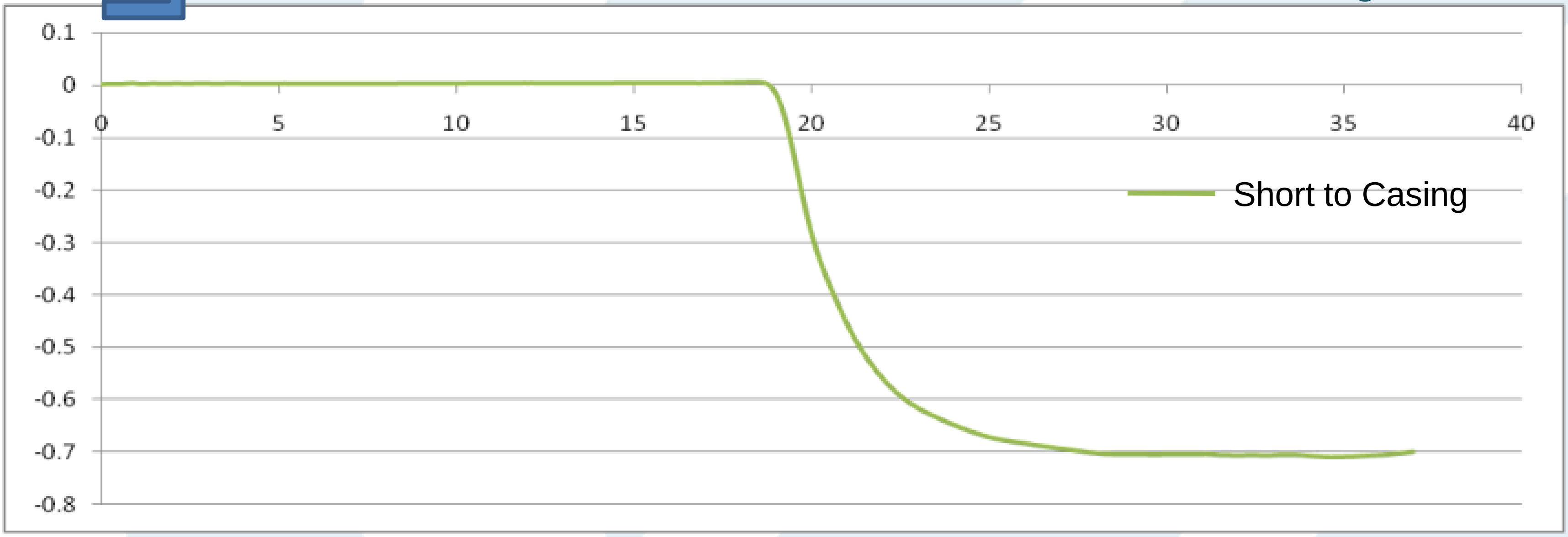
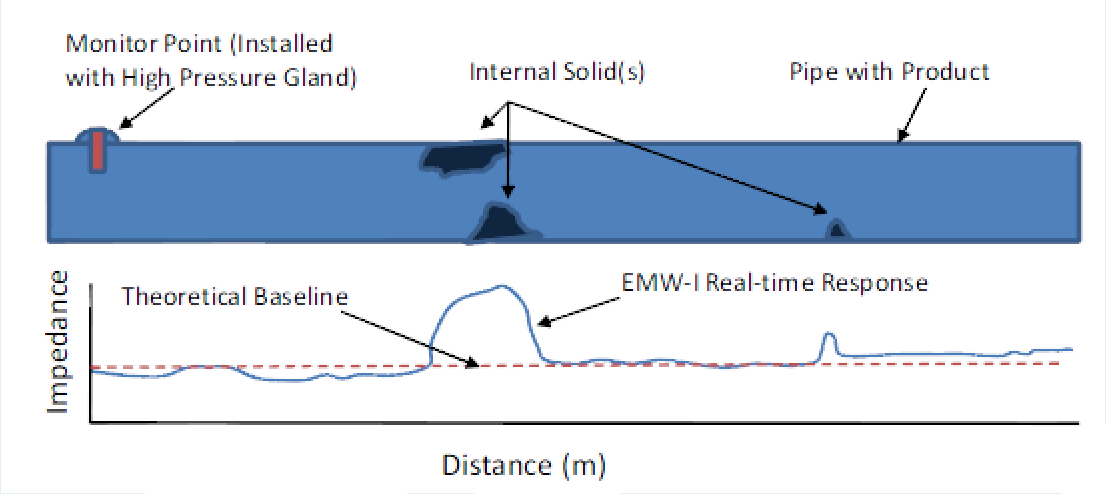


Appendix II -- *EMW-I™*

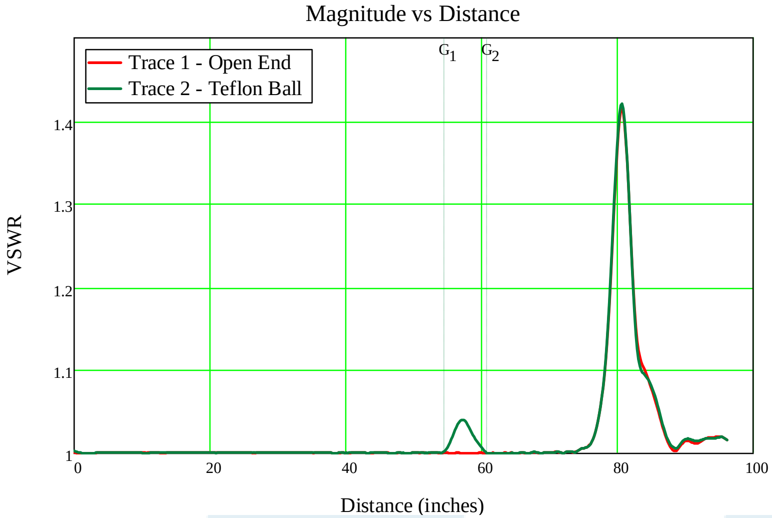
Data examples

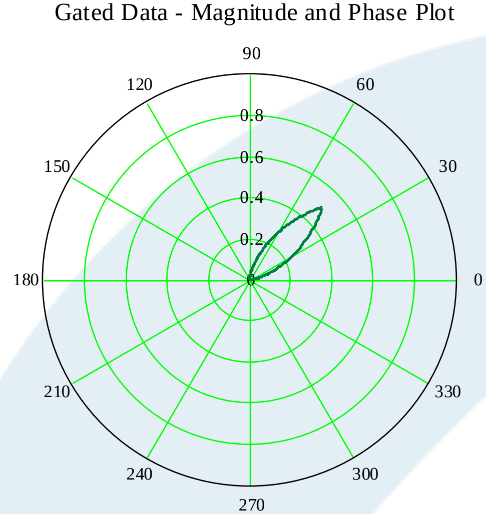
Sludge Detection

- Directionality (currently) requires two access ports.
- Data from both ports is shifted by the known separation distance and overlapped.
- Fluid flowing in the pipe represents a uniform impedance to the instrument.
- Normal fluctuations in fluid density can be averaged out.
- Sludge build up represents a change in density at a fixed location.
- Any non-uniformity inside the pipe will cause energy to be reflected.

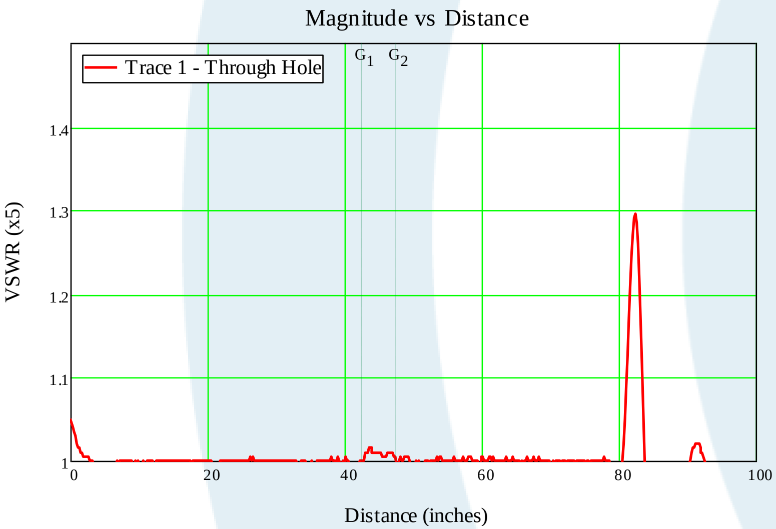


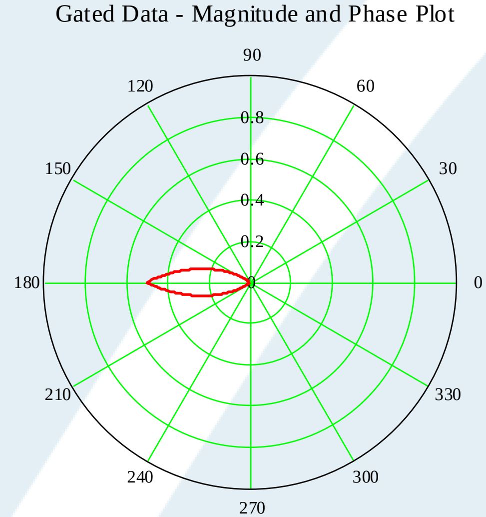
EMW-I™ Data Comparing Positive / Negative Features





Data for a 1 inch by 0.028 inch wall thickness heat exchanger tube. On left, the traces for the baseline and with a Teflon sphere inserted. On right, the magnitude and phase plot for the gated Trace 2.

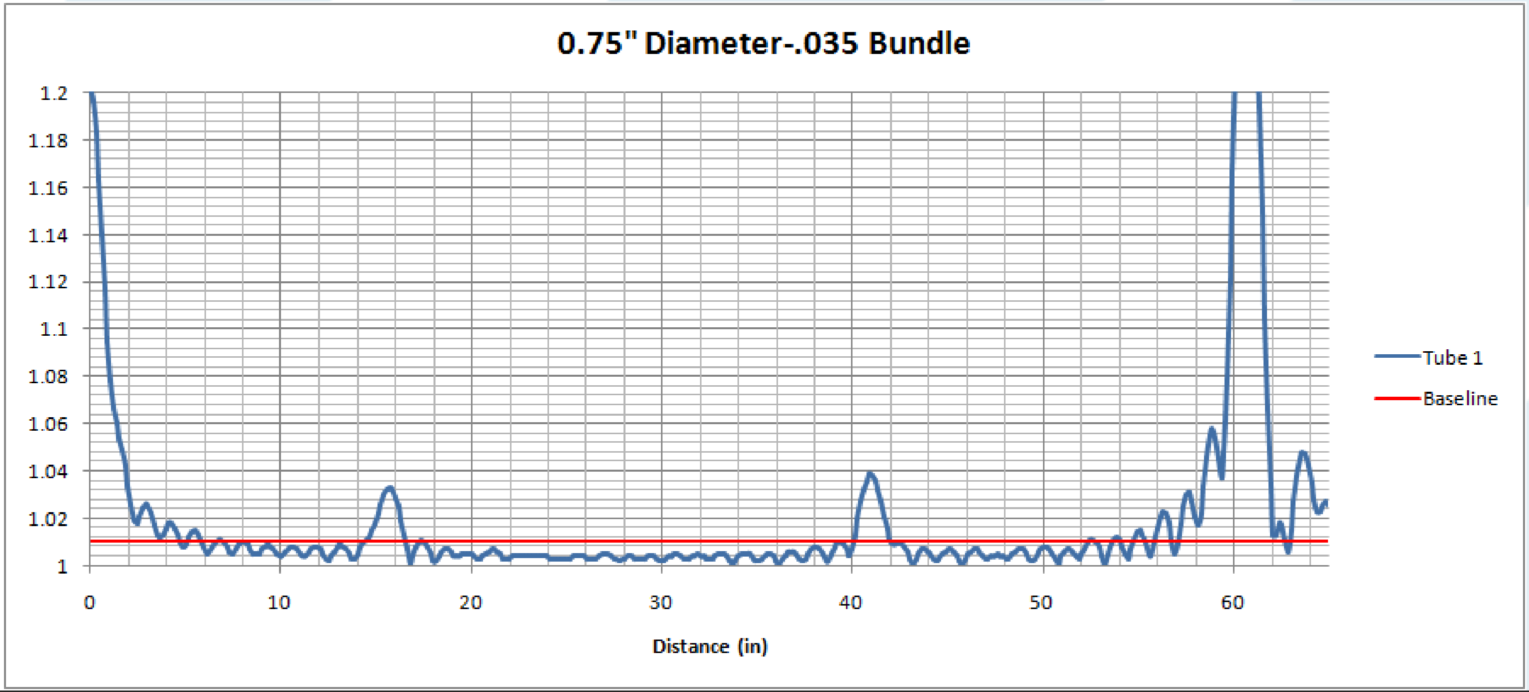




Data for a 1 inch by 0.028 inch wall thickness heat exchanger tube. On left, the traces for the baseline for through-wall hole. On right, the magnitude and phase plot for the gated Trace 2.

Recent Data

- Recently, WaveTrue collected data from tubes used for Eddy Current (EC) calibration.
- These tests showed the ***EMW-I™*** to be on par with EC for detection of pits sized .0052” as shown below.
- ***EMW-I™*** also detected surface crack features representing SCC (stress corrosion cracking).



Detection Ranges

The maximum range and minimum resolution for a 4 inch ID pipe are shown below.

- For pipes with an ID >4 inches, the instrument has a large dynamic range (80 dB).

- In practice, the maximum range achievable will depend on attenuation of the signal.
- The signal can experience attenuation due to conduction losses which are dependent on the conductivity of the pipe material.
- Dielectric losses can occur dependent on the material flowing through the pipe.
- In general, for the same pipe materials, larger pipes have lower conduction losses.
- Overall, attenuation is mainly dependent on the product material.
- We can characterize the material flowing in the pipe to get an accurate estimate for the detection range.