FINAL REPORT – PUBLIC VERSION

Intrinsically Locatable Technology for Plastic Piping Systems

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Abstract

The objective was to develop and test a viable solution for an intrinsically locatable polyethylene (PE) pipe materials with an integral electronic marking system. The project would complete the development, define and test the electronic marker capability, validate the attachment design, and perform laboratory and field testing. Operations Technology Development, NFP (OTD) partnered with Gas Technology Institute (GTI), 3M Company, and a large pipe manufacturer participant on this project. 3M developed the electronic markers and worked with the pipe manufacturer to attach the marker to the PE pipe. GTI provided third party testing, analysis of the developed system, and utility field deployment efforts.

Executive Summary

The vision of the Path Marking solutions for plastic pipes stems from the continued pursuit to develop a higher reliability, higher durability, fast, accurate and easy to use method to locate buried plastic pipe transporting natural gas. Included, is an intrinsically locatable plastic pipe, along with Electronic Marking Tape and Electronic Marking Rope, using passive resonators that are placed every 6 to 10 feet along the pipe. In addition, a system that integrates well with existing tracer wire and can use the same locator, which could also include EMS Ball Point markers and Gas EMS RIFD Point markers.

Electronic markers are detectable passive devices that do not use any batteries. They include electrical or mechanical resonators. Resonators can be energized by an above-ground transceiver (or portable locator) which causes them to generate their own magnetic field at their resonant frequency. The precise location of a buried electronic marker is indicated by the portable locator's display and sound output. Marking buried plastic pipe with an electronic marker gives a unique detection signature for each utility by frequency selection, gives near continuous location detection of the pipe path, and allows for good estimation of the pipe depth.

As a system, it is expected to:

- Enhance safety and durability for natural gas distribution networks
- Simplify installation and lower installation labor costs
- Simplify location and lower the location labor costs

The main project goals were met by the team and participating end users within the allocated time period. Future development of this new technology and its applicability to PE pipe will focus on higher performance in the marker and locator, an optimized attachment process, and implementation into the utility industry.

The accomplishments against the plan are summarized in the following table:

Table 1: Summary of Accomplishments vs Plan

Major Task	Description	Assessment	Output
Marker Technology Development	Develop, Build & Test	Depth, accuracy, stability, environment & longevity.	A 4' and a 3' rugged, flexible marker with 1' detection margin. Met the target specification.
Marker Housing Development	Develop, Build & Test	Bend radius, pipe OD, installation & longevity	Rigid housing used on larger OD pipes due to higher stresses and abrasion when pulled through harsh soil (gravel). Met the target specification.
Attachment Method Development	Develop, Prototype & Test	Pipe OD range, attachment time, pipe installation, & longevity.	Two methods were developed and assessed: tape wrap for small OD pipes (< 2" OD) and a thermally welded housing method for 2" and 4" OD. Met the target specifications for 2" and 4" OD that's extendable to 6". Options for very large OD's would consist of the Path Marking EMS Gas Tape or EMS Gas Rope.
Initial Prototype Testing	Build, Test & Assess	Design capability, environmental effects, installation stresses & longevity.	A total of over 3,000 markers were built and assessed, over 1,300 attachments made to pipes of ¾"~4" OD in MDPE and HDPE, coil and sticks. Met the target specification for the sizes built (3/4"~4" OD).
Utility Testing of ILPP	Build, Pack, Ship, Install and Assess	Installation ease, location ease and accuracy and depth estimation.	Open trench and HDD, ¾" to 4" OD, MDPE and HDPE ILPP installed in 9 locations using standard methods. Met the target goals.
Data Analysis & Reporting	Collect, Analyze & Report	Performance, accuracy & consistency	Successful field installation of 1,200' of ILPP of various sizes and types with 10 participating end users. Fast and easy detection using 3M 7420 locator. Met the target goals.
Project Management	Kick off, Periodic Status Reports, Stake Holder Engagement & Milestone Management.	Progress & spending against the plan.	Kick off in October 2016 and completion in January 2018 (included 3 month extension for the field testing). All updated reports submitted on time. Two PHMSA technology updates and two presentations (OTD, AGA). Met the target goals.

Introduction

Polyethylene (PE) pipe is a strong, tough, and cost effective piping system commonly used in natural gas distribution systems. With PE pipe now accounting for more than 90% of new gas pipe installations, precise detection and location of buried pipe and facilities is critical. However, thousands of miles of PE pipes cannot be precisely located because of issues with tracer wire, offset tracer wire, and inaccurate maps.

Gas pipes that cannot be conveniently and reliably located are a serious concern to utility owners/operators as well as to excavators. The traditional means of locating PE pipe is to place a thin copper tracer wire alongside the PE main during burial. A frequency is induced onto the tracer wire either at a gas service riser or at a connection box installed at ground level. A hand-held receiver (locator) is moved across the presumed location of the pipe until a peak signal of intensity is obtained. Tracer wires serve to help in determining the location of a PE gas main prior to excavation. The added labor and material cost incurred by burying tracer wire results in an additional expense to gas companies. If the tracer wire is damaged or corrodes while in service, the plastic main may not be accurately or continuously locatable, and thus can be vulnerable to third party dig-in damage.

Third-party damage is one of the greatest risks to plastic pipe today. Inaccurate plastic pipe location dramatically increases the chance of third party damage. This risk will continue to rise as the use of plastic piping materials increases. Steel, cast iron, and other metallic pipe can be easily located by conductively or inductively inducing a signal (transmitter) on to the pipe and picking up that signal along the pipe with a receiver. This method can also be used for locating the tracer wire typically buried alongside the PE pipe and other non-metallic pipe. However, tracer wire that is broken or missing, never installed, inaccessible, and with distorted signals from nearby utility lines are all causes for unlocatable PE pipe. Common causes of pipe damage include:

- Unlocatable facilities
- Inaccurate, incomplete records, maps
- Un-mapped, abandoned facilities
- Congestion of underground utilities and above-ground features
- Common trenches
- Soil condition or type

The industry has considered numerous alternatives to tracer wire in order to locate plastic pipe. These have included ground penetrating radar and other highly advanced approaches for location purposes such as Automated Mapping/Facilities Management (AM/FM) systems. However, the various alternatives require costly implementation and are not typically "field friendly." The main objective of this development effort focuses on an intrinsically locatable system readily detected in normal field conditions without the need for additional costly equipment.

While there have been some advancements in plastic pipe locating (radar, acoustics), operators still need a system to allow plastic pipe to be located with traditional, low cost technologies. Developing a method to attach electronic markers to the pipe itself and making it intrinsically locatable could provide such a solution.

The focus of the proposed research was to mitigate third-party pipeline damage at the earliest stages through the development and commercialization of innovative locatable pipe marking systems to allow plastic piping systems to be intrinsically located. Today, more than 90% of the gas distribution pipe being installed is PE pipe using a copper tracer wire for locating the buried underground piping materials. However, these tracer wires are susceptible to breakage or corrosion, rendering the buried plastic material undetectable. Due to its locatability, the pipe marking system being developed, substantially reduces the risk of third party damage and provides local distribution companies a durable solution to this problem.

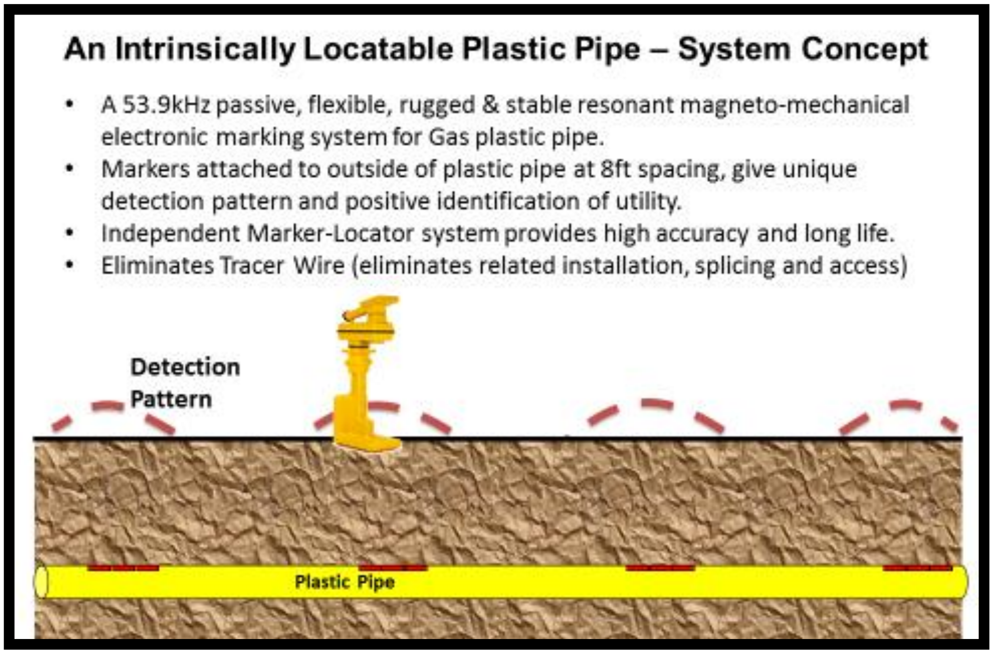


Figure 1: Intrinsically Locatable Plastic Pipe – System Concept

A copper tracer wire is commonly installed with PE pipe today and is the primary method used to locate the pipeline. Utility companies are finding issues with copper wire related to breakage or corrosion. One solution to prevent these issues from occurring is placing intrinsically locatable markers on the pipeline.

3M recently announced the launch of a new product to embed electronic marker technology, based on resonant markers, into caution tape that can be installed with new pipe. The spacing of the electronic markers in the caution tape allows a continuous trace to identify the precise location of the pipe. Modifying the marker system from the caution tape to be permanently fixed to the pipe directly from the manufacturer, would have great benefits to the utility industry.

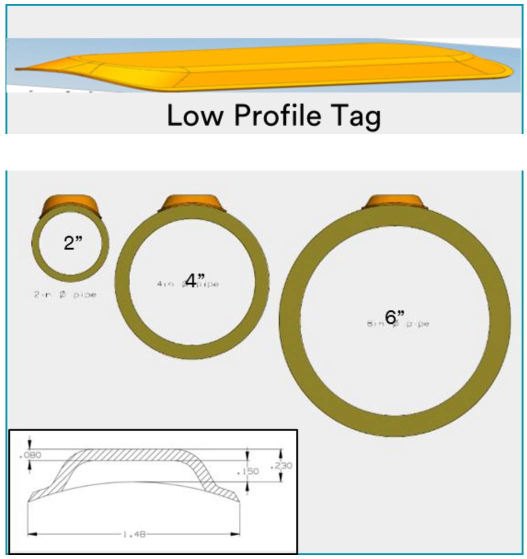


Figure 2: Magneto-mechanical resonator attachment concept to PE pipe

Advantages of this system include:

- The ability to locate the pipe, is not affected if the tracer wire is damaged or broken. Each electronic marker design provides a discrete signal that is not dependent on a continuous path in the same way the tracer wire is.

- The electronic markers are not subject to inference from nearby utility lines or other sources of electrical interference. Tracer wire location signal current has to return through the earth and nearby metallic structures which causes signal distortion than can impact the accuracy of the locate and depth estimates.

- The electronic markers have unique frequencies to ensure the appropriate line is being located. For example, a gas frequency would be established to distinguish between the gas and water lines.

- Long life expectancy of product designed to last lifetime of facility.

- An integrated locator can locate multiple form factors of electronic markers in addition to tracer wire, pipes, cables, and faults.

Task Work as Proposed

The scope of the project was to develop an electronic marking system that would provide locatability to the target depths on various diameter high density polyethylene (HDPE) and medium density polyethylene (MDPE) pipes for natural gas applications. The project would also assess the technology capabilities versus pipe diameter, burial depth, and pipe burial methods (horizontal directional drilling, open trench, etc). Included in the marker development would be the development of a flexible housing to allow the solution to be adaptable to a wide range of pipe diameter sizes. The attachment method would be integrated into the plastic pipe manufacturer process and workflow. The technical team would assist in assessing system performance at selected utility test partners.

This project will perform the necessary final developments and enhancements to the integral electronic polyethylene (“PE”) pipe marking system and perform laboratory and field evaluations to validate the system to be commercially viable as an intrinsically locatable PE piping system.

Work Tasks:

1. **Project Scoping** - This initial task would be to hold meetings with the project team and develop a final development plan. The technology development plan would be reviewed by all parties. Identify and verify current PE pipe and tracer wire installation and location methods and the issues facing the industry. The range of climatic conditions and soil types would also be identified.

2. **Marker Technology Development -** 3M would develop electronic path markers specific to the needs of the team input received during Task 1. The project team would solicit utility end users for specifications required for locate accuracy, performance, durability, and other performance parameters. The first stage of developing an intrinsically locatable plastic pipe solution consists of developing concepts and assessing the detection distance of high output flexible electronic markers using magneto-mechanical resonators tuned to 53.9kHz, which is the frequency used for gas pipe path location. This would be followed by evaluating the location and depth accuracy of these markers when detected with a 3M 7550 pipe/cable locator as well as their performance stability over time under the various relevant environmental conditions. Additionally, during this Task 2, the project team would:

    a. Determine recommended target specifications for the solution from user input at the system level. This would include performance, accuracy, durability and applicability specifications;

    b. Develop concepts for resonator;

    c. Build breadboards of design concepts;

    d. Test the path markers for detection range, accuracy, stability; and

    e. Produce interim reports related to this Task 2, including interim reports covering (i) concepts for flexible marker and detection range results, (ii) assessment of marker accuracy, and (iii) assessment of marker resonant frequency overtime / conditions.

3. **Marker Housing Development** – 3M would use good faith efforts to attempt to develop a low profile PE housing for the resonant markers that can flex without damage to the path marker, having the necessary strength to withstand stresses during attachment, pipe processing, transportation, storage, installation and using materials with a long design life for use with the buried pipe. It is important that considerations be given to the minimum bend radius for the housing to ensure damage does not occur to the marker or the housing itself during typical field installation scenarios. An evaluation of various pipe sizes that the housing could be attached to in order to understand the shear and compression forces on the housing would take place in this task. Consideration to the installation method would be given to ensure the housing can withstand those forces as well. Various testing would be conducted on the electronic marker and housing system to evaluate its overall durability and performance. This would be conducted through a series of impact, temperature cycling, vibration, moisture, and other applicable tests.

4. **Attachment Method Development** - Once the electronic marker and housing is developed and tested, 3M would examine and evaluate various attachment methods of the marker housing to the PE pipe. 3M would consider various attachment methods to ensure proper adhesion to the pipe. An evaluation of the process and attachment methods would be made at this time. Maximum shear stresses and elongation would be determined during the installation process as well as during storage, handling, and pipe installation. Evaluations of the "bond" between the marker housing and the PE pipe would be conducted to determine its effectiveness over time, in varying temperatures, and environmental conditions. Additionally, during this Task 4, the project team would:

    a. Develop concepts for the attachment method;

    b. Determine flexibility and applicability to coil and stick pipe OD sizes;

    c. Fabricate alpha prototype of marker, housing and attachment; and

    d. Produce interim reports related to this Task 4, including interim reports covering (i) Attachment method options and analysis and (ii) development of a set of fabricated pipe samples with markers attached.

5. **Initial Prototype Testing** - Based on the successful outcomes to the previous tasks, PE pipe samples with the integrated locating system would be provided and installed at Gas Technology Institute's (GTI) pipe farm using various industry installation practices. Baseline testing of the system would be carried out. The ends of the installed pipe would be accessible such that a sonde or locating tape can be inserted. This would provide a reference method of locating the pipe to verify the accuracy of the new system. The field samples would be tested periodically to determine any drift or aging of the electronic marking system. This would also allow system testing under various weather and soil conditions. This data would be reported out to all participants for review. Adjustments to the marker-pipe system would be made, if necessary, based on the field evaluations.

6. **Utility Testing of Intrinsically Marked Pipe** - Based on the outcome from Task 4 and 5, and the availability of utility test sites, larger quantities of the intrinsically locatable PE pipe would be prepared. The intrinsically locatable PE pipe would be provided to the interested utilities for installation. The participating utilities would schedule the time and resources to perform the

installations. Representatives from GTI and 3M would be on hand to support the installations and for initial and follow on locating of the pipe. The participating utilities would periodically locate the sample pipe under a variety of conditions to measure the expected longevity of the system. Additionally, during this Task 6, the project team would:

a. Document the installation in the field at a utility company;

b. Make necessary enhancements to the system based on the installation and evaluations by utilities; and

c. Produce interim reports related to this Task 6, including interim reports covering user install support, set locators, and installations and locatability.

7. **Data Analysis and Reporting** - The data from the laboratory, initial in-ground, and in-field utility testing would be gathered and analyzed. Reporting of the pipe marking system performance would be generated from the collected data. The necessary quarterly reporting requirements would be supported. The project work would be submitted in a final report and the results would be summarized and presented in a professional publication or an industry conference. Additionally, as a part of this Task 7, the project team would:

   a. Submit monthly reports during the course of the Work.

   b. Submit quarterly reports during the course of the Work.

   c. Draft Final Report

   d. Final Report

Technical Discussion and Accomplishments

The initial project plan was submitted in July 2015, started in October 2015 and had a 27 month performance period. The plan was developed based on five major tasks that were staggered in time for minimizing the overall project time. An extension was requested in order to complete the field tests installations and data collection.

All the assessments had positive results and showed the capability of magneto-mechanical resonators used for buried path marking of plastic pipe as well as taped and welded housing attachments, as detailed under Performance vs. Target Specification.

Critical parameters identified & target specification developed based on end user surveys. The following critical parameters are the focus of all tasks:

- ***Accuracy*** *of location of the marker/pipe under various soil & environmental conditions*
- ***Reliability*** *of the system is enhanced by using individual marker elements*
- ***Longevity*** *is achieved by design and validated through simulation and accelerated aging*
- ***Applicability*** *to pipes of various sizes, types and installation methods*
- ***Compatibility*** *with current practices and instrument technologies used by customers*

	CRITCAL VALUE	**TARGET Specification**
✓	Detection Limit	> 5'
✓	Detection Gap	< 4' max gap
✓	Location & Depth Accuracy	Position +/- 4", Depth +/- 4"
✓	Pipe Types & OD Limit	Coil & Stick, PE ≥ 3/4" OD
✓	Installation Methods	Open Trench, Plow & Pulled (HD)
✓	Soil Types	All Types (Dry sand to wet clay)
✓	Longevity	> 30 years by design (ongoing)

✓ Target specifications that have been achieved with margin
○ Target specifications that are under investigation and development

Figure 3: Critical parameters identified and target specifications

Task List

TASK	Assessment Criteria	Description	Output
1- MARKER TECHNOLOGY DEVELOPMENT (Flexible high output resonator: design, prototype build and evaluate. Procure equipment, tooling, fixtures. Measure variables in the assessment criteria for detection range accuracy and longevity. Report results. Fabricate all the resonators needed for Alpha testing)	**Detection Depth**	Develop, build, test 53.9kHz flexible marker for 48" detection @9dB SNR, estimate soil effects and report results.	* Measure using 3M Dynatel 7550-ID Pipe/Cable/EMS Locator * Estimate reduction due to soil at 53.9 kHz
	Detection Gap	Build test fixture and assemble sample markers for preliminary field test. Assess detection gap at 2', 3' & 4' distance. Map the field levels for detection gap.	* Measure detection gap using 3M Dynatel 7550-ID Pipe/Cable/EMS Locator * Estimate reduction due to soil at 53.9 kHz
	Location Accuracy	Assess location accuracy at 2', 3' & 4' distance. Map the field levels for distance.	* Measure location accuracy using 3M Dynatel 7550-ID Pipe/Cable/EMS
	Depth Accuracy	Assess depth accuracy at 2', 3' & 4' distance.	* Measure depth accuracy using 3M Dynatel 7550-ID Pipe/Cable/EMS
	Marker Stability & Longevity	Build test samples, assess the stability of marker resonant frequency & gain over temp, time & environmental conditions including earth's magnetic field and gravity effects. Build fixtures to simulate earth's magnetic field. Use ovens for simulated aging.	* Measure shift due to earth's magnetic field. * Measure shift due to temperature * Measure shift due to gravity * Estimate time drift
2- MARKER HOUSING DEVELOPMENT (Flexible PE marker housing for the resonator: mechanical design, prototyping, SLA's, machining, testing, modeling, load and stress simulation. Aging effect analysis. Fabricate all housings for Alpha samples)	**Bend Radius**	Assess operating bend radius and minimum bend radius for not damaging the housing	* Measure marker signal level versus bend radius with MM Marker installed * Measure minimum bend radius
	Pipe Sizes	Assess applicability to various pipe sizes for load compression and shear forces.	* Generate FEA model for compressive forces resulting from pipe & soil. * Apply to various pipe OD sizes and assess applicability. (Use OD 4", 2", 1.5", 1", TBD)
	Installation	Assess impact of maximum load in compression and shear resulting from installation method.	* Generate FEA model for shear forces resulting from installation method. * Apply to various pipe OD sizes and assess applicability. *Model OD 4", 2", 1.5",TBD) *Model HD, Open trench
	Housing Longevity	Assess housing creep.	* Estimate housing creep * Test water seal at PSI TBD * Assess UV exposure effects

TASK	Assessment Criteria	Description	Output
3- ATTACHMENT METHOD DEVELOPMENT (Attachment for various sizes and types of plastic HDPE pipe: stress assessment for various installation methods, weld process development, weld testing. Fabricate pipe with markers for Alpha field testing. Aging test requirement and relevant standards testing.	**Attachment Process**	Assess feasibility of pipe attachment at various pipe processing steps	* Determine pipe condition, time available and process impact.
	Attachment Time	Assess attach process time vs. attachment methods	* Measure weld attach time for candidate methods.
	Installation Methods	Assess all the stress factors on the marker during processing, storage, handling & installation	* Determine the maximum stress, shear and elongation to the pipe before the attachment fails (detaches).
	System Longevity	Assess the aging effects on the attachment over time, temperature and environment.	* Evaluate attachment peel strength over temperature. * Assess aging test requirement based on attach method.
	Certification Testing	Assess applicable pipe strength and safety with and w/o the marker	* Run applicable certification standard test on pipe to determine impact on the pipe and the marker.
4- FIELD TESTING	**Field Testing**	Assess installation methods of various pipe OD sizes, open trench and horizontal directional drilling	* Evaluate housing/carrier integrity after pulling 1", 2" & 4" OD pipes in soft, medium and hard soil. Check signal detection using 7420 locator.
5- USER TESTING	**User Field Trials**	Assess installation by gas company members of Gas Technology Institute and Operations Technology Development.	* Evaluate detection performance using 7420 locator and installation experience.

Technical Status: Performance vs. Target Specification

Critical Specifications and Results

Resonator performance

Detection depth marker design capability data is shown below. The markers are detectable reliably to over 63" with very high frequency stability (Cpk=1.42). Multiple runs exceeding 3,000 markers were built and confirmed the high marker yield.

The recommended target maximum burial depth is 48" in order to allow for grade change that may increase the depth.

Carrier and Housing performance

Carrier design and assembly

The carrier is used to seal and protect the resonator during the life of the product. It's made of HDPE that is chemical resistant and designed to sustain the stresses due to load, impact, bend and shear. The carrier design has been optimized and tested to meet or exceed all the target specification. The welded carrier creates a strong seal for the resonator components and passed all the QA tests.

The design team developed a pressurized water tank tests and established the design capability, as well as an air pressure burst test to assess the weld strength using ultrasonic welding methods.

The carrier can be welded using hot plate or other thermal weld technique. Several are suitable and economical.

Welded Housing, Stretching, Coiling and Reverse Coiling Simulations:

In this work, the team examined the latest housing design for the underground plastic pipe marking program, including the specific weld detail that's planned. This new design focuses on relieving stress in the plastic pipe through softening of the marking system's housing component. The system comprises the same internal marker capsule as previous designs, but refines modifications to the attachment housing of which the capsule is constrained to the pipe.

25% Axial Pipe Elongation Simulation:

Two models were examined, both consisting of the same geometry, but with modifications to the attachment area. The simulation for 25% axial elongation shows the least stress on the pipe due to the housing.   An image of the fully attached corrugated housing is shown in Figures 4 and 5.

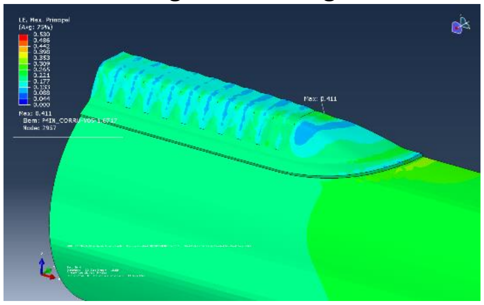


Figure 4: Corrugated Housing Design attached to 4" pipe – External assembly view

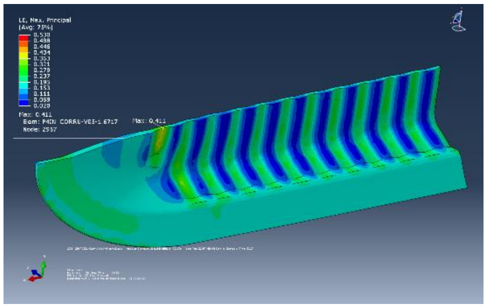


Figure 5: Corrugated Housing Design Attached to 4-inch diameter pipe – Inside component view

The inverse coiling simulations reflect the marker/housing mounted on the inside coiling surface of the pipe. The latest corrugated design modifications ultimately reduced the maximum strains seen during coiling and coiling dwell. Strain contour plots of these results can be viewed in Figures 6 and 7 below.

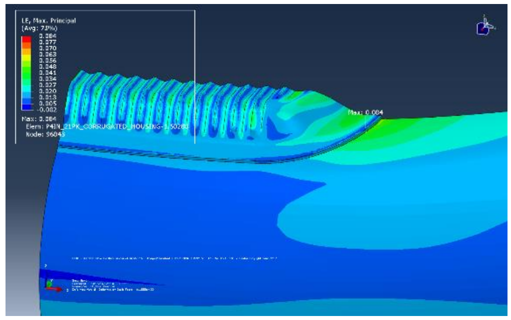


Figure 6: Strain contour plot of inside coiling simulation immediately after coiling event

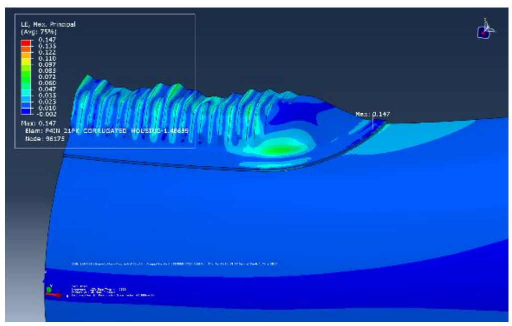


Figure 7: Strain contour plot of inside coiling simulation 1 hour after coiling event

The corrugated housing design also relaxes nicely after the coiling event. A low level of strain (7.6%) still exists in a localized area of the housing which is not viewed as a serious concern. Overall, the new corrugated design offers a robust solution for reducing stress during pipe coiling and storage. It does not impart significant strain to the pipe and should enable stable performance of the pipe under typical loading cycles.

Stick pipes do not exhibit significant bending which allows for the usage of a smooth thicker housing than for a 2” diameter pipe that is coiled.

Attachment options and performance

Two attachment processes will be used, these methods were tested in GTI’s field test site. Various sizes and types of locatable pipe were trenchlessly installed using a horizontal drilling rig. The pipes were pulled through sandy, clay, and rocky soils and pulled out and the housings and markers were examined.

For small pipes of OD less than 2”: these pipe undergo much less stresses during coiling and installation than larger OD pipes. Therefore, an adhesive tape attachment solution will be used.

Examples of a wrapped tape attachment are shown in Figure 8 for a 4’ Marker and in Figure 9 for a 3’ Marker. The 3’ Marker is recommended for burial depth up to 3’ and is detectable to 4’ which is suitable for service lines. The 3’ Marker provides a lower cost solution and is half the length of the 4’

Marker which is detectable to 5' in the ground.

Figure 8: 4' Marker on 3/4" pipe

Figure 9: 3' Marker on 3/4" pipe

Several taped solutions were assessed in the field, each has different benefits relating to material cost or attachment process cost.

Figure 10: Example of marker taped to pipe

Figure 10 above shows a tape wrapped marker on a ¾" OD MDPE pipe This simple tape wrapping process can be easily automated and can be integrated into the pipe making process.

For larger pipes (2" OD and larger): These pipes can undergo severe stresses during the coiling and un-coiling process and during installation such as horizontal drilling in harsh soils. These pipes require a rugged abrasion resistant solution, such as a hard shell housing that is welded to the outside of the pipe. Figure 11 shows hot plate details for a hot-plate thermally welded housing attachment. Figure 12 shows the thermal fusion machine by McElroy that was modified to weld the 2" and 4" ILPP field test samples.

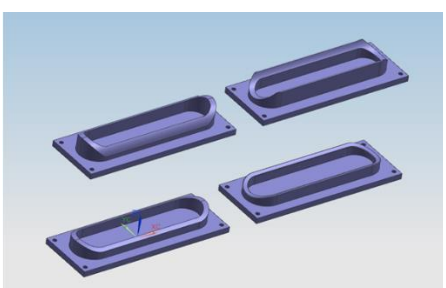


Figure 11: Heater plates to attach the housings.

Figure 12: modified McElroy fusion equipment

Figure 13 below shows a housing on a 4" OD IPS MDPE pipe with the latest corrugated housing design and hot plate weld detail. A marker is located inside the housing.

Figure 13: 4’ Marker and housing fused to a 4” MDPE pipe

Pipe handling, shipping and installation results

Small OD pipes, such as ¾”, move very quickly during the extrusion process as well as the reeling and re-reeling processes. Taping is faster than hot plate welding and may be suitable for small pipe in-line with pipe extrusion. Pipe manufacturers may develop their own preferred techniques. For assessment purposes, the team identified an orbital taping method as well as a “peel and stick” attachment that may be suitable. Final reporting on the throughput would be determined once such a machine is built.

For pipe of 4” OD and larger, it’s feasible to attach the housing to the moving pipe in an in-line process due the slow speeds at which the extruded pipe moves.

For 2”extruded pipe, more space will be needed (~ 10’ length) in order to achieve an in-line attachment process. The final determination will come from building the machine and assessing the specifics.

Over 1300 markers were attached either through wrapping of tape on small OD pipes, or through welding housings (corrugated and smooth) on the 2” and larger OD pipes.

The various attachment methods used during this project met the handling, shipping and installation demands in the GTI and utility field tests.

Reliability and Longevity Discussion

The critical success factors for a viable ILPP solution have been identified, characterized and analyzed. Along with the capability of the detection range, attachment method and field installation stresses, the reliability and longevity of the system have been analyzed and characterized through modeling, bench testing, field installations and accelerated aging.

Failure modes have been identified, characterized, modeled, tested and validated successfully to meet the target specification towards a 50-year life under current standard installation practices followed by North American natural gas companies.

Mechanical Failure, gain loss due to water ingress in ribbon and magnet compartments:

The resonator compartment has to remain sealed and must keep water out of the carrier. A water ingress pressure test of 30 psi for 15 minutes can be used to test the weld seal. Additionally, an air pressure test can be used to test for no air leak to a minimum of 30 psi (60 psi preferred) for 10 seconds.

A leak would consist of an air bubble stream of at least 1 bubble every 2 seconds under maximum pressure.

The housing and/or tape are the delivery systems to place the markers on the pipe at fixed intervals, and provide additional protection for the carrier.

Under severe forces, the carrier could be crushed. The carrier/housing should be rated for a continuous load of ~300 lbs. An impact load corresponding to IK10 (20 Joules) would be a good spec to apply for buried markers. This design is capable of IK10 impact test and 300 lbs continuous load.

Drift Failure, gain reduction due to frequency drift and gain reduction:

Resonators have been specified, designed and tested for a target life of 50 years, showing only a couple of inches or reduction in range.

Environmental and Mechanical Stresses

Ambient Temperature:

The effect of ambient temperature was studied and its effect on the resonant frequency, Q and Gain on the magneto-mechanical markers measured with plots shown below.

The following graph, Figure 14, shows the high stability of the resonant frequency of the resonator over temperature that will meet the target detection range specification.

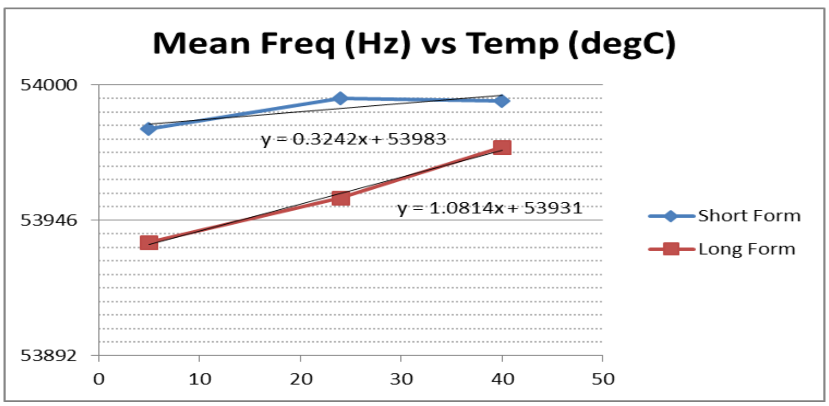


Figure 14: Plot shows the mean resonant Frequency (Hz) of the resonator vs Temperature (degC)

The resonance quality factor is also very stable over temperature, as shown in the plot below, Figure 15:

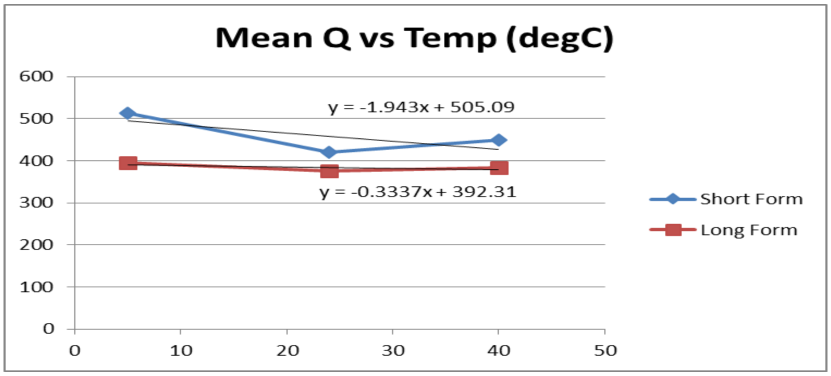


Figure 15: Plot shows the mean resonance Quality Q vs Temperature (deg C)

The critical performance specification, referred to as Gain measured in dB, is directly related to the detection depth with 53dB = 63". As shown in Figure 16 below, the gain change over temperature is insignificant (< 1" over 35 deg C temperature change).

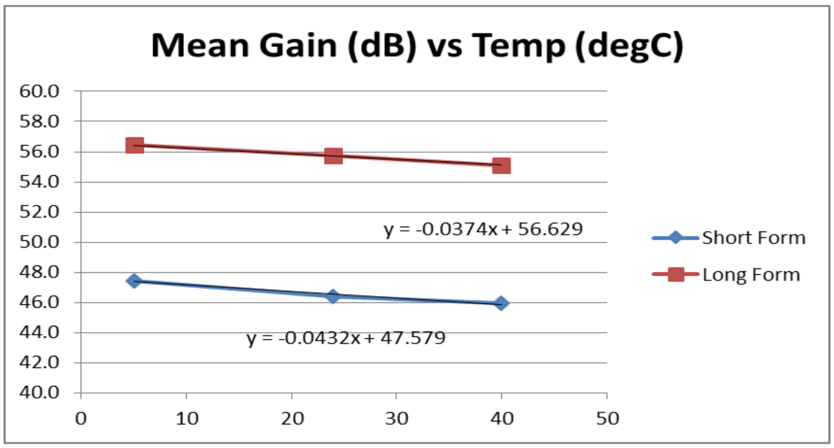


Figure 16: Plot shows the mean Gain (dB) vs Temperature (degC)

The 4' burial marker is referred to as the "long" form, while the 3' burial marker is referred to as the "short" form.

The short marker, even though with a shallower detection depth, may provide a higher value and a viable option for shallow PE pipe installations and is included in the technology/solution assessment.

UV Exposure during outdoor storage

The weathering and UV stability of the marker assembly for the Intrinsically Locatable Plastic Pipe solution should be compliant to ASTM D2513 for plastics type C, black with 2% minimum carbon black, or E, colored with UV stabilizer. The UV stability requirements are further defined in the Plastic Pipe Institute document, "Polyethylene Resin Testing Requirements to Support ASTM D2513 UV Exposure Limits of Polyethylene Compound (TN-47/2013)". The requirement is that the plastic components should be sufficiently UV-stable to allow storage out-of-doors for not less than 3 years without appreciable loss of properties. At the current time, there are three (3) plastic components in the system: the "carrier", which is composed of high density polyethylene (not UV stabilized, not colored), the yellow medium density polyethylene "housing" (UV stabilized), and the black high density polyethylene "housing" (UV stabilized). The carrier will not be directly exposed to outside storage conditions as it will either be covered by tape to attach to the pipe (< 2" diameter pipe applications) or it will be attached to the pipe within a plastic housing (≥ 2" diameter pipe applications).

There will be a choice of UV stabilizers that will meet the target specifications, the final choice will be up to the manufacturer.

Compression, Shear and Expansion Stresses:

The carrier and housings are designed to sustain the expected normal loads consisting of the pipes (coils and stick) of various diameters. The carrier is designed to withstand over 300 lbs of continuous load.

The welded housings add ruggedness to the solution and allows it withstand several hundred pounds of shear in harsh soil (such as gravel) during Horizontal Drilling installation operations.

Open trench and plowing methods do not subject the ILPP to significant stresses.

Two attachment methods were designed to accommodate the various stresses at lowest cost: Tape Wrap and Welded Housing. Both methods allow the carrier to "float" while the pipe stretches or contracts without affecting or compromising the carrier seal integrity.

Pipe coiling puts stress on the carrier and housing. The stresses were modeled for the various solutions, prototyped, bench and field tested. The appropriate and feasible design refinements where accomplished.

Aging and life prediction

An accelerated aging study was conducted on 220 samples of the long form resonator in welded carriers. The study can project the life of the resonator for proper detection by a locator over time.

The results are shown in Figure 17 below: the performance drift is extremely slow, equivalent to approximately 2" of detection signal at 4' at 50 years.

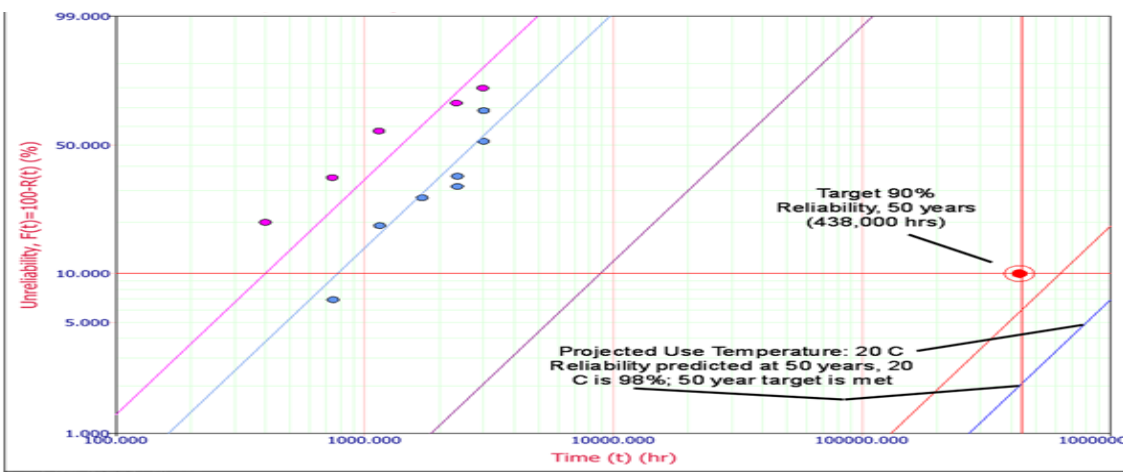


Figure 17: shows capability of 50 years + of the resonator life

Pipe integrity considerations and relevant standards

Integration with existing standards and practices

Validation of Intrinsically Locatable Plastic Pipe Performance

The Intrinsically Locatable PE pipe (ILPP) with the markers attached were evaluated to ensure that the PE pipes meet the ASTM D2513 standard. A series of tests were performed on PE pipe that contained fused housing and markers (ILPP) to validate that the attachment did not have any detrimental effects on the pipes short-term and long-term performance. Various samples of ILPP was used for the testing. This included 2” and 4” MDPE and HDPE pipe specimens.

The following tests were completed and/or are still on going:

Test Method Number	Title
ASTM D1599	Standard Test Method for Resistance to Short-Time Hydraulic Pressure of Plastic Pipe, Tubing, and Fittings (Quick Burst)
ASTM D1598	Standard Test Method for Time-to-Failure of Plastic Pipe Under Constant Internal Pressure (Long Term Hydrostatic Testing or LTHS)

Quick Burst Testing per ASTM D1599

Quick burst (QB) testing is performed to determine the resistance of materials to increasing hydraulic pressure over a short time interval. It consists of loading a specimen to failure by continuously increasing internal hydraulic-pressure while the specimen is immersed in a temperature controlled environment. It establishes the short-time hydraulic failure pressure.

Accelerated Long Term Hydrostatic Stress Rupture Testing per ASTM D1598

Accelerated Long Term Hydrostatic Stress Rupture (LTHS) tests were conducted on the as-received pipes in accordance with ASTM D1598. This test is performed to determine failure time of plastic pipe in a controlled environment. It consists of exposing test specimens to a constant internal pressure at a constant temperature.

Summary of ILPP Validation Testing

Table 2: Summaries of MDPE and HDPE 2” OD ILPP Integrity Validation Testing

2" ILPP MDPE Validation Test Results Summary				
Property	**Test Method**	**Control Pipe**	**ILPP Pipe (avg. results)**	**Comments**
Quick Burst Hoop Stress	ASTM D1599	3184.99 psi	3201.80 psi	Ductile pipe failure not at marker
Long Term Hydrostatic Test (LTHS)	ASTM D1598	3653 + hours	3653 + hours	Specimens still on test
2" ILPP HDPE Validation Test Results Summary				
Property	**Test Method**	**Control Pipe**	**ILPP Pipe (avg. results)**	**Comments**
Quick Burst Hoop Stress	ASTM D1599	3617.87 psi	3655.51 psi	Ductile pipe failure not at marker
Long Term Hydrostatic Test (LTHS)	ASTM D1598	3653 + hours	3653 + hours	Specimens still on test

Table 3: Summaries of MDPE and HDPE 4" OD ILPP Integrity Validation Testing

4" ILPP MDPE Validation Test Results Summary			
Property	**Test Method**	**ILPP Pipe (avg. results)**	**Comments**
Quick Burst Hoop Stress	ASTM D1599	3257.74 psi	Ductile pipe failure not at marker
Long Term Hydrostatic Test (LTHS)	ASTM D1598	1050 + hours	Specimens still on test
4" ILPP HDPE Validation Test Results Summary			
Property	**Test Method**	**ILPP Pipe (avg. results)**	**Comments**
Quick Burst Hoop Stress	ASTM D1599	3995.24 psi	Ductile pipe failure not at marker
Long Term Hydrostatic Test (LTHS)	ASTM D1598	1050 + hours	Specimens still on test

Note: All LTHS specimens are still on test – ASTM LTHS requirements at a hoop stress of 650 psi is approximately 1100 hour test duration. All of the samples have already far surpassed this requirement as of the submittal of this report.

Utility Testing of Intrinsically Locatable Pipe (ILPP)

To support the field evaluation of the ILPP, the team constructed approximately 12,000' of ILPP consisting ¾", 1", 2" and 4" MDPE and HDPE pipe.

The markers were taped on the ¾" and 1" PE pipes and PE housings were used to hold the markers on the 2" and 4" pipes by welding the housing to the PE pipe.

The ILPP pipe was provided to ten (10) utilities for installation and evaluation. The participating utilities scheduled the time and resources to perform various installations of the ILPP. These installations included both main and service piping and the utilities used various methods to install the pipe (open trench, horizontal directional drilling, and plowing). Representatives from GTI and 3M were on hand for the installations and for initial and follow on locating of the ILPP pipe.

Testing through installations/evaluations at the following utilities:

- Utility A
- Utility B
- Utility C
- Utility D
- Utility E
- Utility F
- Utility G
- Utility H
- Utility I
- Utility J

Figure 18: 3M Dynatel 7420 Locator set up for the field test

Utility A

Date	**5 Oct 2017 (Revised Oct 24 2017)**
Company Name	Utility A

Install location address	**1. Location A** **2. Location B**
Installation depth	1. ~36” 2. ~48”
Installation method detail	1. HDD (rod size: <2”, back reamer size: NONE, Lubricant: NONE) 2. HDD (rod size: 2”, back reamer size: 5”, Lubricant: Yes)
Pipe size & type	1. ¾” MDPE yellow coiled ILPP 2. 2” MDPE yellow coiled ILPP
Installed length	1. ~70’ – ¾” MDPE 2. ~90’ – 2” MDPE

Figure 19: Directional drilling installation of the ILPP in very rocky soils

Figure 20: ILPP pipe attached to the back reamer to be pulled into the ground

Figure 21: Condition of the PE pipe and housing after being pulled through the rocky ground

There were no concerning events during the pull and the all markers were located after installation. The crew pulled out the first marker and cleaned of to evaluate the condition. Overall, the installation and location of the pipe was successful.

Comments from Utility A regarding the installation:

- "This will save a lot of time. We will be able to locate any section without having to set up a transmitter. Think about having to connect a transmitter a 1/2 mile away from the locate."
- "This just survived our toughest earth. Tracer wire usually breaks in these conditions."

Utility B

Date	Nov 1 2017
Company Name	Utility B

Install location	Location A
Installation depth	About 36” to 48” deep
Installation method detail	HDD (rod size: 2”, back reamer size: 4.5”, Lubricant: Bentonite
Pipe size & type	¾” and 2” MDPE yellow coiled pipe
Installed length	~500’ of 2” and ~40’ of ¾”

Figure 22: Site of ILPP installation and crews locating ILPP after installation

Utility B installed approximately 500’ of 2” ILPP and 40’ of ¾”. The 2” pipe was directionally bored in next to the street in the front yards of several houses. The 40’ service pipe was bored in to feed a customer. All comments were positive but the technicians did ask about the ruggedness of the markers that were attached with tape (service tubing). Once the ¾” pipe was located to the house, the technicians concerns were addressed. Overall, the installation and location of the ILPP pipe was successful.

Utility C

Date	Sep 28 2017
Company Name	Utility C

Install location	Location A
Installation depth	2” and 1” coiled pipe buried ~48”
Installation method detail	HDD - back reamer size: 5” Spin Paddle, Lubricant: None
Pipe size & type	1”, 2” MDPE yellow coiled pipe
Installed length	Approx. 100' of 2" pipe for Run #1 and approx. 175' - 200' for Run #2. Approx. 60' of 1" pipe for Service Line Run #1 and approx. 45' for Run #2.

Figure 23: 1” and 2” ILPP trenchless installation at Utility C’s training center

Utility C installed four sections of pipe installed by HDD – 2” main and 1” service piping. About 1 month later, Utility C technicians used the plow method to install additional 1” service piping. The installation and location of the ILPP pipe was very successful.

Utility D (had to cancel due to damaged pipe sample and no time for replacement sample)

Utility E

Date	Sep 26, 2017
Company Name	Utility E

Install location address	Location A
Installation depth	2” Pipe ~36” deep, 1” pipe ~18” deep
Installation method detail	HDD (rod size: ?, back reamer size: 4”, Lubricant: None
Pipe size & type	¾”, 1”, 2” MDPE yellow coiled pipe
Installed length	Approx. 425' of 2" pipe and approx. 75' of 1" pipe

Figure 24: Utility E crews installing ILPP pipe using both trenchless and open trench methods

There were two - 2” ILPP pipe sections pulled for a total of 425’ and 75’ of 1” ILPP pipe pulled to service two homes. The 2” pipe was installed close to 36” deep and the 1” pipe was pulled in around 18” deep. All markers were located indicating that tape and PE housing worked as designed during HDD pulls. Utility E employees were very pleased with the installation and performance of the ILPP. Only suggestion made was regarding the tapping of the marker to the service tubing. They asked if these markers could be fused on similar to the 2” piping.

Utility F

Date	**Oct 5, 2017**
Company Name	Utility F

Install location address	**Location A**
Installation depth	30” – 36” deep
Installation method detail	Open cut
Pipe size & type	2” MDPE yellow and ¾” MDPE yellow
Installed length	500’

Figure 25: Crews validating the locatability of the installed ILPP at Location A

Utility F crews installed a 500’ section of ILPP pipe in the easement of a new subdivision on the Location A AF base. The 500’ section of 2” pipe was placed in an open trench, connected to adjacent sections PE pipe and then backfilled. The markers were located and compared with tracer wire locations. The also validated the markers location by digging two potholes – the marks were spot on. Utility F liked the accuracy and liked the fact that the EMS markers had unique frequencies to differentiate between the various utilities (gas, water, electric, etc.).

Utility G

Date	Nov 8 2017
Company Name	Utility G
Install location address	Location A
Installation depth	~36 - 48” deep
Installation method detail	HDD (rod size: 1¾”, Spade size: 4.5”, Lubricant: None
Pipe size & type	¾”, 2” MDPE yellow coiled pipe
Installed length	

Figure 26: Trenchless installation using HDD equipment at Utility G’s training center

Utility G crews pulled in about 80’ of 2” ILPP coiled pipe and 30’ of ¾” ILPP pipe. The bores were exceptionally difficult due to the boulders, cobble, pebbles, course silt and clay. The crews intended on installing longer lengths of pipe but the difficult soil prohibited the crews from further drilling. All markers were located and the lead marker pulled from the bore was a little scuffed up but looked good considering the challenges during the bore.

Utility H

Date	
Company Name	Utility H

Install location address	Location A
Installation depth	3' ~ 4' deep
Installation method detail	Open cut and HDD
Pipe size & type	2" and 4" MDPE yellow (2" coiled – 4" stick pipe)
Installed length	

Figure 27: 2" and 4" ILPP installation in Location A

The installation included 200' of 4" stick pipe and 500' of 2" coiled pipe. During the initial pipe inspection it was found that some pipes had weld marks from markers that had been removed in the manufacturing process. Also some pipes had some surface damage from the banding used to tie pipes down. Besides from the material issues, the overall pipe installation and marker location was successful.

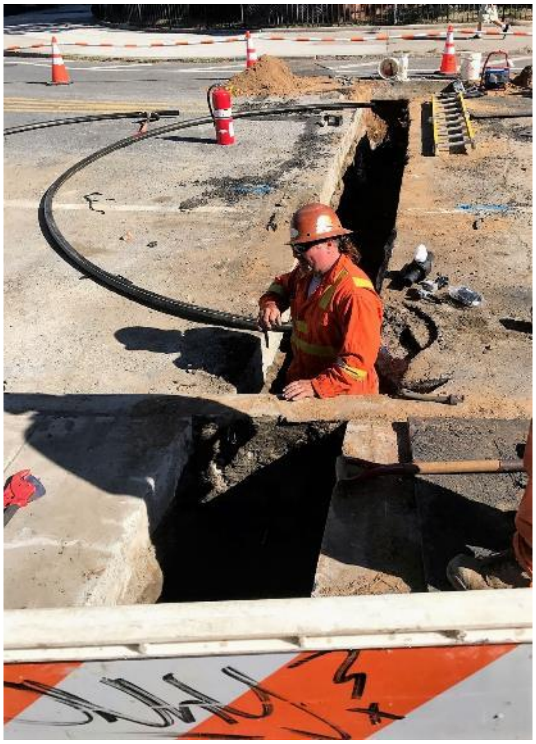
Utility I

Utility I received ILPP pipe and is conducting various laboratory testing. As of the creation of this report, no information was received as of the results of their testing.

Utility J

Date	28 Sep 2017
Company Name	Utility J

Install location address	Location A
Installation depth	3 - 4' deep
Installation method detail	Open trench ~40'
Pipe size & type	2" HDPE black coiled pipe
Installed length	40'



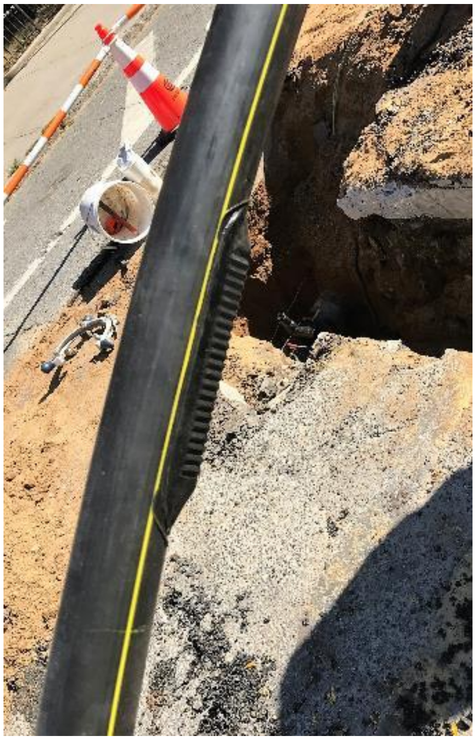


Figure 28: Crews installing ILPP pipe to replace aged pipe in Location A

Utility J installed 2" HDPE ILPP pipe to replace existing pipe in Location A. The pipe was installed via open cut. Utility J employees were very satisfied with the pipe and installation.

Utility Field Installation Summary

All of the pipe samples used were installed using normal installation practices (open trench, directional drilling, and plowing) and procedures and all of the ILPP pipe and markers were locatable after the installation, over the exact installation location.

Installation of ILPP in the field tests consisted of adding the normal tracer wire to the pipe. Normal ILPP installations would not require the addition of a tracer wire or termination and access boxes. The ILPP system makes the pipe detectable without connecting a transmitter to apply a trace tone to the wire from an access point and does not require continuity, bonding or grounding.

To locate the ILPP, the technician (locator) would go on location and sweep at the gas path marking frequency to pinpoint the markers and thus the pipe location. Depth estimation is available with a simple push button measurement when the locator is positioned over a marker.

ILPP Samples Schedule Build:

Figure 29: 2" Coiled Pipe with corrugated housing

Figure 30: Coiled MDPE and HDPE 250' and 500' 2"

Figure 31: 4” OD 40’ long MDPE and HDPE stick pipe – using the corrugated 4’ housing

Transportation and Installation

All the ILPP pipe was transported and installed by the utility in ten (10) locations around the country using normal practices and all the markers were locatable after the installation, over the exact installation location. Tracer wire was also installed with the ILPP to allow for standard locating practices.

Path Marker Location Specifications

All the medium and small path markers were located successfully and met the target specification for location.

Depth measurements were taken and a few measured against actual depth with acceptable results. The final depth estimation accuracy of the locator should be (+/-10%+/-2”) or better.

Table 4: Detection Specification for ILPP Samples

Description:	Locatable Plastic Pipe
Maximum Detection Depth:	
Small marker (3.75” length):	4’
Medium marker (7” length):	5’
Distance Between Markers:	
Small Marker:	6.3’
Medium Marker on 2” and smaller pipe	8.5’
Medium Marker on 4” pipe	10’

Depth limits

The low frequency electronic markers which are used for buried applications operate in the 50~100k Hz frequency range. At these frequencies, the soil is almost transparent which provides full range detection under all tested soil conditions.

The signal reduction over distance from the locator varies with the inverse sixth order of distance. This provides a challenge for increased detection, however with the latest advancement of these resonators at 3M, a significant increase has been accomplished over previous generations.

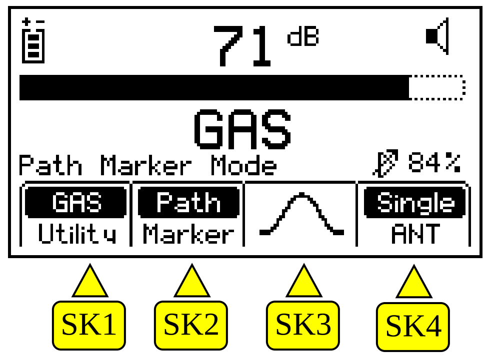
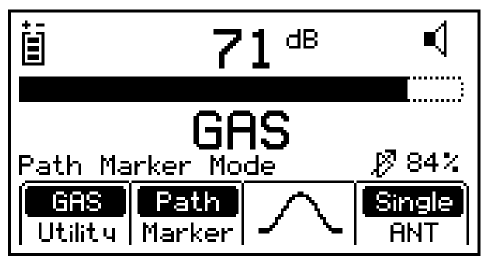
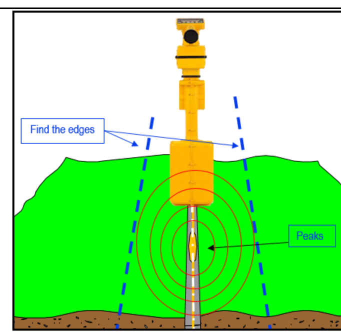
Work continues for further enhancements in the resonator as well as the locator, which is the other half of the system. We can project a roadmap for a 6’ detection and deeper marker/locator systems in next generations.

Location and Marking method

Operating the 7420 EMS Locator

Locate Operations

No access points or transmitter connections are required for the locatable PE pipe.

Step	Instruction	
1.	Turn unit on.	
2.	7420 - Press locate if the unit is in a menu mode. Select EMS-iD/Path from locate Menu.	
3.	There are two modes for locating (Peak and Peak/Null) Peak Mode - This mode provides a peak signal response when over the path marker. The path direction can be determined in this mode when the handle is in line with the path and providing the strongest signal response. Peak/Null – A combination of Peak and Null to provide maximum signal continuity along path.	
4.	*Set yellow SoftKeys[SK] as follows:* SK1. Press until **GAS** is displayed. SK2. Press until **Path** is displayed. SK3. Select search mode - Peak. *SK4.* Single Antenna should be the default but Dual Antenna is useful when there is noise interference.	
5.	For this evaluation, we recommend using Peak mode, which provides location accuracy over markers. This mode will have the strongest signal over the path marker.	
6.	Steps to locate *Locatable PE Pipe*: • **Sweep for markers on pipe.** • **Find signal peak and edges.** Signal is strongest when handle is in line with path and over marker. • **Press Depth Key** for displaying the depth Mark path as required. • Locate next marker and repeat.	

Path Marker Specifications

Table 5: Path Marking Specifications (Temperature & Detection)

Description:	Locatable Plastic Pipe
Operating temperature	-4° F to 122° F (-20° C to 50° C)
Storage temperature	-4° F to 140° F (-20° C to 60° C)
Maximum Detection Depth: Small marker (3.75” length): Medium marker (7” length):	 4’ 5’
Distance Between Markers: Small Marker: Medium Marker on 2” and smaller pipe Medium Marker on 4” pipe	 6.3’ 8.5’ 10’

Recommended ILPP Solution(s)

We foresee more than one solution for markers and attachment methods to convert a PE pipe to be intrinsically locatable (ILPP). This is expected, since pipe OD ranges used in the US Gas installations spans greater than 10x1 ratio with weight per foot of over 100x1 ratio. Markers can be made to have a lower cost but lower detection range that maybe suitable for shallow installations (3’ or below).

The harshest installation environments where used to assess the attachment methods suitable for various pipe sizes.

Marker range options:

Two marker lengths were developed and assessed at the Gas frequency of 53.9kHz:

- A long form marker design that’s around 7” long having a detection range over 5’ and recommended for up to 4’ burial.
- A short form marker design that’s around 4” long having a detection range over 4’ and recommended for up to 3’ burial.

Advancements in technology of the marker and locator system is expected to increase the detection range over time.

Attachment method options:

Two attachment methods were developed and assessed:

- A simple and fast tape wrapping attachment of the marker on small OD pipes of less than 2” OD was suitable under harsh HD installation conditions.
- A rugged corrugated or smooth housing thermally welded to the outside of the pipe, for 2” OD and larger, keeps the marker on the pipe under harsh HD installation conditions.

Large OD pipes:

With rugged tape, larger OD pipes can be converted to ILPP through a tape wrap attachment process, while the larger OD pipes would always require a very rugged solid solution.

Location best practice

Locating an ILPP segment is faster and simpler than locating tracer wires since there's no requirement to connect a transmitter at a junction or access box. This saves a time consuming step especially where the access point is far from the location or construction area to be swept.

There's no frequency selection required when locating an ILPP, or a far ground bonding assessment that is normally required when using a tracer wire.

Path Marking Gas Frequency is the only selection necessary, thus eliminating the frequency selection process required for tracer wire location.

No connection and no disconnection of a transmitter is required when locating ILPP segments. The markers are always ready to be energized and detected by a surface locator, similar to point electronic markers.

Buried utility location congestion issues are largely eliminated for an ILPP segment versus PE with tracer wire. Congestion and difficulty in accurately locating and identifying a segment is caused by tracer wire return currents flowing in adjacent infrastructure and generating a magnetic field on the surface that is detectable by the locator.

Location error of a T-joint caused by a distorted field pattern from a tracer wire T is eliminated when using ILPP segments. This is due to the additive nature of all ILPP markers giving symmetry of location at a T structure while tracer wire fields generate magnetic fields that add or subtract causing non-symmetrical field shape which causes an error in location.

Depth estimation is inherently more accurate over an ILPP segment than for a tracer wire due to the ILPP system not having to rely on ground currents to flow that could get on adjacent utilities causing field distortion leading to depth estimation errors.

In summary, locating an ILPP segment is expected to be faster, easier and more accurate than tracer wire, when buried per the recommended depth guidelines, providing a longer product life and eliminating lightning susceptibility by eliminating a long conductor near the pipe (the tracer wire).

The locating unit, the enabler of this technology, should operate at the Path Marking Gas frequency and have a field pattern for detecting a resonant electronic marker positioned horizontally.

Locating equipment manufacturers will address the new advancements in the ILPP system by modifying or designing new units that are capable of detecting ILPP markers.

ILPP symbol creation for as-built drawings

A universal symbol for ILPP should be developed and used on as-built drawings in order to assist in the identification of ILPP segments. It would be feasible to add an attribute to the pipe bar code.
The variation of the marker spacing, such as 6', 8' or 10' marker spacing can be reflected in the symbol itself.

Attachment qualification procedures

The basic function of the marker is to electronically mark a buried pipe and be detectable at a specific frequency to a specific depth using a 3M 7xxx series locator.

Key features are:

1) that it's attachable to pipes from 3/4th inch OD to ~ 8" OD (Path Marking Rope or Tape is recommended for the very large sizes, coiled or stacked (where applicable);

2) sustains pipe shipping and handling as well as installation stresses of Horizontal Directional Drilling without detaching or leaking water into the ribbon or magnet compartment.

The design life of the marker is over 50 years, which the magnetic components of the resonator have shown capability, as long as the HDPE carrier plastic maintains a water seal for up to 5' burial in the ground.

Two attachment configurations:

The product has two basic configurations:

1) A marker that is taped around a plastic pipe,
2) A marker placed under housing that is welded to a plastic pipe.

The marker consists of an electronic resonator that is housed in HDPE.

The housing comes in MDPE or HDPE and is welded to the corresponding pipe of same material, the function of which is to keep the marker attached to the pipe. The welded housing provides additional water seal to the resonator elements inside the marker carrier.

Testing a Marker:

A marker test uses a fixture and benchtop instruments controlled by a PC running test software. The frequency, gain and resonance quality are measured to determine whether the signal from the marker meets the detection range specification.

Testing an Attachment:

In addition to load, whether transient impact or continuous, any attachment qualification should consist of a detachment strength test to assess the shear force required to detach along with abrasion.

The forces that the attachment undergoes depends on the size of the pipe. There will be three sizes/types of attachments that are suitable for the pipe sizes used by the US Gas companies.

A simple shear test will suffice for taped attachment methods.

In the case of a housing that is welded to the outside of the pipe, the effect on the pipe has to be assessed, characterized and controlled.

Parametric qualification testing would consist of the pipe wall thickness and roundness as well as bending in the case of coiled pipes in order to qualify the attachment process.

The current welded housing designs do not add stress to the pipe and can maintain pipe wall thickness integrity guidelines easily with readily available equipment. The equipment has to be customized to fit in a pipe manufacturer's best practices and adapt to different production line layout.

All markers are 100% tested when they reach the attachment machine.

Also, the Markers can be tested after the attachment to the pipe. A marker test is fast, under 1 second and can be conducted on a moving pipe using mostly off the shelf equipment, a pc running marker test software and using a simple fixture interface.

Conclusions

The focus of the this research effort was to mitigate third-party pipeline damage at the earliest stages through the development of innovative locatable pipe marking systems to allow plastic piping systems to be intrinsically located. Today, more than 90% of the gas distribution pipe being installed is PE pipe using a copper tracer wire for locating the buried underground piping materials. However, these tracer wires are susceptible to breakage or corrosion, rendering the buried plastic material undetectable. Due to its locatability, the locatable PE pipe marking system being developed, substantially reduces the risk of third party damage and provides local distribution companies a durable solution to this problem.

3M and GTI have joined forces to mitigate third-party pipeline damage at the earliest stages through the development of an innovative locatable pipe marking system to allow plastic piping systems to be intrinsically located.

Advantages of an intrinsically locatable plastic pipe include:

- Ability to locate the pipe is not affected if cut or damaged.
- The electronic markers are not subject to inference from nearby utility lines
- Save steps during installation – eliminates tracer wire and related installation, splicing and access
- Save steps during location – eliminates transmitter connection
- Unique frequency for various utility pipes and conduits
- Eliminates susceptibility to lightning from a long conductor laying on the pipe
- Long life expectancy of product designed to last the lifetime of facility.

The research team has developed an integrated electronic marker that will provide locatability to coiled or "stick" polyethylene pipes for gas and other utility applications with a variety of sized plastic pipes. The team has assessed the technology's capability versus pipe diameter and pipe burial methods (horizontal directional drilling, open trench, etc.) in the lab and simulated field conditions. Based on the successful outcome of these evaluations, the team worked with 10 natural gas utilities across the US to further evaluate the locatable PE pipe in various field and climate environments and using common installation methods (open trench, directional drilling, and plowing), demonstrating the advantages of an intrinsically locatable plastic pipe.

The main project goals were met by the team and participating end users within the allocated time period. Future work related to this new technology and its applicability to PE pipe will be focused on optimizing the attachment process and enhancing the performance of the marker and locator towards deeper depths. Involving all the stakeholders would be necessary to complete a robust final procedure for quality assurance testing of the attachments, full integration into existing PE manufacturing plants and a locator upgrade roadmap for path marking applications.