DETECTION OF UNAUTHORIZED CONSTRUCTION EQUIPMENT IN PIPELINE RIGHT-OF-WAYS

Presented to

Natural Gas Infrastructure Reliability Industry Forums

by

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Prevention of 3rd-Party Damage Is a Major Gas Industry Concern

- **Third-party damage on HP pipelines can be extremely costly and disruptive (e.g. Edison, NJ)**
- **DOT statistics from 1994-2001 give 224 3rd-party incidents on transmission lines: 7 deaths, 35 injuries, and $167 million in property damage**
- **One incident cost ~$25 million**

  - **Prefer to detect encroachment into right-of-way before damage occurs**

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Minimizing False Positives and "Masked Events" Is Critical for Industry Acceptance

- Encroachment is common, 3rd-party damage is rare
- Economics requires monitoring long distances from one location
- Pipelines in noisy areas will have "events" occurring simultaneously
- Thus, being able to detect and distinguish simultaneous events at different locations is important
- Also critical to identify what is causing encroachment

An Optical Fiber Sensor Permits Detection of Unauthorized Construction Equipment Pipeline in Right-of-ways BEFORE the Pipe Is Hit

- **Optical fiber sensor buried along pipeline**
- **Compression of soil and vibrations change light transmission properties of the fiber**
- **Light pulses and an OTDR* detect these changes**
- **After disturbance, fiber returns to normal (fiber is not broken)**

*** OTDR = Optical Time Domain Reflectometry**

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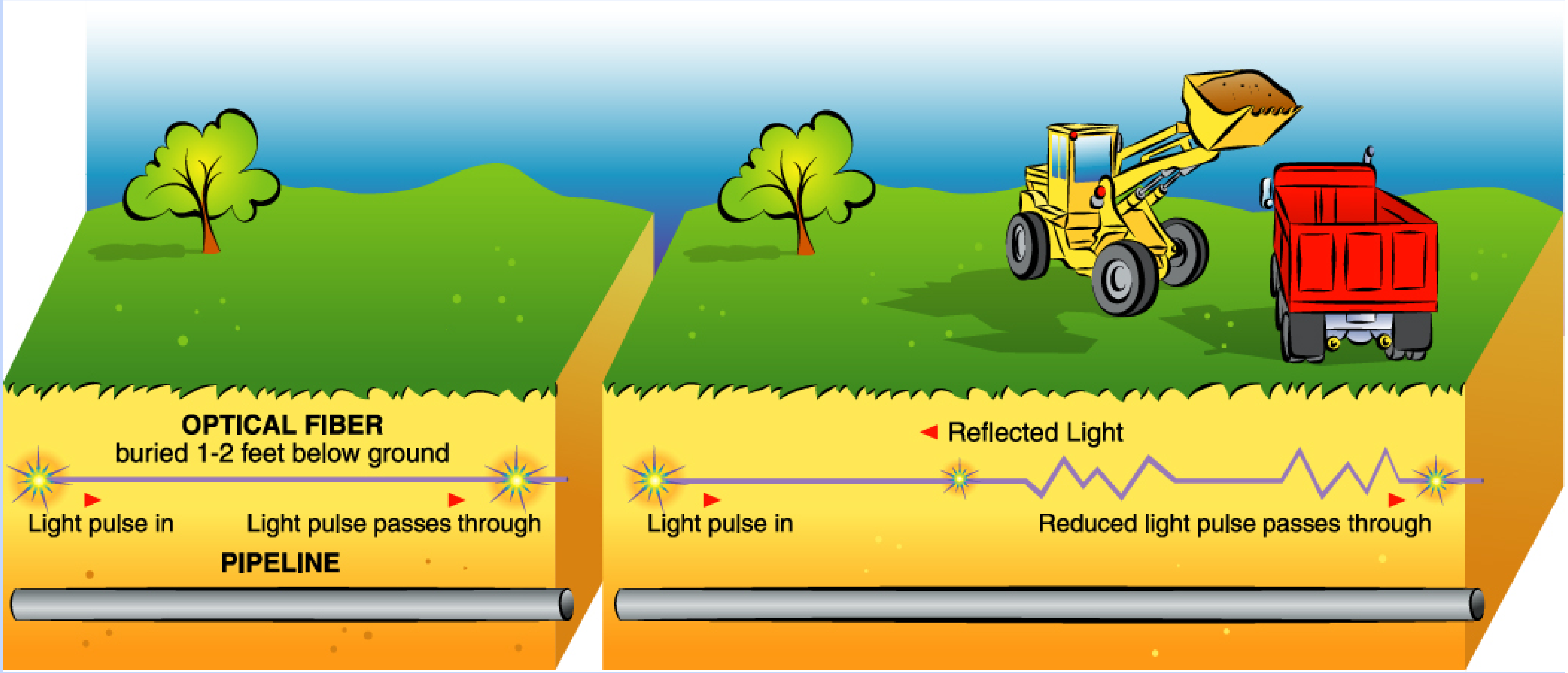
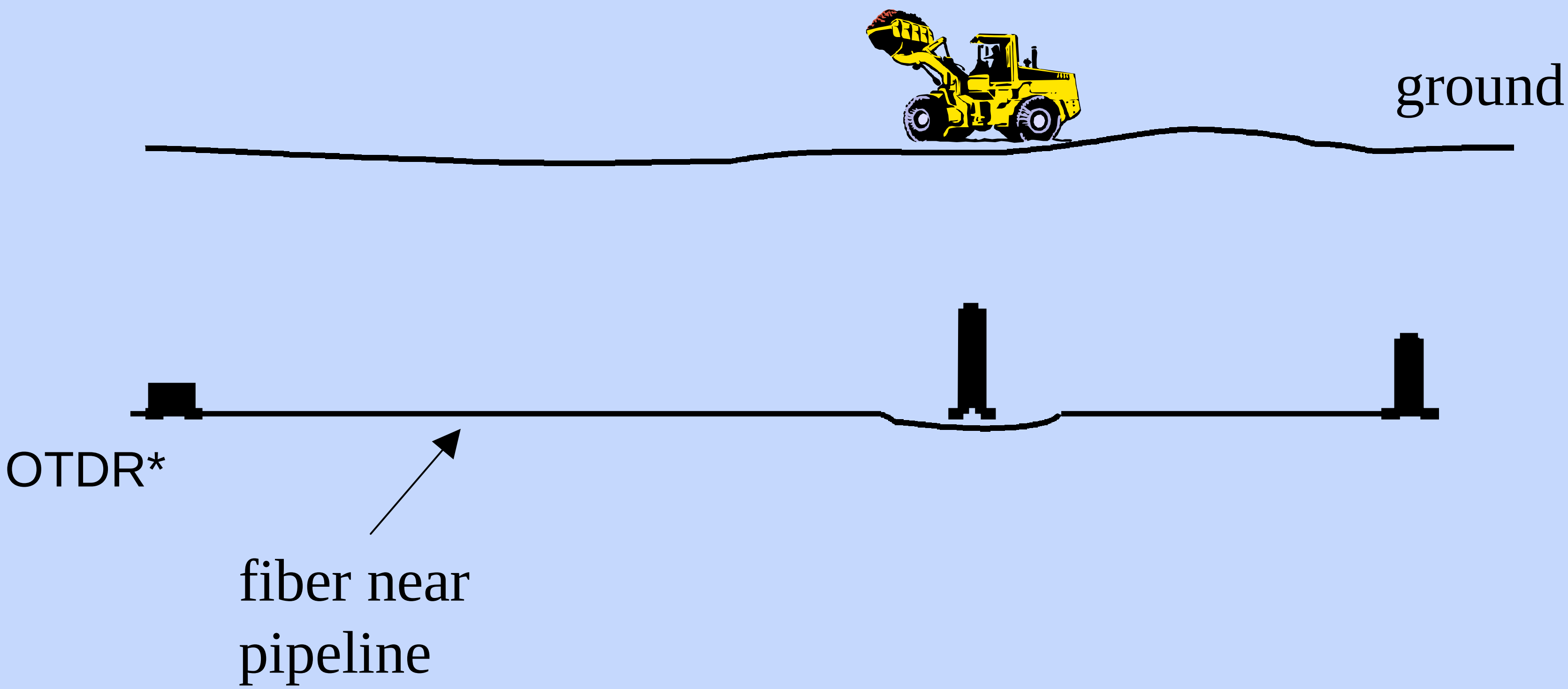
OTDR Technique Can Discriminate Simultaneously Occurring Events



Round trip travel time of a light pulse locates encroachment.

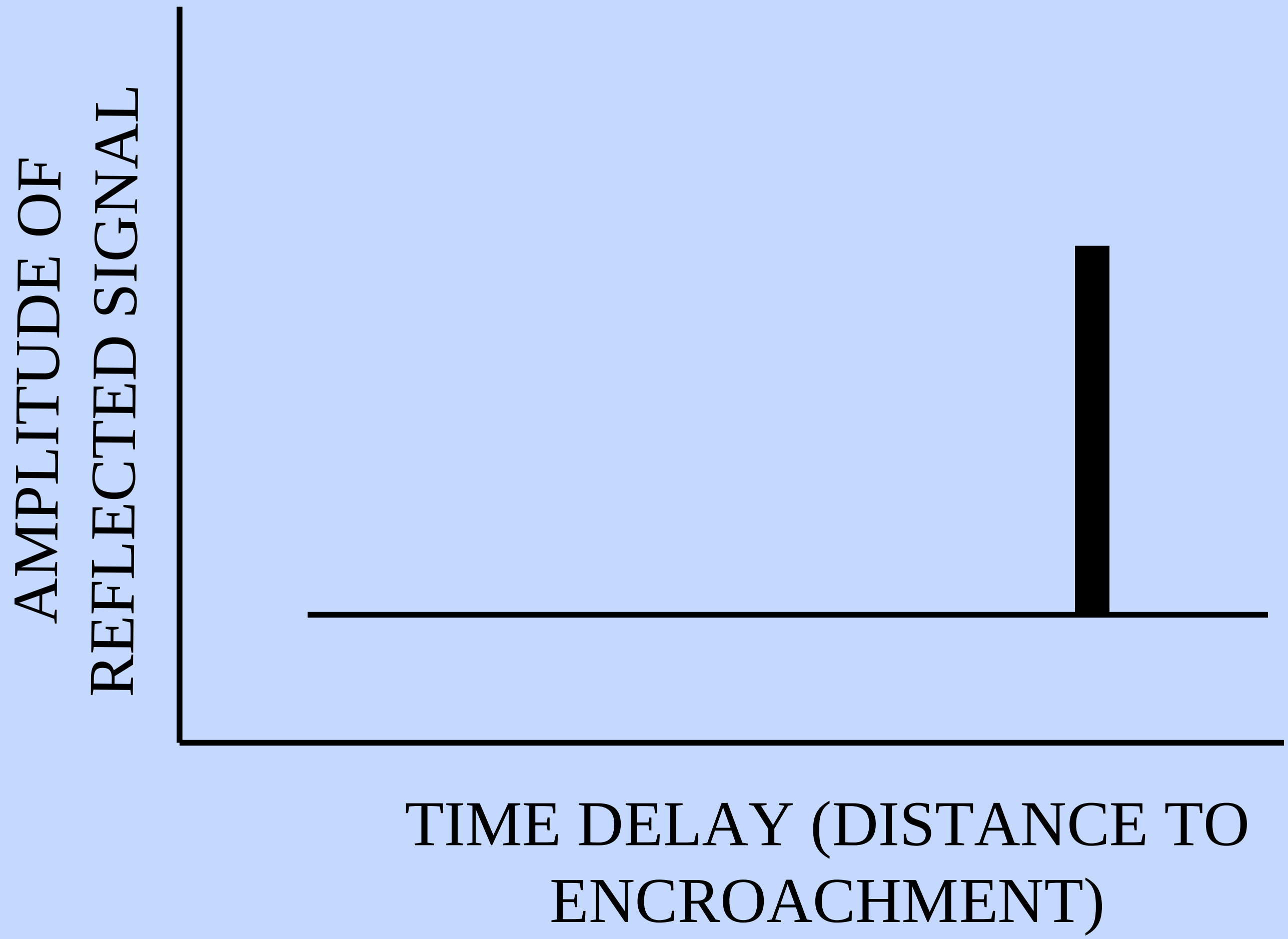
Variations in amplitude identify type of encroachment.

Disturbances to the Fiber Will Reflect Part of a Light Pulse

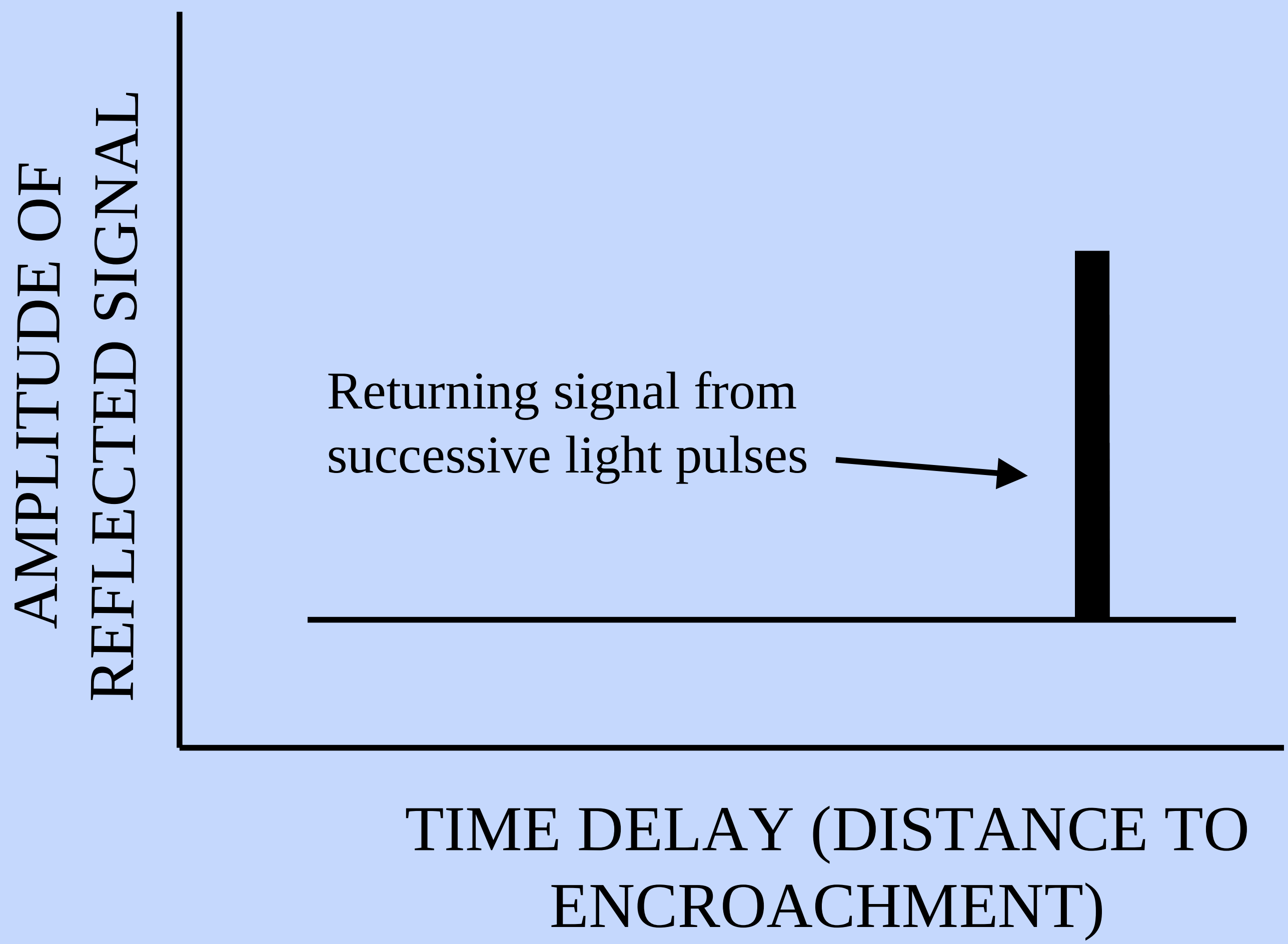


***OTDR = optical time domain reflectometer**

When Displayed on an Oscilloscope, the Position of the Signal Is Proportional to Distance to the Encroachment



The Variation in Signal Strength Will Be Used to Discriminate Among Encroachment Types



Optical Fiber Sensor Must Detect and Identify Potential Hazards Before Pipeline Is Harmed

Key technical issues:

- **Demonstrate the ability to detect encroachment**
- **Develop methods to discriminate between potentially hazardous and benign encroachments.**

Rayleigh Backscattering With Custom OTDR Selected as the Best Sensing Choice

Methods of Detection:

- **Rayleigh backscattering**
- **Brillouin scattering**
- **Distributed sensors**
- **“Whole” fiber monitoring**

Earlier Work Demonstrated Potential for Optical Fiber Encroachment Sensing

- **Buried fiber in an interferometer detected construction equipment and footfalls**
- **Buried fiber and low-cost OTDR detected backhoe**
- **Both “proof-of-concept” experiments identified required improvements**

A Custom OTDR Is Needed to Detect and Discriminate Encroachment

- **A backhoe can enter the right-of-way, set-up, begin excavating, and damage the pipe in 30 minutes**
- **A conventional OTDR requires too long to collect data—we must speed up the process**
- **A conventional OTDR displays attenuation of the fiber as a function of distance—we must monitor fluctuations at a given distance with time**

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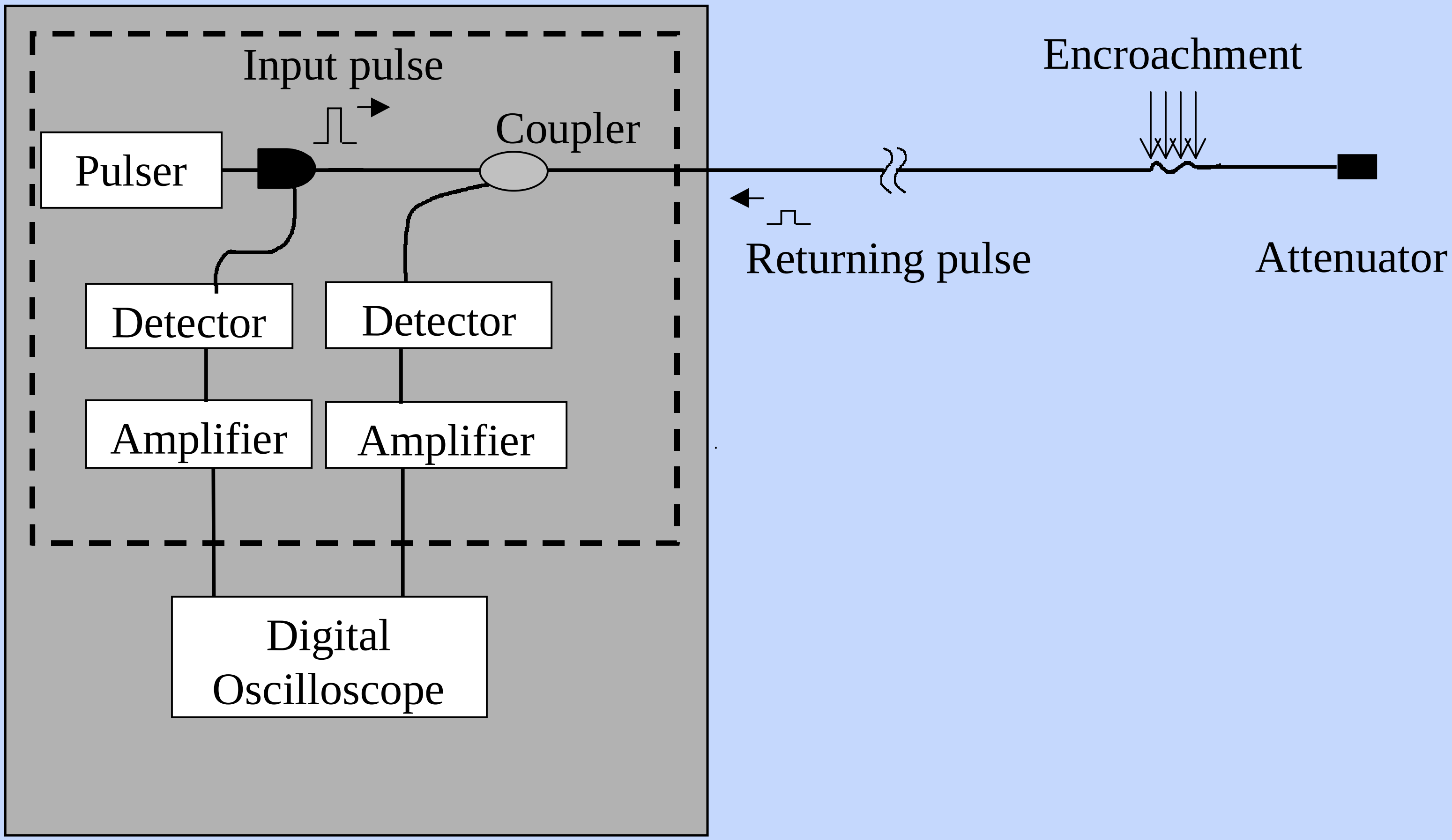
OTDR Schematic



One Goal Is to Use an Optical Fiber that Is Sensitive to Vibrations and Stress

Manufacturers try to make optical fibers <u>in</u>sensitive to stress and vibration

Some promising sensing candidates are:

- **Hergalite**
  - **Spiral wound to increase microbending**
- **Single-mode, with 650 nm cut-off frequency**
  - **Rayleigh scattering at higher frequencies with little pulse broadening**
- **Multi-mode, large diameter core, graded fiber**
  - **Larger cores are more susceptible to vibration**

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Optical Time Domain Reflectometry Can Divide Fiber into 2-meter Sections

- 100 MHz Digital Oscilloscope (10 nanosecond digitization)
- Velocity of light in fiber = 3 x 10^8 m/sec divided by ~1.5 index of refraction = 2 x 10^8 m/sec
- 2 x 10^8 m/sec times 10 x 10^9 sec = 2 meters
- Use narrow 10 nanosecond pulse

Proof of Concept on 1 Kilometer Fiber

- **1 kilometer = 500 sections**
- **Round trip time = 5 x 10^{-6} sec**
- **Separate by 10 x 10^{-6} sec to be sure pulses don’t overlap**
- **Can signal average 1000 times and still have 100 Hz frequency resolution**

Rayleigh Scattering from Frozen Density Fluctuations Set Minimum Attenuation

- **Rayleigh Scattering is caused by variations in the density of the fiber**
- **Rayleigh Scattering is proportional to**
  - λ^{-4}, **more scattering at shorter wavelengths**
  - $1 + \cos^2 \theta$* **implies light is scattered backwards**
- **Density fluctuations frozen into fiber during manufacture set the required detector sensitivity**

*** θ is the angle of scattered light with respect to the incoming light**

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The Project Has 7 Tasks

- Research Management Plan
- Technology Status Assessment
- Construct, Program and Test Custom OTDR
- Select, Install and Test Optical Fibers
- Collect Data Characterizing Right-of-Way Encroachment types
- Develop Techniques to Distinguish Potentially Harmful from Harmless Encroachment
- Demonstrate Sensitivity and Discrimination Capabilities

Task 3. Design and Build Custom OTDR:

- Provide spatial resolution of ~2 meters
- Detect simultaneous events
- Collect time waveform at each event
- Provide time resolution sufficient to discriminate among encroachment signals

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Task 3. Design and Build Custom OTDR:

- Custom OTDR is built and programmed
- Pulse and detector are designed and built

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Task 4. Select, Install and Test Optical Fibers:

- **Test fibers in GTI laboratory and Buried Pipe Facility**
- **Bury optical fibers along operating transmission line.**
- **Trench size to be determined, probably 4 inches wide by less than 18 inches deep by 0.6 miles long**

Task 4. Select, Install and Test Optical Fibers:

- Candidate optical fiber sensors identified and purchased
- Four potential sites identified in southern Chicago area

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Task 5. Collect Data Characterizing Right-of-Way Encroachment Types

- **Potential hazardous: trencher, moling equipment, & farm tractor**
- **Benign: mowing equipment, motorcycle, ATV, thunder, airplanes, highway traffic, & pedestrians**
- **Repeat 1 and 2 seasonally (frozen, wet, dry conditions)**

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Task 6. Develop Techniques to Distinguish Potentially Harmful from Harmless Encroachment

- **Approach assumes each “encroachment” has unique signals that can be discriminated**
- **Use spatial extent and signal amplitude as a function of frequency and time as discriminaters**
- **Encroachment will be characterized by rapidly changing signals compared to slow environmental changes**
- **Develop, test, and improve signal discrimination techniques**

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Task 7. Demonstrate Sensitivity and Discrimination Capabilities

- **Demonstrate technology to DOE NETL and gas industry representatives at the end of 24 months.**

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Summary

- Prevention of 3rd-party damage is a major gas industry concern
- A minimum of false positives is critical for industry acceptance
- An optical fiber sensor & OTDR is a promising method of detecting unauthorized construction equipment pipeline in right-of-ways BEFORE the pipe is hit
- OTDR technique can discriminate simultaneously occurring events
- A custom OTDR is needed to detect and discriminate encroachment
- Must collect data fast enough to characterize signals

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