# Acoustic Leak Detection

Gander Newfoundland 2006

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# Overview

- Background on Leakage and leak Detection
- Water Loss Management
- Fundamentals of Correlation

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# Leakage

- The unintentional escape or loss of water from a distribution network.
- Can range from a drip to a major gusher from a burst pipe.
- Main failure due to water loss from improperly sealed joints, defective service connections & corrosion holes.
- Water is a scarce resource- in some countries water is more expensive than petrol so leaks are unacceptable.
- A pin-sized hole in a water pipe under 40 p.s.i. loses over 2,000 gallons of water a day or as much water in a week as what’s normally used in a household of four.

# Causes of Leaks

- Water corrosivity
- Third party digging
- Ground heave & slip
- Thermal changes
- Earth loading
- Ground support: pipe spans
- AC corrosion from power lines
- DC corrosion from trams & utilities
- Age & neglect
- Road salts
- Ground corrosivity
- Microbially induced corrosion
- Traffic loading

# Leakage Problem

- The severity of leakage problems varies across the globe, but it is significant in all parts of the world.
- In the UK, it's legislated that a certain percentage of distribution mains must be surveyed for leaks each year.
- A pin-sized hole in a water pipe under 40 p.s.i. loses over 2,000 gallons of water a day or as much water in a week as what's normally used in a household of four.
- One estimate states that as much as 40% of the water supply is lost as a result of pipe leakage in African cities.

*Managing Water. Fatemah Farag, Al-Ahram, Egypt, December 16, 1999. http://www.dams.org/news_events/media.php?article=212*

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# Does Leakage Matter

- Water Utilities are the largest user of electricity in the US, consuming an estimated 75 Billion kW-h annually (3% of total) Von Sacken, 2001
- 5-10 billion of electricity expended on pumping water for leaks
- Leaks can cause damage to infrastructure
- Leakage water often finds it's way to sewage systems, where it is treated…an additional cost (Thornton et al 2002)
- Leakage requires larger infrastructure than necessary
- Watersheds are taxed unnecessarily

# Water Leakage Rates at 60 psi

| HOLE SIZE [MM] | LEAKAGE [LITRES/MIN] | LEAKAGE [LITRES/HR] |
|---|---|---|
| 0.50 | 0.50 | 30.00 |
| 1.00 | 0.97 | 58.20 |
| 1.50 | 1.82 | 109.20 |
| 2.00 | 3.16 | 189.60 |
| 2.50 | 5.09 | 305.40 |
| 3.00 | 8.15 | 489.00 |
| 3.50 | 11.30 | 678.00 |
| 4.00 | 14.80 | 888.00 |
| 4.50 | 18.20 | 1,092.00 |
| 5.00 | 22.30 | 1,338.00 |
| 5.50 | 26.00 | 1,560.00 |
| 6.00 | 30.00 | 1,800.00 |
| 6.50 | 34.00 | 2,040.00 |
| 7.00 | 39.30 | 2,358.00 |

**PERCENTAGE ADJUSTMENT FOR PRESSURES OTHER THAN 5 BAR**

| | |
|---|---|
| 1 BAR | 45% |
| 2 BAR | 63% |
| 3 BAR | 77% |
| 4 BAR | 89% |
| 5 BAR | 100% |
| 6 BAR | 110% |
| 7 BAR | 119% |
| 8 BAR | 127% |
| 9 BAR | 134% |
| 10 BAR | 141% |

# Pipe Leakage Evaluation

- Identify & locate high leakage areas.
- Prioritize areas for leak detection based upon data from routine network maintenance.

  Methods used:

  - Burst & leak history
  - Water Audits (unaccounted for water consumption)
  - DMA/Flow measurement (flow into less flow out of network)
  - Hydrostatic testing (pressure testing)
- Repair leaks.
- First need to know the leakage situation

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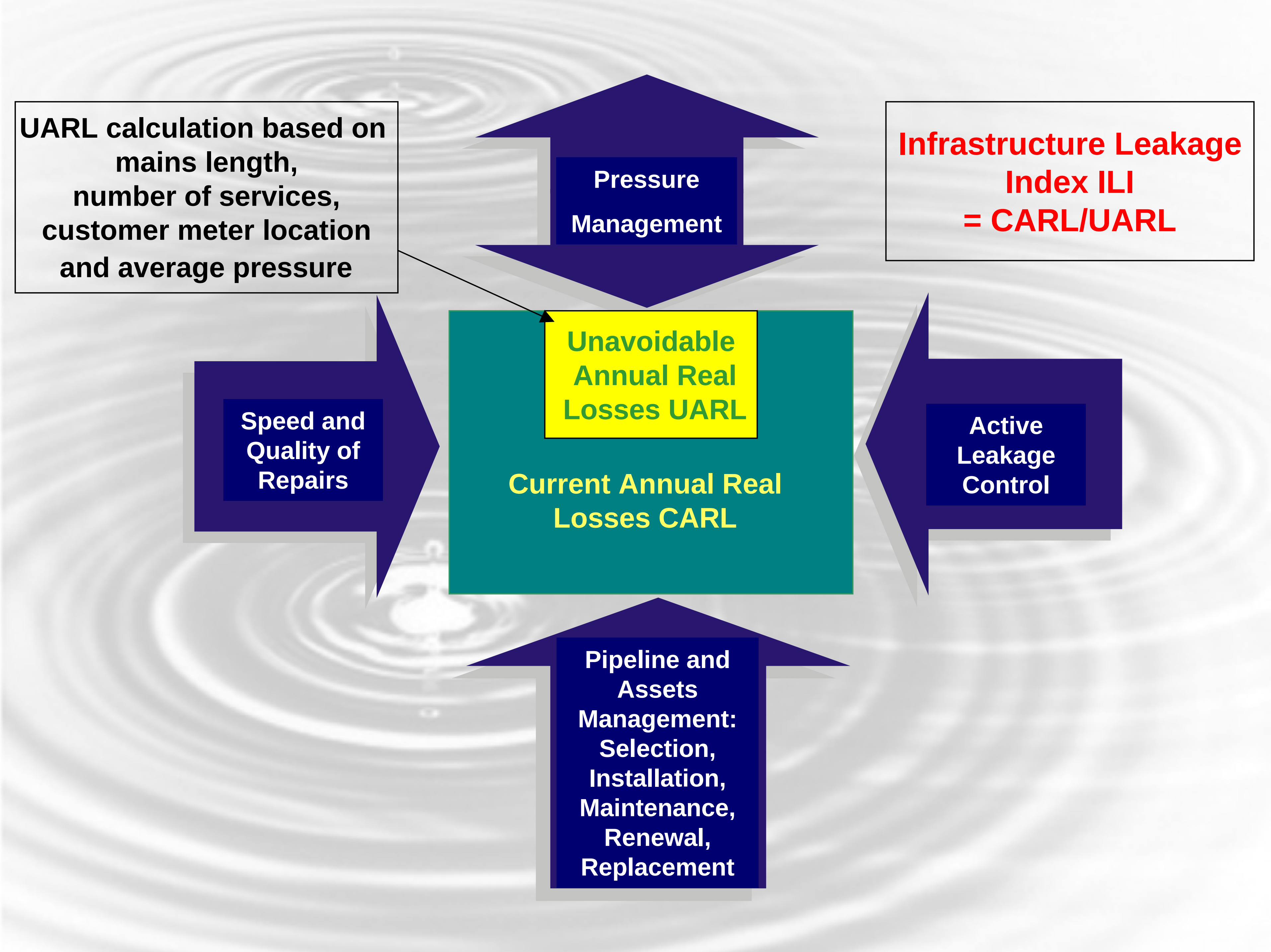
# Components and Definitions

| Water Balance Component | Definition |
|---|---|
| System Input Volume | The annual volume input to the water supply system |
| Authorized Consumption | The annual volume of metered and/or unmetered water taken by registered customers, the water supplier and others who are authorized to do so |
| Water Losses | The difference between System Input Volume and Authorized Consumption, consisting of Apparent Losses plus Real Losses |
| Apparent Losses | Unauthorized Consumption, all types of metering inaccuracies and data handling errors |
| Real Losses | The annual volumes lost through all types of leaks, breaks and overflows on mains, service reservoirs and service connections, up to the point of customer metering. |
| Revenue Water | Those components of System Input Volume which are billed and produce revenue |
| Non-Revenue Water (NRW) | The difference between System Input Volume and Billed Authorized Consumption |

# AWWA – IWA Water Balance Sheet

<table>
<tr><td rowspan="9">System Input Volume</td><td rowspan="4">Authorized Consumption</td><td rowspan="2">Billed Authorized Consumption</td><td>Billed Metered Consumption</td><td rowspan="2">Revenue Water</td></tr>
<tr><td>Billed Unmetered Consumption</td></tr>
<tr><td rowspan="2">Unbilled Authorized Consumption</td><td>Unbilled Metered Consumption</td><td rowspan="7">Non Revenue Water</td></tr>
<tr><td>Unbilled Unmetered Consumption</td></tr>
<tr><td rowspan="5">Water Losses</td><td rowspan="2">Apparent Losses</td><td>Unauthorized Consumption</td></tr>
<tr><td>Customer Meter Inaccuracies</td></tr>
<tr><td rowspan="3">Real Losses</td><td>Leakage on Transmission & Distribution Mains</td></tr>
<tr><td>Leakage and Overflows at Reservoirs</td></tr>
<tr><td>Leakage on Service Connections up to metering point</td></tr>
</table>


UARL calculation based on mains length, number of services, customer meter location and average pressure
Pressure Management
Infrastructure Leakage Index ILI = CARL/UARL
Unavoidable Annual Real Losses UARL
Speed and Quality of Repairs
Current Annual Real Losses CARL
Active Leakage Control
Pipeline and Assets Management: Selection, Installation, Maintenance, Renewal, Replacement

# Unavoidable Annual Real Losses (UARL)

- UARL (gallons/day) = (5.41Lm + 0.15Nc + 7.5Lp) x P where
- Lm = length of water mains, miles
- Nc = number of service connections
- Lp = total length of private pipe, miles = Nc x average distance from curbstop to customer meter
- P = average pressure in the system, psi

# Infrastructure Leakage Index (ILI)

- Ratio of Current Annual Real Losses (CARL) to Unavoidable Annual Real Losses (UARL); good for operational benchmarking for real loss control.

# Water Loss Methodologies

- Pressure Control
- District Meter Areas (DMA’s)
- Leak Noise Surveys
- Leak Correlation Survey’s
- Noise Logger Survey’s

# Locating Leaks & Breaks

- **Methods used are**:
  - Acoustic
  - Acoustic with Correlation
  - Infrared Thermography
  - Chemical
  - Mechanical
  - Ground Penetrating Radar
- Acoustic & acoustic with correlation are by far the most popular methods.

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# Limitations of Leak Detection Methods

| Method | Application | Limitations |
| --- | --- | --- |
| **Acoustic** | Listen for audible sound with listening sticks or ground microphone | •Must to be over or on pipe.<br>•Ground dampening.<br>•Experienced operators.<br>•Background noises.<br>•Have to be close to leak.<br>•Plastic pipes a problem.<br>•Accuracy. |
| **Acoustic with Correlation** | 2 sensors strategically placed on opposite sides of the leak input sound spectrum to a computer.<br>Correlation program uses delay in sound spectrum to pinpoint leak location. | •Can be expensive.<br>•Contact location required.<br>•Quiet leaks difficult to correlate<br>•Poor performance on PVC/large diameter |

# Limitations 2

| | | |
|---|---|---|
| **Infrared Thermography** | Infrared radiation detector locates temperature differences caused by leaking water. | •Expensive.<br>•Significant operator training & experience.<br>•Accuracy<br>•Weather limitations. |
| **Chemical** | A tracer in the pipe escapes through the leak & is detected at the surface. | •Expensive & time consuming.<br>•Exact pipe location.<br>•Depth limitation.<br>• Accuracy. |
| **Mechanical**<br><br>**Ground Penetrating Radar** | Drilling holes or opening up pipe<br><br>Radar generates an image based on the reflection of radar waves from changing densities of soil/pipe | •Expensive & time consuming.<br>•Damage to other utilities.<br><br>•Hard to interpret |

# Acoustic Survey

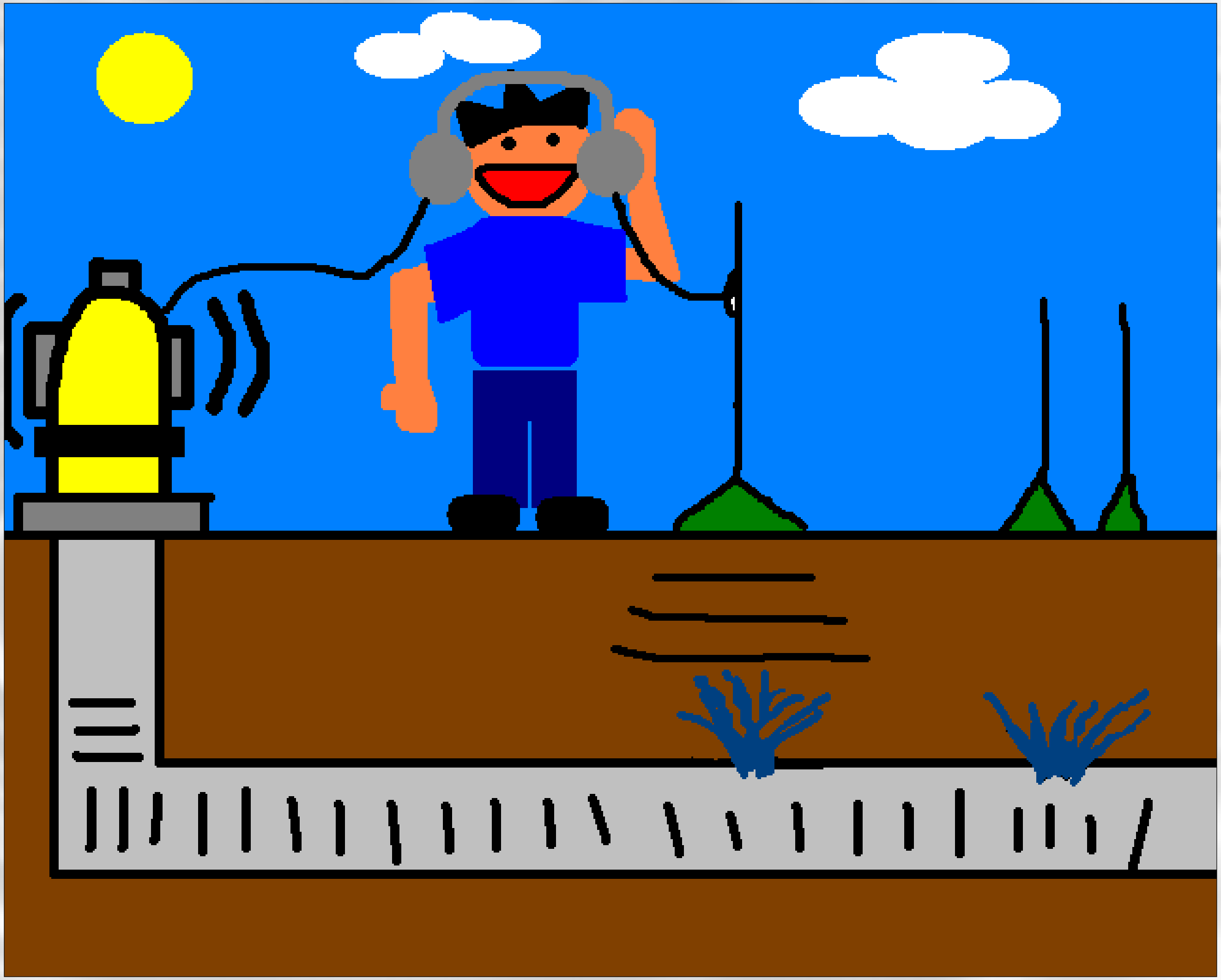
**Advantages:**

- Fast, a large area may be covered quickly
- A skilled listener can hear most leaks

**Drawbacks:**

- Listening requires some skill
- Quiet leaks may not be heard
- Will not work on PVC if you are not close to leak or if there have been PVC repairs
- Frozen Ground is a problem for surface based survey

# Acoustic Survey



# Correlation Survey

**Advantages:**

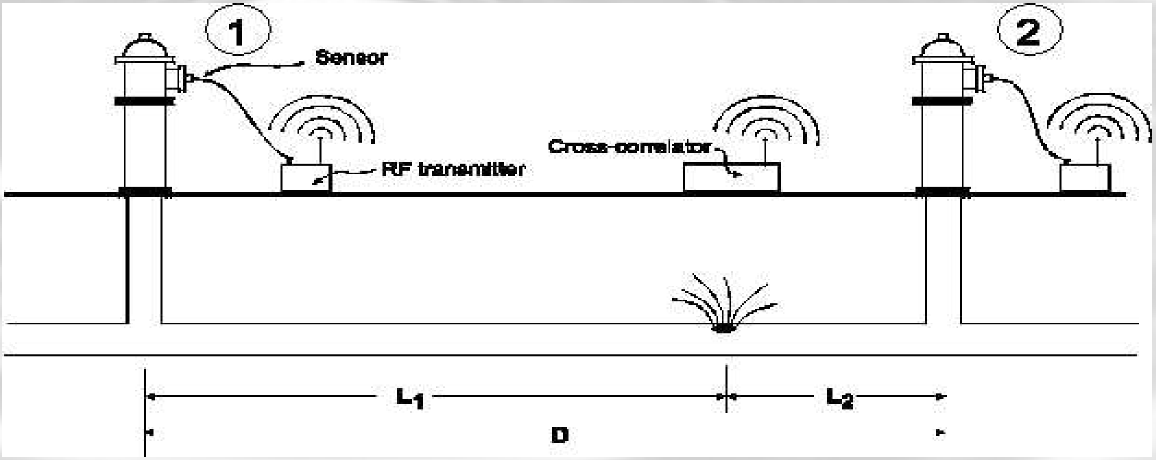
- Can find leaks their listeners can't
- Less dependant on listener's skills
- More accurate method of locating leaks
- Easy to use
- Finds leaks in all types of distribution pipes

**Drawbacks:**

- Slower than acoustical survey
- Some areas may be difficult to correlate
- Can't correlate hydrant leaks for dry barrel hydrants

# Correlation Background

- How it works
- Bracket the leak with two sensors
- The leak noise takes longer to arrive a point 1 than point 2
- Correlator measures this difference and determines the exact leak location: d=vt where v is the acoustic wave velocity

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# Correlation Background 2

- Leaks makes noise
- Travels as a ‘coupled wave’
  - Fancy way of saying it travels in both the water and the pipe
  - Compression in water, dilatational in pipe
- Correlation is passive, we are not sending any signal into the pipe, only listening to the sound of the leak

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# Transducers

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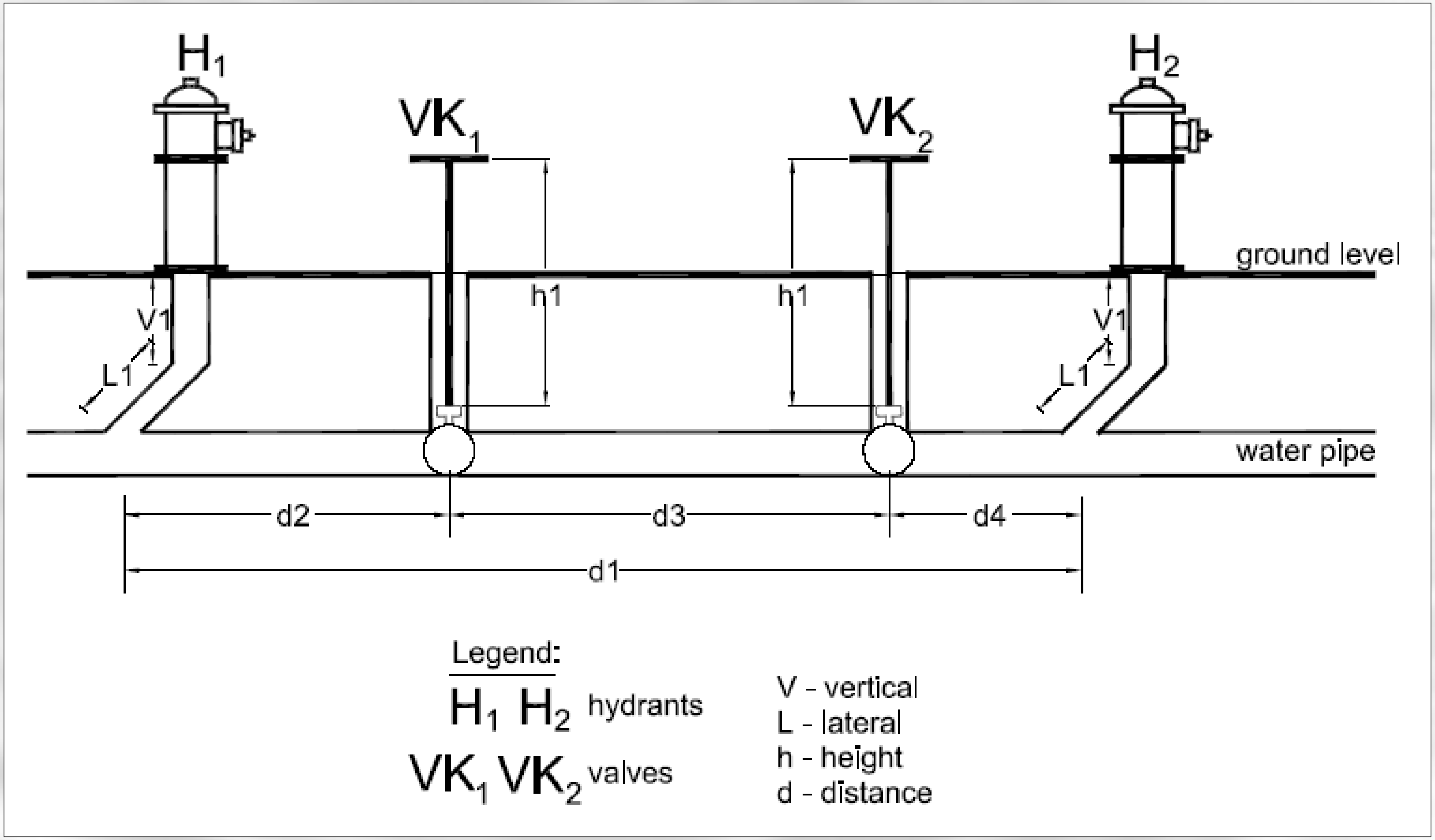
# Distance Measurement

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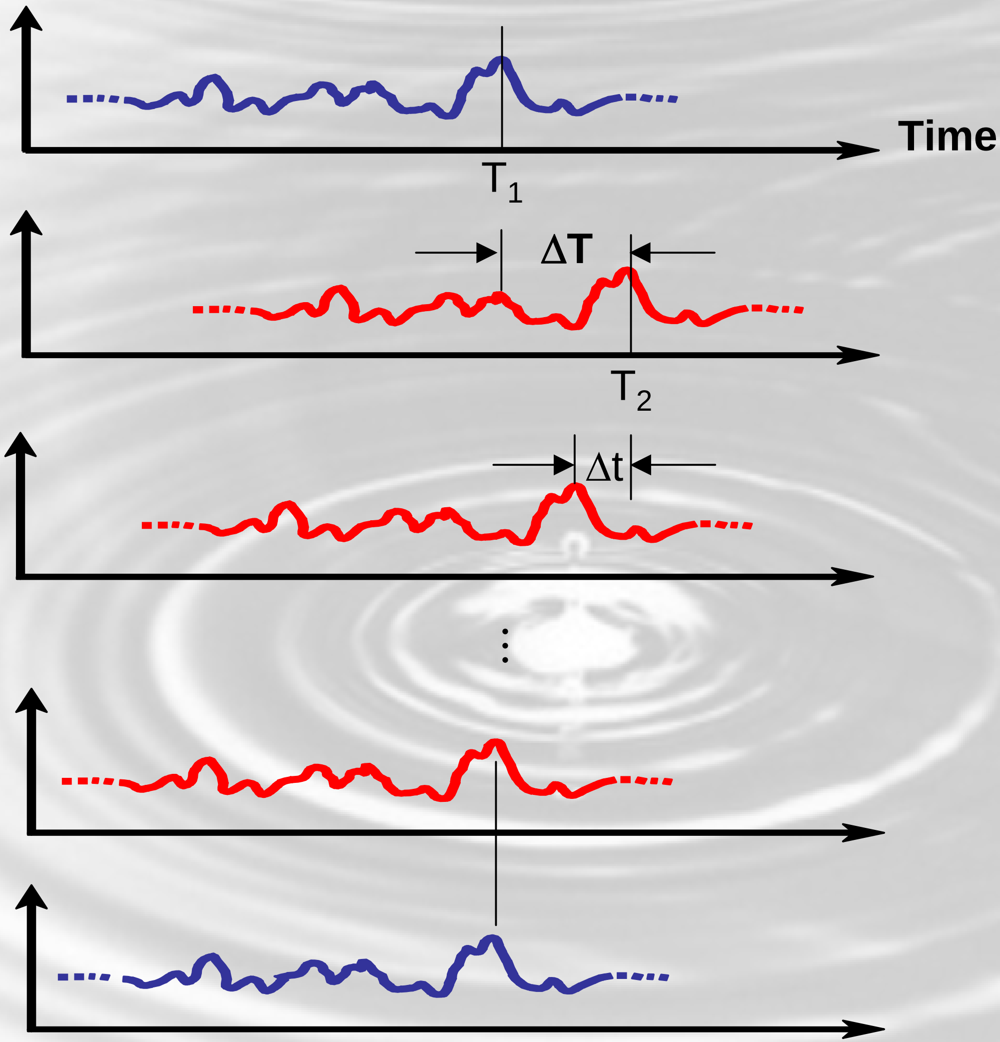
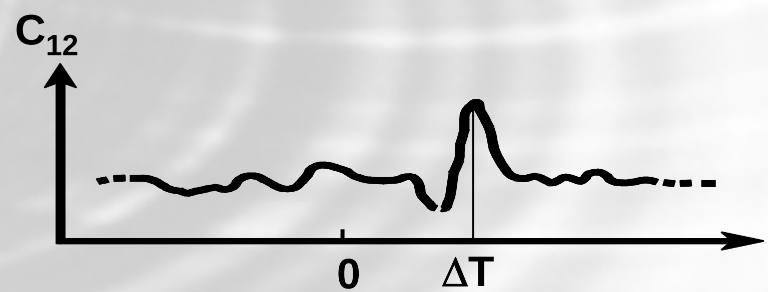
# Advanced Correlation

Two signals are time shifted and added together: When the time shift is correct the correlator shows a peak




$$C_{12}(\tau) = \lim_{T \to \infty} \frac{1}{T} \int_0^T x_1(t) x_2(t+\tau) dt$$



# Advanced Correlation 2

- From the previous figure, the correlation is dependant on the similarity of the two signals to get a good ‘sharp’ correlation peak
- Sometimes peaks are not so sharp…may be very wide which affects accuracy of the locate
- Why?

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# Advanced Correlation 2

- Signals change as they travel through the pipe, may travel different distances
- Different fittings may have different dynamic response to the leak noise
- This can affect plastic pipes more than metallic

# Advanced Correlation 3

- There is a measure of how similar the two signals are at the two sensors
- This is called ‘Coherence’
- Coherence is a measure of the similarity of the two signals
- When two signals are identical coherence is 1

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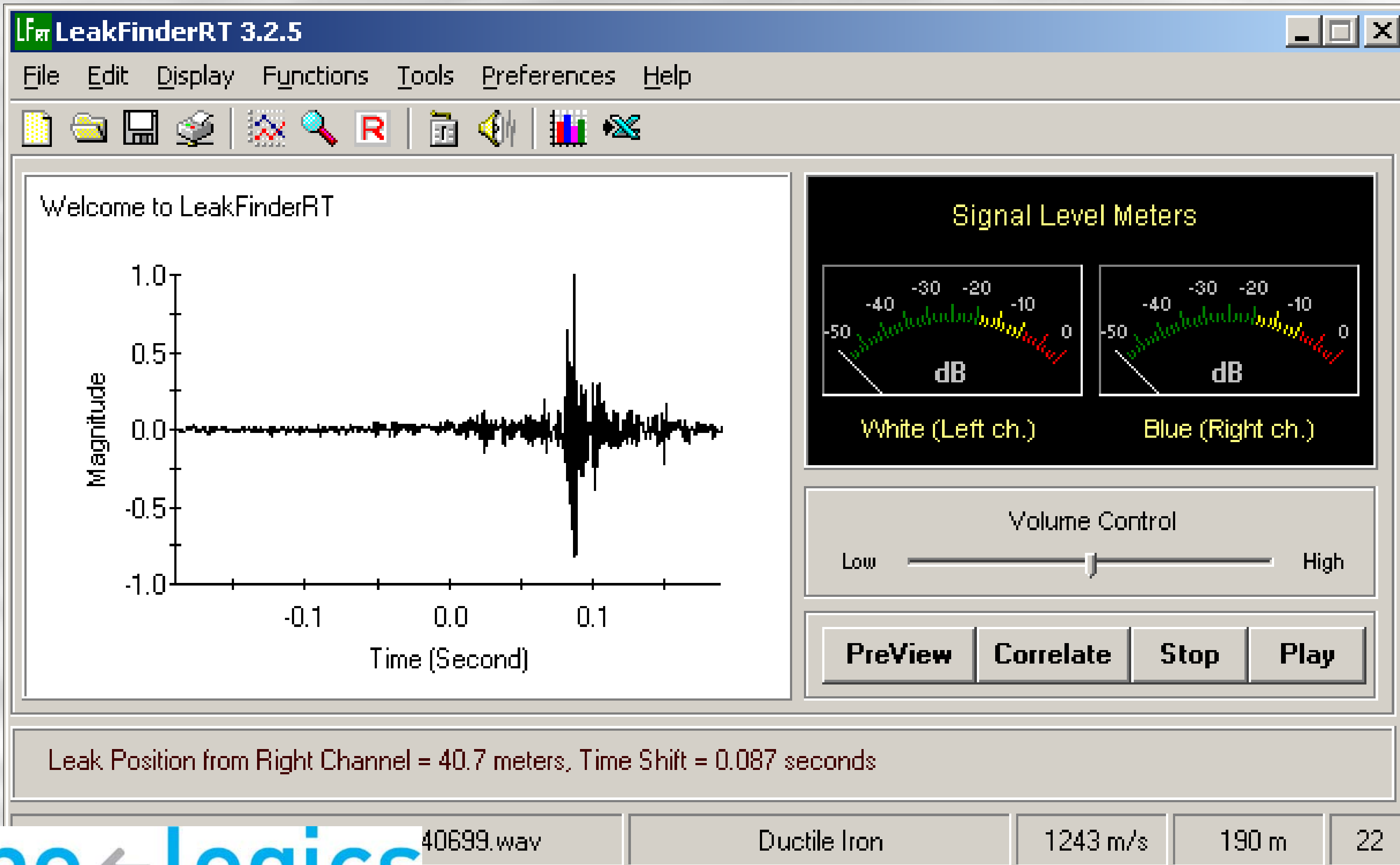
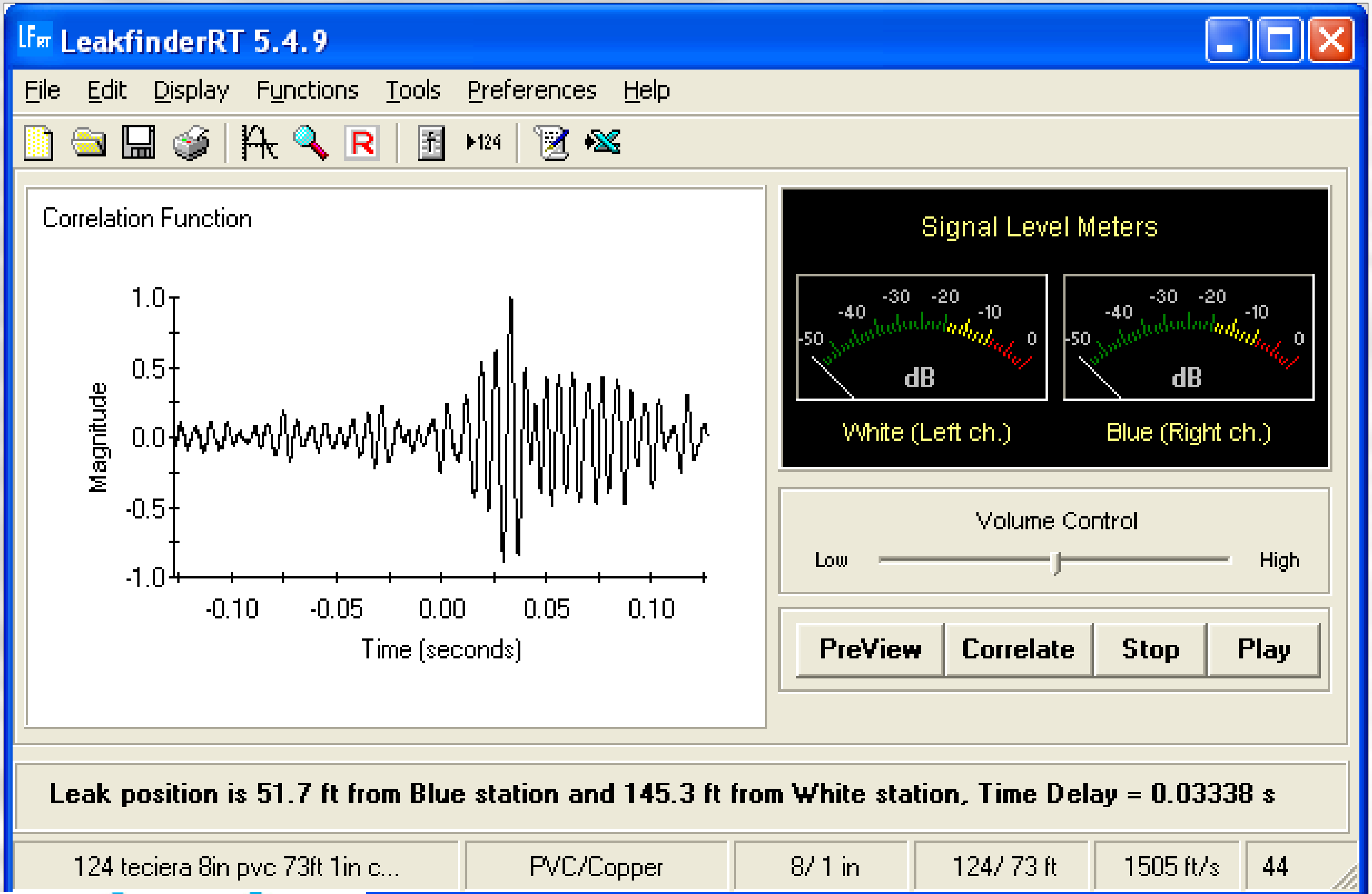
# ‘Normal’ Correlation



# Wide Correlation



# Physics of PVC and Large Diameter Pressure Waves

- Need to understand the wave mode: Water Hammer
- Advantage of PVC is that it damps water hammer: Not Good
- Coupled mode: Compression wave in water, circumferential mode in pipe
- Frequency: As will be seen, very low, in some cases subsonic

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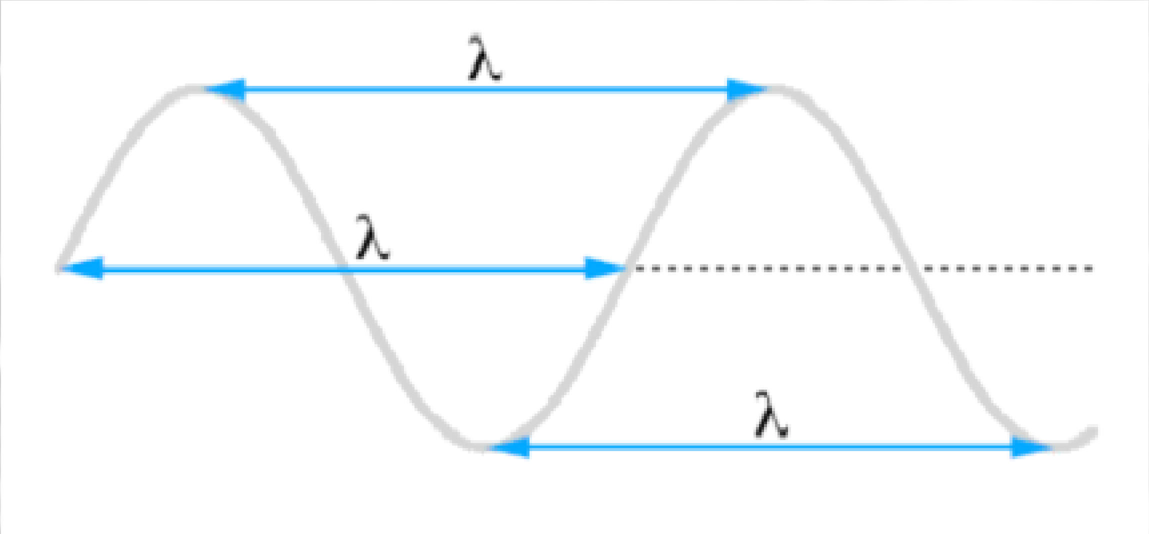
# Wavelength

- Leak Sound in PVC has a very long wavelength

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# Wavelength in 6” PVC

Speed of Sound in Water (10 C): 1447 m/s

$$\lambda = \frac{v}{f}$$

Wavelength in water at 10 C,

$$f = 20Hz$$

$$\lambda = \frac{1447}{20} = 72.4m$$

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# Physics of PVC and Large Diameter Leak Detection

- Need to understand the wave mode: Water Hammer
- Advantage of PVC is that it damps water hammer: Not Good
- Coupled mode: Compression wave in water, circumferential mode in pipe
- Frequency: As will be seen, very low, in some cases subsonic

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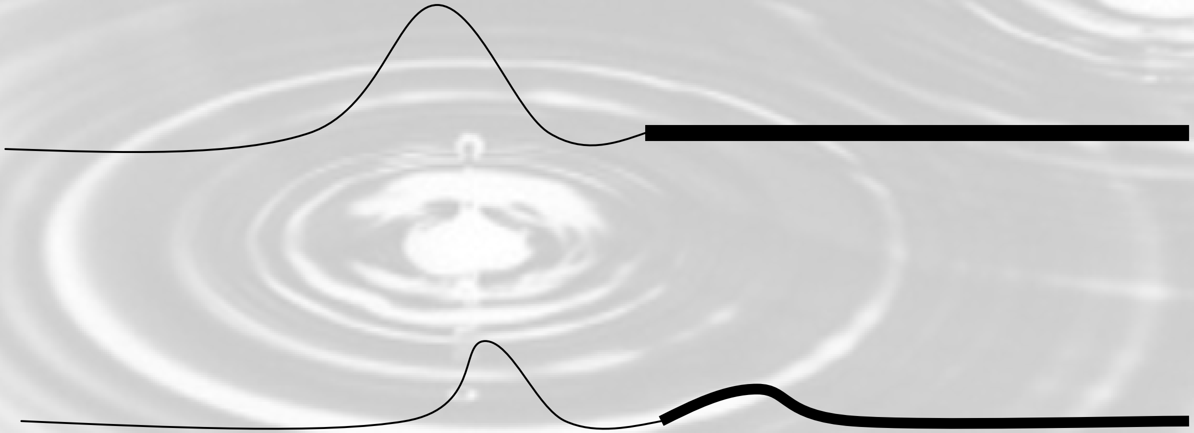
# Impedance

Reflection of Waves (Impedance): The rope analogy



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# Causes of Impedances

- These changes are called impedances in Physics, and can be caused by:
- VALVE KEYS
- 90 degree turns
- Change in diameter
- Change in material

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# Classic Impedance Example

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# Hydrophone Mounting

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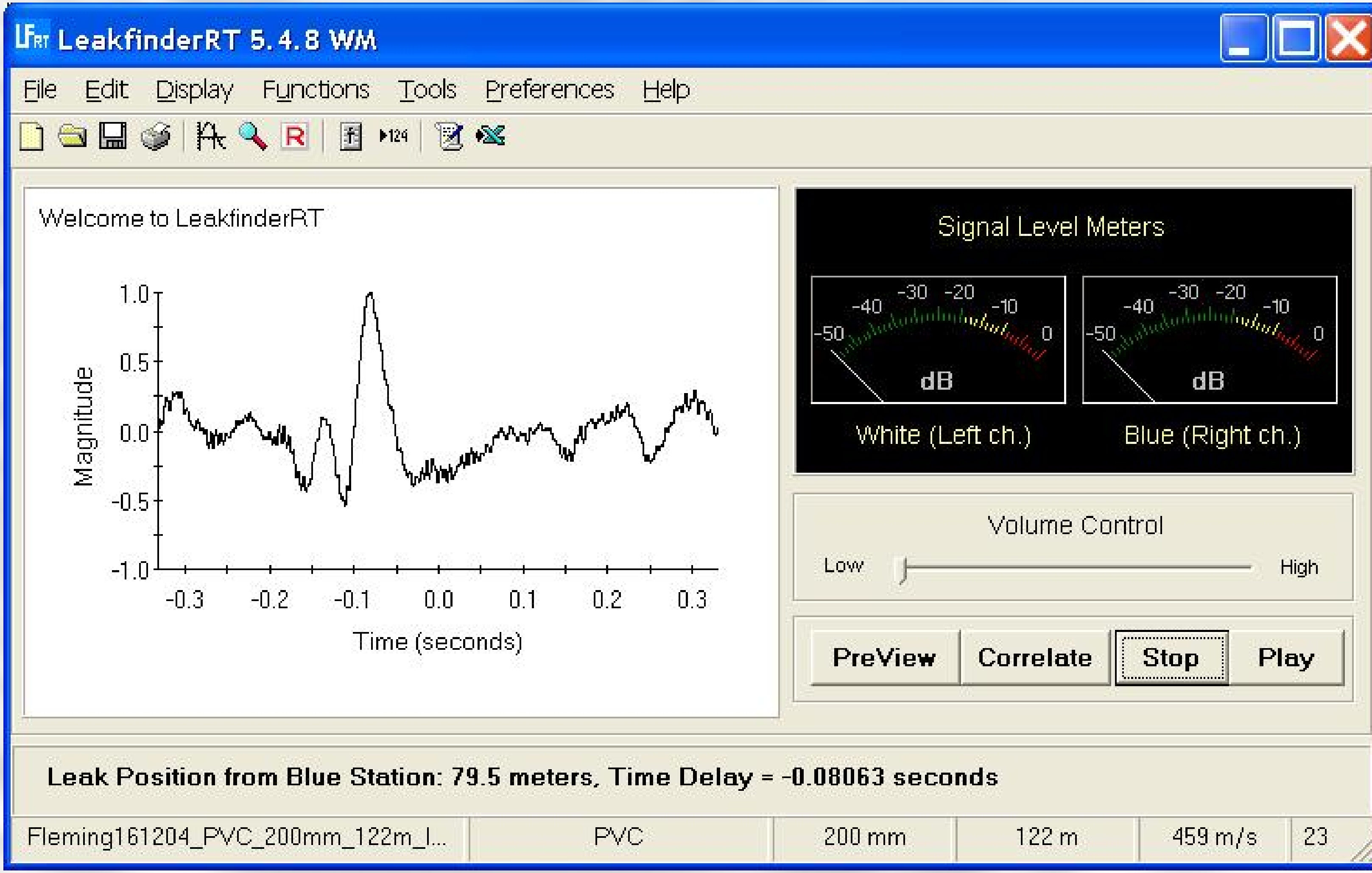
# Case Study 1: 200mm PVC, Leak on Service Saddle; Correlation Function

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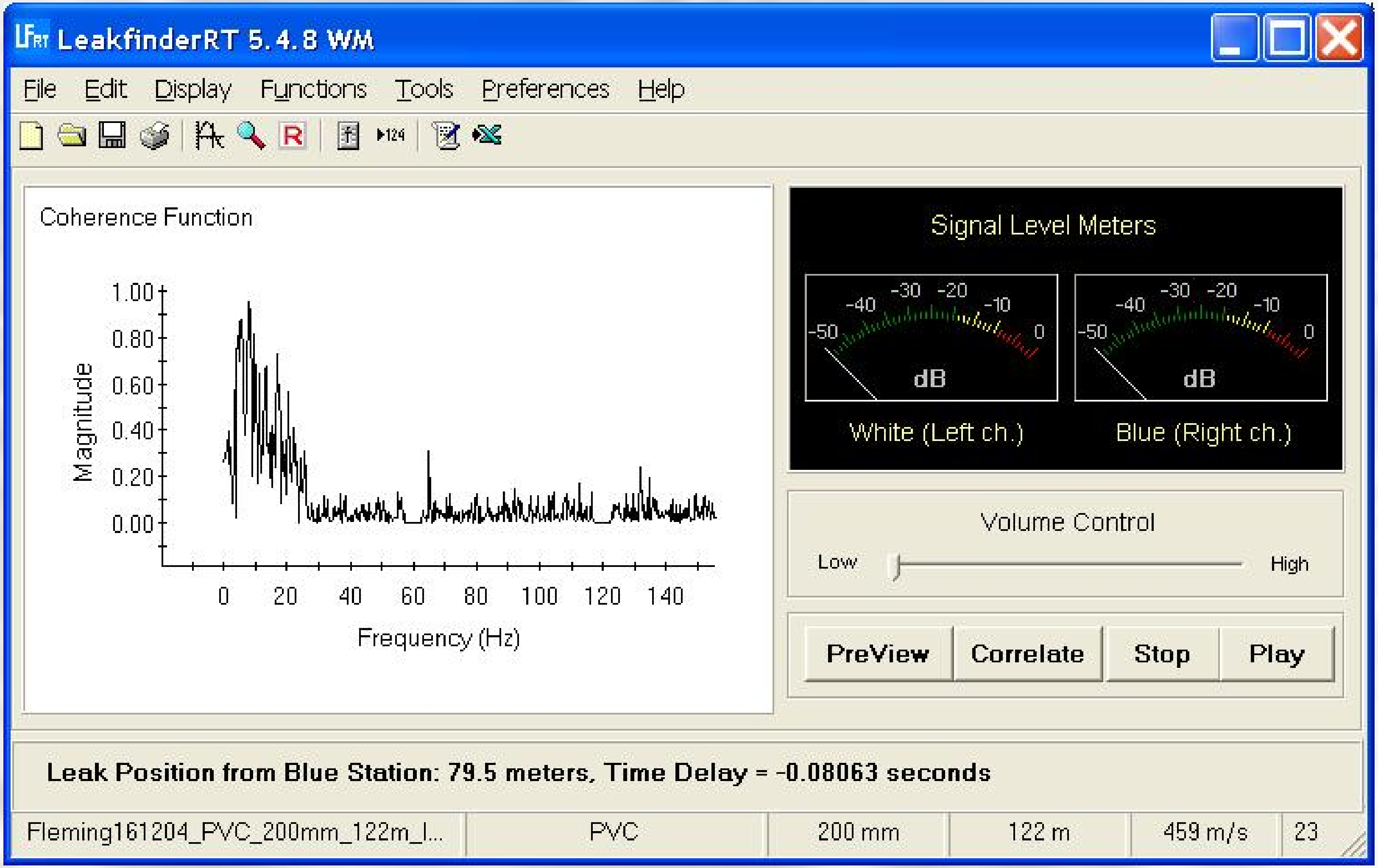
# Case study 1: Coherence Function

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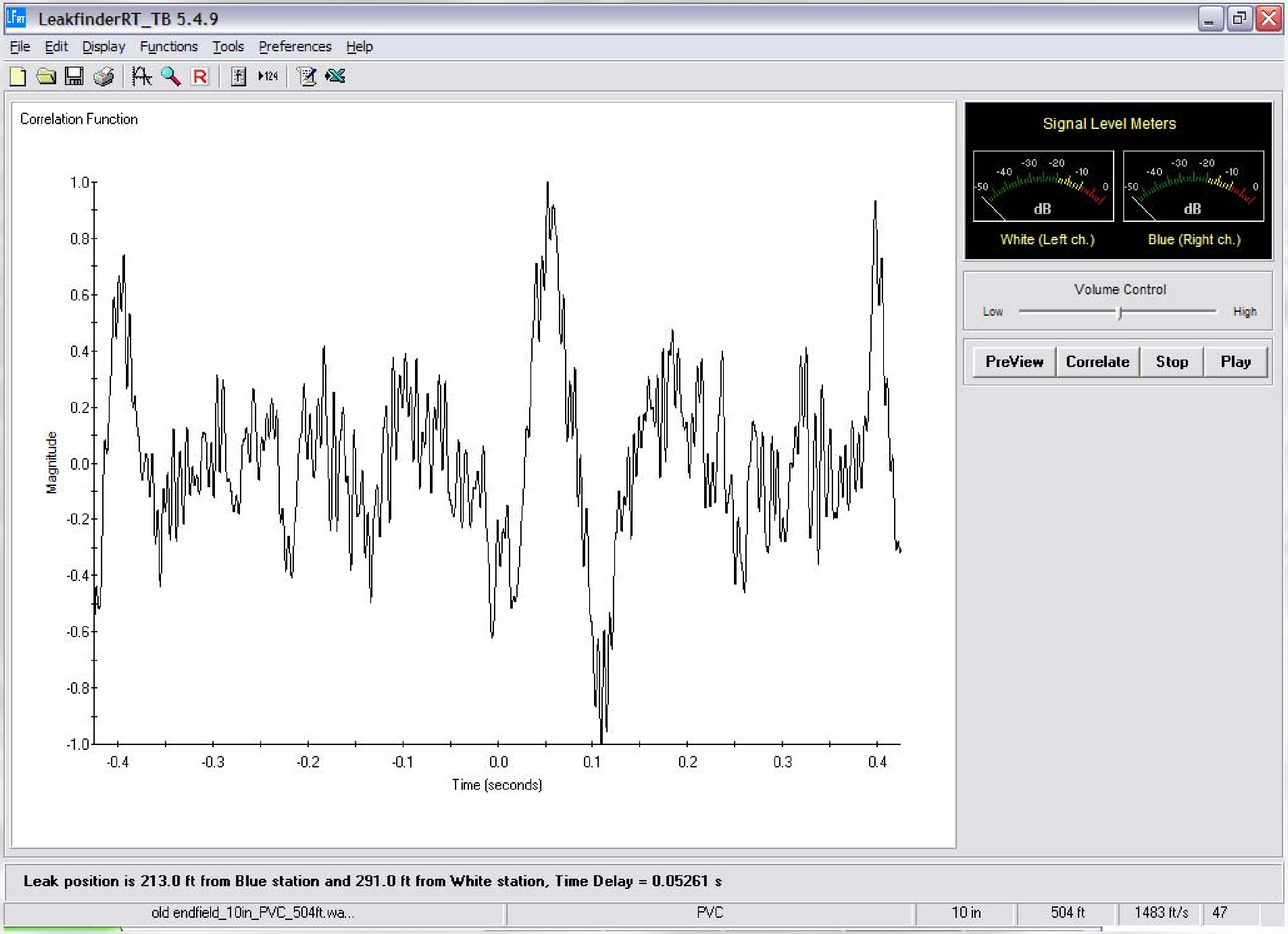
# Case Study 2: 250mm PVC, Abandoned Service

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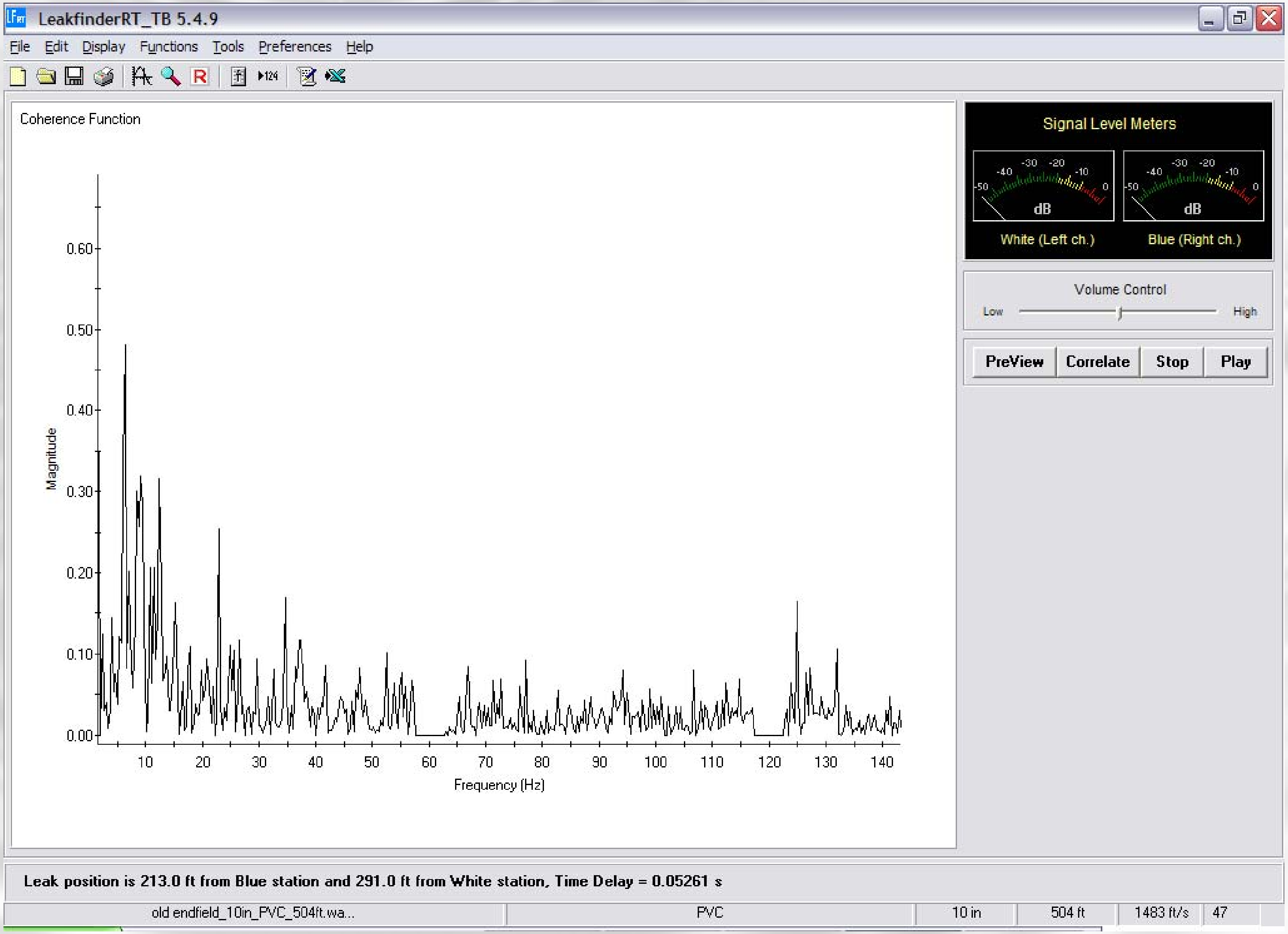
# Case study 2: Coherence

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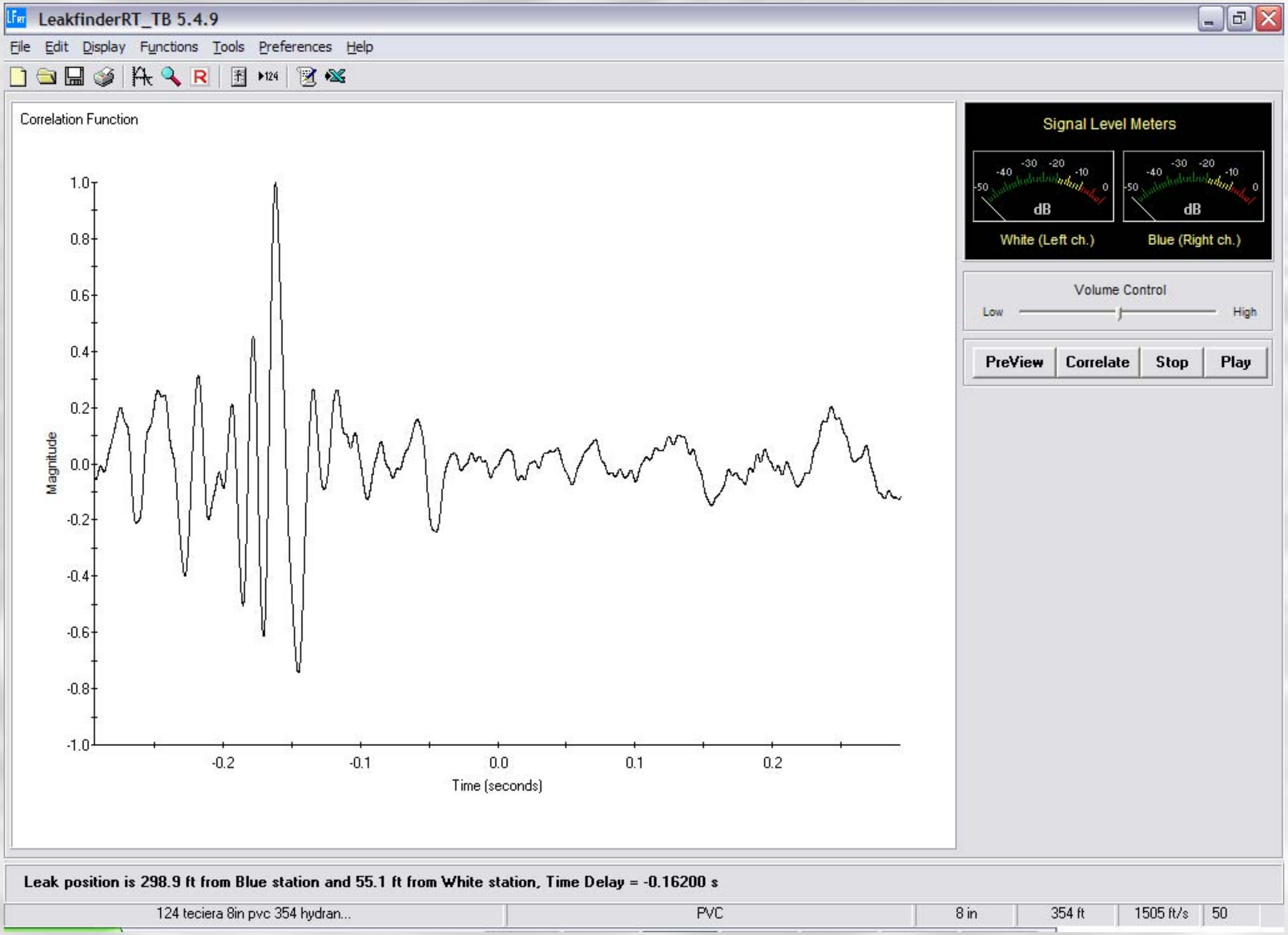
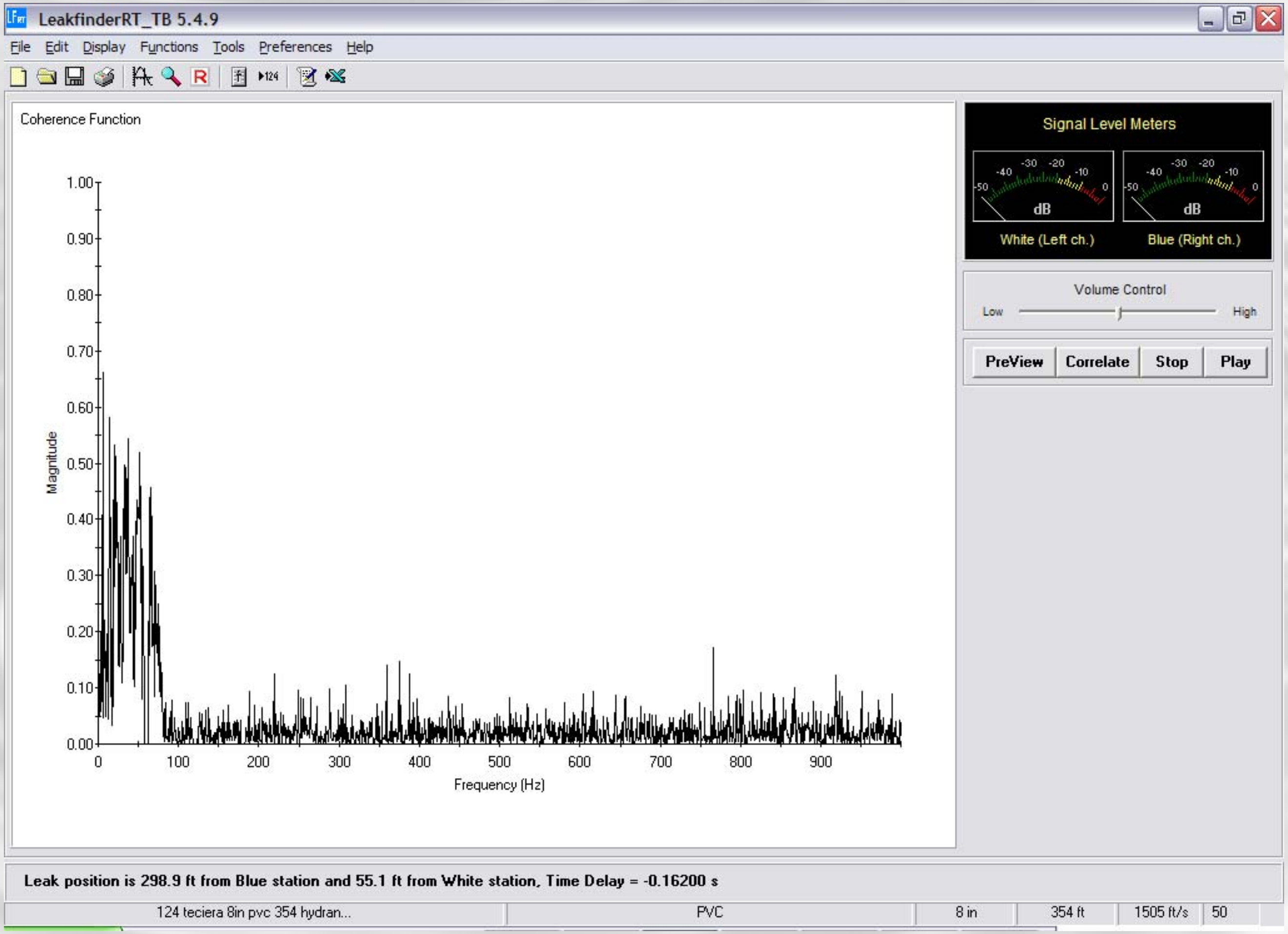
# Case Study 3: 200mm PVC Service Leak



# Case Study 3: Coherence

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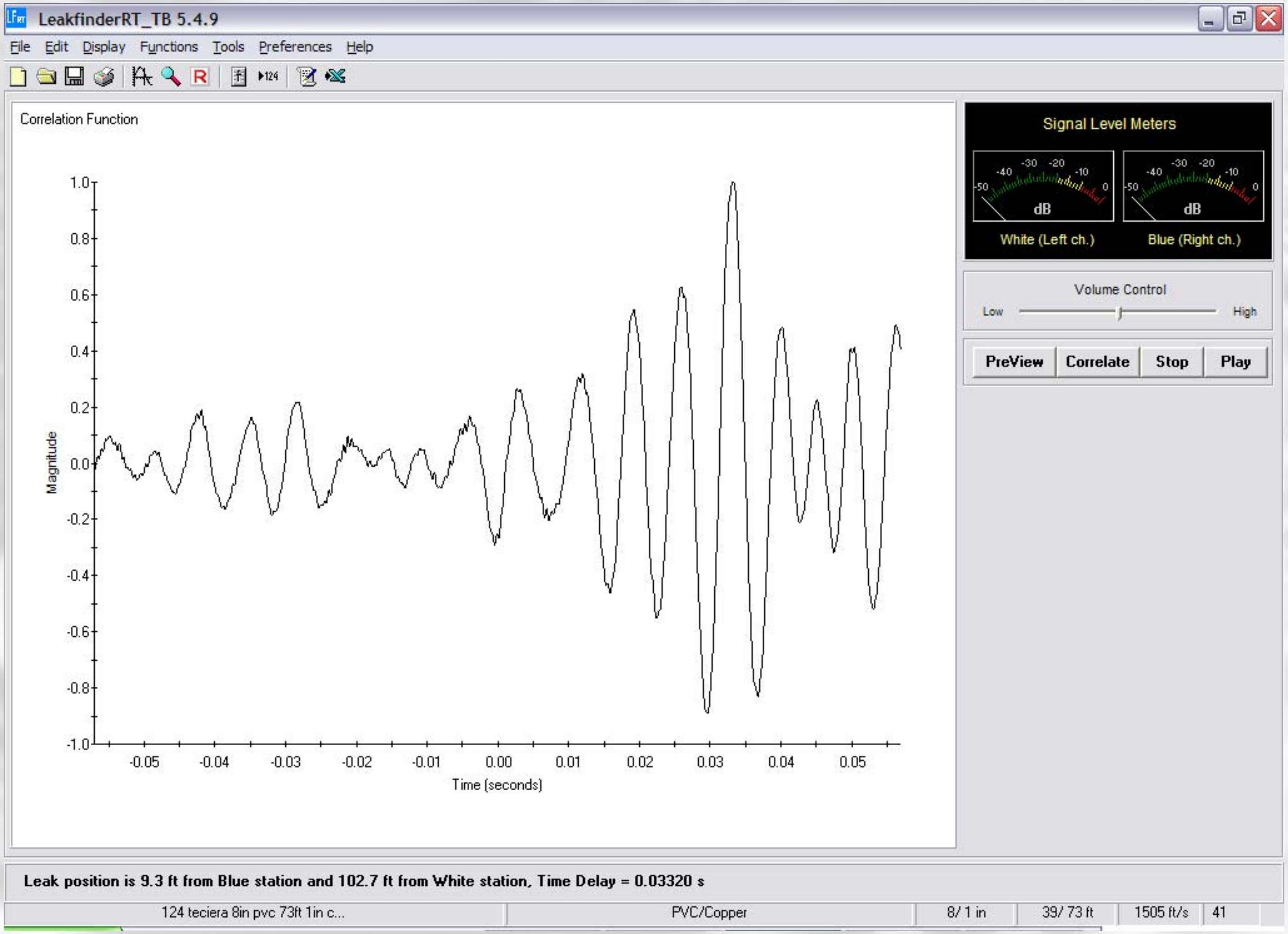
# Case Study 4: Same as 3, service to hydrant

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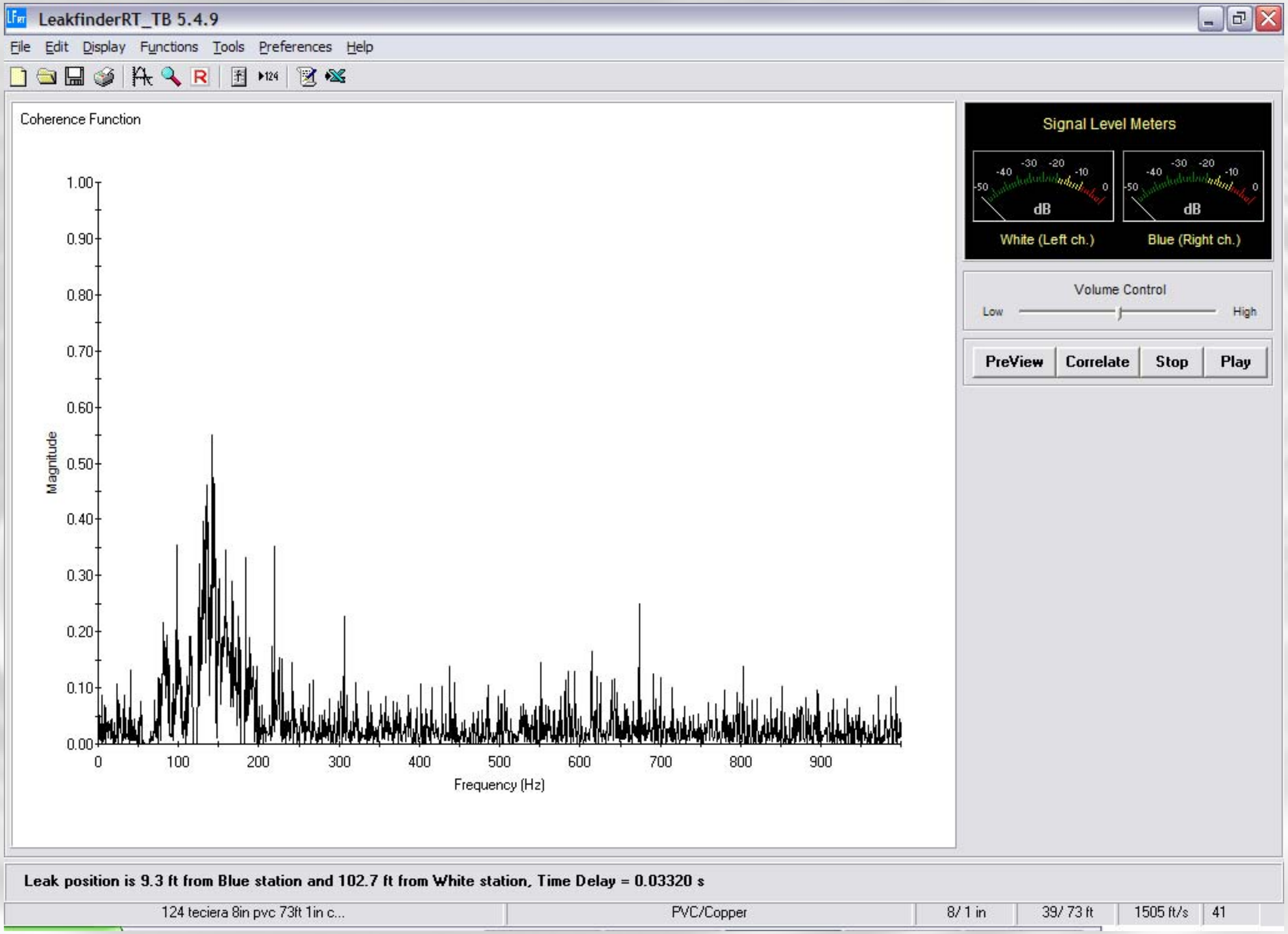
# Case Study 4 Coherence

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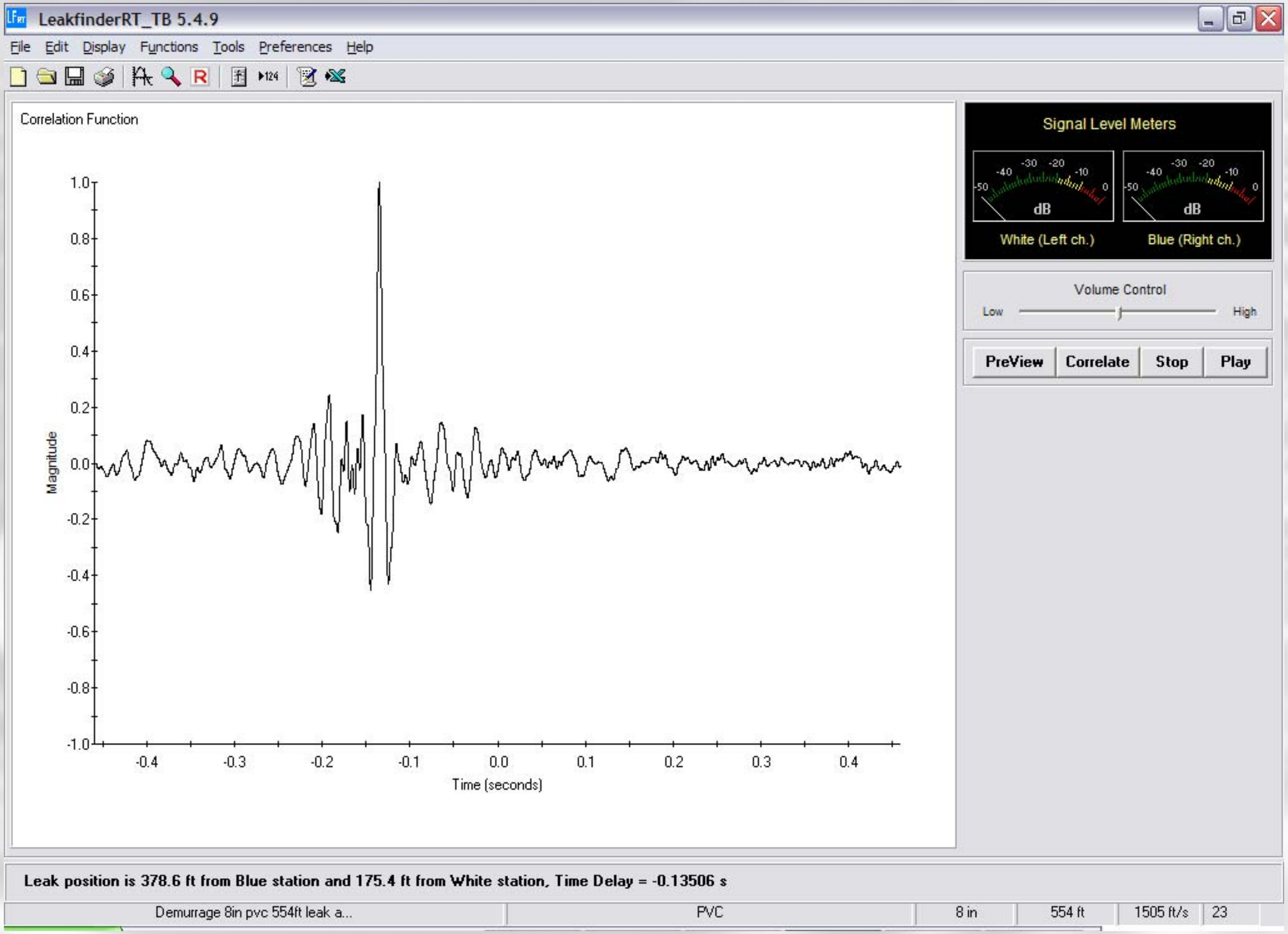
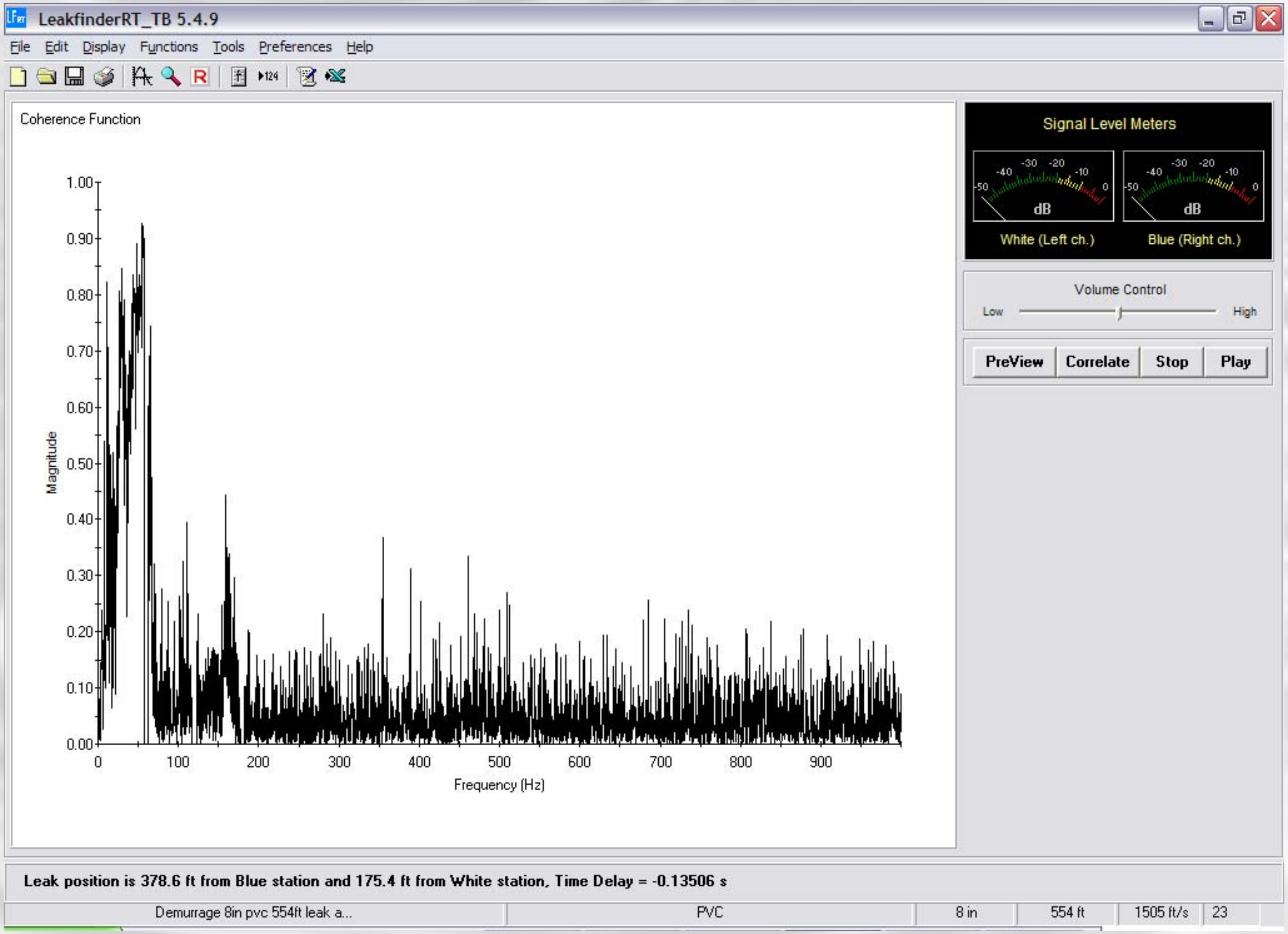
# Case Study 5: 8” PVC Service Leak



# Case Study 5: Coherence

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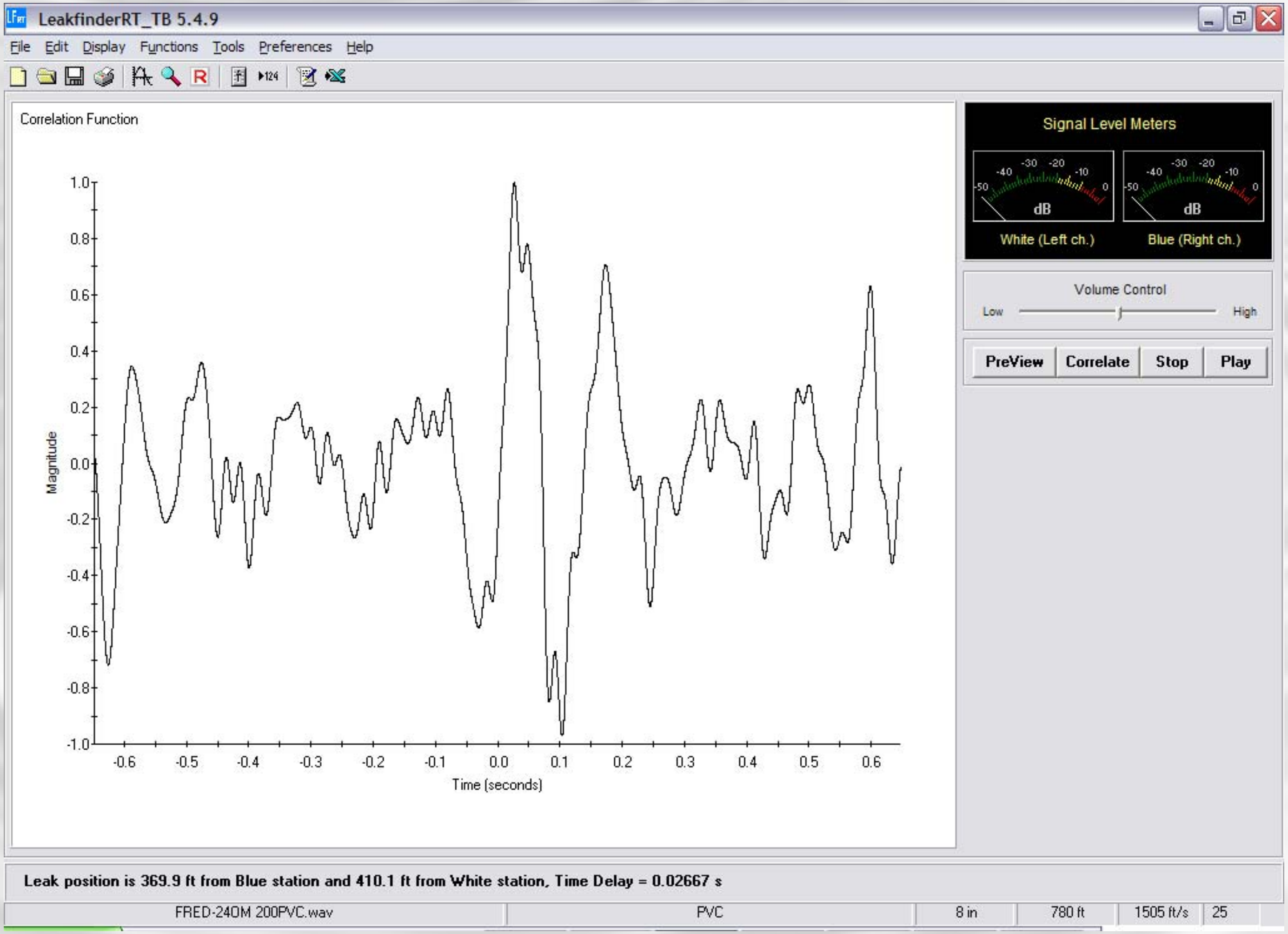
# Case Study 6:

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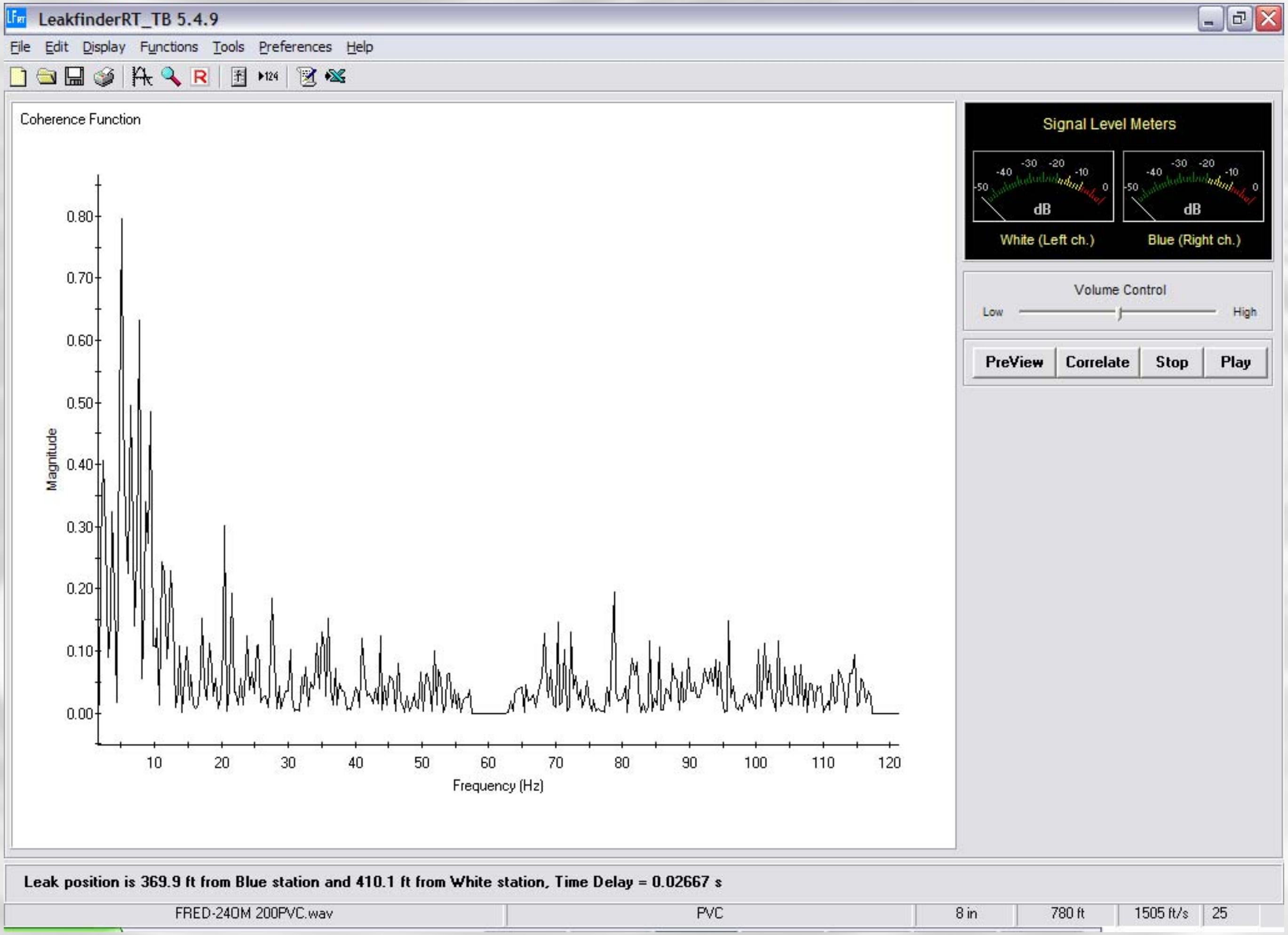
# Case Study 6: Coherence

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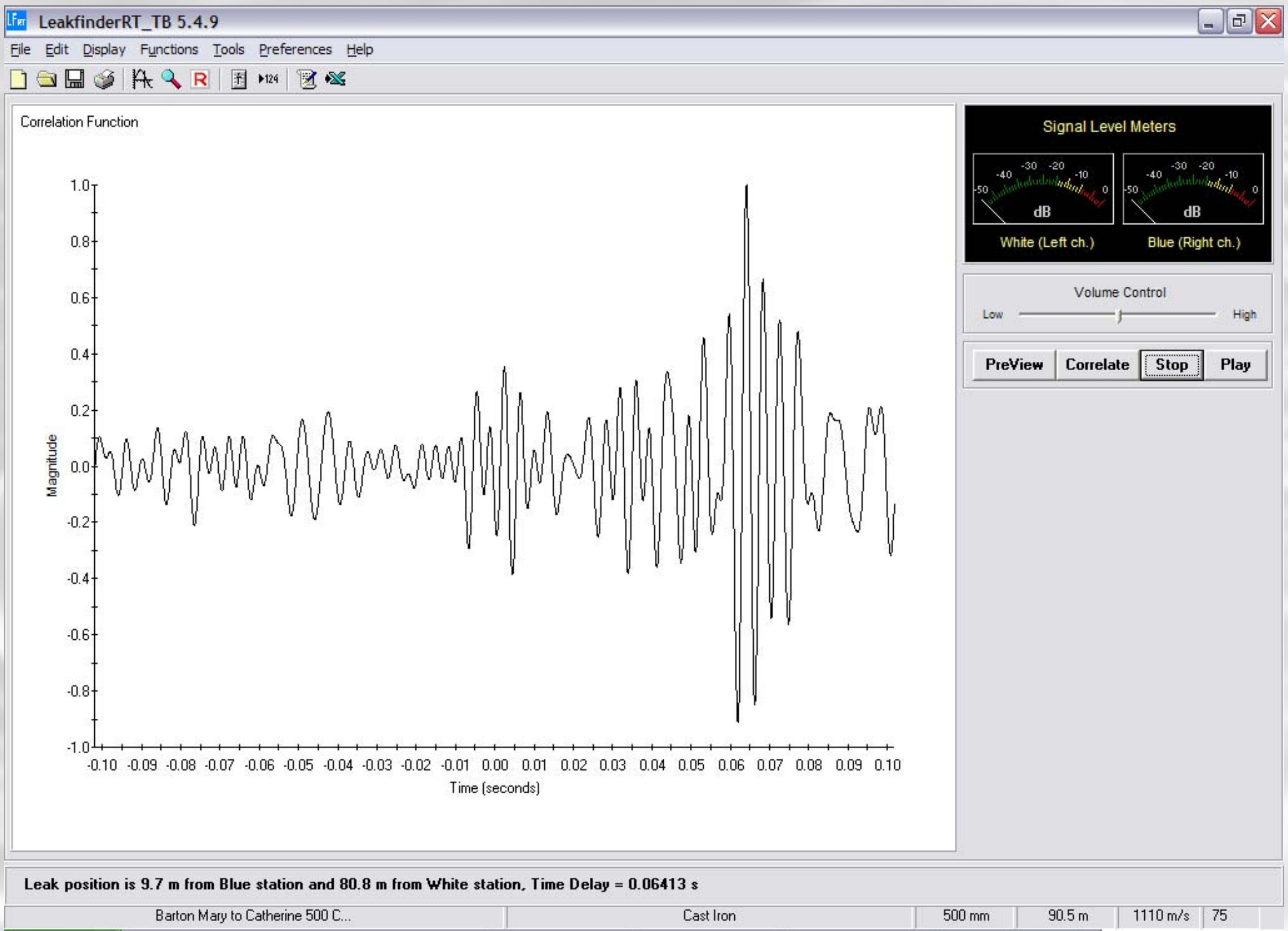
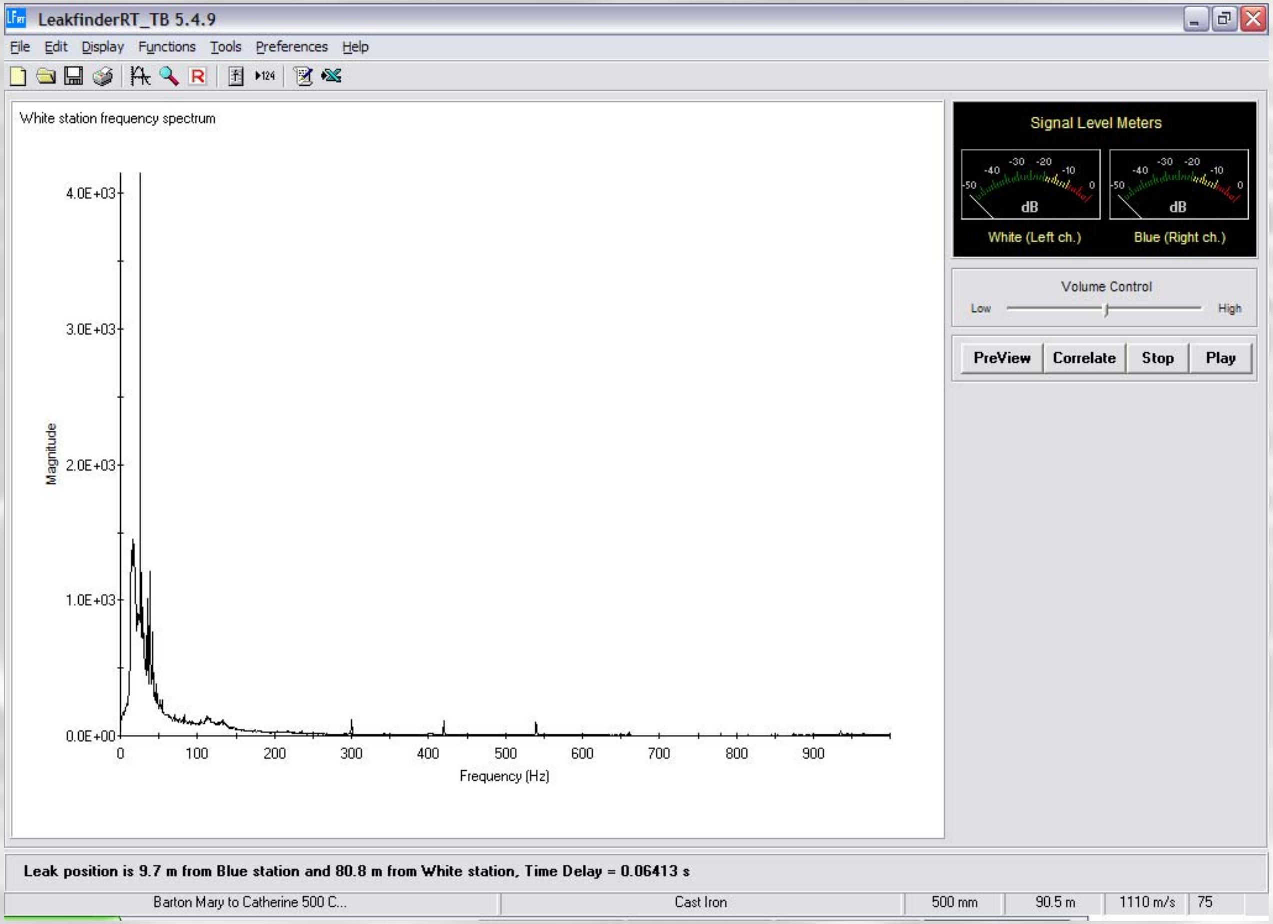
# Case Study 7: 500mm CI



# Case Study 7: Frequency Spectrum

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