DLD

Digital Leak Detector

- Digital Sound Quality
- Sensitive
- Lightweight
- Easy to use

Flow Metrix
Advanced Leak Detection Systems

DLD

Features

Digital Audio Processor

- Dynamic range compression - accentuates leak sounds, reduces loud noises
- Hears leaks where other instruments cannot
- Precise digital filters block ambient noise
- Automatic rejection of electrical interference (60dB)
- Lightweight (< 1 lb.)
- Wearable, strap or belt clip

User Interface Buttons

LISTEN: Click on/off or press-and-hold to listen
VOLUME: 45 dB range in 29 steps
FILTER: Five digital filters for:

- Ground (Gnd): Hard surfaces, soil, plastic pipe
- Service (SEr): Service pipes
- Contact (Con): Valve, hydrant, service connections
- Survey (SUr): Surveying
- Open (OPn): Full listening range

High-Resolution, Waterproof Universal Sensor

- Contact microphone for meters and fittings
- Ground listening plate with quick-release sensor
- Magnetic base for hydrants and valves

Smart Volume Limiting

- Continuous, automatic volume protection
- Suppresses clicks, pops and sudden loud sounds

Automatic Leak Location

- Leak Index Score from 0 to 999 provides a visual determination when you are over the leak

Technical Specifications

Digital Audio Processor Unit:

Frequency range:	30 - 4,000Hz
Power supply:	2 AA alkaline batteries
Battery life:	> 12.5 hours continuous listening
Display:	LCD
Protection:	IP54, weatherproof, splash-proof
Weight:	15 ounces (408.2 grams)
Dimensions:	5" x 3.5" x 1.5" (127mm x 88.9mm x 38.1mm)

Accessories:

Carrying Case:	Rugged, light-weight
Probe:	Stainless steel; connects to sensor

Universal Sensor:

Type:	High-resolution piezo-ceramic
Sensitivity:	20V/*g*
Resolution:	0.05µ*g*/√Hz
Protection:	IP68, waterproof, fully submersible
Shock proof:	6,000*g*

Ground Microphone Unit:

Dimensions:	Height - 34"; Disk - 4.5" diameter (h = 860mm; d = 114mm)
Weight:	2 lbs. (910g) with sensor attached
Materials:	Rod - anodized aluminum Disk - stainless steel

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ZCorr: Multi-Sensor Overnight Leak Survey and Pinpointing In One Step

The ZCorr system is a new, systematic approach to pipeline surveying. ZCorr digital correlating loggers offer significant advantages over listening loggers by detecting and pinpointing multiple leaks in a zone overnight. ZCorr's technical advances make leak surveying viable for water utilities at less effort and cost.

The ZCorr Concept

ZCorr is a software-driven approach that allows a distribution system leak survey to be efficiently directed from the office, integrating leak detection data, maps, and database tools to:

1. Plan the survey and print deployment orders
2. Pinpoint leaks and print repair reports
3. Track survey progress and performance

The ZCorr survey has 3 steps: DEPLOY, RETRIEVE and ANALYZE. Each step can be performed either in the office or in the field.

1. Deploy

Eight ZCorr loggers are held in a compact *Docking Station*, which is connected to a PC. The docking station communicates with the ZCorr logger electronically, without cables.

The PC software user:

- Sets the synchronized recording times (by default, 3 AM, 3:30 AM, and 4 AM)
- Places the loggers on a map image
- Optionally prints a deployment work order

The ZCorr loggers are then deployed in the field in readiness for the nighttime recording.

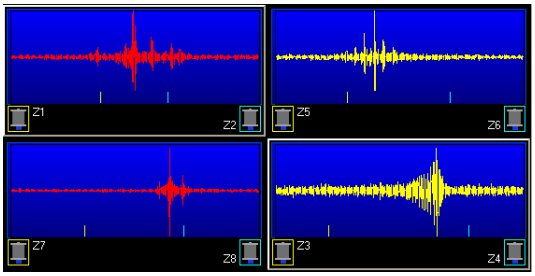
Deployment is typically in underground valve chambers, on fire hydrants, or other pipe fittings.

2. Retrieve

During the night the synchronized ZCorr loggers record at the user-programmed times. Recorded vibration samples are saved in memory. The loggers then enter low-power mode until they are reconnected with the docking station.

3. Analyze

The recorded data is downloaded from the ZCorr loggers, via the docking station, using the PC software. Eight loggers produce 28 distinct pairs for correlation analysis. ZCorr analysis finds all significant leak noise correlations automatically. Results are ranked by *Correlation Score* (0 – 100), scored by the determination of leakage versus usage, correlation signal quality, and the smallest estimated error in pinpointed location of any leak(s).



How ZCorr Loggers Work

The ZCorr system has several patented[1] innovations, described in the next sections, in the areas of synchronization (timing), data recording, processing, and PC software analysis.

[1] U.S. Patent #: 6,567,006

Real-Time Clock

At the heart of the ZCorr logger is an ultra low-power, temperature-compensated Real-Time Clock (RTC). The RTC is used to synchronize ZCorr loggers via the docking station. Over an 18-hour period, between deployment and retrieval for an overnight recording, an ordinary wrist watch would drift in time by up to 50 parts per million (ppm), i.e. about 3 seconds. In a correlation analysis this could lead to errors of 10,000 feet or more in the pinpointed location of a leak. Using a combination of ultra-low power electronic and software techniques, timing drifts are reduced by a factor of 2,500 times. The patented method of timing compensation restricts errors in leak location to typically less than 3 feet.

Recording

The ZCorr logger is fitted with a low-noise piezo-ceramic acceleration sensor, known as an accelerometer. Accelerometers sense vibration and convert it to a tiny electrical charge. Sensitive conditioning electronics amplify and filter this electrical response. As with audio and other amplifiers, the accuracy, precision, and intrinsic noise level of the amplifier is more important to the recording quality than the gain or volume level, *per se*. In an accelerometer, intrinsic noise is often defined by *resolution* and gain is referred to as *sensitivity*. In ZCorr, a sensitivity of 1V/*g* at a resolution of 0.025 µg / √Hz is followed by additional electronic gain.

The earth's gravitational field is defined as having a constant acceleration of 1 *g*. In contrast, leak signals are sensed from pipes as a varying pattern of acceleration as small as micro*g*'s, i.e. millionths of *g*'s. These are imperceptible levels of vibration to humans and require very low-noise, precise electronic amplification and filtering to preserve the leak signal. In addition, in a correlating logger the sensor is positioned very close to the logger's electronics. Most real-time correlators can advantageously separate the sensor and recording electronics by a long cable. To overcome this potential interference problem, the ZCorr logger uses a custom-designed discrete amplifier and filter circuit, integrated very closely with the sensor.

Digitizing of the analog signal is performed with a 23-bit ADC. Most acoustic loggers use between 8 and 12 bits, allowing a digitizing resolution of between 1 part in 256 and 4096. Vibration signals on pipes have a useful dynamic range of up to 80 dB, i.e. one part in 10,000. A 23-bit ADC, with a resolution of 1 part in over 500,000, is therefore adequate and necessary to preserve the fine detail of pipe vibrations and the leak signal.

Data Processing

After digitizing, the pipe vibration signal is encoded and saved in low-power memory. The ZCorr data processor is programmed to employ special encoding techniques in different situations. For example, different pipe materials (plastic, cement or metal), large-diameter pipes, and long distances between loggers (with the presumption of very small leak signals), are all situations where the encoding is set to enhance the leak acoustic signature.

Data Downloading

Data is downloaded to a PC via the ZCorr docking station. A waterproof connector facilitates a high-speed data link between the logger, docking station, and PC. This is the final link in the chain of high resolution recording, processing, and data transfer for correlation analysis.

ZCorr Data Analysis

ALFA Optimal Correlation

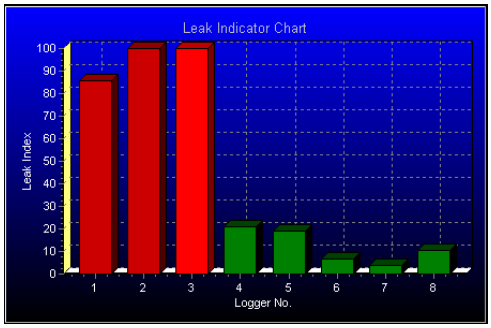
Flow Metrix has developed an advanced leak noise correlation method called *ALFA*, or Automatic Leak Frequency Analysis. ALFA works by identifying a leak acoustic signature in 2-logger recordings. The leak sound may be very different between the 2 loggers, both in sound level and frequency pattern, and is often not audible or otherwise discernible to the human user. The ALFA process identifies the acoustic signature of the leak sound at each logger and designs an optimal correlation filter that is unique for that 2-logger recording. The ALFA filter concentrates on the leak sounds and discards other vibrations, for example those due to normal flow, transient usage, and environmental sounds such as traffic.

ALFA is particularly useful with large-diameter pipes, multiple leaks, and noisy environments. The graphic above shows a ZCorr correlation result with 6 correlation peaks, identifying 6 leaks in and outside a 530-foot recording span.

Another benefit of ALFA is enhanced productivity. Recordings in a zone with one or more leaks may readily produce a total of 28 correlations, one for every possible pair of loggers. ALFA produces 28 optimal correlations, each ranked by Correlation Score, without the need for time-consuming experimentation with manual filter settings.

Enhanced Listening Analysis

Unlike listening loggers, which only store statistics, ZCorr stores actual CD quality recorded nighttime sound.



A *Leak Index* (a 0 – 100 ranking) for each logger shows the sound levels present at the quietest time of the night. Each logger is represented by a bar (red = abnormal leak index; green = normal). The listening and sound analysis provide additional capabilities that can supplement the correlation information.

Data Management

The ZCorr PC software includes:

1. Electronic maps converted from the utility's Geographic Information System (GIS) and integrated into the ZCorr user interface
2. An integrated Data Manager that:
   - Stores an unlimited number of ZCorr recordings in a database
   - Provides typical database functions, such as searching and sorting
   - Can export recording information and results to other database and GIS software programs

Financial Benefits of a Leak Survey Program

The following Financial Benefit Analysis is typical for a small town (population 20,000 – 50,000) or a network region. The example distribution system has:

- 100 miles of mains pipe
- 10,000 service connections
- Daily production of 4 million gallons
- Unaccounted for water of 15%

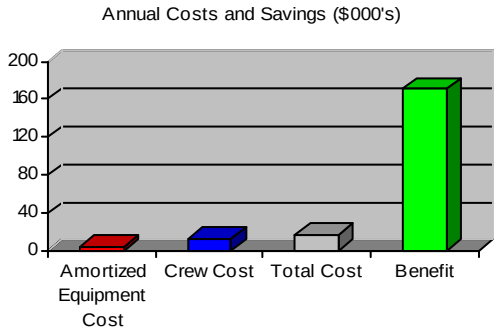
Using the Flow Metrix *Water Loss Calculator* software program[2], approximately half of the unaccounted for water is likely to be recoverable leakage (the remainder is due to meter error and un-metered or unauthorized usage). Recoverable leakage is expected to be 312,000 gallons per day, with 4 mains leaks at 30 gallons per minute (gpm) and 15 service line leaks at 6.5 gpm.

Eight ZCorr loggers deployed overnight at spacings of 1,000 feet will survey an estimated 2 ½ miles of pipe. This pipe mileage includes lateral mains and services that convey leak sounds to the loggers. The operational expense is calculated for one leak detection crew for 3 hours, at a total cost of $100 per hour. The entire distribution system is surveyed in 44 nights. The value of lost water is taken to be $1.50 per thousand gallons.

The chart below shows a benefit of over $170,000 per year, with a total cost of $17,700, i.e. an annual crew cost of $13,200 plus the ZCorr equipment cost amortized over 5 years ($4,500). The operational expense outweighs the capital expense, despite the fact that ZCorr is significantly more productive than other leak detection methods. The financial benefit of recovered leakage pays for the entire leak

[2] www.flowmetrix.com

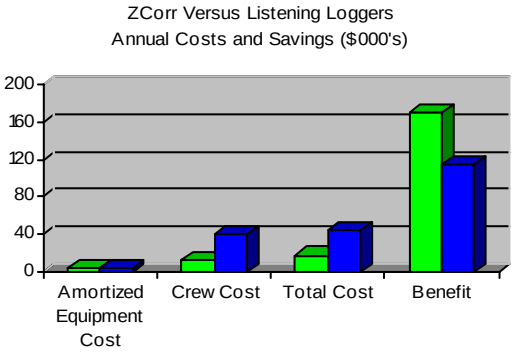
detection program and generates a considerable surplus to invest in other operations and maintenance activities.



Productivity Comparison: ZCorr Versus Other Logger Technologies

Correlating loggers such as ZCorr offer significant advantages over listening loggers:

1. A single overnight correlation study of 3 recordings almost completely eliminates any false positive detection of leak noise.
2. A listening logger can only register leak noise that is close to or louder than background vibration levels. In contrast, the ZCorr correlation process is capable of detecting and pinpointing leak noise that is inaudible and over a hundred times quieter than background noise.
3. The ZCorr correlation process simultaneously detects and pinpoints multiple leaks between any 2 loggers.



The bar graph above compares the capital and operational expense of ZCorr (green bars) and listening logger (blue bars) survey programs. The following assumptions were made:

1. The listening loggers are used for 3 nights at each location
2. Three times as many listening loggers are needed at 1/3 the cost of ZCorr loggers
3. Two thirds of leakage is successfully recovered using real-time correlation to investigate true (30%) and false (70%) positive detections.
4. One third of recoverable leakage is missed; typically very quiet long-running service line leaks.

The correlative domain is more sensitive to - and specific for - leak noise. This advantage translates into finding more leakage with less operational effort and less equipment cost. The table below shows a comparison of ZCorr correlating loggers and simple listening loggers:

Parameter	*ZCorr*	*Listening Logger*	*Comments*
Inter-logger spacing	800 – 1,500 feet	Up to 500 feet	ZCorr loggers have wider coverage
Duration of deployment	Overnight	1 – 7 nights	ZCorr loggers work overnight
False positive rate of leak detection	Less than 5%	67 – 90%	Listening loggers have a high false positive rate
Sensitivity to leak noise	Very high	Moderate	The correlation process will detect & pinpoint inaudible leak sounds
Operational effort	About 20 minutes per logger	20 minutes per logger + leak verification + leak pinpointing effort	It is time-consuming to rule out leakage when the majority of indications are false positives

Summary

The ZCorr correlating logger system is operationally viable for most water utilities with over 2,000 service connections. It has superior performance and is cost-effective, compared to other leak survey methods.

Equipment

DigiCorr III

The third generation of the DigiCorr - the original true digital correlator. DigiCorr III uses state-of-the-art sound processing and high resolution digital radio links to find leaks other correlators miss. DigiCorr technology is patent-protected (U.S. Patent No. 5,974,862).

ZCORR

Flow Metrix's Digital Correlating Loggers give breakthrough price/ performance in detecting and pinpointing leaks over several miles of water distribution system pipe. Their patented technology makes highly synchronized sound recordings overnight from valves. After daytime retrieval of the loggers, Flow Metrix's advanced signal processing software automatically pinpoints any leak(s) present. ZCorr technology is patent-protected (U.S. Patent No. 6,567,006).

UNILOG

These light-activated digital sound loggers economically survey a wide area of a distribution system for leakage. They rule out leakage in most areas, allowing leak pinpointing efforts to be productively concentrated in areas where leaks are probable.

MLOG

MLOG is a network of intelligent, leak detecting sensors which monitors the entire water distribution system 365 days a year. MLOG is the first affordable and comprehensive solution to minimizing water losses in a distribution system. Leak detection data is collected automatically by radio from throughout the distribution system (optionally as part of the meter reading process). With many advanced software features, the patented MLOG system can detect and localize leaks and direct pinpointing, repair and remediation efforts (U.S. Patent No. 6,957,157).

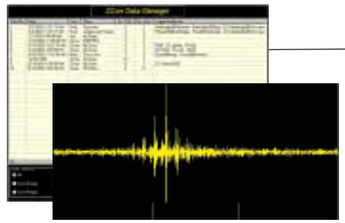
Flow Metrix develops cutting edge products which are the framework for true enterprise solutions to water loss management. Our products are designed to fit the specific needs of every type of utility and its budget. All Flow Metrix products are patented or patent pending.

Our enterprise solutions have been designed to ensure success in reducing Unaccounted For Water and maintaining the integrity of your distribution system infrastructure and include the following:

- •Planning - We help you design a complete leakage management plan, including digital map integration
- •Training - We train utility personnel to implement your plan efficiently and effectively
- •Digital Leak Detection Equipment - We help you determine which equipment you need to make your plan work
- •Analysis - We support you through the analysis stage by helping you understand your results and by providing a comprehensive analysis service
- •Support - Flow Metrix Support is always available, offering assistance either on-site or via telephone, fax or email

DLD

DLD is the first true digital leak detector in the industry. It is light-weight and easy to use. Using dynamic range compression and digital precision, DLD eaily identifies leaks that are undectable with other leak detectors.



Analysis

Flow Metrix's advanced leak detection software allows unprecedented ease-of-use: leak detection at the press of a button in the field to analysis of the distribution system in the office. Data from our products can be sent electronically to Flow Metrix for comprehensive analysis. You will receive the analysis results and report via email.

Training

Flow Metrix's professional training team will explain the leak survey plan and method to utility personnel, teach them to use the equipment, and assist in implementing the plan at all stages.

Support

Flow Metrix is most proud of its applications and technical support organization - unequaled in the industry today. Customers may contact Flow Metrix Support via our toll-free number, fax or e-mail for assistance. Problem resolution begins immediately.

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Flow Metrix, Inc.

Enterprise Solutions for Water Loss Management

Flow Metrix is a growing, dynamic, and innovative company, providing technologically superior leak detection solutions to the water industry while maintaining a company-wide dedication to building positive and energetic relationships with our customers.

DigiCorr: The Original True-Digital Correlator

Water demand is now doubling every 20 years and it is predicted that approximately 60% of the world's population will be short of water by 2025. With losses from water distribution systems varying from 10% to 60% (dependant upon geography, measurement method and politics) it is widely recognized that these losses are not sustainable. This paper identifies the important role of the leak noise correlator for modern leak location in water pipes. It sets out the major innovations and advantages of DigiCorr, compared to the older technologies in other leak noise correlators.

History of Correlation

The first leak noise correlator was developed in Europe and introduced in the late 1970's (shown in Figure 1 together with late1990's low-cost analog correlator.

Figure 1, Leak Noise Correlator circa 1979.

This correlator was able to find leaks but was very large, had limited range, and needed cables for sensor connection. The early 1980's saw the introduction of radio systems which gave easier deployment and faster leak location. The leak signal was continuously amplified and filtered, and its resolution was reduced for transmission as an FM analog radio signal. The signal degraded with range and was transmitted with as much radio power as permitted. Today the FCC limits radio-frequency power in many frequency bands. This approach is essentially unchanged today in analog correlators.

History of Digital Correlation

The first digital correlator, the *DigiCorr*, was developed by Flow Metrix (Maynard, MA) in 1997. The unique elements of the DigiCorr are:

1. **Complete Digital Signal Path from Sensor** to process CD quality sound directly from the sensor
2. **Digital Data Radio Communication** with a 1-MHz bandwidth to transmit this CD quality sound to the correlation processor.
3. **Intelligent Field Sensor Units (FSUs)** in constant two-way communication with the correlation processor. The FSUs record vibrations optimally according to the pipe and environmental conditions.
4. **Advanced digital signal processing capabilities** to pinpoint leak sounds that conventional correlators are unable to hear or distinguish from ambient noise or pipe vibrations.

DigiCorr III is the latest evolution of DigiCorr. Innovations include:

1. **Automatic Leak Frequency Analysis (ALFA)** characterizes and uses the specific time-frequency signature of leak sound to improve pinpointing precision and aid identification of multiple leaks
2. **Delayed Recording Mode** means that operation is unlimited by radio range restrictions or access to pipes
3. **Digital Mapping and Database Tools** for detailed analysis of an unlimited number of recordings and creation of an audit trail.

Aren't all Correlators Digital?

All leak noise correlators since the late 1970's have used digital logic for correlation processing. Several patented processes together make DigiCorr and Archimedes innovative:

- Digitization of the recorded leak noise as soon as electrically advantageous after the sensor and with the highest attainable resolution.

- Transmission with CD sound quality through the digital radio system to the correlation processing stage, providing a high resolution leak signal which can be pinpointed where conventional correlators sometimes fail.
- Advanced PC-based digital signal processing to analyze data more effectively than older, expensive microprocessor-based units.

Figure 2. The DigiCorr III Field Sensor Unit (FSU), with intelligent processing and 2-way digital radio communication.

Leak Noise Resolution

The idea of a 'digital data path' has been uniquely introduced in the DigiCorr. This digital data path is at the core of the patented DigiCorr architecture[1]. The sensor, a micro-machined accelerometer, is a purely analog device which transduces the analog pipe vibration into an analog charge. An ultra low-noise charge amplifier converts the flow of charge to a signal voltage suitable for digitizing. The sensor is hermetically sealed in a stainless steel vessel designed to isolate this circuitry from the environment both physically, electrically, and magnetically. Alternatively, a hydrophone sensor can be used, where suitable fittings allow, providing direct detection of the acoustic energy from the water. A low-noise, electrically shielded cable brings power into the sensor from the FSU and conveys the signal voltage to the digitizer at a necessary distance within the FSU.

[1] US Patent No. 5,974,862, Lander et al., "Method for detecting leaks in pipelines". Patent pending in other territories.

Why Not Digitize in the Sensor?

To preserve the fidelity of the signal voltage it is important to isolate sources of interference physically from the sensor and charge amplifier. The inevitable interference sources encountered include:

1. *Noise from the digital power supplies needed for the digitizer and processor*. This noise is kept physically remote from the sensor by the cable. The low-noise cable appears 'invisible' to the digitizer because the impedance of the cable is many millions of times lower than the input impedance of the digitizer.
2. *Electromagnetic ('60-Hz') interference from power lines*. This interference is removed digitally in the PC software, eliminating the need for leak signal distorting electronic filters.
3. *Interference caused by movement of the cable, due to wind or environmental vibrations*. This low-frequency interference is picked up by the sensor in all correlators. When transmitted it can significantly limit the resolution of the leak noise. It is removed in DigiCorr by software digital signal processing, both in the FSU and the PC software. Artifact due to the 'tribo-electric effect' (caused by vibration of the charge amplifier itself), is avoided altogether in DigiCorr & Archimedes by selection of materials.

The Intelligent Digital FSU

Once the signal voltage reaches the FSU it is immediately digitized without any filtering. The variations in amplitude of the acoustic signal depend upon the noise in the pipe, particularly the low-frequency components. This range is very wide (on the order of 1:10,000). Conventional correlators can transmit a signal range of the order of only 1:100 and therefore must significantly reduce the resolution of the leak noise. DigiCorr uses software programmable-gain and a 16-bit Analog to Digital Converter (ADC), achieving a useful signal range of over 1:500,000. DigiCorr is therefore able to capture the signal from the pipe at any level and to convert it to a digital representation with better than CD quality.

DigiCorr's digital data radios are inherently 2-way devices, putting the FSUs in constant communication with the correlation processor (PC software). This permits the correlation processor to:

1. Manage power in the FSUs remotely
2. Program the FSU with the recording parameters that best suit the environment (large-diameter or plastic pipes, long range, etc.)
3. Implement unique features, such as remote access and delayed recording, under user control

Unlike conventional correlators, DigiCorr can optimize its recording protocol (sampling rate, data resolution, transmission coding, and other parameters) in every recording. The recording protocol is set transparently to the user, in response to commands from the PC software and digital processing performed in the FSU.

Digital Data Radio Communication

DigiCorr uses sophisticated frequency-hopping spread spectrum (FHSS), digital radios, which operate at 2.4GHz. These radios are sometimes called "software" radios because of their ability to transmit large amounts of digital data intelligently.

Conventional Frequency Modulated (FM) radios transmit an analog representation of the vibration sensed from the pipe. The sound quality deteriorates with distance transmitted and is typically poor (analogous to a 78-rpm record) upon reception at the base station. If another transmitter is present at the same frequency then the transmission will be blocked (jammed). FM radios in leak noise correlators typically transmit at 433 - 470 MHz, with an available bandwidth of 25 kHz (or 10 kbps) and require product approval in most parts of the world.

In contrast, FHSS digital radios utilize a bandwidth of 1 MHz (or typically 256 kbps). This makes it possible for DigiCorr to transmit high resolution vibrations sensed from the pipe. The transmission is a true digital signal (approximately equal to or better than CD quality). Within certain power and antenna limits DigiCorr can be programmed for license-free use worldwide.

If another transmitter is present, frequency hopping radios will automatically switch to another frequency channel to avoid jamming. This feature is becoming particularly important with the proliferation of wireless devices. If the radio-frequency environment is noisy (poor reception, other transmitters, etc.) DigiCorr will automatically re-transmit any data from the FSUs that was not received by the base station.

ALFA – Automatic Leak Frequency Analysis

Introduction

DigiCorr has introduced a powerful new software tool – ALFA. Conventional leak noise correlators are limited by:

1. Their need for manual selection of discrete filters at the base station.
2. Disturbance of the correlation from flow noise, usage, traffic and other environmental noise
3. Loss of the leak noise correlation due to limited recording resolution

The need for discrete filters has significantly limited the usefulness of conventional leak noise correlators. A skilled operator must sometimes experiment with a selection of filters either to detect a leak or to pinpoint the leak accurately. Occasionally a leak is missed (does not correlate) because no single (parametric) linear bandpass filter is able to isolate a coherent leak sound at both sensors. This process can be time-consuming for the user and requires their attention after each recording. Multiple leaks present in one recording can be missed.

How ALFA Works

DigiCorr uses a system of Automatic Leak Frequency Analysis (ALFA) to detect and pinpoint leak sounds with no user intervention. ALFA is a digital signal process capable of isolating (multiple) leak sounds individually at either sensor and statistically optimizing their correlation at each possible value of time delay. It can be thought of as constantly scanning the data arriving at each sensor, looking for energy that is coherent in time and frequency between the two sensors. Unlike conventional filters, ALFA is able to extract leak sounds from the recording even when much greater noise may be present at the same frequencies. It is able to

collect leak sound energy from many different frequencies – not just a single frequency band - and to discriminate among multiple sources of leak sounds. ALFA tracks the spectral patterns of leak sound over time to 'tune in' to the leak sound even when other noise dominates the recording. Once ALFA has registered the characteristics of the leak sound, the results of the correlation process will be significantly less susceptible to disruption by ambient noise, such as traffic, or changing flow noise due to usage variations. A key aspect of ALFA is that this tracking and characterization of leak sounds is performed uniquely and optimized in every recording.

The Benefits of ALFA

With ALFA an accurate registration and pinpointing of each leak sound occurs automatically with every recording. This includes multiple leak sounds within a correlation span and leak sounds that would have been lost in analog FM radio transmission). When no leak is present no correlation occurs. It is not necessary to re-record with many different filter settings to ensure that 'no leak' is truly present.

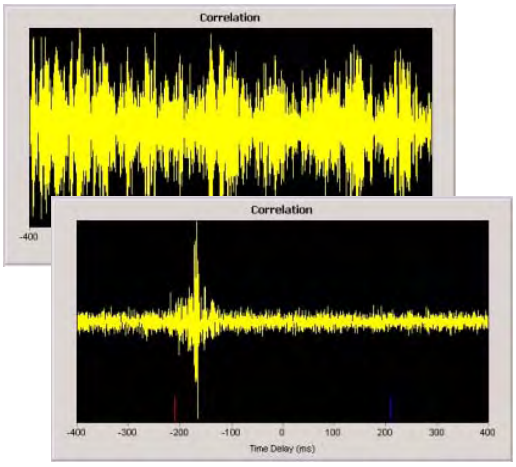


Figure 4. Comparison of Correlation With and Without ALFA Processing.

The benefit of ALFA is shown in Figure 4. The screen above and left depicts the digital correlation result over 869 feet of 4" diameter cast iron pipe. No correlation peak is observed. The screen below and right shows exactly the same leak noise data file but processed using ALFA filtering. A correlation peak indicates a leak at 91 feet from the red sensor.

Leakage Management Tools

ALFA makes possible the software tools for leakage management available in DigiCorr *Pro*. Because ALFA works transparently it is possible to make recordings from many sites, analyze that data and pinpoint the leak in the field, and also automatically store that data.

DigiCorr is the first correlator that can be used for network-wide surveying and analysis:

1. A single 60-second recording is analyzed, saved, and any leak(s) present are pinpointed without user intervention.
2. An unlimited number of recordings can be archived in a built-in database.
3. Any recording can be retrieved for subsequent analysis or review by searching for text addresses, map locations, dates, etc.
4. The DigiCorr database can be read by popular database, spreadsheet, and statistics software programs to analyze leakage by zone, pipe material, pipe size, dates etc.
5. The DigiCorr database can be flexibly extended by the user, for example, by adding fields for pipe age, pressure zone etc.

DigiCorr Results

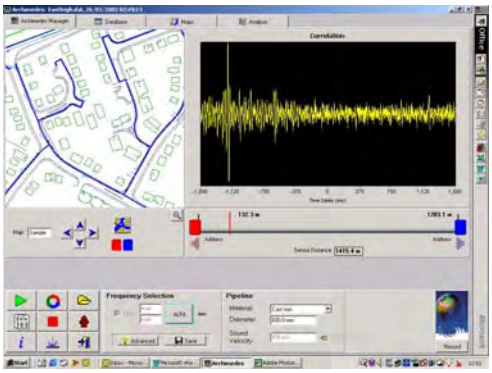


Figure 5. Correlation result with sensors nearly a mile apart (4,643 feet) on a 24" cast iron trunk main.

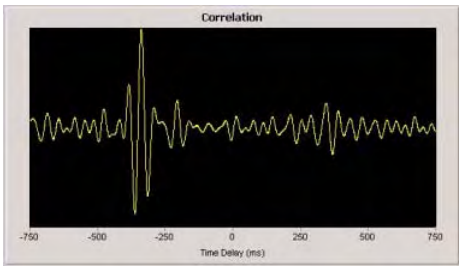


Figure 6. Pinpointed leak on polyethylene (MDPE) pipe over a distance of 512 feet.

MLOG: Comprehensive Pipeline Integrity Management For Water Distribution Systems

Water loss from pipelines impacts ecological and infrastructure integrity. MLOG is the first proactive permanent tool for continuous assessment of pipeline integrity. An enterprise solution, MLOG enables water utilities to prevent water loss and manage pipeline integrity in a sustainable and affordable manner.

Water Distribution Systems

Water distribution systems in the U.S. typically draw water from surface or underground sources. Water is treated and pumped into a network of transmission, distribution, and service pipes.

This buried infrastructure is documented by Geographic Information Systems (GIS). Pipelines are currently maintained by excavation and infrequent acoustic surveys – little changed in 150 years.

The U.S. Environmental Protection Agency estimates that up to $200 billion will be required by 2025 to maintain and rehabilitate the aging pipeline infrastructure. The MLOG system addresses a pressing need for monitoring pipeline integrity automatically, 365 days a year.

Water Losses

Breaks in transmission and distribution pipes, with diameters ranging of 2 to 96 inches, may occur randomly due to corrosion and stress or because of third party damage or ground movement. Mains breaks have a tendency to occur on cold Winter nights, when the pipe is weakest and the static pressure is maximal. The mains break below spilled over 1 million gallons of water in 48 hours, at a rate of 400 gallons per minute (gpm).

Perhaps surprisingly, such mains breaks typically account for less than 1% of water produced annually. A chronic service line leak of 7 gpm will lose more water every 90 days and will typically run undetected for several years. One in approximately every 600 – 1,000 services will fail every 12 months[1], due to corrosion or stress. Losses from long-running pipeline leaks, the majority in smaller service pipes, typically account for 5 – 15% of total water produced. These leaks often do not propagate a strong acoustic signal during the daytime since operating pressures (and therefore sound levels) are reduced, flow thru the leak is laminar, and usage flows on the mains masks the audible leak sound energy. As a result long-running leakage – which forms the core of water loss - is often difficult to detect during daytime acoustic surveys.

Economic Cost of Lost Water

The amount of lost water in a distribution system can generally be predicted using some simple assumptions and readily available operating data[2]. Service line leakage predominates, typically accounting for more than 70% of total water lost. Breaks in mains tend to occur in particular areas related to pipe types and diurnal pressure variations[3]. The cost of pipeline integrity failures in water distribution systems include:

- Production / treatment cost of lost water
- Wholesale or retail value of lost water
- Damage to buried infrastructure (power, communications etc.) caused by pipeline breaks
- Capital and interest expense invested in surplus production facilities
- Intangible costs from depletion of water resources, water scarcity, and hurdles to economic development

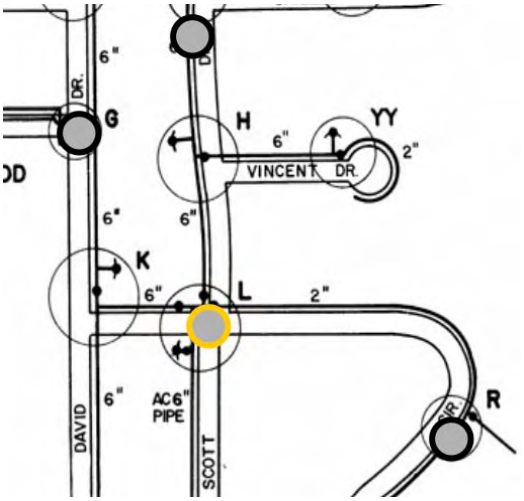
[1] See www.flowmetrix.com and www.iwahq.org.uk
[2] Flow Metrix has a simple *Water Loss Calculator* software program which can be used by any water utility with over 5,000 service connections.
[3] See references in *Note 1* above.

There is a tendency to underestimate the true cost of pipeline integrity failures by considering only the immediate operational cost, i.e. production / treatment expenses.

The MLOG Concept

The MLOG sensor is a low-cost, battery-powered sensor, permanently installed near a water service meter. The sensor is waterproof and can be installed indoors or in outdoor meter pits.

MLOG sensors are installed by field crews, typically on every 10th water service, or about every 500 feet of water mains. An installation plan is developed within the MLOG software program from a graphical mapping interface.



Installation can advantageously be performed on the same schedule as installation of meter or *Automatic Meter Reading* (AMR) equipment. Once installed the MLOG sensor is maintenance-free, with a 15-year battery life.

MLOG Analysis

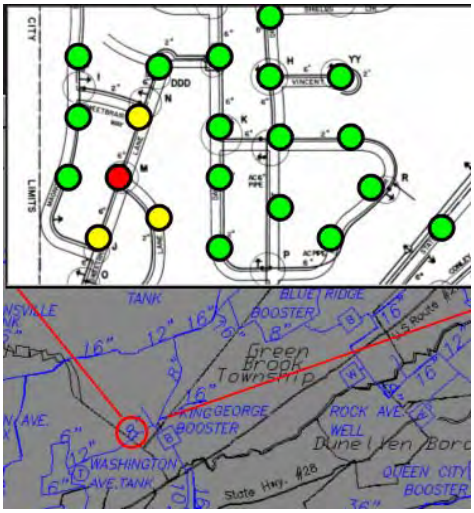
Every night each MLOG sensor records vibrations over a period of 4 hours. The recordings are processed to characterize the evolving nighttime sound patterns over days and months. The processed sound patterns are stored in memory and transmitted by radio on demand.

MLOG PC software analyzes all available data from the entire distribution system and assigns each MLOG sensor a *Leak Status*:

- No leak present
- Possible leak
- Probable leak
- No data available

The MLOG software provides tools for:

- Visualizing leak locations on water distribution system maps
- Ranking all MLOG sensors by leak status and other factors
- Printed and electronic reports



Acoustic Leak Index™

The *Leak Index* is the signal processing heart of the MLOG system. It is a number from 0 to 100, indicating the likelihood of a leak being present in the vicinity of each MLOG sensor. The MLOG analysis considers many factors in computing leak index:

1. Historical sound patterns at each sensor.
2. Groups of MLOG sensors, with unusual or changing activity. A group may be defined by

geography, particular types of pipe, or other user-defined characteristics.

3. Information from leaks discovered previously. The MLOG software is able to refine the definition of a leak acoustic signature, improving the accuracy of leak identification, size & type.

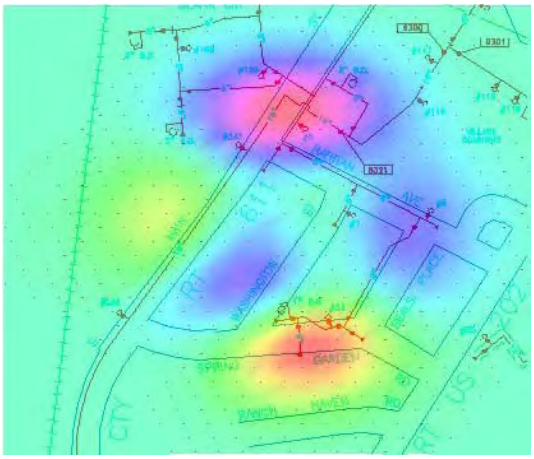
Status	Log #	Log ID	Address	Zone	Map	Date Installed	Date Last Read	Leak Index
●	18	1018	Log18	Easton	A1	2/14/2002 11:29 AM	7/30/2003 7:17 PM	100
●	21	1021	Log21	Easton	B1	2/14/2002 11:29 AM	7/30/2003 7:17 PM	94
●	223	1223	Log223	Easton	C4	2/14/2002 11:29 AM	7/30/2003 7:17 PM	90
●	69	1069	Log69	Easton	A2	2/14/2002 11:29 AM	7/30/2003 7:17 PM	85
●	139	1139	Log139	Easton	A3	2/14/2002 11:29 AM	7/30/2003 7:17 PM	83
●	94	1094	Log94	Easton	B2	2/14/2002 11:29 AM	7/30/2003 7:17 PM	82
●	12	1012	Log12	Easton	A1	2/14/2002 11:29 AM	7/30/2003 7:17 PM	81
●	11	1011	Log11	Easton	C2	2/14/2002 11:29 AM	7/30/2003 7:17 PM	80
●	128	1128	Log128	Easton	A3	2/14/2002 11:29 AM	7/30/2003 7:17 PM	80

The leak index for every MLOG sensor in the network can be ranked to show locations with the greatest likelihood of leakage.

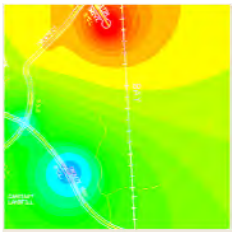
One particular innovation of the MLOG system is the system-wide, adaptive approach to characterizing leak sounds. The MLOG sensor uses patented signal processing techniques[4] to model the vibration patterns present in its vicinity and track them over time.

MLOG Color Map™

The MLOG color map™ plots the leak index over a geographical area, superimposing a solid color map from blue (low leak index) to red (high leak index) on a utility GIS map.



In the MLOG Color Map above, 2 (red) areas of leakage are discerned. This image guides the pinpointing crews to deploy Flow Metrix's leak noise correlating tools to verify 2 or more leaks. Subsequent feedback from the detection and pinpointing process helps the MLOG software learn to identify leaks more effectively. Printed reports



and MOG color maps speed the leak pinpointing and verification process. Electronic reports allow the utility to add information about non-revenue water and pipeline integrity to GIS.

MLOG Data Collection

A key feature of the MLOG automatic leak detecting system is the transparent and effortless collection of data from MLOG sensors distributed throughout the water distribution system. MLOG transmits leak detection data to a central computer in one of 2 ways:

- Via AMR, typically with a fixed installation radio network, reading MLOG sensors every few hours
- With a handheld MLOG radio controller carried by utility personnel, reading MLOG sensors every 30-60 days

Connecting MLOG Sensors to an AMR Network

AMR networks are proprietary wireless data networks which convey utility meter readings to a central computer. Fixed installation networks typically read meters every few hours, while drive-by systems read meters on a data collection schedule; usually every 30 – 90 days.

The MLOG sensor interfaces seamlessly to different AMR units by emulating a register-encoded water meter. In some cases the MLOG sensor can connect to the same AMR port as the meter, transferring its data before the meter has been read. This allows the MLOG sensor to be retrofitted to an existing AMR unit. A few drive-by AMR systems are capable of receiving up to 30 days of MLOG sensor data. AMR data from MLOG sensors is separated from the billing data by software, prior to being analyzed in the MLOG PC software. In general, fixed installation AMR is a superior means of reading MLOG sensor data because:

- Leak information is delivered effortlessly to the utility desktop every day
- A response time to new leaks of less than 24 hours is typical

MLOG sensors provide complementary data to the meter data: the meter registers billing revenues while

[4] US Patent: *Tracking vibrations in a pipeline network,* publication date and patent number pending

MLOG data provides the means indirectly to measure and recover non-revenue water.

Collecting Data From MLOG Sensors With a Radio Controller

The MLOG radio controller automatically downloads leak information when brought near an MLOG sensor. The portable controller is battery powered and can store data from over 4,000 sensors. Data is then transferred to a PC through a USB port.

The controller communicates with the MLOG sensor using a sophisticated wireless protocol, operating license-free in the U.S. under FCC rules, part 15.247[5]. MLOG is an intelligent (software programmable), short-range radio device, designed to minimize its radio emissions and power consumption and to maximize speed and reliability of communication.

The designer of wireless instruments for utilities faces a number of important choices. The first is the frequency of operation, ranging from 300 to 2,400 MHz. In general devices that use lower frequencies (up to 500 MHz) have longer range in urban areas but can transfer only small amounts of data. Devices that operate at high frequencies (greater than 1,000 MHz) can transfer more data and link to more distant receivers, if the receiver is located in line-of-sight and/or at elevation, such as on rooftops. Single-channel devices require a license and are vulnerable to jamming.

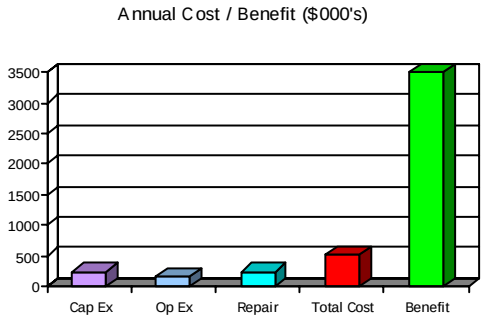
Invariably there are trade-offs involved in picking the frequency of operation. These include cost, range, bandwidth (how much data can be transferred in a given time period), immunity to jamming (the bet that a little used channel today will remain quiet in the coming 10 – 20 years), connectivity in a typical environment (urban, suburban, rural), and the expected location of the receiver (fixed at elevation, vehicle-based, or handheld).

MLOG is a multi-channel device that operates in the frequency band 902 – 928 MHz. It is *frequency-hopping*, which means that it can intelligently *hop* among multiple frequency channels to avoid jamming. MLOG is also a *spread-spectrum* device, meaning it regularly hops from channel to channel to spread radio emissions over a wider bandwidth. As a frequency-hopping, spread-spectrum device MLOG has a software-programmable radio with enhanced performance:

- Always able to communicate with a controller
- Avoids collisions with other transmitters
- Sends and receives large quantities of data quickly and reliably
- Minimizes radio power consumption to achieve a 15-year battery life

Achieving Sustainable Minimal Levels of Lost Water

To examine the economics of an MLOG deployment, consider a hypothetical urban/suburban utility with 1,000 miles of mains, 80,000 service connections (serving a population of 500,000), and daily production of 80 million gallons. Assuming unaccounted for water at 15% (typical for the U.S.) and a value of $1.50 per thousand gallons, the utility is losing over $3.5 million annually ($44 per account).



Using the Flow Metrix *Water Loss Calculator* this utility statistically might have 100-300 service line leaks and 20-100 mains leaks at any one time. The capital expense (Cap Ex) of 8,000 MLOG sensors is less than $3.00 per service annually, amortized over 5 years. (NB: The MLOG sensor is specified for 15 years.) Operational (Op Ex) and pipe repair expenses are both reduced compared to routine expenditures in reactive leak repair programs. A total payback time of less than 2.5 years is typical.

Summary

The MLOG system is a complete solution for recovering lost water and monitoring pipeline integrity. Benefits include optimizing operating resources and long-term reduction of the financial and other costs of developing water resources.

[5] FCC ID: RIC-MLOG01