# Network-distributed Ultrasound

**Jeff Anderson, Mark Feydo and Bruce Pellegrino**

Sensor Networks, Inc.

176-500 Technology Drive,

Boalsburg, PA 16827

Abstract:

High-frequency analog RF ultrasonic signals, typically in the 1 – 10 Mhz range, are transmitted over coaxial cables. In order to maintain signal amplitude, quality and fidelity, the cables should be as short as possible – generally less than 150’ (45.7 m). For applications where very long distances are required, it becomes necessary to place the UT instrumentation close to the transducer and digitize the data before sending it the required longer distances. This paper discloses and compares three different network topologies and approaches to remoting the UT system: Modbus over RS-485, Cellular and LORA WLAN. Additionally, the paper will review several practical and cost-effective examples for remote UT monitoring at various Oil & Gas and Power Generation facilities.

Introduction:

Industrial plant ultrasonic testing applications, such as those typical at refineries, chemical, nuclear and fossil power plants, sometimes require expensive, bulky or complicated instrumentation that does not easily lend itself to portability. In some of those cases, it is impractical or undesirable to bring the UT instrument very close to the area of test. These applications therefore require the use of very long (> 150’ or 45.7 m) cables. If dual-element probes or multi-element transducer arrays are needed for area coverage or other reasons, then the quantity and complexity of the cable bundles become both expensive and bulky to manage. Cable breakage, wear & tear also become issues of availability and economics.

In addition, long cable lengths cause signal degradation especially at higher frequencies.

1. The longer the cable the more chances for it to act as an antenna and pick up noise from the environment limiting the ability to measure small signals.
2. The cable will attenuate the pulser signal as well as attenuate or limit the ability of the UT Transducer to propagate a received signal back to the UT instrument receiver. Attenuation rates can be as high as 3.3 dB at 10 MHz per 100’ (30.5 m) of RG-174 cable on both the pulse and receive signals.
3. At longer lengths, the cable can look like a transmission line to the Pulser (which contains higher frequency content) potentially resulting in reflections in the cables. The results of which could be multiple excitations of the UT transducer causing reduced resolution.

An alternative approach to multiple, long coaxial analog cables is to place the entire UT system very close to the transducers, digitize the signal output and then use a simpler, lower-cost twisted-pair cable such as RS485 or wireless technologies to send the data to a common location for analysis, review and archiving.

**Development and deployment of digital networks:**

Over the past few years, several digital network topologies have been developed which can be used individually or combined with each other and a common interface / web-based back-end. These include:

- Hard-wired Modbus over RS485
- LORA WLAN (Wireless Local Area networks)
- Cellular over standard commercial networks

**Modbus over RS485:** Modbus is an industrial communications protocol commonly used for field instrumentation such as temperature, pressure, flow measurement and bi-directional control of valves, etc. In the case of a digital ultrasonic network, multiple UT devices can be daisy-chained together using standard RS485 cable. Typically, the UT device can be a single, small, low-power circuit board containing the pulser, receiver, amplifier, multiplexer, digitizer and communications hardware. The Modbus network can support up to 32 devices, 1,500' (500m) of cable and can terminate into either a tablet, laptop, desktop PC or a plant's Digital Control System (DCS). This represents a closed "in the fence" network system with no connectivity to the internet or cloud unless the PC-captured data is intentionally uploaded. Some sites or company's IT departments require closed systems for cyber-security reasons and some applications such as buried pipe or process control require hard-wired Modbus solutions.

Illustration of a wired, multi-drop Modbus system for UT thickness data collection over a large area.

**LORA WLAN:** LORA is a Long-Range wireless local-area network protocol being developed as an international standard for low-power, low-cost, bi-directional data transfer in the Internet of Things (IoT) arena. LORA uses the 915 MHz frequency spectrum which is in the unlicensed ISM band in the US. Other frequencies are used outside of the US to comply with the regulatory requirements of those countries. LORA is defined as a star network, thus each node had a direct connection back to the gateway. A single gateway can support thousands of end-nodes. The gateways then provide Wi-Fi, Ethernet, Cellular or Satellite backhaul of the data to the internet.

Including a LORA radio module into the UT instrument allows for the elimination of probe cables hence much faster and simpler installations. The UT instrument is powered by a battery further eliminating the need for power cables being run to the UT instrument. The star-network topology eliminates the need for each node to act as a repeater for other nodes. This extends battery life in comparison to competing MESH networks, such as WiHart, that require the repeater functionality.

Example of a wireless UT sensor network along with a typical UT thickness & temperature node.
The entire UT / wireless system resides on a small printed circuit board (PCB).

**Cellular:** Another recent development is a device using a cellular radio for data backhaul. Because the instrument can connect to and uses available, third-party cellular networks, it avoids the problems and high costs associated with mesh network, gateways, and plant IT infrastructure. This allows the deployment of even single inspection points at relatively low costs, without the expense of gateway installation and IT personnel evaluation. The instrument is connected via an available cellular network to a cloud server that is running an application software which is designed to communicate with the instrument for collecting ultrasonic or other data associated with the integrity of the asset being measured. The application software is also designed to store readings and has a browser-based user interface that allows for the display of data and asset integrity information. The application can be viewed through standard browser enabled devices such as laptop computers, tablets and smart phones.

Ultrasonically, the system consists of a single ultrasonic channel that is multiplexed up to 16 single-element or eight dual-element transducers. The ultrasonic channels are programmable and can be deployed with various transducers types and/or frequencies. Dual-element transducers have become the industry's recommended standard for corrosion thickness gauging due to their superior performance in detecting pitting, ability to measure thinner (0.040" or 1.0 mm) wall sections and operate over a wider temperature range such as zero to 300˚ F (-20 to 150˚ C). Additionally, a temperature-measurement channel is also included such that temperature measurements can be taken concurrently with the thickness readings for correcting for temperature-induced measurement changes.

Battery powered, self-contained 8 dual-element cellular system can be programed to take UT thickness measurements at any user-defined time interval. Data is sent to a web portal where it is trended.

**Installed Sensors:** One such example is the monitoring of material degradation and/or metal loss due to corrosion and erosion which is a widespread issue in the O&G and Power Generation industries for tanks, high-energy piping, pressure vessels, and other critical assets. Metal loss can result in loss of pressure containment with resulting consequences that can include: loss of life, damage to assets, disruption of service, environmental harm, loss of public image, fines and others. As such, asset inspections are required by operators and are mandated in regulations and codes such as 29CFR–1910; API 570, ASME Sections V & XI, ASTM E797 and NACE's IP 34101.

While there are many methods for measuring wall thickness, a predominant method is the use of portable ultrasonic equipment. Ultrasound is non-intrusive as it is applied to the outside of the pipe or vessel, is accurate and relatively low cost to deploy in most situations. However, it does have several shortcomings including that the ultrasonic transducer or probe needs to be applied in direct contact to the external surface of the pipe requiring scaffolding, excavation, stripping of coatings or insulation, etc. Thus, the cost of access to the structure often far exceeds the basic cost of inspection. Furthermore, a trained and certified inspector is required to operate the ultrasonic instrumentation, requiring personnel to sometimes be exposed to potentially hazardous environments. The accuracy and repeatability of ultrasonic measurements are operator-dependent and recent studies have shown that the probability-of-detection (POD) can be poor. Finally, the measurements are only performed periodically, taking a snap-shot of plant condition.

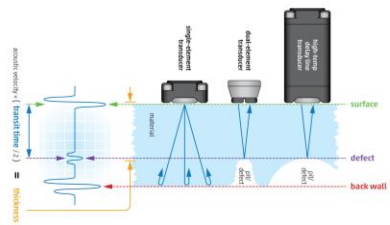
Many end users are interested in investing in new technology to overcome these concerns. In the process industries, such as in petrochemical or refineries, all critical process parameters are measured in real time. Obtaining information on vibration, flow, temperature, pressure, PH, equipment upsets or unusual conditions are monitored and reported on a continuing basis via Key Performance Indicators or KPI's. The automation of thickness measurements would alter the paradigm from the current, manual/periodic measurements to thickness and corrosion rate as an on-line process and plant health variables that can be used to optimize asset usage and inspections.

Installed ultrasonic sensors are emerging as a new technology to compete with manual UT inspections and existing corrosion-rate monitoring solutions due to the potential for high data quality, non-invasive installation, and ability to operate remotely without operator interaction. As with UT thickness gauging, the solution is based on the ultrasonic principle. A transducer is used to convert electrical energy to high-frequency acoustic or ultrasonic energy and vice-versa and is semi-permanently attached to the surface of the object or asset under test. The transit time between the initial electrical-excitation pulse and return echoes (or between echoes) is used to calculate wall thickness. Features such as the distance to the back-wall or the distance to a pit or crack can be very accurately measured with this technique.

Operationally, the installed-sensor solution is similar to manual thickness gauging however it is fundamentally different in that the transducers and instrumentation are deployed permanently. This addresses several of the shortcomings of existing solutions. Some of the major advantages are as follows:

- Instrumentation and probes are deployed on the asset in a permanent or semi-permanent fashion and can be accessed remotely, thus the cost of access is reduced over time and operators are not deployed to the point of the inspection. Once the instrumentation is deployed, data can be accessed from a convenient access point for the manual data collection option or can be accessed remotely, via the Internet, for integrated systems.
- Due to the fixed transducer position and instrumentation, operator-to-operator, probe-to-probe, and instrument-to-instrument variability is eliminated. This removes significant sources of error and allows for improved measurement resolution, precision and accuracy which is particularly important for accurate corrosion-rate trending. Data can be collected on a more frequent basis (>1X per day) for automated systems. This allows for more accurate corrosion-rate trending through statistical data analysis, such as linear least squares regression.

- The system can be deployed with an integrated temperature measurement device so that changes in material acoustic velocity due to temperature variation can be automatically removed from the measurement, thus eliminating another significant source of measurement error.
- The data is accessible. Wired and/or wireless installed sensor systems can make use of various forms of data backhaul including the plant wired or wireless intranet, industrial wireless networks such as 802.15.4, (wireless HART, ISA100 or ZigBee), and satellite or cellular networks for remote collection points, allowing practically real-time data/asset health availability.



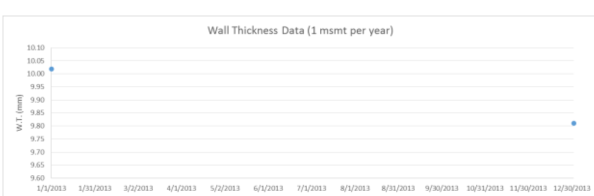
Single-element, including ultra-high-temperature delay-line, and dual-element transducers can be used with installed sensor systems.

A 16-, 32- or 64-channel ultrasonic system can be configured to support area coverage.

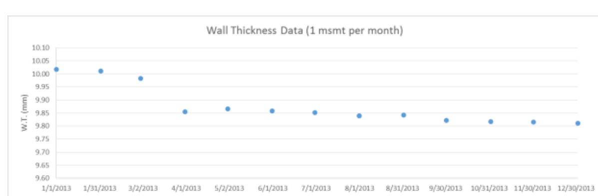
**THE POWER OF HIGH-FREQUENCY & HIGH-QUALITY DATA**

A major advantage of installed ultrasonic sensors is the ability to collect a larger quantity of high-quality thickness data than would be otherwise available from manually collected measurements. The large amount of data allows first-of-all visibility to the dynamics of wall-thickness reduction. Corrosion rates are often not constant and can vary between periods of virtually zero corrosion to episodic events causing corrosion rates of hundreds or thousands of MPY. The use of data of marginal quality and spaced over long time periods can either overestimate or underestimate corrosion rate and does not allow insight into the actual corrosion history of an asset.

A data set including eight distinct corrosion rates with noise having a standard deviation of 0.0004” (0.01mm). Progressing from a to d is the same data, displaying discrete measurements from the data set on intervals of 1X per year, 1X per month, 1X per week and 1X per day.



**(a)**



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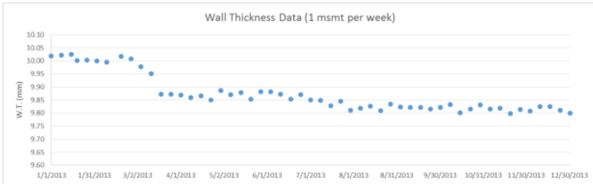
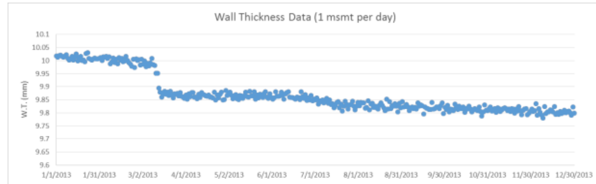


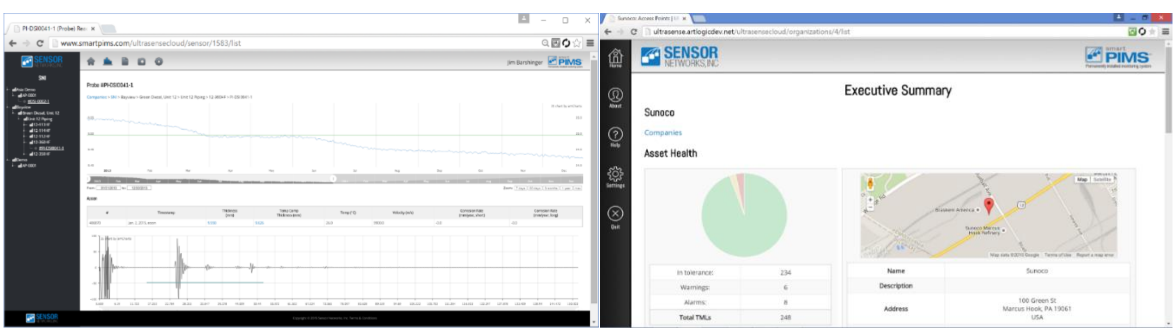

**(b)** **(d)**

**Wall-thickness monitoring data with collection intervals of: (a) 1x/year, (b) 1x/month, (c) 1x/week and (d) 1x/day.**

When considering a measurement of once-per-year as might be normally obtained from manual UT measurements, only a coarse corrosion-rate calculation is available. Over several years, an operator might get a general understanding for the long-term corrosion rate, but statistically it is impossible to place an uncertainty on this measurement so the ability to use the corrosion rate as a predictive tool (for scheduling maintenance for instance) is poor. Moving to even a relatively infrequent measurement cycle of 1X per month allows a much better picture of the process of wall-thickness reduction. Separate corrosion rates are evident in the data, including evidence of an episodic event of very high wall-thickness reduction. While a large improvement over a once-per-year measurement cycle, the relatively small amount of data still limits the ability to calculate corrosion rates accurately. Thus, the ability to distinguish two different corrosion rates is impaired which limits the efficacy of using the measurement as a process-control tool.

More frequent measurements, for instance once-per-week, once-per-day or even more often, allows statistical tools to be used to characterize and remove measurement noise, achieving corrosion-rate measurement precision in the range of 1 MPY. As such, installed ultrasonic thickness measurements become a tool for monitoring process conditions as they impact the corrosion/erosion rate within a piping circuit, vessel, heat exchanger shell, or other asset. Numerical tools such as data filtering and linear regression are easily deployed in software.

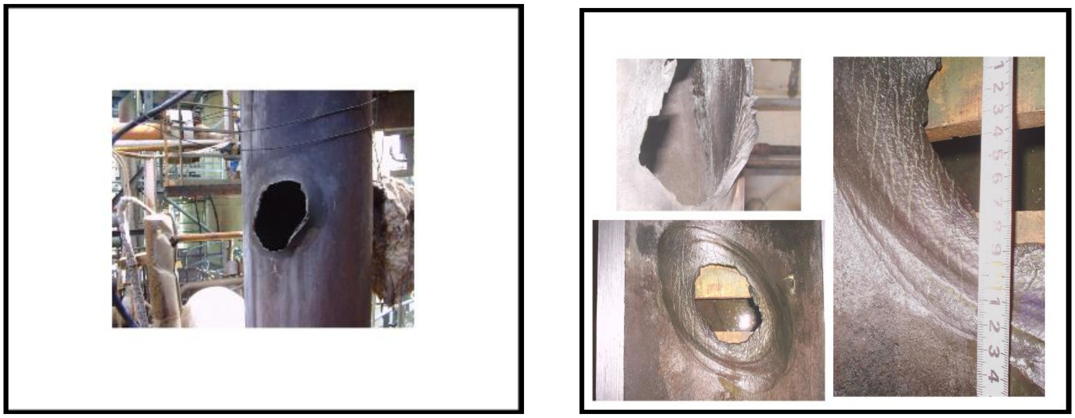
**Web Portal for data management:** Another unique benefit of network-collected data is that it can be readily uploaded in near-real-time to a centralized, cloud-based, secure web-portal enabling multiple parties across the organization to access the data at any time.




**Web portal can display, analyze, trend & archive all data and summarize into macro or executive views.**

**Typical applications:**

Injection/Mix-point corrosion has been responsible for many serious refinery incidents and is episodic in nature, only happening for certain process conditions or during process upsets. API 570 specifies inspection guidelines and NACE IP 34101 provides specific process guidelines to minimize injection point damage. While manual UT and RT provide static monitoring of potential damage areas their use may not coincide with the timeframe where episodic damage occurs and therefore will require repeat inspections of potential damage areas. Installed UT sensors can provide dynamic monitoring of suspected injection point damage locations without repeated access mobilizations.

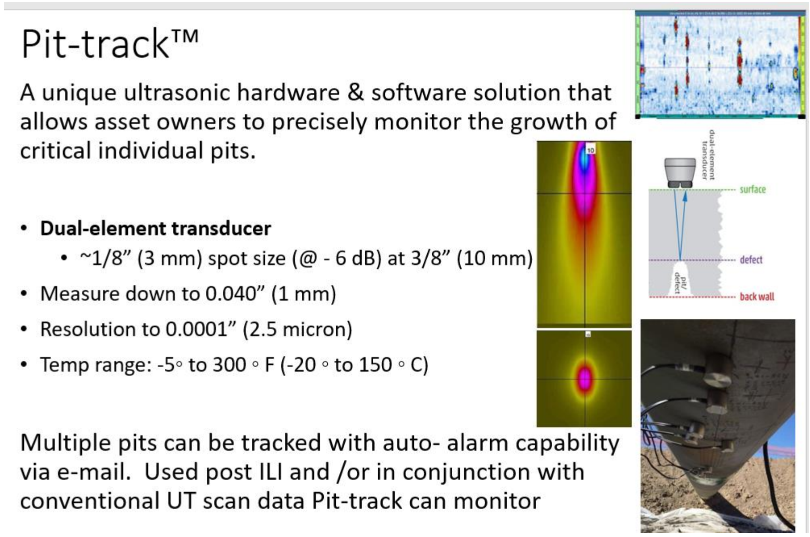


**Pipe failures due to Injection/Mix-point corrosion.**

Crude Unit Overhead with Chemical Injection and/or Water Washes is subject to periodic inspections per API 570. Many overhead lines have no platform access making these inspections difficult and costly. UT and RT can provide useful inspection data, but it is costly to obtain if crane access / scaffolding is required. Installed UT sensors can be installed and accessed on a continuous basis to reduce cost of access and to improve plant operational knowledge.

**Crude unit overhead line corrosion monitoring at 300-degrees F using multiple dual-element transducers and cellular back-haul.**

Smart-pigging is the often-used solution for monitoring pipelines, and most large-diameter, long-distance transmission lines are fitted with the proper valves, pig launchers, to allow inspection with smart pigs. Most secondary lines however are too small in diameter and not appropriately configured to allow pigging, thus requiring excavation and visual inspection. Federal regulations such as 49 CFR require repeated excavation of problem areas. Installed UT sensors can be buried in problem areas and then can be periodically measured without further excavation costs.




Sand Erosion can occur at change-in-direction or diameter in offshore production risers due to solids production. This erosion is typified by a smooth surface with a sand dune pattern. Riser locations where sand erosion may occur can be difficult to access and inspect with conventional UT or RT in addition to the high mobilization costs of personnel to offshore facilities. Helicopter access to an offshore facility can cost in the range of $50,000 USD per trip. While acoustic technologies can be used to detect the impingement of sand particles on the internal bore of the riser, these techniques only determine the presence or absence of sand and do not measure the remaining wall thickness of the asset. UT installed sensors can be applied to suspect areas for accurate monitoring without the need for manual access and can be integrated with platform or FPSO control systems for a “control panel” view of asset health.


**Conclusion:** Three different digital network topologies, Modbus over RS485, Cellular and LORA-WLAN, have been developed to eliminate the undesirable aspects and effects of using long coaxial cables for ultrasonic inspection and UT thickness monitoring at large industrial plant sites such as refineries, chemical, fossil and nuclear plants. The systems have been used primarily for thickness and basic flaw, such as laminar-defect monitoring and will evolve for flaw detection including phased-array and full-matrix-capture applications. These digital networks can be deployed individually or combined with a common back-end / web portal for data analyis, trending and sharing.