DistribuTECH 2005 Rev. 2/02/04

Water Meter Technology:

Understanding the Meter-to-AMR Interface

Larry Sears, Director of Technology, Hexagram, Inc.

The Water Meter Environment

Since the first public water systems were created in the 1800's, it was important for utilities to measure their customers' usage. In most cases, water meters were installed in basements or pits to prevent freezing; unfortunately their location made them difficult to read.

Beginning in the 1960s, as labor rates increased and security concerns limited accessibility to homes, manufacturers began to develop meters that had the capability to be read without directly accessing the meter. In the 1980s, interest grew in automatic meter reading (AMR) which allowed meters to be read even more efficiently.

All water meters that are to be read electronically must have some means of communicating the meter reading to an electronic "AMR" device. This device may be (1) mounted outside the structure where its display can be visually read by an on-site meter-reader, (2) mounted outside the structure where its "touch-pad" can be electronically read by an on-site meter-reader, (3) mounted at the meter and include a short-range radio for communication with a walking or driving meter reader, or (4) mounted at the meter and incorporate a long-range radio for communication with a fixed-network AMR system that transfers the data directly to the utility office. Please see Figure 1 below.

In all of these cases (with both remotes and AMR), there is the identical requirement that the meters have some type of electronic output that can be connected to other devices which will transmit or process the usage information. This paper discusses the various technologies that are employed to provide this electronic interface.

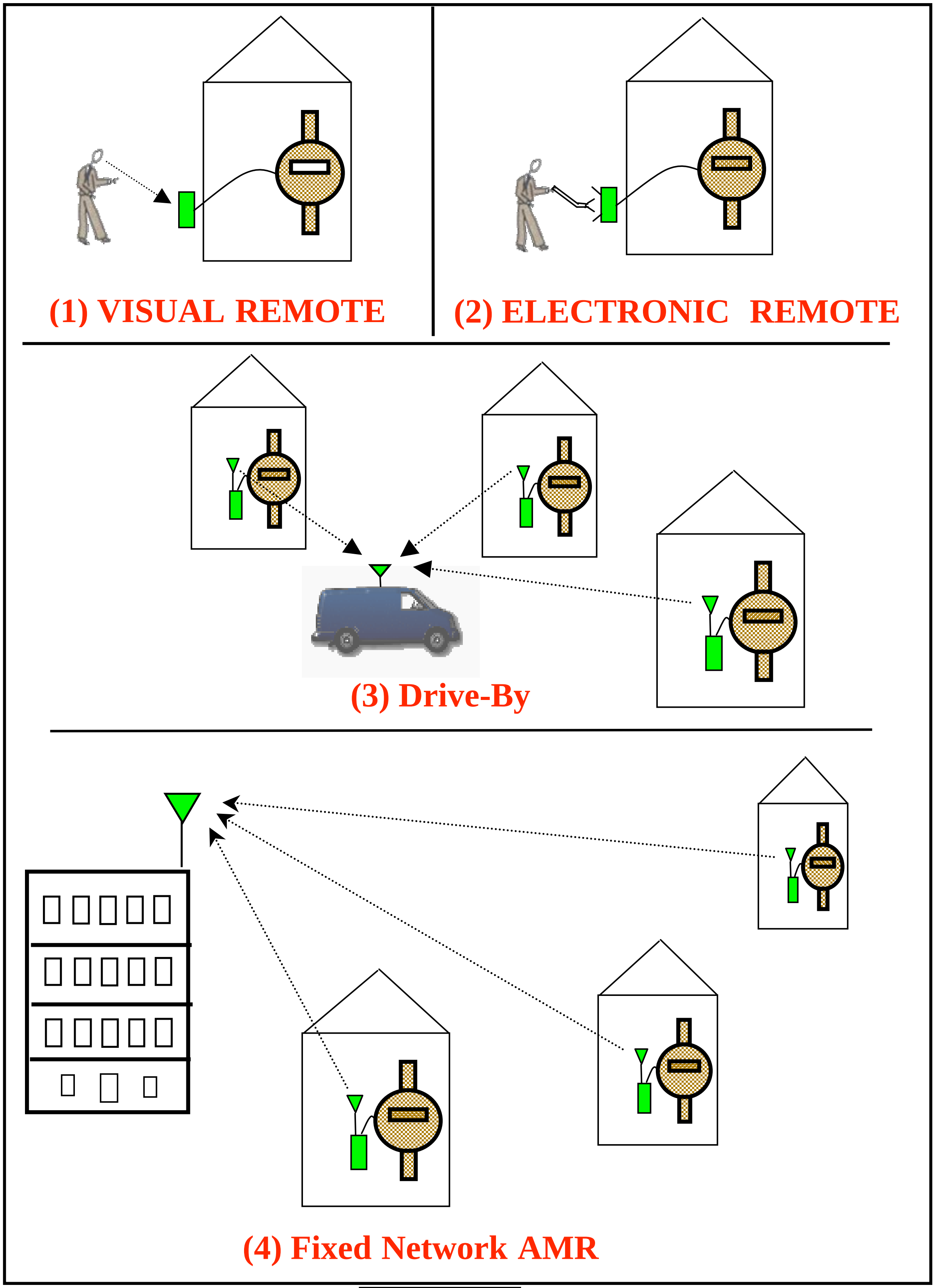
(1) VISUAL REMOTE
(2) ELECTRONIC REMOTE
(3) Drive-By
(4) Fixed Network AMR

Figure 1

Water Meter Basics

Water usage may be measured in two ways. Flow **rate** (as in “gallons/min”) can be periodically measured and then multiplied by time to determine accumulated usage. However, it is more direct to measure **flow** (as in “gallons”) which will result in total volume consumed over a measurement period. The usage is determined by subtracting readings taken at the beginning and end of the measurement period.

Measuring flow can be accomplished in a number of ways. For residential applications, the two most common approaches are **turbine** or **positive displacement** technologies. The turbine meters are known as single- or multi-jet meters and incorporate a turbine which rotates at a speed proportional to flow. By counting the rotations of the turbine shaft, flow is derived. These meters can perform very well, and tend to be small and low in cost. However, it must be noted that the turbine shaft can provide very little output torque; even slight loading of the shaft will change the meter’s calibration.

Positive displacement meters employ some sort of piston-cylinder arrangement which continuously parcels out the water in a series of well-defined, known volumes. These meters can use wobble plate, rotary-vane, or other configurations, but in all cases they employ “positive displacement” chambers to provide good accuracy over wide flow rates. Another feature of these meters is that they can provide reasonable torque at the output shaft.

Both turbine and positive displacement meters require a “register” to count shaft rotations and drive a display. In most cases the register is a small gear box that is coupled to the shaft of the metering mechanism. The gearbox divides the rotations by an initial scale factor, and then drives a gear chain which is connected to a series of dials or wheels that represent decades of usage. The calibration of the meter is quite important, of course, and the positive displacement meter is adjusted by making slight changes in the gear ratio of the initial divider. The turbine meter is calibrated by adjusting the jet or flow path.

Water meter technology is quite advanced, and manufacturers annually produce millions of economical meters with excellent performance. Unfortunately, the basic meter only provides a visual readout which must be located directly at the meter. The necessity to facilitate meter reading and to provide for AMR is what has driven the development of interfaces which allow an electronic device to “talk” to the meter.

Where is it?

Many applications that use a computer or microprocessor require a means to determine mechanical location or displacement. Common examples include the setting of a front-panel knob on a stereo, the position of a throttle plate in a carburetor, or the location of a part in a machine tool. In all cases there is a device which converts mechanical location or displacement to an electronic signal that can be understood by the computer or instrument that is part of the system. This device is called an **encoder**. There are two types of encoders, **incremental** and **absolute**, and there are fundamental differences between them.

Water meter definitions

In the water meter industry both incremental and absolute encoders are used, and the issue of what is "best" has prompted some debate. The industry jargon refers to "pulse" meters and "encoder" meters; however a computer or electrical engineer would find this terminology inaccurate since both meters contain an "encoder"-- which engineers define as either incremental or absolute. What the water industry refers to as a "pulse" meter actually contains an **incremental** encoder; an "encoder" meter contains an **absolute** encoder. For the balance of this paper, we will use the strict definition of "encoder" and refer to "incremental" and "absolute" encoders in place of "pulse" and "encoder" meters.

Incremental encoders

The incremental encoder is a relatively simple device that produces electrical pulses as a shaft or other mechanical object moves. In general, an incremental shaft encoder utilizes some sort of sensing means located on the shaft that opens and closes a circuit or otherwise produces a voltage pulse with each shaft rotation. In the Figure 1 below, the rotating wheel has a bump that closes a contact every time it completes one resolution. If there were two bumps, there would be two pulses per revolution. See Figure 2 below:

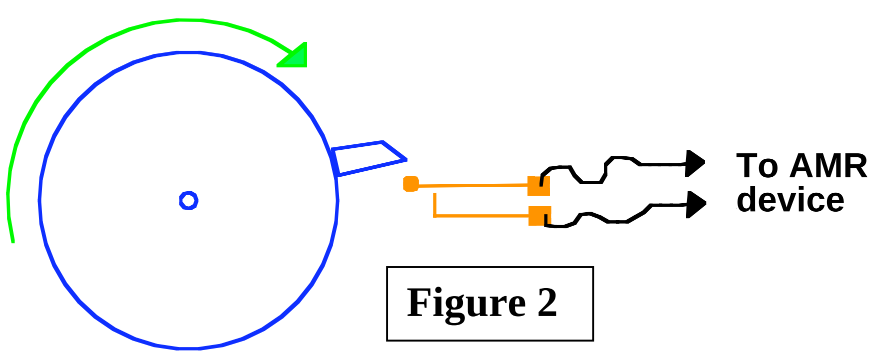

Figure 2

For discussion purposes, let's say that the encoder wheel in Figure 2 is connected to a gear train that the divides the rotations by ten. The output shaft of the gear chain is then connected to a wheel. We would like to use the incremental encoder on the input side of the gearbox to determine the position of the wheel on the output side. If we simply count the number of revolutions of the input wheel we will know (to within 1/10 of a revolution) the position of the output wheel. However as its name implies, the incremental encoder can only register the number of rotations **if we are always there to count them.** If we neglect to count for a while or lose track of the number, we cannot go back and determine the number of rotations that have occurred. Thus we can never be utterly sure that we know the position of the output wheel. If we lose track we can still count the new increment of rotation, but we do not know the **absolute** position of the wheel. That is why this is called an incremental encoder.

Water meters with incremental encoders

In the design of incremental encoders for water meters, the sensor is often placed early in the gear train so that it will count one pulse for each gallon of flow. Note that the number of pulses per gallon is defined as the meter **"resolution".** High resolution is valuable because it can provide leak detection and more precise billing. The diagram below shows a four-digit turbine meter with an incremental encoder:

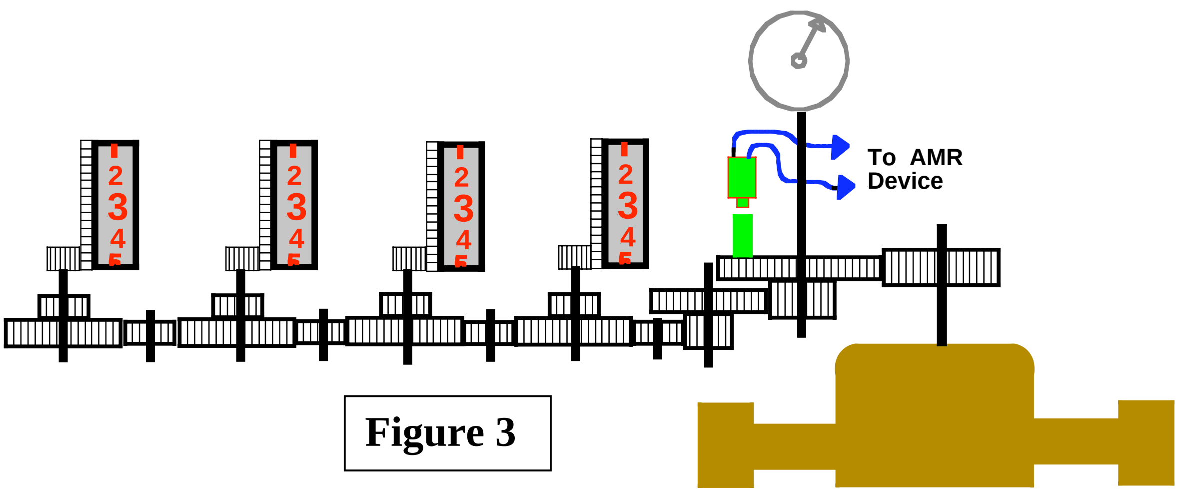

Figure 3

The water flows through the meter body, which has an output shaft that is connected to a reduction gear. (Often a magnetic coupling is used to eliminate the need for shaft seal at the meter body). In this example, this gear rotates once per gallon, and is coupled to a clock-style "leak" dial which displays very low flow. This gear also drives the incremental encoder, producing one pulse per gallon. There is additional reduction by a factor of 10 or 100 before driving the first number wheel of the billing display. Each following number wheel is driven from a gear that divides the rotation by an additional factor of ten. As a result, while the display may have a resolution of 100 gallons (the "billing unit"), the incremental encoder can provide one pulse per gallon.

Sensors for incremental encoders

The heart of the incremental encoder is, of course, the device which senses shaft revolution. While the sensor is conceptually simple, it is challenging to design a reliable, low-cost sensor that requires little or no power and will last for millions of operations. The most obvious approach would be to use a simple switch or contact that is actuated by the shaft (as in Figure 2). In practice this design would be problematic; however it does reveal the stringent requirements that this application requires. First, in many cases an extremely low-torque sensor is required so that it can be employed with turbine meters without affecting accuracy. In general this implies that a sensitive, non-contact form of sensing is required. Second, the long-life requirement dictates the use of a low-wear mechanism. Finally, the requirement for reliability and meter accuracy means that the switch contacts must operate dependably, even when the meter has been in service for millions of actuations. Even more challenging, the contacts must reliably operate even after the meter has not been used for years; this is demanding because contacts that are regularly actuated stay "clean". However contacts that are at rest for long periods may become plated with insulating oxide or polymer films. A final issue concerns the possibility that contacts will produce spurious pulses under conditions of shaft vibration or other unexpected conditions.

Currently there are only a few types of sensors that are widely used in pulse-type water meters.

1. Magnetic reed switches are hermetically-sealed glass capsules which contain a pair of contacts that close when in proximity to a magnetic field. These switches are non-contact and are actuated by a magnet mounted on the shaft; they are very popular and feature long life and low cost. Reed switches can provide excellent performance, but they must be carefully selected and qualified.

2. Weigand sensors are solid-state sensors which produce a voltage pulse when actuated by a magnet. Since they are true solid-state devices, they promise almost unlimited life.

3. Other technologies for incremental encoders include optical, inductive, capacitive, or Hall-sensing schemes. All of these solid-state approaches offer features such as long life and reliability; however, since they require electric power to operate, they are often limited to special applications.

4. The "generator remote" requires mention because of its important place in the history of meter reading. These products first appeared in the 1950's, and were the first practical solution to inaccessible meters. These devices were a type of incremental encoder that was used exclusively with positive displacement meters. As the output shaft rotated, it would wind a spring which stored mechanical energy. After exactly 50 or 100 revolutions, an escapement would trigger and release the stored energy into a mechanism that would spin a small electric generator. The generator would generate an electrical pulse which would increment an

electromagnetic counter which was remotely mounted in an accessible location and wired to the meter. The meter reader could then perform a visual read. This equipment was supplied by most meter vendors and was, for many years, the only solution to inaccessible meters.

Conceptually ingenious, the generator remote suffered, unfortunately, from poor engineering and general technical mismanagement. The generator "head", although somewhat complicated, was surprisingly reliable. Unfortunately the remote counter was a fairly precise device that had to be sensitive enough to be actuated by the limited energy provided by the meter generator. In many cases this counter was not manufactured by the meter company and was provided by manufactures of similar devices. Possibly as a consequence of this outsourcing, these counters were rarely suitable for the utility environment and performed very poorly. Their enclosures were insubstantial and, in a curious flare-up of engineering optimism, were not sealed. As a result, the counters were notably inaccurate as they "lost" counts due to shaft binding caused by flexing of the mechanism, freezing, and insect intrusion. Even more unanticipated, the counters would occasionally register extra counts; this was usually due to the counter being sensitive to slamming doors or other mechanical shock.

Meter manufacturers rarely addressed these deficiencies, and massive numbers of generator remotes remained in service even though performance was poor. Currently few, if any, meter manufacturers continue to manufacture these devices.

In any case, the history of the generator remote illustrates the crucial requirement that a meter-reading device using an incremental approach must be very carefully designed. It is also worthwhile to note that the unfortunate history of the generator remote has left a legacy of doubt regarding the inherent reliability of incremental encoders. Given the poor execution and support of the technology, this reputation may be unwarranted.

Application of meters with incremental encoders

As shown in Figure 2, the output of the encoder is electrically connected to some sort of output device. In all cases this device must contain a counter which will accumulate the count for display or transmission. Clearly this device must count reliably, or else the value displayed by the counter will differ from the usage recorded by the mechanical register. Therefore, the connection between the encoder and the counter must never be broken; for this reason, if the meter and counter are physically separate there is usually a provision for sensing and reporting tampering. Note that an incremental encoder requires that the counter must always be prepared to count pulses and must never lose its count or be reset. This requirement is inherent in the use of incremental encoders, and is a disadvantage in their application.

When the incremental meter is used with visual remotes, the pulses from the meter are fed, via a wire, to a counter/display which is accessible by the meter reader. In "touch-pad" applications, the counter accumulates the counts and maintains the current meter reading. When the meter is to be read, the meter reader probes the "touch pad" with a wand. The current counter value is then converted to a series data stream and is forwarded to the handheld.

In drive/by and fixed-network applications, the counter value is converted to serial data which is wirelessly transmitted to a receiver. Note that a touch pad or RF device must always have a battery if it is used with an incremental encoder; it is necessary to power the counter.

Absolute encoders

The absolute encoder is more complicated then the incremental encoder, but it offers the advantage that it can display the actual position of a shaft at any time, without depending on an external counter to derive it implicitly. An absolute encoder employs a group of switches or sensors to produce a unique digital "word" for each position of a wheel. In one common design called a 'brush" encoder, the wheel contains four tracks of copper segments, with each track containing 10 segments. There are four brushes, or contacts, which slide over each of the tracks as the wheel rotates; each brush represents one "bit" of a four-bit digital word. The presence or absence of the copper trace makes or breaks a circuit and changes each bit from a digital "one" to a digital "zero". The traces are arranged in a special pattern to produce a unique output for each of the 10 positions.

The segments are arranged in a special pattern so that ten unique digital "words" are produced as the wheel rotates one revolution. The signals from the four brushes can be connected to digital logic which converts the digital word to a format which can be displayed or transmitted. See Figure 4:

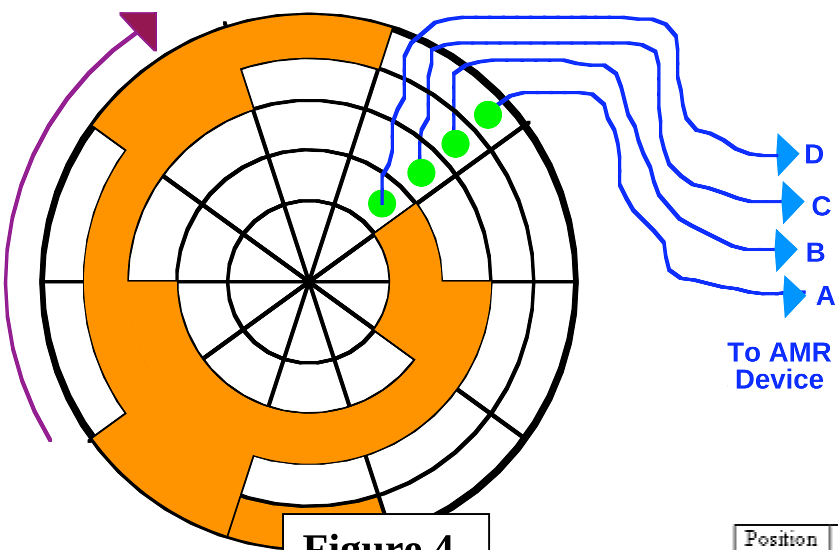

Figure 4

Position	Brush A	Brush B	Brush C	Brush D
0	0	0	0	0
1	1	0	0	0
2	1	1	0	0
3	0	1	0	0
4	0	1	1	0
5	1	1	1	0
6	1	0	1	0
7	0	0	1	0
8	0	0	1	1

Water meters with absolute encoders

Water meters with absolute encoders contain the same basic mechanical elements as meters with incremental encoders. The schematic diagram below shows a four-digit meter with an absolute encoder:

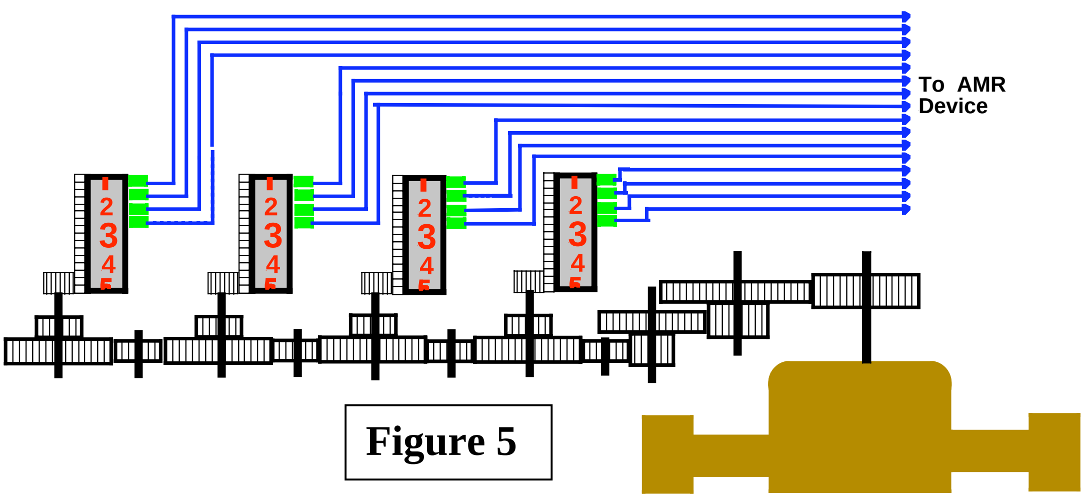

Figure 5

The meter body output shaft is connected to a gear reducer that drives the least significant display wheel. Each higher-order wheel is driven, in turn, after division by a factor of 10. Each of the six display wheels is equipped with a 10-position absolute encoder, so multiple digits can be recognized. Wires from each of the contacts (4 X 4 = 16 wires) connect to an integrated circuit within the meter that formats the data and prepares it for output.

The absolute sensor has the important advantage of providing the correct value at any point in time, without the need of a counter to keep track of position. It is only necessary to energize the integrated circuit and read out the current position of the dials.

The absolute encoder does, however, have several disadvantages compared to the incremental approach. First, whereas the resolution of the incremental encoder can easily be made very high, the increasing resolution of the absolute meter requires the addition of additional encoded dials; this increases cost. Also, the construction of the absolute encoder is complex; in particular, the "brush" design contains numerous small parts and is subject to contact problems associated with insulating films and finite lifetime due to wear. Finally, all absolute sensors possess, to some degree, the problem of "transition ambiguity". Since the absolute encoder steps through a series of finite steps, there always exists a region of uncertainty between transitions as the wheel rotates from one number to the next. Various electronic techniques can minimize the effect of transitions, and the quality and precision of the encoder will also have an effect. The common approach to overcoming this problem is to verify that the encoder output from each wheel is valid; if not, then an error code or special symbol is transmitted until the wheel fully rotates to complete the transition.

Sensors for absolute encoders

The absolute sensor is complex due to the number of contacts and the reliability and lifetime that is required. The mechanical "brush" encoder is the most common approach, but long-term field experience has indicated the need for more reliable designs. Since the absolute encoder only needs to be energized when the meter is to be read, it is possible to employ "active" sensing instead of passive contacts and still obtain suitable battery life in AMR applications. A number of proprietary technologies have recently been incorporated into encoder meters. These include various optical, capacitive, and inductive sensing means. In all cases these approaches feature non-contact sensing, which is a tremendous improvement over the sliding brush contact. Non-contact sensing will provide essentially unlimited life, and its low-torque requirement improves meter accuracy and permits its use with turbine meters.

Application of meters with absolute encoders

When the absolute meter is used with manual reading, it is usually used in conjunction with a "touch pad" that is wired to the meter. When the meter is to be read, the meter reader places a probe near the pad. Both the probe and the touch pad contain a coil which comprises one-half of a transformer. The probe transfers energy to the pad, which provides operating voltage and "wakes up" an integrated circuit in the meter. The encoder provides the dial position information, which the integrated circuit converts to a serial data stream. The data is transmitted to the touch pad, where it is received by the probe and sent to the handheld.

In drive/by and fixed-network applications, the AMR device provides the voltage to energize the meter circuitry when the AMR device requests a meter reading. The serial data produced by the meter is processed by the AMR device and transmitted to a nearby vehicle or back to the utility.

The absolute encoder may offer security advantages over incremental devices; if the wire between the meter and the pad or AMR device is broken, there will be no error as long as the wire is connected at the moment a reading is taken.

Absolute versus incremental

The question of which is "best", absolute or incremental, is a somewhat provocative question in the water industry. Absolute encoders appear to be preferred by many in the US, yet European water utilities use incremental encoders exclusively and they seem to be doing fine. Also, US gas utilities have many millions of AMR devices in the field that use incremental encoders, and there is little concern about their performance. Also note that, in general industrial and commercial applications, the use of absolute encoders is actually relatively rare; incremental encoders are used in far greater quantity. As mentioned above, some of the opinions held by the US water industry may be a result of past experience with poorly designed products.

Nevertheless, there are very real technical issues which may favor one technology over another. Although the differences may sometime blur as technology advances, it is possible top make some general statements about encoder selection:

Incremental (known as a "pulse" meter)	**Absolute** (known as an "encoder" meter)
Greater resolution	Less opportunity for tamper or to lose data
Less expensive	Lower batter drain
Compact size	Touch pad circuitry is low in cost
No ambiguous states	