The Impact of Signal-to-Noise Ratio on Guided Wave Radar Performance

Magnetrol®

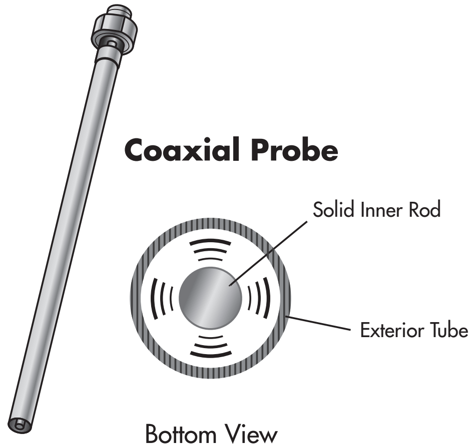
Guided Wave Radar (GWR), although a new technology relative to the industrial level market, has been used successfully in industrial applications for over a decade due to its superior performance, application flexibility, and immunity to changing process conditions. However, even with these benefits, and as is well known to experienced users of GWR technology, all applications are not created equal.

Although several factors can determine the likelihood of success when applying GWR to a level measurement application, most notable is the dielectric constant of the process medium. Process dielectrics range from that of water (very conductive) having a nominal dielectric constant of 80, to very light hydrocarbons (non-conductive) having dielectric constants in the range of 1.4 to 1.7. The effective dielectric constant can be even lower when certain process conditions like boiling, flashing or foaming occur, or when bulk solids are considered. The corresponding "GWR Reflection Coefficients" of these media, which are critical for reliably detecting the process level, range from about 80% for water to less than 5% for hydrocarbons like propane and butane.

GWR is a "contacting technology" because the GWR probe is in direct contact with the medium being measured. Since the signal is "focused" in or around the probe, the primary advantage of having the probe contacting the process medium is that very little energy is lost as the signal travels down the probe. Disadvantages include mechanical issues related to any contacting sensor (such as buildup) and the complications created in the matter of probe selection.

As shown in **Figure 1**, the most "efficient" GWR probe design (one that has the best impedance control and highest sensitivity) is the coaxial probe.

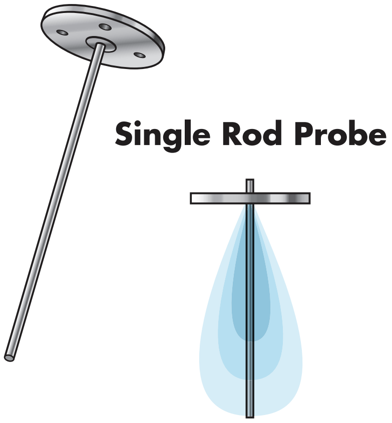
Figure 1



Bottom View
Electromagnetic Propagation

Unfortunately, many applications will not support this probe. This is due to the inherently higher cost structure, and the possibility of the coaxial probe clogging or exhibiting build up, which often drives the user toward other less ideal probe designs. One such design is the single conductor (sometimes called single rod) probe. As shown in **Figure 2**, the single conductor probe is popular because of its simpler design, lower cost and greater resistance to buildup/clogging; however, it is the most difficult probe to work with due to its inefficient propagation and performance dependencies related to the application and installation.

Figure 2



Side View
Electromagnetic Propagation

For example, when inserted directly into tanks or in non-ideal side mounted chambers, the single rod probe has an unavoidable large impedance mismatch at the top of the probe that can interfere with level detection. Single rod probes are also much more affected by extraneous objects in close proximity (i.e. nozzles) and due to its dispersive nature, has much lower sensitivity than other probe types. This combination of unwanted reflections and low sensitivity can make the application of the single rod probe very problematic.

"Signal" and "Noise"

The entire principle of utilizing GWR for level measurement is centered on the ability to detect and act upon the signal reflection (impedance mismatch) at the surface of the process medium. In an ideal world, this reflection from the process medium would be the only reflection present along the entire length of the probe. In this ideal case, the very small amplitude GWR signal reflected from a very low dielectric medium would be easy to detect and interpret, resulting in reliable level measurement and one probe could work for all applications in the world. There would be no need to choose between the different probe types.

In practice, however, this is simply not the case. Many other sources in a typical GWR application can produce unwanted reflections. The amplitudes of these "unwanted" reflections can be large, which makes it difficult to distinguish them from the actual level reflection and compromises reliable level measurement.

For this discussion, we will refer to these two cases as "signal" (desired signal from a level surface) and "noise" (unwanted reflections from anything other than the desired level signal, including electrical noise and other disturbances).

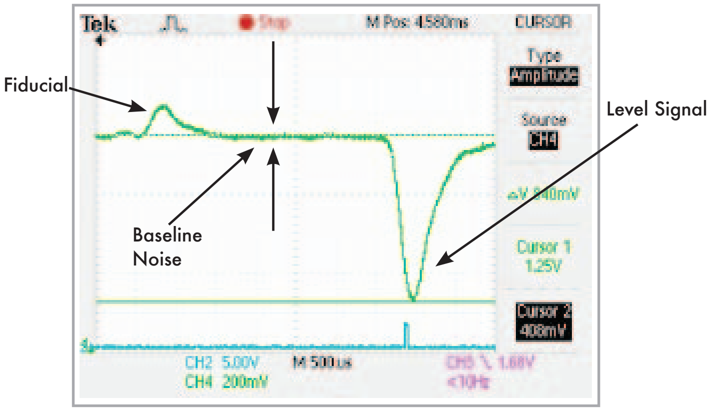
Transmit Pulse Amplitude and Signal-to-Noise Ratio

In recent years, much has been said in the industry about the importance of the amplitude (size) of the GWR transmit pulse. While the size of the transmitted radar pulse is certainly important, it is a fact that pulse amplitude alone will not always yield reliable, accurate level measurement under all process conditions. A far more important parameter in reliable level measurement in difficult applications is the **signal-to-noise ratio (SNR)**, which essentially describes the difference between the desired signal and the unwanted noise.

As in our ideal case mentioned earlier, if the signal is much larger than any noise present, reliable level detection is a relatively simple matter. However, if the amplitude of the noise approaches that of the level signal, loss of accuracy or linearity is the first observed effect due to distortion of the level signal as it passes through and interacts with the noise. Worse yet, if SNR is bad enough, the adverse signal interaction can actually result in a loss of the level signal.

The rest of this paper discusses SNR in more detail, explains the effect of SNR on level measurement, describes how SNR is measured and uses actual test data to show how the Eclipse® Model 706 addresses this critical design issue. The following image provides an example of excellent SNR:

Excellent SNR with a Coaxial Probe



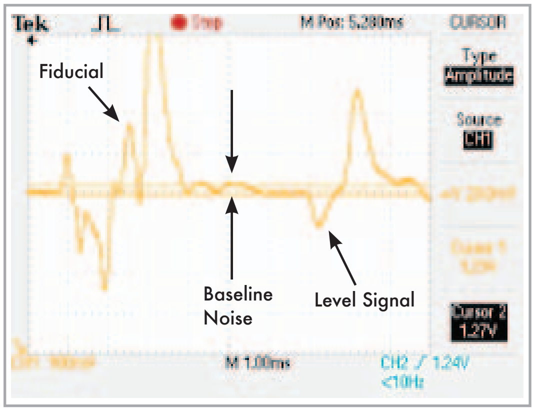
In this image of a coaxial probe measuring water, the water signal is large and there are no noticeable ripples, peaks, bumps or other noise in the baseline of the measurement region. Under these conditions, the signal is approximately 840 millivolts in amplitude. With no visible noise in the baseline, the ratio of the signal to the noise (signal ÷ noise) is very large:

$$\mathbf{SNR = 840mV signal \ / \ 20mV \ noise = 42}$$

The result: Detecting this level signal is a very simple matter.

On the other hand, things look considerably different in the scope trace below:

ECLIPSE Model 706 Single Rod Probe Measuring Oil

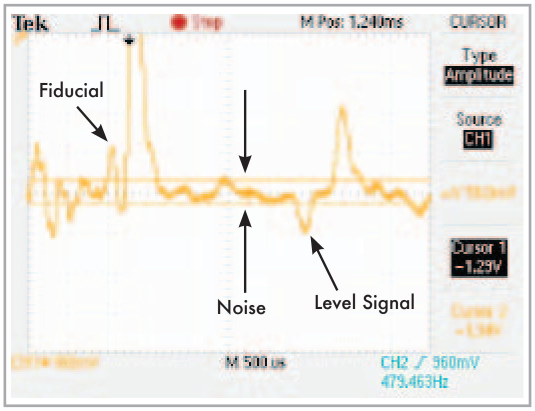


In this image, a single rod probe is measuring oil with a dielectric constant of 2. Although the desired level signal (oil surface) is evident, there are many other irregularities in the waveform baseline. Several factors can create these unwanted signals, and, if they are large enough compared to the signal amplitude, accuracy issues and/or loss of the level signal can result. With a signal of 88mV and 20 mV of noise, the SNR is:

SNR = 88mV signal /20mV noise = 4.40

Although much lower than the previous water example, the scope trace below shows that this SNR is still almost 3 times better than competitive GWR devices under similar conditions.

GWR Competitor: Low SNR with Single Rod Probe



In this case, there is much more noise present. Therefore, the resulting SNR is:

SNR = 88mV signal /56mV noise = 1.57

What causes these "unwanted" reflections? The simple answer is – just about everything. By the pure physics of the technology, and regardless of the manufacturer, the GWR pulse will reflect from any impedance discontinuity in its entire signal path. This signal path originates at the electronics of the transmitter, and includes the internal cable and connectors, the probe connector, the probe itself and the (desired) impedance discontinuity created by the surface the GWR is measuring. Any impedance discontinuity in this entire chain will create a signal reflection, which can then be "re-reflected" by any of the prior impedance discontinuities mentioned above. These re-reflections are a type of noise sometimes referred to as "rattles" and can appear along the baseline of the measurement region (i.e., the noise in the baseline of the previous scope trace).

It would be desirable to eliminate all the unwanted impedance discontinuities, but frankly speaking, it is also impossible. In fact, there are too many practical limits to eliminating unwanted impedance discontinuities to attempt to list them all. However, a good example of a known, unwanted, reflection is one previously mentioned – the top-of-probe discontinuity of the single rod probe.

This large, unwanted reflection is due to the large impedance mismatch (discontinuity) that occurs when the GWR signal exits the nicely contained probe seal assembly and enters the tank. This reflection first travels back up toward the transmitter and, if it is not totally absorbed at the electronics, will be "re-reflected" back down the probe and appear as baseline noise in the measurement range. If this effect is not controlled, it will greatly compromise the low dielectric performance of the single rod probe.

Many GWR manufacturers talk about transmit pulse amplitude; however, beyond the point at which the transmitter signal amplitude is sufficient enough to detect a given dielectric, amplitude plays virtually no role in the detected SNR. In fact, when too many sources of unwanted reflections are present, a larger transmit pulse amplitude will simply elevate the noise at the same rate it elevates the level signal. The resulting change to the SNR is zero – **the larger pulse provides no benefit in and of itself to SNR.**

The only role of a larger transmit pulse is to assure that noise in the system does not become dominant in the overall SNR in low signal return cases (such as long probes under low dielectric conditions). Too small of a transmit signal would result in too small of a received signal in these cases, requiring excessive signal amplification in the level transmitter. In other words, if the transmit pulse is insufficient, at some point the noise contributed by the circuitry could exceed that of the rest of the system.

Transmit pulse amplitudes in advanced GWR transmitters such as the ECLIPSE Model 706 are typically several hundred millivolts. This has been found to be more than adequate to assure that the overall system performance will be determined by the careful design of the RF signal path (from the transmitter to the probe and ultimately the level surface) – and not by the internal noise of the transmitter.

As a result, SNR is the key component of performance that goes beyond simply raising the transmit signal amplitude. For that reason, Magnetrol® redesigned the front-end circuit and other components of the ECLIPSE Model 706 to optimize the SNR.

ECLIPSE Model 706 Transmitter

The new ECLIPSE Model 706 front-end circuitry includes several innovations that not only increase the transmitted pulse amplitude, but also improve the received signal strength and, most importantly, increase the signal to noise ratio.

Diode Switched Design (Patent Pending)

The new ECLIPSE 706 utilizes a new design concept called the Diode Switched Front End, which enhances front-end performance in several ways. The diode switched circuit operates by only connecting the transmit pulse generator to the probe circuit during the brief (one nanosecond) time that the transmit pulse is active. The ultra-fast microwave diode then turns off, and is virtually removed from the circuit. When the diode switch turns off, it effectively decouples the transmit pulse generator from the probe. The result is complete isolation of the receiver circuit from the transmit pulse generator. This maximizes receiver sensitivity by directing all received energy toward the receiver itself.

Many GWR manufacturers also speak of signal isolation, but their components do not offer *complete* isolation. In fact, when their devices are in the receive state, an internal ON resistance creates a small but measurable signal loss in the receiver. The diode switched circuit design does not experience this issue.

Another important feature of the diode switched technique is how it relates to SNR. As mentioned previously, unwanted reflections can occur in any practical GWR system, and the best way of dealing with this issue is to design the electronics with a high quality, broadband 50 ohm impedance match at the signal origin (electronics). This ensures that any unwanted signals will be absorbed by the electronics, and not be re-reflected back down the probe. It also prevents re-reflections from appearing in the baseline of the measurement region, which improves the SNR.

Summary

As more demanding applications require the use of GWR transmitters, it is important to recognize the factors that dictate successful performance. This paper has described the significance of two of these factors: the SNR and larger transmit pulses as they relate to level measurement in GWR systems.

Great care was taken in the design of the new ECLIPSE Model 706 transmitter. This solution combines optimized front-end circuitry and higher transmit pulse amplitude with improved receiver sensitivity and improved SNR to deliver superior performance than previous GWR designs.

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