Ensuring Successful Use of Guided-Wave Radar Level Measurement Technology

By Joseph D. Lewis

Guided-wave radar and time domain reflectometry (TDR) have become increasingly popular for measuring the level of powders and bulk solids in bins and silos. Its use is growing at an estimated rate of 12–15% per year, and the size of the worldwide market for guided-wave radar level measurement devices is estimated to be nearly $65 million, with about $25 million being in solids measurement. This means that more than 13,000 units are sold for use in powder and bulk solids applications every year, and that number is growing.[1] There is a good reason for the technology's increasing use and popularity: it works. However, a few tips will enable users to start up and apply the instrument successfully.

How Guided-Wave Radar Began and How It Works

Guided-wave-radar continuous-level sensors typically use TDR technology. This technology was pioneered in the first half of the 20th century for use in geological applications and later was used to detect cable breaks. In the 1990s, TDR was applied as a means for measuring the level of material in a vessel. In less than two decades, TDR and guided-wave radar have become mainstays for measuring the levels of solids and liquids.

In order to identify and explain the key issues that must be properly addressed to ensure successful use of a guided-wave-radar level sensor in a bulk solids application, it is necessary to illustrate how the technology works.

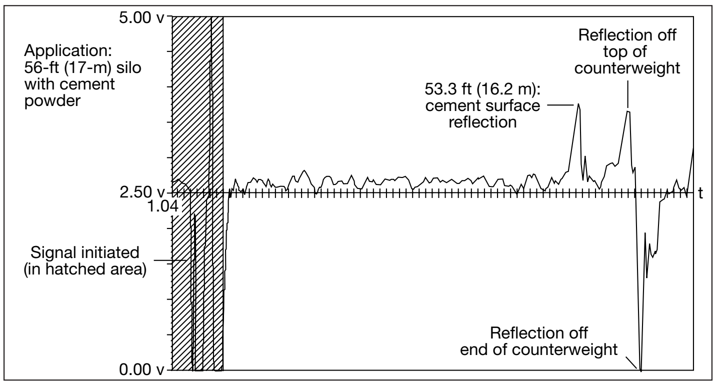

Figure 1: Guided-wave-radar sensor signal in cement application

The level sensor consists of a set of electronics and a probe element. The probe element is called the waveguide. The electronics continuously generate microwave/radar pulses that are transmitted down the probe. The frequency of the pulses is on the low-end of the radar or microwave spectrum—about 1 GHz. These low-power electromagnetic pulses are 1 ns in width.

Because the radar energy is guided to the material surface by the waveguide, the energy is focused and not dispersed into the air, unlike open-air (radar or sonic-type) devices. The size of the energy field sur-

Material	Dielectric Constant (ϵ_r)	Bulk Density (lb/cu ft)
Air	1.0	0
Almonds, shelled	9.0	30–35
Asphalt, liquid	2.5	65
Baking soda	5.7	70–80
Coffee beans, roasted	1.9	22–40
Calcium carbonate	9.1	75
Carbon black, powder	1.4–6.0	4–25
Cement powder	1.5–2.5	85–95
Clinker	2.7	75–90
Corn, whole	5.0	45
Diesel fuel	1.8	52
Ethanol	24.3	56
Flour, wheat	5.0	30–35
Fly ash	1.9–2.6	35–45
HDPE	1.6	35–40
Lime, quicklime	4.8	25–30
Milk powder	1.7	15–20
Nylon	4.0	35–45
Paraffin wax	2.1	45
Polystyrene, expanded beads	2.2	1.5
Potash	5.6	50–60
PVC	1.8	48–52

Table I: Examples of material dielectric constants. Results can vary.

rounding the waveguide or probe depends on the type of waveguide used, which is based on the specific application. This energy field can be as small as 1 in. in diameter or up to about 24 in. in diameter around the probe waveguide. In applications involving powders and granular materials, a single heavy-duty stainless-steel cable is typically used as the waveguide. These cable probes are as large as 0.31 in. in diameter and can handle traction loads up to nearly 4 tons, which is important for solids applications.

Figure 1 illustrates the level of cement powder in a silo measured using a 56-ft cable probe with a 0.31-in. diameter. The installation was good and the signal clean. Radar energy pulses travel at the speed of light along the waveguide. Upon reaching the material surface, the pulses are reflected back with an intensity that depends on the dielectric constant, ϵ_r, of the material being measured. If the material ϵ_r is 2.0, approximately 2.0% of the energy will be reflected. While approximately 80% of the energy is reflected from the surface of water (ϵ_r = 80), granular plastics with dielectrics of 1.6 reflect only 1.6% of the energy. Dielectric constant values for some typical bulk solids are shown in Table I.

When the reflected pulses return, the guided-wave-radar sensor measures the time of flight between the emission and reception of the pulse signals. Half of the time measured is related to the distance of the instrument mounting point to the material surface. The difference between the vessel height and the measured distance is the level of the material in the vessel.

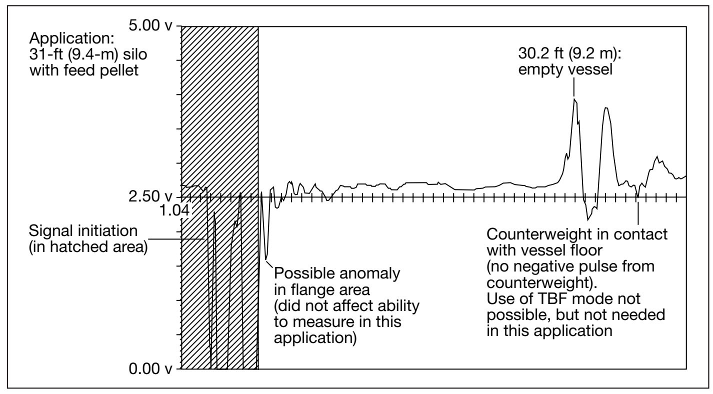

Figure 2: Guided-wave-radar signal in feed application.

Measurements using TDR are not influenced by dust. This is a particularly important feature of the technology when powders are measured, especially during filling with pneumatic conveying systems, In addition, TDR is not influenced by temperature, pressure, or density variations.

Ensuring Success

In addition to following supplier recommendations, users of guided-wave-radar technology

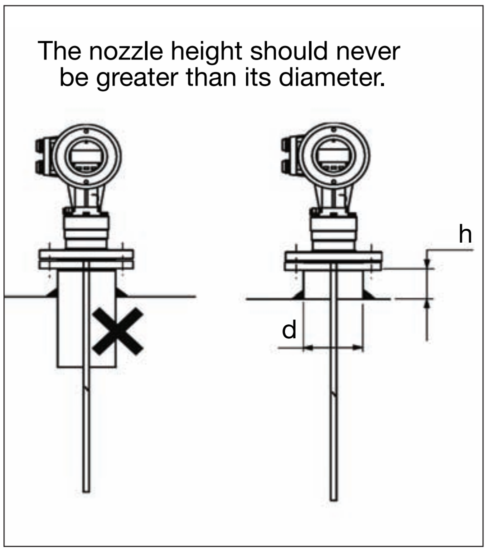

Figure 3: Mounting nozzle, which can be used if necessary but should be avoided if possible. The nozzle height should never be greater than its diameter.

should consider the following four topics to ensure its successful use in measuring powder or bulk solid materials.

Dielectric Constant/Measuring Range. Dielectric constant and measuring range are interdependent. The lower the ϵ_r of the target material, the more challenging the application becomes. The higher the measuring range, the more challenging. The exact relationship depends on the brand and implementation of TDR technology in the level sensor. Therefore, users should consult with a reliable supplier.

Materials that are shown to have ϵ_r values <2.0 do not necessarily generate the signal strength in the reflected pulses to allow the sensor electronics to receive and process it. However, in some units, the signal threshold can be adjusted so that ranges of several meters can be measured with ϵ_r values down to 1.6. Table II presents examples of the relationship between ϵ_r and range. Some manufacturers have developed a modified version of TDR technology known as tank-bottom-following (TBF), which is used in applications in which the dielectric constant of the target material is <2.0.

Tech Tip no. 1: It is important for users in this area to have an accurate and known ϵ_r value for the material to be measured. This enables manufacturers to provide presale application advice based on the material and range, as well as the manufacturers' technology and product. Reliable manufacturers will request samples of low-dielectric or questionable materials so that they can determine their ϵ_r.

Respecting the Electromagnetic Field. Any item that may come within the electromagnetic field of the radar pulses can affect the success of the measurement. Obstructions can present "parasite" reflections. Mounting nozzles or obstructions on the underside of the roof, when they are within the electromagnetic field, can absorb energy and weaken reflected signal strength. They can also present parasitic reflections that may be greater than the reflection off the material surface. The lower the ϵ_r and the greater the distance, the lower the signal strength of the reflection. Obstructions within the electromagnetic field, from the mounting to the probe end, can affect the dielectric constant and range that can be measured.

Tech Tip no. 2: Users should ensure that the mounting method and location will not obstruct the electromagnetic field along the entire length of the probe, from the mounting to the end of the counterweight at the bottom of the probe.

Selecting the Optimal Mounting Location. When considering the optimal

Material	Dielectric Constant (ϵ_r)	Typical Range (m/ft)
Almonds, shelled	9.0	30+/100+
Asphalt, liquid	2.5	30+/100+
Baking soda	5.7	30+/100+
Coffee beans, roasted	1.9	12/40
Calcium carbonate	9.1	30+/100+
Carbon black, powder	1.4–6.0	0–30+/0–100+
Cement powder	1.5–2.5	0–30+/0–100+
Clinker	2.7	30+/100+
Corn, whole	5.0	30+/100+
Diesel fuel	1.8	12/40
Ethanol	24.3	30+/100+
Flour, wheat	5.0	30+/100+
Fly ash	1.9–2.6	12–30+/40–100+
HDPE	1.6	6/20
Lime, quicklime	4.8	30+/100+
Milk powder	1.7	10/33
Nylon	4.0	30+/100+
Paraffin wax	2.1	30+/100+
Polystyrene, expanded beads	2.2	30+/100+
Potash	5.6	30+/100+
PVC	1.8	12/40

Table II: Examples of material dielectric constants and measuring range. The data do not include measuring capability using the TBF method. Results can vary from brand to brand.

mounting location for a continuous-level sensor, the following factors should be considered:

- Angle of repose.
- The desired measuring range.
- Vessel dimensions.
- Internal obstructions.
- Mounting on roof.
- The location of the fill inlet.

Wikipedia defines the angle of repose as an engineering property of granular materials. When bulk granular materials are poured onto a horizontal surface, a conical pile forms. The angle between the surface of the pile and the horizontal surface is known as the angle of repose and is related to the density, surface area, and coefficient of friction of the material. Material with a low angle of repose forms flatter piles than material with a high angle of repose. It is also important to note that materials have a positive and a negative angle. That is, the angle is positive during filling but decreases and becomes negative at some point during discharge.

Tech Tip no. 3: Users should choose a mounting location for the guided-wave-radar level sensor that creates a net-zero effect in regard to the angle of repose. In a cylindrical vessel with center fill and discharge, this location is one-sixth of the diameter from the edge of the vessel. However, it is important to consider the effect of discharging material from the vessel on moving the sensor probe. Even if the effect is slight, users must ensure that the cable probe does not contact the vessel wall (while respecting the electromagnetic field). If needed, users may choose a sensor location slightly closer to the center of the vessel, but anything closer than one-half the radius of the cylindrical vessel is unadvisable. It is also necessary to ensure that the sensor mounting location does not cause internal obstructions to be within the electromagnetic field.

The measuring range and the roof structure itself should also be considered. Ideally, the probe length should be sized to maximize the measuring range, while keeping the end of the probe counterweight off of the cone or vessel wall. The amount of separation needed may depend on the specific technology in question. Figure 2 illustrates the effect on the signal when the counterweight contacts the vessel cone wall. This effect excludes the use of a TBF measuring method that might be needed for very-low-dielectric materials (< 2.0; range dependent).

The roof structure should be strong enough to withstand the anticipated traction loading on the probe, which is based on the material density, the probe length, vessel dimensions, and mounting location. While users themselves must decide how strong the roof structure should be, they can learn the basic guidelines from the supplier. For example, a 33-ft silo with cement powder and a guided-wave radar level sensor with 0.31-in. diameter cable probe produces approximately 1800 lb of traction load on the cable probe during discharge of a full vessel. A load of less than 1 ton is far less than the capacity of the cable probe.

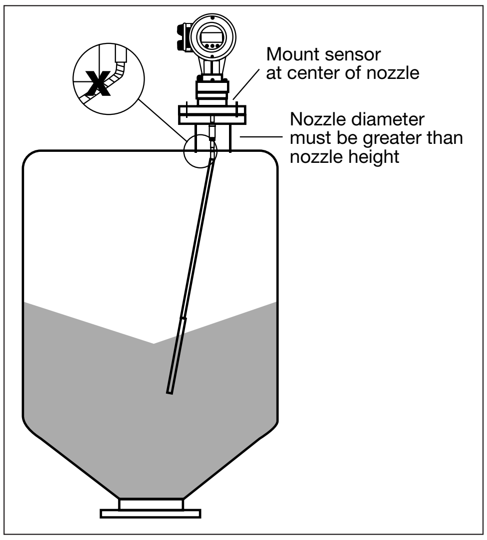

Figure 4: View of mounting nozzle

Tech Tip no. 4: The sensor mounting location will be affected by the fill stream, which is based on the fill inlet location. The sensor should not be installed so that the sensor probe will be in the path of the incoming material. A location as far from the fill inlet as possible should be chosen, although the other sensor location issues should be optimized.

Sensor Mounting. The method for mounting the sensor to the roof of the vessel can determine the difference between success and failure. Users should pay careful attention to this issue in the supplier's installation and operation manual.

Tech Tip no. 5: Whenever possible users should avoid employing mounting nozzles. Figures 3 and 4 present examples of typical mounting-nozzle installations. The ideal mounting method is to mount guided-wave radar sensors plumb, directly inserting them into a welded coupling on top of the silo. Alternatively, an angled or flat mounting flange can be directly mounted to the vessel roof without a nozzle.

If a mounting nozzle of some type must be used (as in the case of a domed roof), the internal diameter of the nozzle must be greater than the height of the nozzle. For a given nozzle height, the greater the diameter, the better. The sensor probe must always be mounted in the center of the nozzle, which eliminates the possibility that the cable probe will become shorted on the nozzle edge during filling or discharge.

The vast majority of guided-wave radar installations are completed without any problem. Eliminating the mounting nozzle or ensuring that it is appropriately sized can resolve 80% of the installation and start-up problems that arise with guided-wave radar units. The remaining installation issues can be addressed by eliminating obstructions within the electromagnetic field or by selecting the proper mounting location.

Conclusion

The demand for guided-wave radar devices has never been higher, and it is growing rapidly. The reasons are simple. The sensors are accurate, reliable under heavy dust conditions (even during filling), and cost-effective (approximately $1800–$2000 on average).

When manufacturers' installation guides and the tips offered in this article are followed, most powder and bulk solids applications will benefit from the use of these sensors. Guided-wave radar technologies have fast become plug-and-play devices, offering greater reliability than other technologies, especially in powders with dielectric constants of ≥2.0. However, even lower-dielectric materials can be measured. For more information, search the Level Measurement blog at www.monitortech.typepad.com.

[1] Market data based on research performed in 2000 by Venture Development Corp. (Natick, MA) for the U.S. Process Level Measurement market.

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