White Paper

Frequency Modulated Continuous Wave Technology

Improving radar accuracy and reliability in challenging applications

EMERSON

Frequency Modulated Continuous Wave (FMCW) technology improves radar level measurement accuracy and reliability in challenging applications

Abstract

The latest non-contacting radar level transmitters offer Frequency Modulated Continuous Wave (FMCW) technology within a two-wire device, which enables the greater measurement accuracy and reliability provided by that technology to be applied to a broader range of applications. This white paper looks at the differences between traditional pulse and FMCW techniques, specifically highlighting the strengths of FMCW-based radar and identifying challenging level measurement applications where FMCW technology is particularly well suited.

Non-Contacting Radar

The efficient operation of process plants relies on accurate and reliable level measurements. These measurements are essential for optimizing process control, inventory management, and custody transfer, all of which can affect profitability. Level measurement also plays a critical role in safety applications such as overfill prevention.

A broad range of level measurement technologies is available to end users, including capacitance, and ultrasonic and guided wave radar, but there are certain challenging applications for which non-contacting radar is most suitable. Non-contacting radar technology provides a top-down, direct measurement of the distance to the surface, which is very accurate and reliable. It can be used with:

- Liquids
- Sludges
- Slurries
- Solids

A key advantage of non-contacting radar is that it is unaffected by process conditions such as:

- Density
- Viscosity
- Conductivity
- Coating
- Vapours

It is also an ideal choice for tanks with moving objects, corrosive products, and wide temperature and pressure requirements, which have no impact on the accuracy of the radar measurements. With no moving parts, built-in diagnostics, and straightforward installation and commissioning, non-contacting radar transmitters are widely adopted for their ease-of-use and low maintenance requirements.

Pulse and FMCW Techniques

To perform continuous level measurements, non-contacting radar level transmitters use one of two main modulation techniques—either pulse or FMCW.

Pulsed Systems

Pulsed systems measure level based on the time-of-flight principle, and use a method called time expansion to convert extremely short time delays to a slower timescale. The surface echo is built up of tens of thousands of short radar pulses emitted from an antenna positioned at the tank top directly towards the process material below. These pulses are reflected from the surface of the material back to the transmitter. The transmitter measures the time delay between the transmitted and received echo signal, and the on-board microprocessor calculates the distance to the process media surface using the following formula: distance = (speed of light x time delay) /2. Once the transmitter is programmed with the reference gauge height of the application—usually the distance from the flange face to the bottom of the tank or chamber—the level measurement is then calculated by the microprocessor.

FMCW Technology

Instead of measuring time, gauges using FMCW technology transmit a radar signal with a frequency increasing over time to create a signal sweep. After the signal is reflected by the process media surface, the echo is picked up by the antenna. As the transmitted signal is constantly varying in frequency, the echo has a slightly different frequency compared to the signal being transmitted at that moment. The difference between these frequencies is directly proportional to the echo delay (i.e. the distance from the transmitter to the process media surface), which enables the level to be accurately measured. An advantage of this technique is that the process variable information is in the frequency domain instead of the amplitude modulated (AM) or time difference domain, which allows more accurate signal conversion. This is the same advantage that FM radio has over AM radio. Most tank noise sources are in the amplitude domain, so FM signal processing can ignore them, and accuracy is not affected.

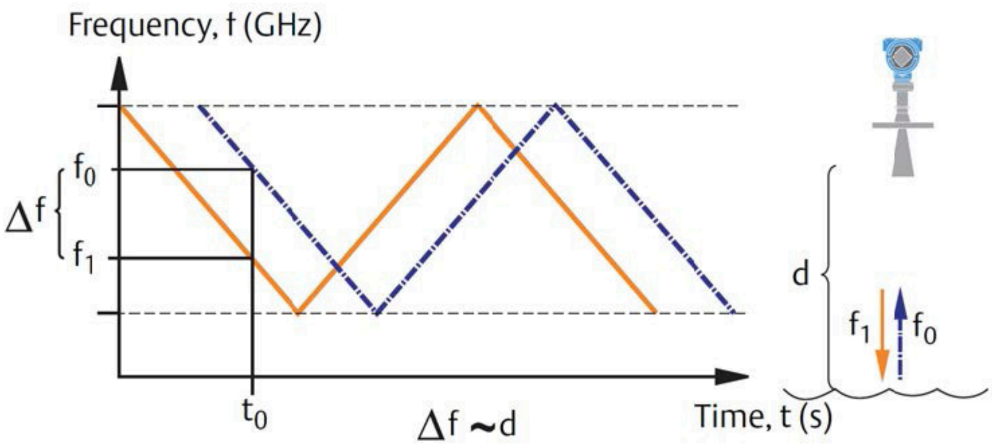

Figure 1. FMCW

FMCW Strengths and Benefits

FMCW Theory

Level measuring radars based on FMCW technology have developed rapidly since their introduction in the 1970s. The superior accuracy and sensitivity provided by these devices compared to those using pulse technology has led to them being recognized as the most stable measurement technique available, and becoming widely adopted throughout the manufacturing and process industries.

The sensitivity provided by FMCW technology is more than 30 times higher than that of pulsed radar transmitters, which maximises signal strength and enables it to deliver superior measurement reliability with greater signal-to-noise ratio (see Figure 1).

If level measurements are being performed using a radar transmitter based on pulse technology, a turbulent liquid surface can lead to a pulse potentially being lost. The radar will misregister and lock onto the next available pulse. Without intelligent software to identify this misregistering, the gauge will display an erroneous measured value, typically 25mm out. For large tanks or vessels storing thousands of gallons of material, this type of error can be significant. The user has no way of knowing that this is a misregistered value. Unlike pulse-based radar, because FMCW does not use a 'time of flight' technique, an error such as this cannot occur, helping to ensure the accuracy and reliability of measurements.

Variations in ambient temperature can also have a significant impact on the accuracy of pulse technology. With pulse radars, there is often no reference for continuous performance and calibration checks, leading to the possibility of unobserved non-linearity and inaccuracy. Also, some manufacturers may use an analogue reference (a wound cable of known length), and these are susceptible to inaccuracy through thermal expansion or contraction of the reference cable.
In FMCW transmitters, the radar sweep must be absolutely linear. To achieve the highest precision, these devices use a crystal oscillator for on-line adjustment of the transmitted frequency. This gives consistent accuracy at dynamic ambient temperature conditions.

For example, in a 17m tank with an ambient range of 118 °C (-48 °C to +70 °C), a FMCW radar would offer measurement stability over the entire ambient temperature range, with a maximum error of plus or minus 0.5mm. For a pulse radar, however, a typical manufacturer's specification states the influence of ambient temperature at between 0.05 percent and 0.1 percent per 10 °C, which would translate to a maximum error of 100-200mm for the same tank.

Application Examples

Here are some examples of applications in which FMCW technology provides accurate and reliable level measurement.

Foam

Foaming liquids may cause weak and varying surface echo amplitudes. The effect of foam on radar measurement can be difficult to predict and depends largely on the foam's properties. In some applications, the foam may dampen out the signal completely, while other types of foam may be transparent to the transmitter. The thickness, density, and the dielectric constant are factors that need to be considered when evaluating an application with foam. On dry foam, the microwaves typically pass through and detect the process media surface below. On medium type foam, the signal can be absorbed or scattered and the results are therefore hard to predict. If the foam is wet, the microwaves are often reflected from the foam surface and thereby the foam surface level is measured. The latest FMCW transmitters have a double surface handling function, which allows the user to select if the foam layer or product surface should be used as output. This enables the product surface to be measured rather than the foam layer in a tank.

Condensation

Generally, FMCW technology is unaffected by condensation and low-pressure steam. However, heavy condensation can affect the measurement. In such applications, air purging may be required to prevent clogging of the antenna. In high-temperature applications, it is recommended to insulate the tank nozzle. Insulation prevents the nozzle from becoming a cold spot, and thus reduces the amount of water build-up and condensation on the antenna. If the temperature in the tank is much higher than the ambient temperature (i.e. the tank is heated and located in a cold area), it might be necessary to heat trace the nozzle in addition to the insulation.

Storage and Buffer Tanks

FMCW technology delivers highly accurate and reliable level readings when applied to both metallic and non-metallic vessels containing any liquid, including oil, gas condensate, water or chemicals. As these transmitters have no moving parts and do not contact the product, they eliminate costly maintenance and improve safety. Additionally, if the FMCW technology is used together with digital reference and filter technology, the highest level of custody transfer accuracy can be achieved. Pulse-based radars can suffer problems if the process material is too close to the antenna, as the signal will travel very quickly between the sensor and the surface, which will affect measurement accuracy.

Blending Tanks

In tanks used for the mixing of fluids, or solids into fluids, level measurements are needed to monitor additions to the process media. These tanks usually have an agitator for mixing, and this kind of obstruction in the tank can cause false signal echoes. However, FMCW technology allows sophisticated software algorithms for masking and ignoring these echoes, so that the accuracy of the radar measurement is unaffected. These algorithms are not possible with a pulsed transmitter.

Reactor Vessels

In tanks used for the mixing of fluids, or solids into fluids, level measurements are needed to monitor additions to the process media. These tanks usually have an agitator for mixing, and this kind of obstruction in the tank can cause false signal echoes. However, FMCW technology allows sophisticated software algorithms for masking and ignoring these echoes, so that the accuracy of the radar measurement is unaffected. These algorithms are not possible with a pulsed transmitter.

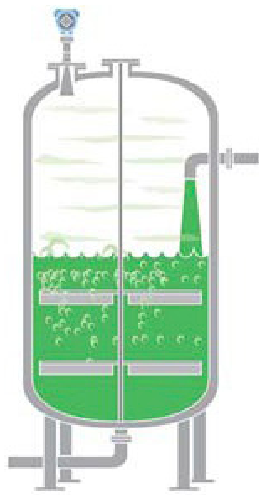

Figure 2. Reactor Vessels Application

Reactor vessels are similar to blending tanks, except that a chemical reaction is required to produce the final product. Here, vapours, foam, and turbulence are often present, while density can change as part of the reaction and pressure can vary from vacuum to positive pressure (see Figure 2). Radar using FMCW can cope with all these factors to provide the accuracy and reliability of measurement required.

Still-pipes

In tanks used for the mixing of fluids, or solids into fluids, level measurements are needed to monitor additions to the process media. These tanks usually have an agitator for mixing, and this kind of obstruction in the tank can cause false signal echoes. However, FMCW technology allows sophisticated software algorithms for masking and ignoring these echoes, so that the accuracy of the radar measurement is unaffected. These algorithms are not possible with a pulsed transmitter.

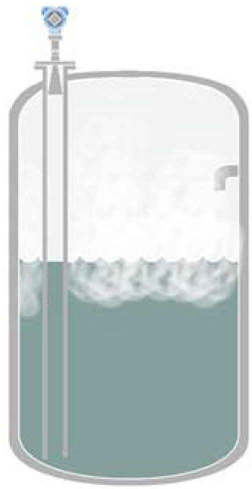

Figure 3. Still-pipe Installation

If the surface of the process media is turbulent, whether from agitation, product blending or splashing, the return signal to a transmitter can be limited. However, the effects of turbulence are usually minor, and in the most challenging conditions, the transmitter may be mounted in a still-pipe to isolate the surface from the turbulence. In addition, a transmitter's measurement performance can be optimised by configuring the appropriate process conditions settings. FMCW technology is an excellent method for level measurement in tanks with still-pipes. Stilling wells minimise foam and turbulence and the tank structure is invisible to the radar because the signal is confined within the stilling well. A radar transmitter can be installed in a still-pipe either when the existing tank connection includes a stilling well or when the measurement is improved by measuring inside a pipe instead of outside (see Figure 3).

High Accuracy and Custody Transfer Applications

The highest performing radar level gauges use FMCW technology, together with digital reference and filter technology, to fulfill OIML R85:2008 custody transfer requirements.

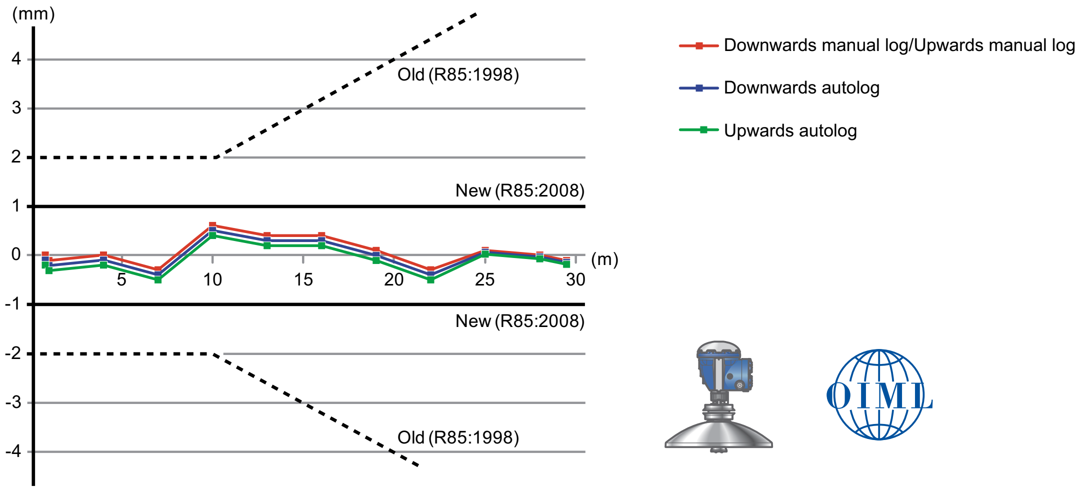

Figure 4. 5900S Fulfills OIML R85:2008 Custody Transfer Requirements.

Open Atmospheric Conditions

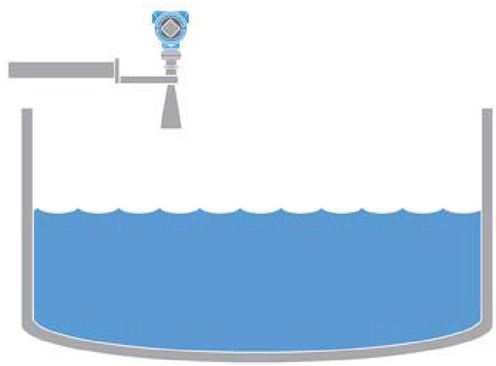

Figure 5. Open Atmosphere Installation

FMCW technology delivers reliable level measurement in applications including sumps, ponds or solids gathered in open piles, regardless of weather conditions such as changing temperatures and wind (see Figure 5).

Two-wire FMCW Technology

Although FMCW technology can provide greater accuracy and sensitivity than the pulse radar technique, traditionally it has required more processing power. Older devices are seen as being 'power hungry' and as a result, FMCW has typically only been deployed within four-wire devices. Consequently, the installation of such devices often necessitates putting additional cable infrastructure in place, which is both costly and time-consuming. This has led to some users sacrificing the additional accuracy and reliability of the FMCW devices and installing two-wire gauges based on pulse technology.

However, the latest non-contacting radars based on FMCW technology have overcome the problem of high processing power requirements.

The greater energy efficiency, which now enables these FMCW devices to be less power-hungry, is provided by unique radar-on-chip technology, which replaces the traditional circuit board. As a result, these devices only require two wires for power and communication, enabling them to be installed widely. This solution enables end users to benefit from the superior accuracy and sensitivity of FMCW technology without needing to install additional infrastructure.

This radar-on-chip technology, with only 12V lift-off, also removes sources of EMC noise which cause signal disturbance. This helps to make further improvements in measurement accuracy and reliability. These devices provide extremely reliable performance, even if loop power is compromised.

An embedded power reserve keeps the devices self-powered for up to two seconds, making them immune to intermittent power losses. Minimum power requirements as low as 12V dc enable the technology to provide accurate and reliable level measurements in challenging applications. These include potentially explosive environments and events such as large power losses occurring as a result of long or old wires being run from a standard 24V dc power supply.

Conclusion

Non-contacting radar transmitters have been widely adopted throughout the process industries as an easy-to-use and low-maintenance solution for measuring level. The two main modulation techniques - pulse and FMCW – are both effective, but with greater sensitivity and accuracy, FMCW has become the preferred choice across numerous challenging applications and for the highest level of accuracy in custody transfer applications. Older FMCW transmitters have been regarded as power-hungry, with the technology being deployed only on four-wire devices. However, as the latest transmitters provide greater energy efficiency, they require only two wires. This eliminates the need for additional infrastructure to be installed, and enables these devices to provide accurate and reliable level measurement in even more challenging applications.

For additional information, visit: www.Emerson.com/RosemountLevel

Linkedin.com/company/Emerson-Automation-Solutions

Twitter.com/Rosemount_News

Facebook.com/Rosemount

YouTube.com/user/RosemountMeasurement

00870-0100-4408 Rev AB, January 2023

ROSEMOUNT™

EMERSON™