White Paper
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Why Radar Antenna Selection is Vital in Marine Level Measurement Applications

Abstract

This white paper explores the considerations that ought to be made when selecting radar-based devices to perform level measurement in the many different tanks found aboard ships. The paper focuses on how the unique characteristics of different antennas contribute to enhanced measurement accuracy and reliability in the challenging maritime environment, thereby helping to optimize the performance of cargo monitoring and fuel monitoring systems.

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Introduction

Accurate and reliable cargo and fuel level measurement is vital in helping to ensure the safe and efficient operation of marine vessels. Because of the large variety of level measurement instruments available, selecting the appropriate device for a particular application can be challenging. While many level measurement technologies are adaptable to multiple applications, there is no single level device that is perfect for every application. However, with more than five decades of consistent advancement, radar has emerged as a favored technology for level measurements in numerous industrial applications, including on various tanks aboard ships. Depending on the application, it is important to select the correct antenna for non-contacting radar devices on these tanks. This paper delves into the specific advantages that different antennas bring to cargo monitoring systems and fuel monitoring applications, and describes some of the fundamental parameters that are of importance for the overall performance of radar-based level measurement instruments.

Fundamental Radar Parameters

Basic Radar Technology Overview

Level measurement instruments employing radar technology emit microwaves to measure the distance to the surface. Microwaves are commonly defined as electromagnetic radiation with wavelengths ranging from 3 to 300 millimeters, and the relationship between wavelength and frequency is inversely proportional, signifying that a shorter wavelength corresponds to a higher frequency.

Over the years, frequency modulated continuous wave (FMCW) has become the primary modulation technique on which non-contacting radar level instruments are based. These devices operate on a continuous transmission of radiofrequency signals. Unlike traditional pulse radars, FMCW radars continuously vary the frequency of their transmitted signals over time. By analyzing the frequency shift between the transmitted and received signals, FMCW radars can determine the distance to the target surface. One key advantage of FMCW radar transmitters in level measurement applications is their ability to provide high accuracy and resolution. The continuous wave allows for precise measurements, making FMCW devices suitable for a wide range of applications.

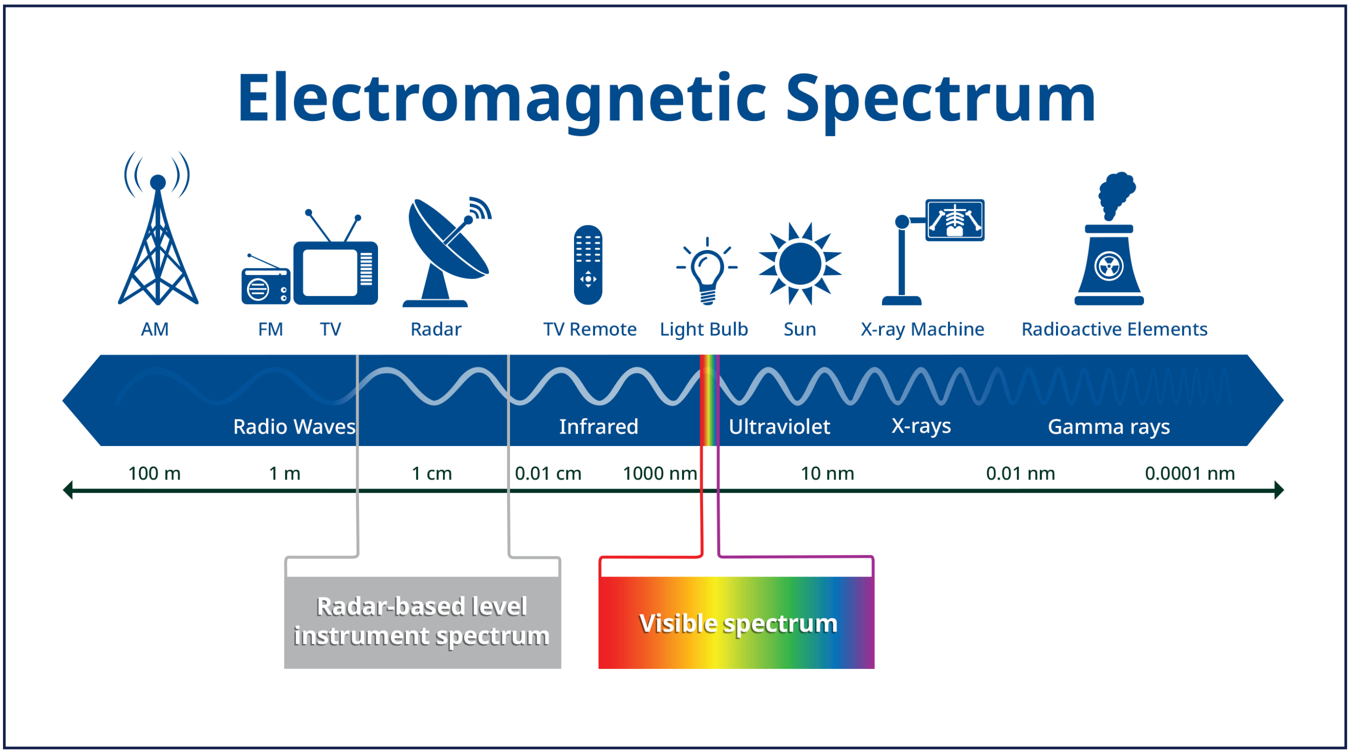
Frequency Bands

Frequency represents a fundamental characteristic of any radar-based level instrument, exerting a direct influence on measurement performance. Historically, three distinct frequency bands, namely C-band (~6 GHz), X-band (~10 GHz), and K-band (~26 GHz), have been employed for level measurements. More recently, radar-based level instruments utilizing frequencies within the W-band (~80 GHz) have also emerged. It is important to bear in mind that not all frequencies are equally well-suited for every application. A careful selection should be made based on the specific requirements of the intended application.

Bandwidth

The bandwidth of an FMCW radar level device refers to the range of frequencies covered by the transmitted signal. In FMCW radar, the frequency of the transmitted signal continuously varies over time, creating a frequency-modulated waveform.

In FMCW radar level devices, the bandwidth is a crucial parameter that influences the device's ability for high resolution, where a broader bandwidth typically allows for better range resolution. The choice of bandwidth in FMCW radar is often determined by the specific application requirements, taking into consideration factors such as the desired range resolution and environmental conditions.



Dielectric Constant

The dielectric value is an important parameter, as non-contacting radar, guided wave radar and capacitance level instruments are all impacted to some degree by the dielectric value of the material to be measured.

In level measurement terms, the dielectric constant (dc) is used to signify the reflectivity of a material. Standard measurements of dielectric are referenced to vacuum with a dielectric of 1. When assessing other materials, their dielectric values are compared to that of a vacuum. In reference to this, some media commonly found in marine tanks tested under the same conditions have the following values at 20 °C.

Medium	Dielectric Constant
Diesel fuel	2.1
Heavy fuel oil	2.2
Crude oil	~2.1 – 2.6
Ammonia	15
Methanol	33
Water	80

The conductivity of a solution is dependent on factors such as its chemical composition, ionization capabilities, and concentration. While there is no straightforward conversion formula from conductivity to dielectric, a general observation is that non-conductive materials typically exhibit low dielectric values, whereas conductive materials tend to have higher dielectric values. However, an important exception to this generalization is water. Water-based fluids, alcohols, most inorganic acids, and caustic materials generally have high dielectric constants. Since water is a polar molecule, its dielectric constant is quite high, while most hydrocarbons, being nonpolar, typically have low dielectric constants.

Radar Signal Reflection

In level measurements utilizing radar technology, the measured media needs to provide sufficient reflection of the transmitted radar signal. In general, the higher the dielectric constant, the stronger the reflected signal. Nevertheless, additional factors also influence the transmitted signal.

As the distance to the target increases, the reflected signal must be stronger to ensure an adequate return to the radar device. Additionally, impact from turbulence or ripples on a liquid surface can lead to signal scattering, diminishing the signal received by the radar device. In cases where agitation is coupled with a low dielectric medium, unintended reflections from internal structures within the tank may surpass the intended liquid level measurement.

The reflectivity of a compound is predictable and is a function of its dielectric permittivity. It can be determined by:

$$R = \frac{(\sqrt{\varepsilon_r} - 1)^2}{(\sqrt{\varepsilon_r} + 1)^2}$$

R = Reflectance
ε_r = Relative dielectric permittivity

As can be ascertained from the equation, when the dielectric permittivity increases, the amount of signal reflection also increases. Meanwhile, the opposite prevails when the dielectric permittivity decreases.

Radar Signal Strength, Antenna, Beam and Frequency

Signal generation is based primarily on the frequency and the size of the antenna. The gain of an antenna is a measure of its ability to direct or focus the radiated signal in a particular direction. The antenna gain is calculated by the following equation:

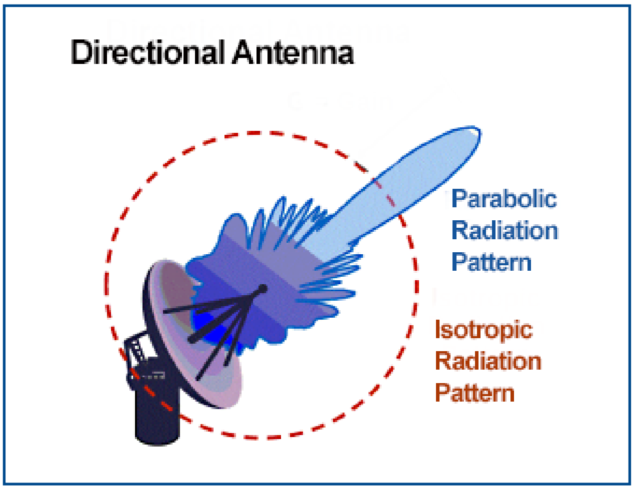
$$G = \eta(\frac{\pi d}{\lambda})^2$$

G = Gain of the antenna
η = Effiency
d = Antenna diameter
λ = Wave length

where the gain (G) of an antenna relates to the antenna diameter (d), wavelength (λ), and efficiency (η), enabling the quantification and optimization of antenna performance for various applications.

Comprehending this equation empowers users of radar-based level instruments to make conscious decisions regarding the suitability of the instrument for different applications.

If antenna size and efficiency are held constant, the antenna gain equation simplifies to $(1/\lambda)^2$. In a practical scenario, a device operating at 26 GHz frequency with a wavelength of 1.2 cm will exhibit a gain six times higher than a 10 GHz device with a wavelength of 3 cm, provided they share the same antenna size.



The same equation can be applied to observe variations in gain among different antenna designs. A comparison can be drawn, for instance, between a relatively large cone antenna and a parabolic antenna. For a device operating at 26 GHz with a wavelength of 1.2 cm and employing a 19.5 cm parabolic antenna with an efficiency of 0.45, the gain is seven times greater than that of a device operating at 10 GHz, utilizing a 15 cm (6”) cone antenna with efficiency 0.70.

This implies that, in applications such as measuring level in the cargo tanks of oil tankers, where the tanks may exceed 15 meters in height and the content has a low dielectric constant, employing a larger antenna can prove advantageous.

Furthermore, the overall beam width of a radar signal is inversely proportional to the frequency of the device. Consequently, a radar device operating at a higher frequency will have a smaller beam width compared to a lower frequency device with an equivalent antenna diameter. This characteristic greatly simplifies the installation of radar-based level measurement devices on marine cargo tanks. Tank designers do not need to keep a substantial portion of the tank free from potential obstructions, which could otherwise compromise the reliability of the measurements.

For instance, at a distance of 10 m and using a 100 mm (4") antenna, a 26 GHz radar device features a beam width of 1.5 m, while a 6 GHz unit has a wider beam width of 7 m. The beam width of the 6 GHz device is 4.6 times larger than that of the 26 GHz unit with the same antenna size.

Increasing the antenna size not only reduces the beam width but also effectively enhances the gain of the unit. Consequently, a larger antenna diameter contributes to an increase in reflectivity, and thus becomes the most advantageous choice for level measurements at long distances on liquids with low dielectric constants.

For any radar level device, the amount of the reflected signal diminishes for lower dielectric liquids and with greater distances. Consequently, measuring on low dielectric liquids becomes more challenging as distance increases. For non-contacting radar devices, enlarging the radar antenna is necessary to enhance both signal strength and the reception of reflected signals. Utilizing a higher frequency device enables this optimization while maintaining a limited antenna size. Going beyond the fundamentals, the device's signal processing capabilities play a crucial role in determining overall performance, affecting the efficiency of signal transmission and reception, as well as the management of power loss.

Applications - Accuracy and Reliability

In the context of level measurements aboard marine vessels, it is important to consider the degree of accuracy that is expected or desired. When using level measurement instruments such as non-contacting radar-based devices, accuracy expectation establishes the criteria for how closely the level readings should match the true level values.

The expected accuracy and reliability of a cargo monitoring system is usually high, as the system must ensure that the contained liquid will not raise above the permitted limits, ultimately eliminating the risk of overfill incidents. These systems predominantly employ radar-based transmitters for measuring level, and such devices are present on a wide range of vessels, spanning from very-large crude carriers (VLCC) to inland barges.

Historically, devices employed for measuring level in fuel tanks have been subject to relatively modest accuracy standards, with a notable reliance on pressure-based measurements in many installations. Nevertheless, the landscape is evolving due to heightened environmental standards, leading to the gradual adoption of radar-based devices, which is particularly evident in alternative fuel applications.

A common factor across all applications is the paramount importance of ensuring the reliability of the measurements and the ability of the device to maintain functionality, especially in the harsh conditions prevalent in the marine environment. While level measurement devices on land-based tanks typically operate in relatively stable environments, marine installations often face challenging weather conditions. This underscores the need to carefully select a suitable level measurement instrument, with a specific focus on such key parameters as, for example, the type of antenna required.

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Summary

When implementing radar-based devices to measure level in various ship tanks, it is crucial to make the right choices regarding antennas. For applications involving long distances and liquids with low dielectric constants, the optimal choice often leans towards a parabolic antenna. This selection ensures high gain, thereby enhancing signal strength by its ability to direct or focus the radiated signal in a particular direction. Additionally, it enhances the reliability and availability of the level measurements, especially in situations characterized by turbulent liquids or other conditions where the measured surface lacks a mirror-like quality. The reduced beam width resulting from the larger antenna also facilitates installation by requiring fewer considerations for the internal tank structure design. This proves particularly advantageous for tall tanks where operator safety and reliability are crucial.

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