

White Paper

# The Impact of Frequency in Non-Contacting Radar Level Measurement



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With over 40 years of continuous development, radar has become the preferred technology for level measurement in many of today's industrial applications. For non-contacting radars, the microwave frequency transmitted by the radar is one area in which there have been recent developments. Traditionally, three different frequency bands have been used for level measurement: the C-band (~6 GHz), the X-band (~10 GHz), and the K-band (~26 GHz). These frequency bands combine many attractive properties for accurate and reliable millimetre-precision measurement. Recently, radars using 75–85 GHz frequencies (the lower part of the W-band) have been introduced as a further option. The use of 75-85 GHz radars is mainly driven by the development of automotive radar applications such as parking sensors.

Frequency is a fundamental property of any radar as it has direct effects on measurement performance. It is important to remember that different frequencies are not equally suitable for all applications. Indeed, radars using different frequencies are required to solve different problems.

This paper will first describe the fundamental physical properties of different frequencies and thereafter explain what practical effects these properties have in some common, real-life level measurement applications. To this end, this paper differentiates between non-contacting radar transmitters using low microwave frequency (C and X-band, 6–11 GHz), mid frequency (K-band, 24–29 GHz) and high frequency (W-band, 75–85 GHz).

## Frequency and wavelength impact

At the fundamental level, radar instruments emit microwaves to measure distance. Microwaves are commonly defined as electromagnetic radiation with wavelengths (the distance from one wave crest to the next, designated  $\lambda$ ) between 300 mm ( $\approx 1$  ft) and 3 mm ( $\approx 0.1$ -in.). The wavelength is inversely proportional to the microwave frequency (the number of wave crests per unit time, designated  $f$ ), i.e. shorter wavelength = high frequency. In the case of microwaves  $\lambda=300$  mm corresponds to  $f=1$  GHz and  $\lambda=3$  mm corresponds to  $f=100$  GHz. The properties of low, mid and high frequency level radars are summarized in [Table 1-1](#).

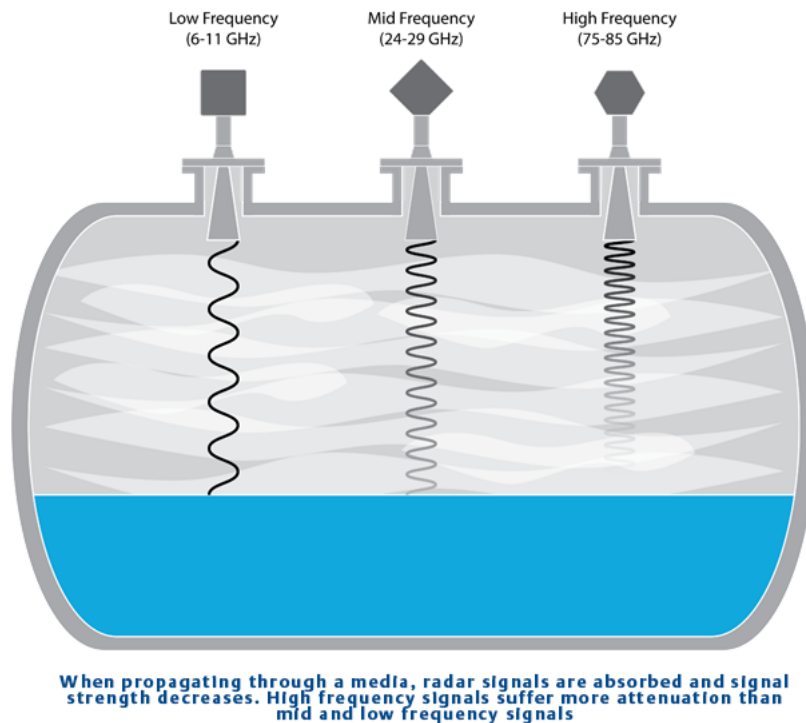
**Table 1-1. Wavelength and Frequency of Low, Mid and High Frequency Level Radars**

Frequency range	Band	Frequency ( $f$ )	Wavelength ( $\lambda$ )
Low	C and X-band	6–11 GHz	50–30 mm ( $\approx 2$ -1.2-in.)
Mid	K-band	24–29 GHz	$\sim 10$ mm ( $\approx 0.4$ -in.)
High	W-band	75–85 GHz	4–3.5 mm ( $\approx 0.15$ -in.)

These different physical properties have direct impact on the suitability of each frequency for different level measuring applications and conditions.

First and foremost, high frequency microwave signals suffer more attenuation (i.e. they are absorbed to a higher degree) when propagating through a medium, resulting in weaker signal return. For a simplified analogy, think of when you hear loud music played by your neighbor: low frequency sound (i.e. bass) will travel long distances and be heard clearly even through walls. High frequency sounds (i.e. treble) however are quickly absorbed and do not carry over long distances or through objects. When it comes to level measurement this means that high frequency radars are more likely to have problems with condensation, vapor, foam, build-up on the antenna, and dust. Low and mid frequency signals with wavelengths in the range of 50 mm to 10 mm are less affected by these kinds of challenges and more likely to pass through them unaffected.

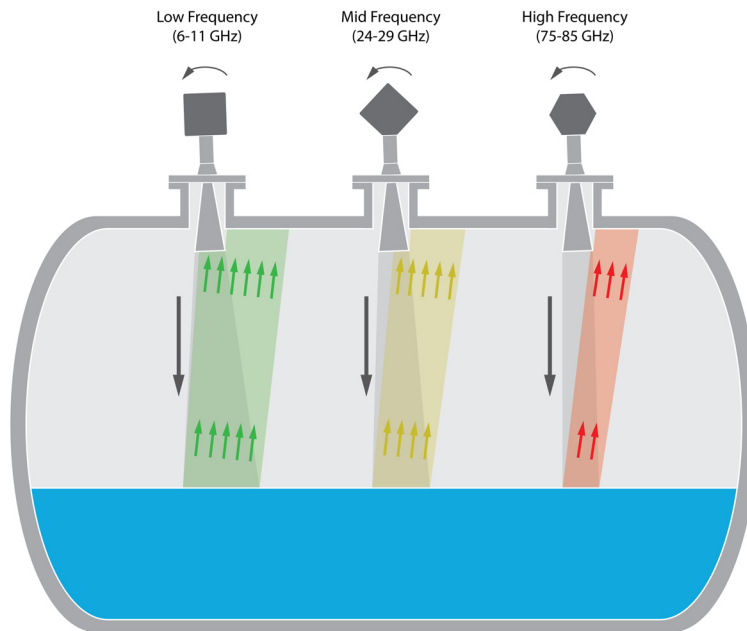
**Figure 1-1. Loss of Signal Strength Due to Attenuation**



Another important effect of the frequency is that it impacts the antenna beam width and beam angle, i.e. how focused the microwave propagation is. The beam angle and beam width is determined by the antenna design in combination with the microwave frequency. High frequency signals can achieve small beam angles with small antennas. Equally, small beam angles can be achieved with low frequency radars, but this requires larger antennas. The benefit of a small beam angle in level measurement is that it can make it easier to avoid hitting installations in the tank. However, a narrow beam width can also be a disadvantage. For example, if there is an obstruction directly below the radar a narrow beam will be completely blocked, but a radar with a wider beam will be only partially blocked and still able to measure the product level.

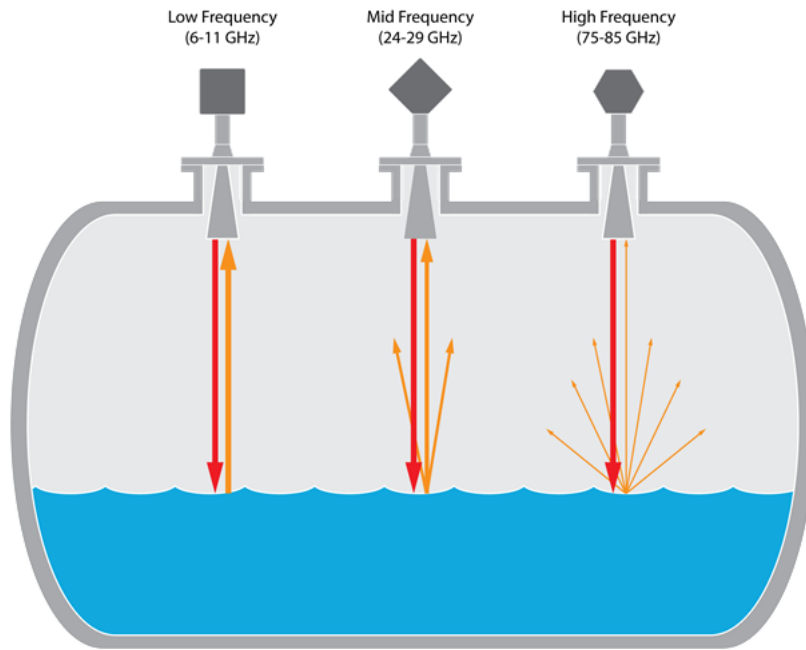
A practical limitation established from experience is that the beam angle should if possible not be smaller than about 4°. A narrower beam makes installation sensitive to misalignment of the antenna. Consider the extreme case: if a radar has a beam like a laser it is almost impossible to align it with the plumb line on a real-life tank. Consequently, the reflected beam will miss the antenna and the signal will be lost.

**Figure 1-2. Misalignment of Antenna**



Finally, waves and ripples on a liquid's surface are common in industrial applications and may cause problems for radar level measurement. Instead of reflecting back upwards towards the antenna, microwaves hitting a turbulent surface may scatter and disperse. Thus, a lot of the signal strength (as much as 90 percent) can be lost and give the radar problems with obtaining an accurate and reliable level measurement. Microwaves remain unaffected by surface irregularities such as turbulence if the wavelength is larger than the ripple size. For example, the signal return of high frequency radars will be affected and scattered by ripples down to 3,8 mm ( $\approx 0.15$ -in.) in size, whereas mid-range frequencies will remain unaffected by turbulence up to 2.5 times as large and be reflected as if from a flat surface.

**Figure 1-3. Ripples and Turbulence Scatter the Reflection**



**Microwaves with short wavelength are more easily scattered also by small waves on the liquid surface, leading to weaker signal return.**



# Low, mid and high frequencies: strengths and weaknesses

It is clear then that the frequency has a major impact on the type of application a radar is best suited to. The following is a guide to the challenges that exist within some common level measurement applications and the implications of frequency choice.

**Table 1-2. Strengths and Weaknesses of Low, Mid and High Frequency when Applied to Common Level Measurement Challenges**

	<b>Low frequency: 6–11 GHz</b>	<b>Mid frequency: 24–29 GHz</b>	<b>High frequency: 75–85 GHz</b>
Strengths	<ul style="list-style-type: none"> <li>• Can handle obstacles in line of sight</li> <li>• Least attenuated by conditions such as:                             <ul style="list-style-type: none"> <li>○ condensation</li> <li>○ vapor</li> <li>○ dust</li> <li>○ build-up</li> <li>○ foam</li> </ul> </li> <li>• Least affected by waves or ripples</li> <li>• Very good performance in still pipes</li> </ul>	<ul style="list-style-type: none"> <li>• Can handle obstacles in line of sight</li> <li>• Reliable despite conditions such as:                             <ul style="list-style-type: none"> <li>○ condensation</li> <li>○ vapor</li> <li>○ dust</li> <li>○ build-up</li> <li>○ foam</li> </ul> </li> <li>• Reliable despite waves or ripples</li> <li>• Supports small nozzles (≥1 1/2-in.)</li> </ul>	<ul style="list-style-type: none"> <li>• Narrow beam can help avoid obstacles</li> <li>• Supports antennas for very small nozzles (≥3/4-in.)</li> <li>• Supports very short measuring ranges</li> </ul>
Weaknesses	<ul style="list-style-type: none"> <li>• Requires larger antenna and nozzle</li> <li>• More difficult to measure very short ranges</li> </ul>	<ul style="list-style-type: none"> <li>• Affected by heavy vapours (e.g. anhydrous ammonia, VCM)</li> <li>• Affected by dense foam (e.g. latex, molasses)</li> </ul>	<ul style="list-style-type: none"> <li>• Narrow beam needs free line of sight</li> <li>• Sensitive to conditions such as:                             <ul style="list-style-type: none"> <li>○ condensation</li> <li>○ vapor</li> <li>○ dust</li> <li>○ build-up</li> <li>○ foam</li> </ul> </li> <li>• Most affected by waves and ripples</li> <li>• Sensitive to inclination of the gauge</li> <li>• Not suitable for still-pipes and chambers</li> </ul>

# Application suitability

## Dirty and contaminating applications

Dirt and contamination build up on the antenna over time and this affects the strength and direction of the radar signal. Low and mid frequency signals are less sensitive to this contamination and can pass through the build-up more or less unaffected.

With high frequency signals, more of the energy is absorbed by dirt covering the antenna and the direction of the beam may also be diverted. A deposit of uneven thickness covering part of the antenna can redirect the beam by about 1.5°. For a radar with narrow beam angle, this can cause problems because the return echo will not be directed straight back at the antenna, leading to loss of signal strength.

Low and mid frequency technology is therefore more suitable for dirty and contaminating applications.

## Tanks with condensation and/or vapor

Condensation and vapour is sometimes a challenge for radar level measurement. Water reflects microwaves much more strongly than most industrial liquids. Condensation and vapour can therefore cause the reflection from the product surface to be obscured by 'noise' from water droplets. This is more problematic for high frequency signals because their shorter wavelengths also reflect strongly from very small particles like steam and aerosols.

Low and mid frequency technology is therefore a better choice for applications with steam and condensation. It should be noted, however, that for condensation the design of the antenna is also of critical importance. Antennas with flat, horizontal surfaces should always be avoided.

## Applications with turbulence, waves and ripples

In general, low and mid frequencies perform best in applications with turbulence, waves and ripples. Small ripples on the liquid surface is especially detrimental to high frequency measurements. The short wavelength means that the signal reflection will be scattered also by small surface movements causing loss of returning signal strength. Longer wavelengths are reflected as if from a flat surface and are therefore better suited to this type of application.

## Applications with foam

Just like dirt and condensation, a layer of foam on top of the liquid will absorb the radar signal and make accurate measurement more difficult. Foam can have very different properties depending on which product it comes from, but once more, lower frequency generally provides better measurement reliability and accuracy.

For dense and thick foam (e.g. from beer, molasses and latex) 6 or 10 GHz works best. For lighter foam, 26 GHz performs very well. High frequency technology should be avoided in applications with foam.

## Bulk liquid storage tanks

In very large tanks, for example those used for bulk liquid storage at tank terminals, the size and placement of nozzles are typically not a restraint when it comes to choice of radar device. Obstructions and disturbing objects in the tank are usually not an issue either. Due to the vessel size, waves and ripples are often present on the liquid surface. Condensation is also common. As previously explained this causes problems for high frequency technology.

Many bulk storage tanks are floating roof tanks where measurement is performed through still-pipes. Low frequency radars are preferred as they are less sensitive to build-up on the pipe wall, slots, and pipes that are not completely straight. High frequency radars have difficulties in such situations.

Furthermore, bulk storage tanks often have significant roof movements due to sunlight and shade, wind, and tank bulging. This causes problems for high frequency radars because their narrow beam width makes them very sensitive to tilting, if the axis moves from the vertical plumb line. Tilting can result in the reflected signal 'missing' the antenna opening. It also makes installation of high frequency radars challenging as they must be installed absolutely level in order to perform correctly. Low frequency technology is therefore the most appropriate choice for this kind of application.

## Small to medium size vessels

This kind of vessel, typically 1–20 m (3–66 ft.) tall, is among the most common in process industry. They are used for a broad range of tasks: from intermediate storage to blending, separation, and as reactor vessels. Process connections are usually 2–4-in. and conditions inside the tank are often difficult with one or several challenges such as condensation, contamination, turbulence, foam, etc. Mid frequency technology is a good choice in this kind of tank due to its versatility - it combines small antennas with good reliability in difficult conditions. Low frequency radars may be less suitable due to the small nozzles and high frequency technology is less able to cope with the tough process conditions.

## Small tanks/buckets

In very small tanks, about 0.5–1.5 m (1.6–5 ft.) the size and placement of nozzles can be a limitation. The short measuring range and need for small antennas mean that high and mid frequency technology are attractive options for these applications. But of course, previously mentioned challenges such as condensation, contamination, turbulence and foam must be considered where applicable.



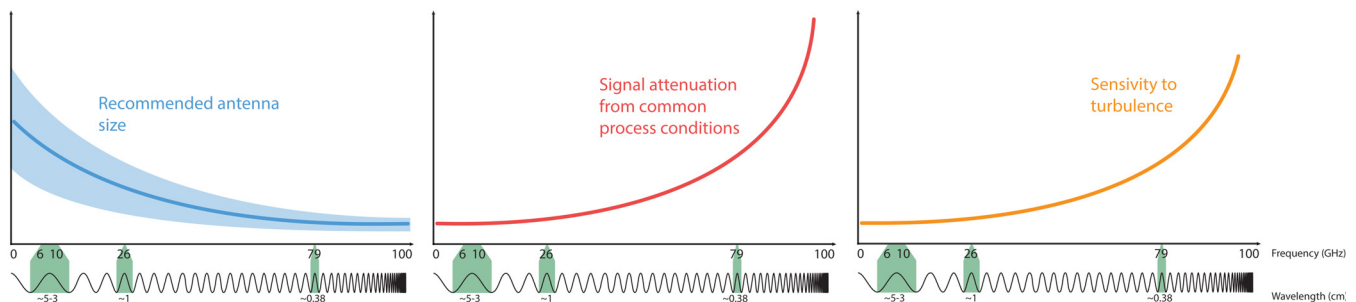
## Solids

For measuring the level of solids the best frequency to use is very much application dependent. Each technology has its strengths and weaknesses. Low and mid frequencies are able to cope with dust, condensation, and with coarse solids. High frequency works well with very fine powders. Condensation is generally challenging for high frequency radars, but with solids yet another problem arises: condensation in combination with certain solids causes rapid material build up. This will quickly clog small nozzle openings and cover the small antennas of high frequency radars.

## Summary

Radar level measurement has come a long way since its introduction 40 years ago and the technology will continue to develop and improve. The recently introduced radars using the 75–85 GHz frequency range may have benefits in level measurement applications for very small tanks with small process connections and very short measuring ranges. However, the fundamental suitability of 6–11 and 24–29 GHz frequencies for reliable mm-accuracy level measurement cannot be overlooked. High frequency technology will usually perform well in less challenging process conditions, but fundamental microwave physics shows us it is less suitable when the going gets tough. In contrast, low and mid frequency technology was developed specifically to meet the toughest level measurement challenges in the most demanding industrial applications. And the reason these instruments have been such an incredible success is because they provide reliable and accurate measurements in almost all applications.

**Figure 2. Relation Between Frequency, Antenna Size, Signal Attenuation, and Sensitivity to Turbulence**



**As the frequency increases antennas can be made smaller. However measurement performance in the presence of many common process conditions is impacted negatively.**

For more information on Rosemount next generation radar, see [Emerson-Process.com/Rosemount/Level](http://Emerson-Process.com/Rosemount/Level).

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