Frequency and Antenna Selection Effects on Accuracy of Free Space Radar

Accuracy of free space radar depends on frequency, beam angle, antenna configuration and installation.

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Free-space radar transmitters for level measurement typically use 6, 26 and 80 GHz frequencies. Recently, there has been a lot of hype concerning high frequency radar transmitters, where some manufacturers claim: the higher the frequency the better the performance. This is not necessarily true. Instead, accuracy is dependent upon a combination of frequency, beam angle, antenna configuration and installation but most importantly the dielectric constant of the product itself.

Free Space Radars

There are two major operating principles for free space radar transmitters: Time of Flight (TOF) and Frequency Modulated Continuous Wave (FMCW). Both have "time" as the base for a distance measurement.... But calculate "time" in a different way.

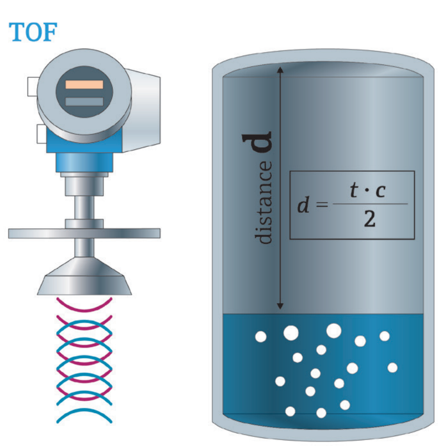


Figure 1: Time-of-flight radar calculates level based on the time it takes for a microwave pulse to travel to and return from the surface of the material being measured.

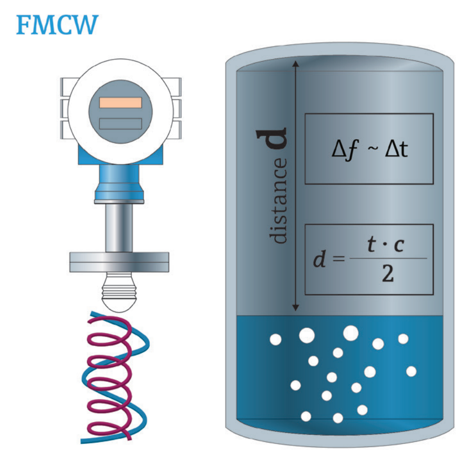


Figure 2: Frequency modulated continuous wave radar measures level based on the difference in frequency sent vs frequency being received.

TOF radar uses a microwave pulse launched from the transmitter. When the microwave energy reaches the material being measured, there is a change of impedance due to the dielectric constant (gas phase to liquid or solid surface) that causes the energy to be reflected. The amount of energy reflected is dependent on the dielectric of the material being measured. High dielectric materials, such as water, reflect all or most of the energy emitted. Low dielectric materials, such as hydrocarbons, reflect smaller amounts of energy.

The radar times how long it takes for the microwave pulse, moving at the speed of light, to reach the surface and return. This time divided by two provides the distance to the surface being measured. The transmitter then subtracts the distance from the span of measurement resulting in the level of product inside a tank or silo.

FMCW radar also uses microwave energy directed at the surface of the material being measured. Like TOF radar, the amount of energy reflected is based on the dielectric of the material. FMCW radar transmits a continuous stream of energy instead of a pulse, and the frequency is continuously modulated or varied. So, for an 80 GHz FMCW radar, the transmitter frequency may start at 79 GHz and ramp up to 81 GHz.

The transmitter compares the frequency it's receiving back from the product surface to the frequency it's sending out. The difference between the frequencies is equal to the time it took for waves to hit a surface and come back. Just like in the TOF radar, distance subtracted from the span of measurement results in level (Figure 2).

Manufacturers will cite all sorts of reasons why one is better than the other, but both technologies should be considered, with the best one selected depending on the application. Both technologies use microwave energy traveling at the speed of light and energy reflected based on the dielectric of the material being measured, and both measure "time" to determine distance or level.

Frequency Effects

There are a number of contributing factors including frequency, antenna type, installation conditions and the dielectric constant of the material being measured that affect accuracy and availability of a measuring signal.

Transmitter frequency affects accuracy, beam angle and antenna size. Low frequency transmitters are generally less accurate in comparison to higher frequencies due to the poorer resolution of the signal generated by the lower frequency. Figure 3 shows an envelope curve comparison between 6 GHz and 26 GHz radar transmitters. The 26 GHz radar (red line) generates pulses that are approximately one half the length of the 6 GHz pulse (blue line).

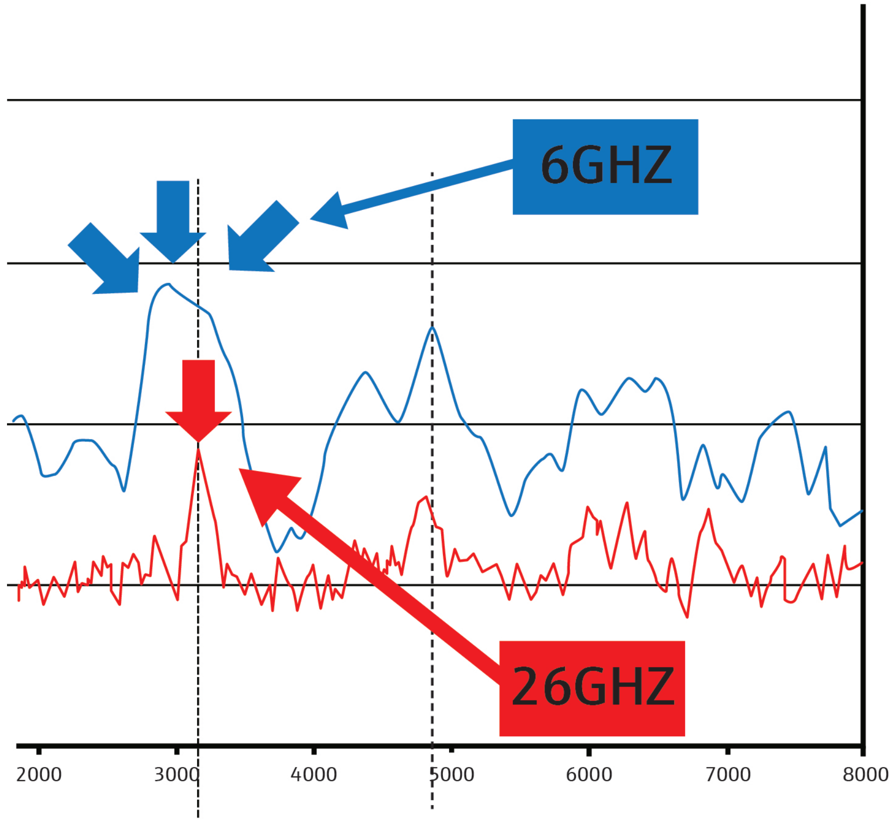


Figure 3: Comparison of 6 GHz and 26 GHz radar transmitters in the same application showing the sharp peak using 26 GHz to the rounded peak of a 6 GHZ radar reflection.

This provides a sharper return and higher accuracy.

The 6 GHz pulse is much wider than the 26 GHz pulse. The transmitter interprets this pulse and determines where the level is located. The blue arrows indicate the interpretation can be several points. The transmitter can interpret the leading edge, the center, or the following edge as level, which affects accuracy. The 26 GHz transmitter pulse is much sharper, which limits interpretation to a single point, shown by the red arrow. The result is that accuracy for the 6 GHz transmitter is typically six to ten mm while the 26 GHz transmitter provides two to three mm accuracy in process applications. Advanced algorithms can be applied to come to <1 mm accuracy for tank gauging applications.

Reflection peaks from 80 GHz radars are also quite sharp, which makes evaluation of the exact level quite easy. Process radars using 80 GHz can have an accuracy of one mm in process applications, while tank gauging and custody transfer radars using 80 GHz can have accuracies of <0.5 mm.

Frequency also affects the beam angle of the signal propagated by the transmitter. Lower frequencies generate wider beam angles than higher frequency transmitters. A wide beam angle may be more suitable than a narrow beam angle in some applications.

Antenna Considerations

Antenna size and type also affect the beam angle. The lower the frequency and smaller the antenna, the wider the beam angle (Figure 4). Increasing frequency and/or increasing antenna size reduces the beam angle.
Many believe the smallest beam angle is the best choice for level measurement, and this is true as a general rule. Reducing the beam angle

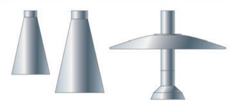
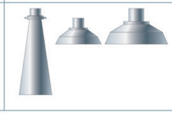
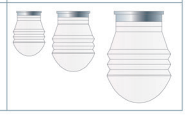
Antenna Size	6 GHz	10 GHz	26 GHz	80 GHz
2″	---	---	18°	4°
3″	---	---	10°	3.5°
4″	---	21°	8°	3°
6″	23°	15°	5°	---
8″	19°	10°	4.4°	---
10″	15°	8°	3.3°	---
18″(17″)	7°	(6)°	---	---
				

Figure 4: Beam angle comparisons of frequency and antenna size.

allows the microwave energy to more easily avoid the vessel wall, agitators and other internal tank obstructions. Providing a radar transmitter with a beam angle that does not intersect the vessel wall or obstructions is ideal.

However, it's important to understand that even if the beam intersects obstructions or the wall, this does not necessarily mean the installation will be unsuccessful. Intersecting the wall will cause some energy loss but is often inconsequential. Obstructions in the beam path can be "mapped out" eliminating them from signal evaluation.

We can't stress the information in the previous paragraph enough. It is often thought if the beam angle intersects the vessel wall it disqualifies the application for free space radar. While radar installation where the beam angle does not intersect the vessel wall is ideal, it's rarely attainable due to mounting nozzles and other interferences. Through proper selection of frequency, antenna size and tank mapping, a successful application is most often achievable.

Measuring Ranges

Frequency and antenna size have an influence on measuring range. But the dielectric constant of the material being measured and the installation conditions of the measurement also greatly influence the measurable range.

Low frequency signals have a longer wave length and will travel farther than higher frequencies. Radar transmitters with high frequency emitters are capable of measuring ranges of approximately 100 feet which is ok for most applications.
Antenna size and type also have an influence on transmission range. Larger antennas provide greater range and energy focus than smaller antennas. Figure 5 shows a range comparison for standard horn style antennas. As shown, larger antennas provide greater ranges. The style of antenna also affects the range of measurement. Figure 5 shows typical horn style antennas, but there are also "tear drop," parabolic, rod and planar antennas. All of these antenna styles are used to provide solutions to different application requirements and measuring ranges.

Installation Conditions

Even the best radar in the world will give poor results if not installed correctly. Conditions present in the installation must be considered. The dielectric constant of the material being measured, mounting type and location and the surface of the target all have an effect.

Condensation, usually from water, forming on the antenna of a radar transmitter can cause problems. Water has a high dielectric of about 80 DC. In a typical horn style antenna, water droplets condensed on the inside of the horn can cause interference affecting launching of the electromagnetic signal. This interference causes "noise" in the signal and reduces energy. Enough condensation can cause the radar to lock in the near zone, resulting in failure.

To combat condensation problems, several special antenna designs have been developed to help "shed" condensation, reducing the loss of energy and signal noise (Figure 6).

If the traditional horn style antenna must be used for application conditions, it's possible to add a purge connection to keep the radar free of condensation or dust build up. Since air is very low in dielectric, it does not interfere with the microwave signal. Purging with 60 to 70 psi air, as a blast activated by a solenoid, will keep the horn clear and is the most commonly used method.

Some manufacturers provide diagnostic capability to monitor the area of incoupling, which indicates when condensation or build up reaches a level that may start to interfere with the signal. These advanced diagnostic capabilities can be used to perform maintenance, such as purging the antenna prior to a failure condition. The ability to provide preventive maintenance reduces downtime and emergency maintenance requirements.

	Antenna Size	1.5	2	3	4
	Range in Meters	25	40	60	70

Note - maximum ranges shown based on materials with a dielectric constant greater than ten

Figure 5: Radar transmission range by size of a horn style antenna.

Figure 6: Antennas designed to shed condensation.

Turbulent and irregular surfaces can cause transmitter energy to scatter or reflect, with lost energy not returning to the transmitter. In the past, the recognized solution would be to use a low frequency radar with a large beam angle. Consider a ball being bounced off an irregular surface such as a piece of corrugated roofing material. A small ball (tight beam angle) will most likely bounce off in any direction other than straight up. A large ball (wider beam angle) will hit the surface over a greater area and will tend to bounce straight back up again.

While this is all true, special algorithms have been developed to provide level measurement in turbulent surfaces using high frequency transmitters. This provides more or less the best of both worlds: tighter beam angles and reliable measurements. But is not a fix for all applications.

Internal obstructions in the vessel must also be considered. Agitators, heating coils, thermowells and other components inside the vessel can interfere with the radar transmission. The narrow beam angle of the 80 GHz radar does a good job of avoiding most obstructions; the remaining ones need to be eliminated from the signal evaluation to prevent the transmitter from seeing these as false level signals.

Typically the interfering signals are "mapped out" so the radar transmitter ignores them. Figure 7 shows the level measurement signal evaluation with an agitator mapped out. The red line in figure 7 is the signal provided by the return of the microwave energy. The black line is the superimposed map which eliminates the agitator reflection from evaluation and allows the transmitter to follow only the actual level signal. For a signal to be valid and evaluated as a level signal it must be higher than the map.

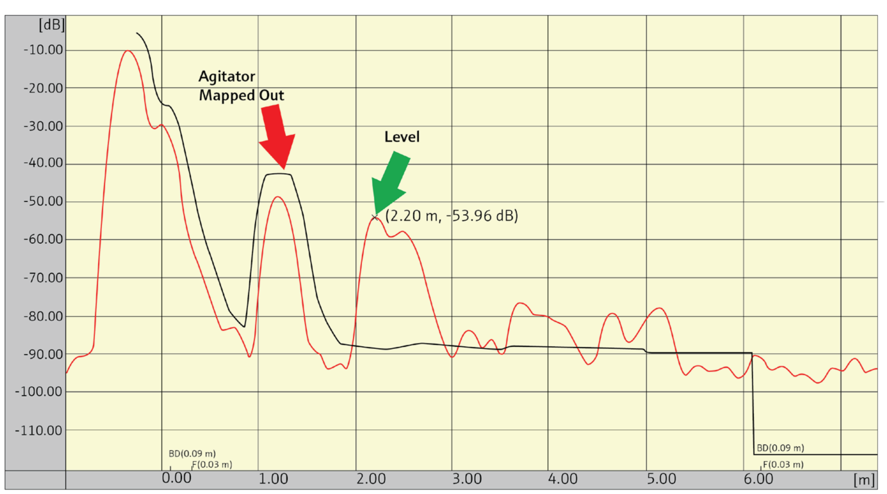


Figure 7: Envelope curve showing agitator signal mapped out.

Mounting Transmitters

The radar transmitter's mounting location on the vessel must also be considered. It's often assumed mounting the radar in the center of the vessel is the best placement as it puts the antenna farthest from the vessel wall. But mounting the transmitter in the center of the vessel, especially a doomed roof vessel, is a bad idea because the roof can act like a parabolic dish and concentrate stray secondary microwave reflections and direct them back to the antenna (Figure 8). These secondary reflections can be stronger than the primary level reflection.

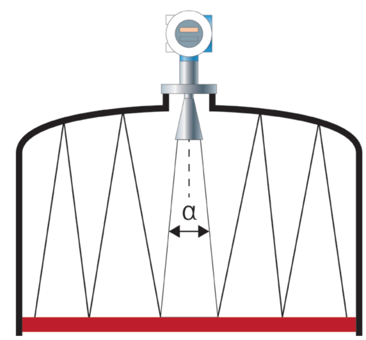


Figure 8: Mounting in the center of a tank can result in generating strong secondary reflections.

A good rule of thumb is to mount the radar transmitter at approximately one third the diameter of the vessel if possible. However, it does not mean a radar transmitter wouldn't work if it's not located in the ideal location. Mapping, as previously discussed, can solve many mounting location problems. This, along with filters and proper set up of the transmitter, will often provide a reliable measurement in mounting locations that are not ideal.

Mounting a free space radar in a stilling well or bypass installation can be challenging. It's important to understand how microwave energy is transmitted in a stilling well to select the radar that provides the best accuracy. A standard horn antenna can be used for stilling wells but the accuracy will be less than normally specified. This is due to the way energy is transmitted from a horn style antenna in combination with how it propagates in a pipe instead of through free space.

Figure 9 shows a horn style radar installed in a stilling well. As indicated, the microwave energy bounces from side to side as it travels down the stilling well and then again on the way back. This causes the energy to travel a longer distance which reduces the accuracy. A horn style radar that provides 2 mm accuracy in an open vessel installation will not have accuracy anywhere close to that when installed in a stilling well. For best accuracy in a stilling well, a planar style antenna should be used. The planar antenna provides an elliptical energy transmission which results in the energy following a straight line path in the stilling well.

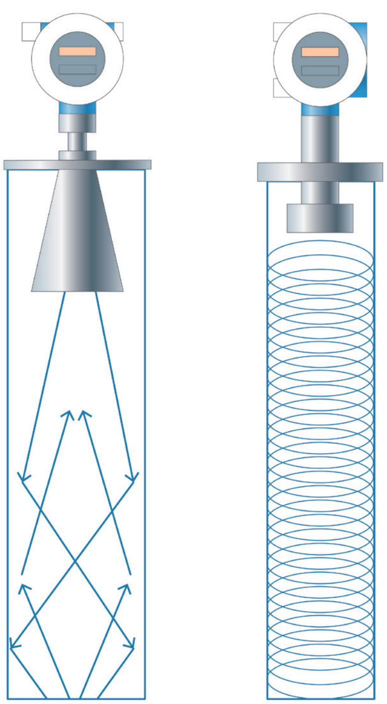


Figure 9: Radar signal from a horn antenna (left) in a stilling well does not follow a straight line. A planar antenna (right) is specially designed for stilling well applications.

If a horn style antenna is used, it's important the horn diameter matches the inside diameter of the stilling well. If there is a space between the stilling well and the horn, energy will wrap around behind the horn causing excessive noise and reduction in energy.

Summary

It is not just the frequency of a radar that is important, but antenna design, smart algorithms and location play a big role in successfully measuring the level in a tank or silo. The more difficult the application and higher the accuracy requirement, the more critical it is to have the optimal frequency and antenna design. Reviewing the application details and working with a supplier or consultant who has experience with radar transmitters will provide the best result for your requirement.

About the Author

Gene Henry is a senior level business manager for Endress+Hauser in the U.S. and has more than 40 years of experience in the instrumentation field. He started his career as an instrument foreman in the phosphate mining industry, and has spent the past 25 years in instrumentation sales, providing consulting services to industrial and municipal plants. In his current role, he works closely with the sales force on level applications and in the development of marketing strategies for Endress+Hauser level products in the U.S.

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