Radar sensors for level measurement
Which frequency for which application?

By J Skowaisa, VEGA

Faster, higher, farther – within the last five years tremendous strides have been made in the development of radar sensors for level measurement of liquids and bulk solids. Yet selecting the right sensor still is not always easy. A bit of theory and some concrete examples bring light into the instrument jungle.

New electronic components and ingenious instrument designs have made sensors even more powerful and have opened ever broader areas of application for radar technology. Frequency ranges that could not be realised just a few years ago now promise a solution to many of today’s challenges. Yet it is difficult for the average user to recognise the advantages of the various technologies and benefit from them to the fullest extent possible.

Radar technology - very simple in principle
Radar sensors are complex devices that are able to detect levels in widely different applications through the interplay of ultra-modern microwave components and complex signal analysis. Experienced specialists and ultra-modern, costly technology are necessary for the development of the instruments – their adjustment and handling, however, should be as easy as possible for the user.

There are two different methods for measuring the distance to the surface of the medium – the pulse radar method and the FMCW method. Whereas the pulse method measures the running time of the microwave pulses by means of a special sampling method, the FMCW principle calculates the distance through a frequency comparison, using a continuous signal modulated into the frequency. For the user this hardly makes a difference, though the complex signal processing of the FMCW method does make an FFT (Fast Fourier Transformation) necessary. This demands considerably more computing power from the processor, either increasing energy consumption or slowing down the cycle time of the measurement.

During the early stages of development of radar sensors, the choice of frequency depended on the availability of suitable electronic components. That is why frequencies in the vicinity of 10 GHz were used. Later, manufacturers orientated themselves to the internationally authorised wavebands, such as the C, K and W bands, with frequencies of approx. 6 GHz, 25 GHz and 75 GHz. Every frequency has its strengths and weaknesses, therefore it is not possible to speak of the most suitable frequency for radar sensors – it all depends on the respective application. It is, however, a fact that sensors in the frequency range of 25 GHz have a market share of approximately 80% today and are very well suited for the majority of applications. One important measure of the performance of a radar instrument is system sensitivity, i.e. the ability to distinguish between large and small reflection signals. A great deal has been done in this area within the last few years - new microwave components have opened up completely new areas of application. High sensitivity is very important, especially for sensors that are used for measuring bulk solids, since only a fraction of the emitted energy comes back to the receiver. The sensitivity of radar sensors for bulk solid materials extends up to 100 dB, which means that signals 10 billion times smaller than the transmitted signal can still be measured. These dimensions become clearer using a mechanical example – if it had the sensitivity of a modern radar level sensor, a truck scale that normally weighs fully loaded semi-trailer trucks with up to 40 tons would also be able to measure the weight of a single hair!

Antenna systems – adapted to the application and the frequency
To make the most of the advantages of radar technology in all sorts of different applications, the antenna system must be the right one for the respective measuring task. Basically, three different antenna principles are available: antenna systems based on reflection, e.g. horn antennas or parabolic dishes, antenna systems that make use of the refraction of microwaves on plastic surfaces, e.g. rod antennas or spherical antennas, and planar antennas that emit signals via conductive structures on a PTFE or ceramic substratum. From an engineering standpoint, all antenna systems and frequencies can be combined. However, antenna dimensions for low frequencies often get very big and the mechanical limits of such devices are quickly reached.

Since the focusing properties of an antenna system depend not only on size but also on frequency, this is one of the essential distinguishing features of an antenna. And advantages generally result from using a higher frequency. For example, if the frequency of a radar sensor is doubled, an antenna about a quarter of the original size is required to obtain the same signal focusing. The advantages are obvious: better signal focusing reduces the disturbances gener-
ated by vessel installations, agitators or structured container walls – in other words, higher frequencies make it possible to use smaller process fittings. Quite independent of the frequency, however, smaller antennae lack the gain, that is, the signal amplification resulting from the directivity of the antenna. A larger antenna surface can take in more energy and thus generate larger signals. This is especially important for media with bad reflective properties, such as plastic granules or solvents.

**Effects of the application on the frequency range**

The great advantage of radar technology is the fact that the measuring technique itself is hardly affected by the process conditions, and the design of the sensors can be adapted to widely different applications.

The propagation of microwaves is virtually independent of the ambient temperature. Running time changes due to different pressures, manifest themselves only in pressures over 10 bar. In general, the propagation of microwaves is not influenced by the composition of the gaseous phase in the vessel, but there are exceptions: ammonia and vinyl chloride. Both damp the microwaves: all the more the higher the frequency. In practice, this means that instruments with a low emitting frequency should be used for these applications, especially for large measuring ranges. There are, of course, more application-specific factors that influence the measuring techniques, and considerable differences exist between the measurement of bulk solids and the measurement of liquids.

**Liquids – a standard task for radar sensors today**

In principle, measuring liquids is quite simple, as the product surface is generally flat and the radar signals are reflected directly back to the sensor. But the situation is quite different in process vessels with agitators or applications into which steam is fed: turbulent surfaces scatter a part of the transmitted signal and, if an agitator generates

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**Abbreviations**

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<tr>
<th>Acronym</th>
<th>Definition</th>
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<tr>
<td>FFT</td>
<td>Fast Fourier Transformation</td>
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<tr>
<td>FMCW</td>
<td>Frequency-Modulated Continuous-Wave</td>
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<td>PTFE</td>
<td>PolyTetraFluoroEthylene</td>
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a vortex, a very large portion of the signal is deflected and rendered useless. Excessively strong focusing of the radar signals is disadvantageous here. At the same time, a sufficiently large antenna is required to get an adequate return signal if the application deals with solvents.

Condensate and possibly also splashing medium often accumulate on the antenna system, leading to reflection and damping of the microwaves. The thickness of the deposits must always be seen in correlation to the wavelength of the emission frequency. Such deposits have a stronger influence with higher frequencies due to the shorter wavelength of the signals. In practice, this means that a 1 mm-thick accumulation appears three times as thick to 25 GHz as to 6 GHz and has a roughly ten times stronger damping effect with 76 GHz. Foam on the product surface has an even stronger influence. The higher the frequency, the stronger the damping caused by the foam – a shorter wavelength unavoidably results in signal loss.

A good compromise for applications in liquids is 25 GHz. Instruments using this frequency have good signal focusing and are still largely immune to condensate deposits on the antenna system. Thanks to the sensitivity of radar instruments, which has increased considerably in the last few years, even foam is no longer a problem – the product surface is easily detected right through the foam.

**Bulk solids – reliable measuring results thanks to innovative technology**

Due to the often steep repose angles of solids, part of the radar signals are reflected laterally at the product surface, and all the more the finer the medium is. This means that rough bulk solids are considerably easier to measure than very fine-grained products that form really smooth, uniform mounds, such as sugar or quartz sand. In principle, the granulate size of the medium must always be seen in relation to the wavelength or the frequency of a radar instrument. So, when considering a sensor operating at 75 GHz, a product approximately three times finer should deliver a reflection similar to one generated by a sensor operating at 25 GHz. In practice, however, hardly any difference can be discerned – whether cement, fine sugar or quartz sand is measured with 25 GHz or 75 GHz: the reflected signals are similarly large.

The advantages of sensors with an especially well-focussing antenna system come into play mainly in measurements in silos with heavily structured container walls, such as segmented silos, or containers with internal installations and struts. Thanks to the good signal collimation practically no disturbing reflections arise, making it easy for the software to select the right signal as an echo.

A slightly larger measuring surface, ie a wider signal beam, can also be of advantage for bulk solids. With very coarse bulk solids, the signal is reflected in many places. A stronger reflection often results from a wider signal beam than from a more strongly focussed one. Moreover, really uniform bulk solid funnels or mounds are rare, so a part of the signal is always reflected back from the various structures of the surface – in such cases, too, an antenna system with less powerful signal focusing helps.

One very important topic in connection with the measurement of bulk solids is the influence of dust and dust deposits on the antenna. By and large, microwaves are hardly affected by dust particles in the air. In extremely dusty situations like pneumatic filling, signal damping does occur, manifesting itself in the signal amplitude of high-frequency sensors. Dust deposits directly on the antenna system, however, have a much stronger effect on the measuring result. Dust muffles the signals all the more strongly the shorter the sensor wavelength is – this means that high-frequency sensors are subject to considerably stronger influences in this area than instruments with a lower frequency. Whereas the antenna systems of 25 GHz sensors can be often protected from a heavy dust build-up by a simple dust cover, the antenna systems of 75 GHz instruments frequently require cleaning with compressed air. This increases the work and expense of installation and usually leads to additional costs during operation.

**Conclusion**

In daily practice, it becomes obvious that every frequency has both advantages and disadvantages and that the entire application must be taken into consideration in each case. Through the extensive application knowledge built into software algorithms for signal analysis and the selection of the right criteria relating to the operating conditions, the slightly less powerful signal focusing of 25 GHz radar sensors compared to those with 75 GHz can be more than compensated for in many cases. On the basis of the simple selection of measured media and their properties during adjustment, the instruments are able to analyse the typical echo signals of different applications. The result is reliable measurement in widely different media and vessel shapes, independent of dust and build-up and guaranteeing long-term, maintenance-free operation.

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