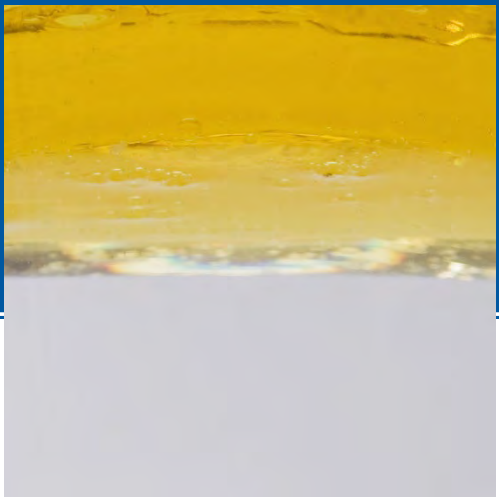




SOLUTIONS FOR TRICKY LEVEL MEASUREMENT CHALLENGES

When it gets tricky!

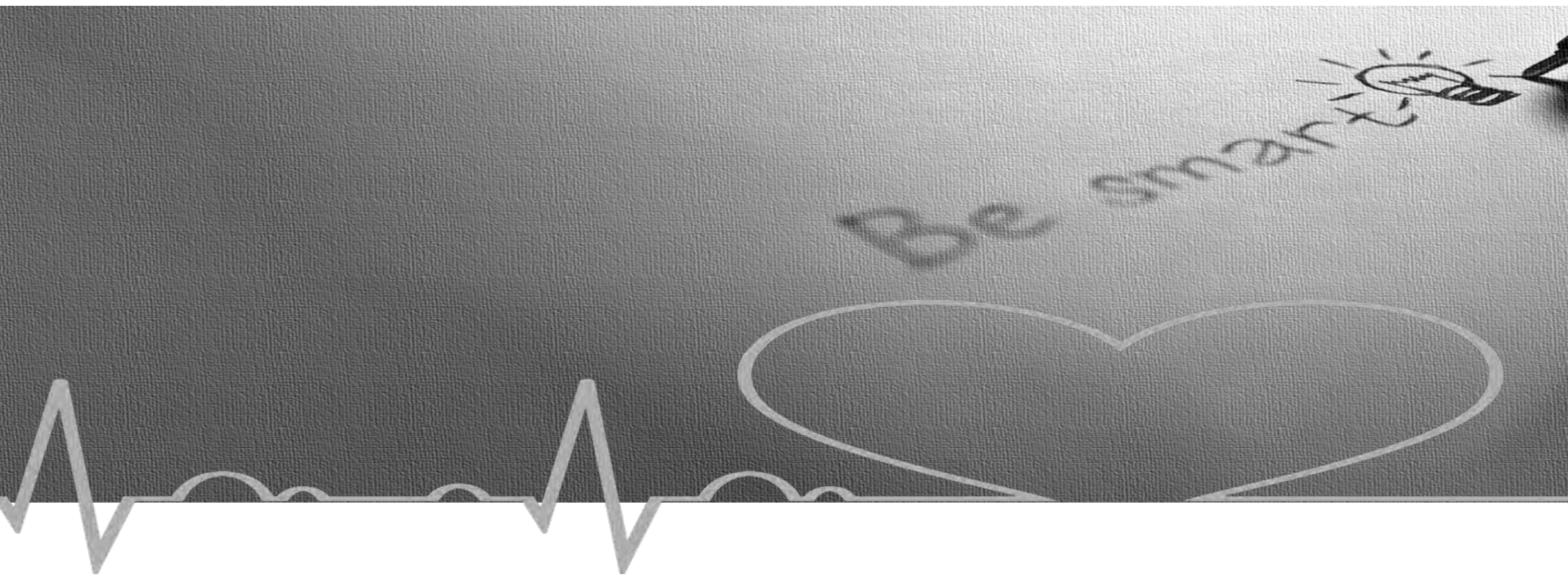
WHITE PAPER

MULTITALENT TDR IN SOLIDS & LIQUIDS

Nikolas Oppenberger
Product Management

What is radar?

Radar is the abbreviation for "*radio detection and ranging*" which means "*radio-based location and distance measurement*". This technology is based on electromagnetic waves. A radar device emits a concentrated electromagnetic wave, which is reflected by objects as an echo and then evaluated by the device according to various criteria.



Depending on the application, the following information can be obtained from the reflected waves:

- the angle or the direction to the object
- the speed of an object (Doppler effect)
- the contours of an object
- the distance to the object

The latter point means that radar technology is also used for determining fill levels. This has become increasingly important in recent decades and has been continuously developed. The areas of application now extend from simple storage tank applications to complex process containers with a wide variety of challenges.

In food and beverage production in Southeast Asia for example, guided radar technology has been used for many years to monitor fill levels, mainly in storage silos and tanks. As this technology defies extreme process conditions in terms of temperature and pressure, it is the first choice in Russia, predominately in the oil and gas industry and in the chemical sector. Classic areas of application in Europe and the USA are within the water and wastewater industry and in cement production.

In addition to the free-radar sensors, the radar category also includes those based on guided microwave technology, which are often referred to as TDR (Time Domain Reflectometry) or GWR (Guided Wave Radar). With 10% market share in the bulk goods and 15% in the liquid sector, these are among the most widespread level measuring devices. Above all, the versatility and insensitivity to changing process conditions makes the TDR sensor a popular all-rounder. Reason enough to take a closer look at this technology in this White Paper.

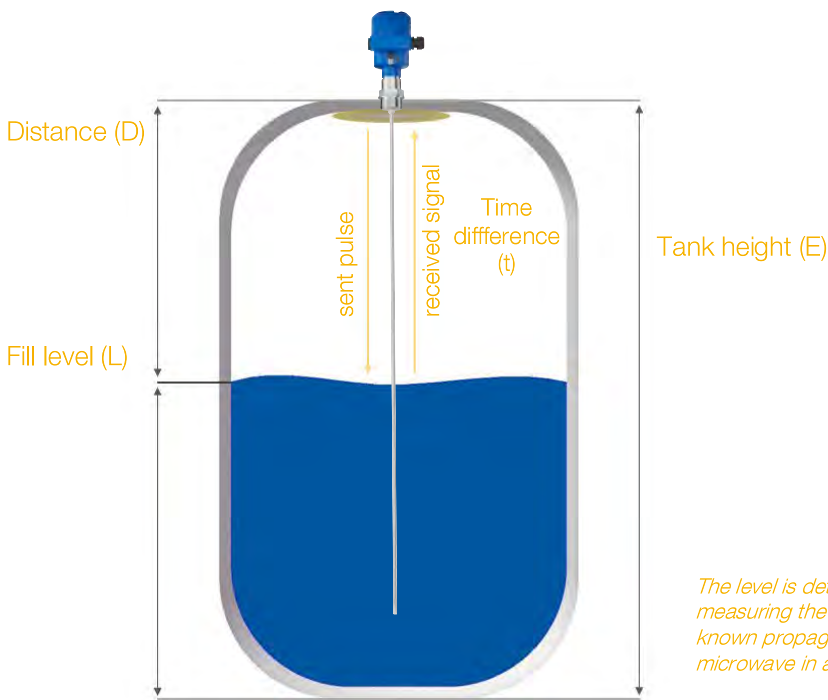
How does level measurement with guided radar work?

The basic principle of a level sensor based on TDR is simple. The electronics generate an electromagnetic pulse, which is coupled to a probe and guided downwards along it. When the wave hits the material surface, some of the energy is reflected.

This so-called echo signal is also routed back along the rod to the electronics, recognized by it and converted into a fill level indication by means of a transit time measurement. The transit time **t** is the time difference between the transmitted pulse and the received echo signal. Since the speed of propagation of an electromagnetic wave in the carrier medium air can be equated with the speed of light **c**, this simple relationship can be used to calculate the distance **D** to the media surface.

$$D = c * \frac{t}{2}$$

The fill level is then determined by entering the container height.



The level is determined by measuring the transit time t and the known propagation speed of the microwave in air.

Why is guided radar technology so well suited for level detection?

The basic principle is easy to understand, but when looking at real live industrial applications significantly greater challenges are encountered. Superimposed gases and vapours, temperature and pressure fluctuations, surface movements of the medium and strong dust development are typical problems that can make precise and reliable level determination difficult. Even under these challenging conditions, TDR sensors perform reliably and with high precision.

The speed of propagation and its importance for level determination

In addition to an exact determination of the transit time, a decisive factor for the accuracy of a radar sensor is the propagation speed of the microwaves. This in turn depends on the dielectric constant of the carrier medium. Radar level measurement devices are usually calibrated in the carrier medium air, which by definition has a DK value of approx. 1. This value changes slightly due to gases and vapours that can form above the actual medium.

However, the change has only a marginal influence on the propagation speed of the microwaves. The accuracy of the radar sensor is therefore not affected. The situation is similar with regards to changes in temperature and pressure. For example, a **temperature of 2000°C (3632°F)** only results in an **accuracy deviation of 0.026%.** Even **pressures up to 40 bar / 580 psig** have no noticeable influence on the propagation speed of electromagnetic waves, which also guarantees a precise and reliable measurement.

This insensitivity to the most diverse process challenges makes TDR sensors a universal all-rounder in a multitude of applications. The spectrum ranges from bulk solids to liquids as well as high pressure / high temperature applications. Interface layers can also be easily measured with these sensors. In the field of TDR technology, UWT offers a wide range of designs that offer the ideal solution for every application and combine functionality with economics.

The question of the right frequency

With radar level measurement devices, there is always the question of the level of the frequency. While **contact-free radar sensors work with high frequencies of up to 130GHz**, the **guided microwave technology uses a comparatively low frequency of 1GHz**. There are arguments for high-frequency and low-frequency radars. In general, it can be said that low frequencies are significantly less susceptible to process-related interferences such as build-up, condensate, dust, steam or foam. All these interferences have one thing in common, they dampen the emitted electromagnetic waves, thereby weakening the signal, which can ultimately lead to incorrect measurement results. That signal weakening is significantly less pronounced in the low-frequency TDR sensors. Therefore, these sensors are used very successfully for measurements of certain industry-specific media, for example in steam boilers or in interface processes.

How do TDR sensors master the challenges of bulk solids applications?

There are many challenges in the bulk goods sector. High, narrow silos and large measuring distances, pouring cones, build-up, dust, materials with low DK values and high mechanical tensile forces pose particular challenges for measuring technology. TDR sensors prove to be true all-round talents.

DUST

If things are a little more demanding...

A tiresome everyday problem: dust! A well-known companion in bulk solids applications. Here, however, less the house dust, but rather the process-related strong dust development e.g. during a filling process. However, TDR sensors are not unsettled by this.

The low-frequency microwave pulses are hardly influenced by strong dust development.

This guarantees a reliable measurement result.

BUILD-UP

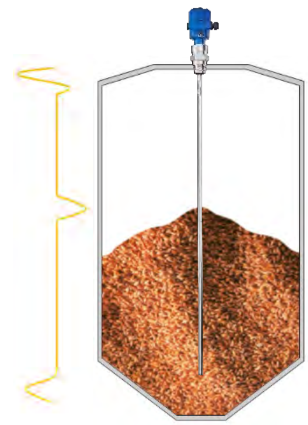
If things are a little more demanding...

Cement or flour are classic examples of the fact that build-up can sometimes occur on parts in contact with the process in solid applications. With TDR sensors, such a process-contacting part is the probe. It is either a rod or a rope. The respective surfaces are designed in such a way that **product deposits are minimized**. In addition, the rope variants can be covered with a **PA coating**.

Even if there is some build-up, the TDR sensors deliver reliable measurement results due to the low signal attenuation.

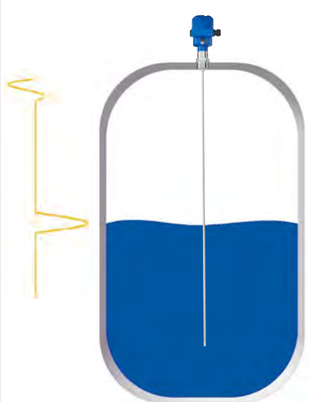
LOW DK VALUES

If things are a little more demanding...



Low DK-value
(grain = 3)

*The echo curve for media **with low DK value**.*
Characteristic are the lower amplitude of the echo signal and a signal propagation through the medium with a negative downturn at the end of the probe.



High DK-value
(water = 80)

*Echo curve for media with a **high DK value**. The large amplitude of the echo signal and the strong signal attenuation by the medium are characteristic here. The end of the probe can therefore not be recognized.*

One question one is always confronted with when determining the level using radar technology is the dielectric value of the medium. The higher the DK value, the more energy is reflected by the medium. The amplitude of the echo signal will be correspondingly larger, which increases the measurement accuracy. If the DK value is low, little energy is reflected and the majority of the energy radiates through the medium to the end of the probe. The end of the probe is recognized as a negative downturn in the echo curve, provided the signal has not been completely damped before.

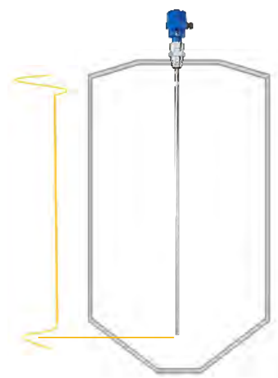
Low DK values (in the range 1.3 - 5) are mostly characteristic of bulk goods. Weak echo signals are the result, which presents the TDR sensors with special challenges. The value 1.5 is given as the magic limit in many data sheets. Media with lower DK values do not reflect the amount of energy required for direct echo analysis. If the value does fall below the limit value, another distinctive aspect of the radar technology is used: **the relationship between the speed of propagation and the carrier medium.**

The propagation speed of the emitted microwave pulses depends on the carrier medium and its DK value. In air, with a DK value of approx. 1, electromagnetic waves propagate at the speed of light. As already mentioned, a large part of the microwave energy penetrates materials with a low DK value. The microwave propagates further in the medium, but here at a slower rate of propagation.

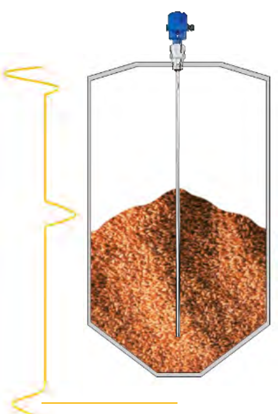
This effect is used to determine the fill level of materials with a very low DK value indirectly via the probe end projection.

PROBE END PROJECTION

If something gets lost...



If the silo is empty, the negative downturn in the echo curve and the actual end of the probe match



When the silo is filled with material, the negative downturn in the echo curve appears further away due to the lower propagation speed of the microwave pulse in the material. For the echo processing software, the probe appears to be longer than it actually is

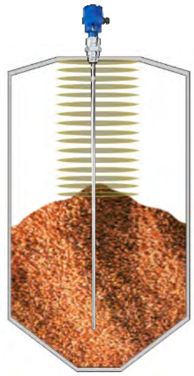
If you compare the echo curves of an empty and a full container, there is a second difference in addition to the amplitude of the level echo. The signal of the probe end appears farther away with a container filled with material than with empty containers. This shows the dependence on the speed of propagation and the carrier medium. While the microwave can always spread out in the free space in the empty container to the end of the probe, it must penetrate the medium in the filled container in order to reach the end of the probe. The propagation speed of the electromagnetic wave is now reduced within the medium. This makes the end of the probe appear farther away than it really is.

The **echo processing software** uses this effect for indirect level determination. This is used when the amount of energy reflected by the product is not sufficient for direct echo signal evaluation. This means that the fill level can still be determined if the DK value falls below the critical limit of 1.5.

The **probe end projection** offers a second useful advantage that comes into play during commissioning. The rod or rope probes are often ordered in standard lengths so that they are actually too long for the application. In such a case, these can be easily shortened and their new length is automatically determined using the probe end signal. A click on the control module is usually sufficient.

BULK CONE

If things are a little steeper...



Since the microwave pulses are guided along a probe, cones of material have no influence on their reflection behaviour. This prevents signal loss due to microwaves reflected to the side

Bulk cones are a well-known phenomenon in bulk solids applications. They form in the course of filling and emptying processes. Due to the conical surface shape, signal loss and measurement errors can occur. Here TDR sensors offer a decisive advantage. Since the microwaves are guided along the probe, **signal loss due to signals reflecting away is eliminated**. This also simplifies echo analysis. In addition, due to the low frequency, the emitted waves have relatively large wavelengths (30cm), the reflection behaviour of which is less dependent on the surface shape of the material.

HIGH TENSILE FORCES

If it is a little more difficult...

The robust design of the coupling makes TDR sensors particularly resistant to the tensile forces acting on the probe. A rope break is therefore impossible

The larger the silo, the greater the forces that act on the rope. The tensile force is determined by the silo height, silo diameter and bulk density.

The **coupling design** specially adapted for bulk goods in combination with a **strong steel cable** makes TDR sensors particularly robust. The sensors can withstand tensile forces of up to 30kN on the rope. This prevents a rope break.

A second, economical design variant (12 kN tensile load) is offered for applications that place less stringent requirements on stability.

HIGH SILOS	*If it's a little higher...*
 *With a maximum rope length of up to 75 meters, TDR sensors are also suitable for use in high silos*	With a maximum **rope length of 75m**, TDR sensors are ideal for use in high silos. Since the emitted microwave pulses are less strongly attenuated due to their low frequency (1 GHz), they deliver a sufficiently large measuring signal even over large measuring distances.

Exemplary application of the TDR in SOLIDS

NG 3000 in high storage silo for cement

www.uwt.de/tdr-cement-application

Special Challenges:

- ✓ dust-intensive process environment
- ✓ material prone to build-up
- ✓ high process compatibility

How do TDR sensors master the challenges in the liquid area?

Due to its flexibility, the TDR technology is predestined to be used in liquid applications. Similar to the bulk goods area, measurement technology is also confronted with a variety of challenges, the characteristics of which however differ from those of the solids. **Steam, condensate, agitators or heating coils, distinctive separating layers, wave movements, volatile substances or limited space due to smaller container sizes** are all circumstances that can make it difficult to determine the level. Here, too, TDR sensors prove to be true all-round talents. The so-called coaxial version in particular provides excellent measurement results.

STEAM & CONDENSATE

If things get a little cloudy....

A condensate cone, which acts as an isolator between the coupling and the probe, increases the measurement reliability and also makes it easier to drain the condensate.

In applications where steam forms over a liquid, TDR sensors are excellent for determining the level. This is mainly due to the fact that the low-frequency microwave pulses emitted do not lose their signal strength in a vaporous atmosphere. This guarantees reliable level determination.

Since the composition of the steam is strongly dependent on pressure and temperature, the runtime can be affected under extreme process conditions. This in turn affects the measuring accuracy. In order to compensate for the changes in runtime, the TDR sensors specially developed for these applications have so-called **steam compensation** *(this is discussed in more detail in the chapter on high-pressure / high-temperature applications)*. However, steam compensation is not required in standard applications.

If condensate forms again from steam, this also has no effect on a reliable level determination. The basic requirement for this is a corresponding sensor design, which is characterized by the fact that the rod and process connection are insulated from one another. This ensures a clean signal coupling to the rod even if condensate is formed in this area. A conical shape of this insulation also helps to prevent condensation and makes it easier to drain.

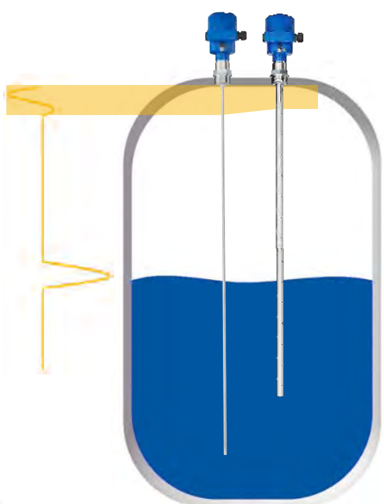
NARROW SPACES

When things get a little tighter...

TDR sensors with coaxial probes are the most reliable type of level determination.

A popular type of installation for TDR sensors is the bypass. The effect of the bypass tube is comparable to that of a coaxial tube.

Heating spindle inside a tank: No problem for TDR sensors with a coaxial probe. Even coils are not a source of interference with a coaxial probe.



Thanks to the signal bundling, TDR sensors with a coaxial probe can still detect signals in close range. This enables the tank to be filled up to the top edge.

Achieving a consistently constant process temperature is a process-critical component for many liquid applications. A uniform temperature distribution is achieved via heating rods or heating spirals within the tanks. The problems for guided microwave technology are obvious. With TDR technology, a microwave pulse is guided downwards along a probe in free space. The energy radiates within a radius of 300 mm (11.81in) around the probe. This means that both the container wall and the heating elements generate interference signals when they are within the effective radius of the microwave pulse. Measurement errors or signal loss are the consequence. This can be remedied by using a **metallic coaxial tube**, which is welded to the process connection and encloses the rod probe. The energy is focused within the coaxial tube, which completely eliminates external interference. Minimum distances to container walls or internal fixings such as heating elements and agitators therefore do not have to be observed. This so-called coaxial effect also occurs when TDR sensors are installed in standpipes or bypasses.

The **energy focus** of the coaxial solution offers another great advantage, which is important in small containers. TDR sensors have an area at the start of the probe where no measurement is possible. This arises because so-called noise occurs during the coupling of the microwave pulses onto the probe. Due to this noise, level signals in the upper range, which varies between 80 and 150mm depending on the quality of the coupling, cannot be interpreted and evaluated as such.

Due to the bundling of energy through the coaxial tube, the echo signals become larger, which means that fill level signals near the start of the probe can also be determined. The **block distance**, in which no measurement is possible, is reduced to only **30 mm (1.18 in)**. Filling to just below the top of the container is therefore no longer a problem.

Another side effect of bundling the energy is that even media with a **DK value less than 1.5** can be measured.

A coaxial version can also be helpful if the liquid is subject to strong **wave movements**. The coaxial tube not only protects the probe from strong lateral forces, it also calms the surface of the liquid inside the tube. Precise measurement results and avoiding probe damage are further advantages of this device version.

MEDIA CHARACTERISTICS

What needs to be taken into consideration...?

There are innumerable liquid substances with different properties. Three questions that can help you choose a suitable TDR sensor:

Are the sealing and insulation materials used chemically resistant?

Acids or alkalis can put enormous strain on the materials used in the TDR sensors. The coupling in particular therefore consists of high-quality and chemically resistant materials that maximize the life of the sensors. FFKM or PEEK are suitable materials in such cases.

Are the parts in contact with the medium suitable for food?

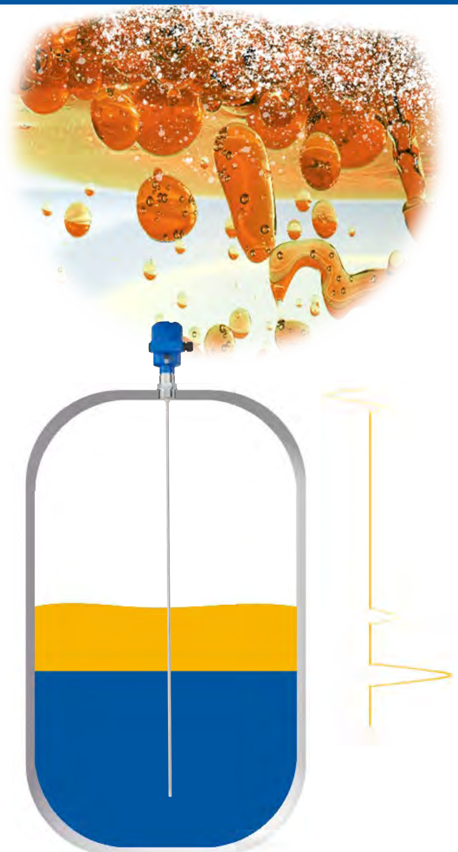
TDR sensors come into contact with the medium. It is therefore important that the probe, especially the surface finish, and the process connection meet the relevant standards.

Are the substances to be measured toxic or volatile (VOC)?

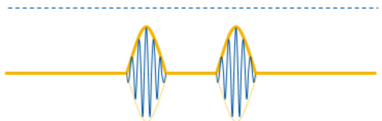
TDR sensors are designed in such a way that it is impossible for gases of hazardous substances to escape into the immediate vicinity where people may be present. Special sealing solutions are used for this. The area of signal coupling is sealed using a borosilicate glass seal, the so-called Second Line of Defense (SLOD), in order to guarantee maximum safety.

INTERFACE MEASUREMENT

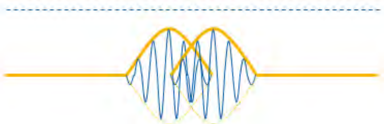
If something separates...



TDR sensors process the echo signals in envelopes. The width and slope of the envelope is largely determined by the bandwidth. The larger the bandwidth, the steeper and narrower the envelope. A higher bandwidth consequently leads to a better resolution, as a result of which two echo signals in quick succession can be better separated from one another. Steeper envelopes also increase accuracy.



Resolution of second, short consecutive echo signal with a large bandwidth.



Resolution of second short-duration echo signal with low bandwidth.

TDR sensors are particularly well suited for one specific measuring task: interface measurement. Oil floats on water. A phenomenon that everyone knows. The two substances cannot be mixed together. They break up. The transition from oil to water is called the interface. Level measurement of interface layers is a widespread standard, particularly in the chemical and oil & gas sectors. TDR sensors are the first choice for this measurement task. The reason for this are special software algorithms and the special property of the emitted microwave pulses:

The ability to penetrate substances with a low DK value.

Due to the comparatively low frequency, the microwave energy is not so strongly attenuated by substances with a low DK value. For the interface measurement, this means the following:
If the emitted microwave pulse hits the upper layer (e.g. oil), a small amount of energy is reflected, the remaining energy radiates through the upper layer and hits the lower layer (e.g. water). There the microwave is reflected a second time and runs back along the probe to the sensor. The microwave pulse is thus reflected twice, once from the upper and once from the lower layer. The echo processing software is able to record and evaluate the two reflected signals. Both the total fill level, interface layer and the upper layer thickness can be determined. A dynamic change in the layer position and upper layer thickness is also possible and does not affect the measurement result.

A critical point that must be considered when measuring the interface layer is an adequate thickness of the upper layer. Depending on the sensor, this varies between 50-100 mm (1.97-3.49 in). This is due to differences in quality in terms of echo resolution, which is determined by the bandwidth. The higher the bandwidth, the sharper and steeper the echo signals. This makes it easier to separate and analyze echo signals in quick succession, which is common for interface measurements. The steeper slope increases the accuracy. TDR sensors that can measure thin interfaces with high precision therefore have a wider bandwidth range.

The following four conditions must be met:

- ☑ Upper layer thickness max. 50mm
- ☑ DK value of the upper layer known
- ☑ DK value upper layer < DK value lower layer
- ☑ Difference in DK values > 10

TDR sensors in high pressure / high temperature applications

In addition to the standard TDR sensors, which are mostly designed for process temperatures up to 200°C (392 ° F) and 40 bar (580 psig), TDR sensors were developed that are specially designed for process temperatures up to 450°C (842°F) and up to 400 bar (5801 psig) pressure. The requirements for sensor design are significantly higher here. And the emitted electromagnetic microwave pulses are also significantly influenced under certain process conditions. But the measurement technology experts have also developed intelligent solutions for this.

ROBUST AND DURABLE

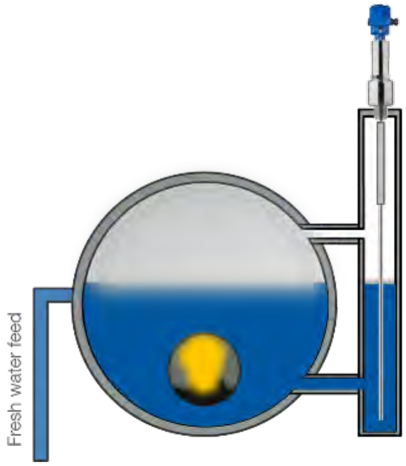
The robust design of a TDR sensor for high pressure / high temperature applications. High-quality and insensitive materials prevent the penetration of water vapor into the interior of the coupling. The result is reliable measurement results over a long period of time.

When it gets extreme…

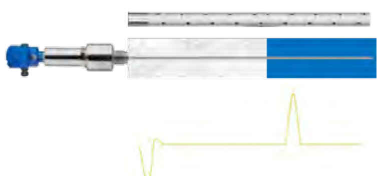
A great challenge in high-pressure / high-temperature applications is to combine robust sensor design with low-noise and low-loss signal coupling. Appropriate cooling sections and sealing solutions have to be developed due to the extreme conditions. The dimensions of the coupling thus increase. Low-loss signal coupling over such a long distance is only possible through a high-quality, matched material selection in conjunction with a corresponding design of the coupling. Because the better the signal quality of the emitted signal, the better the quality of the reflected signal and thus the measurement result.

STEAM

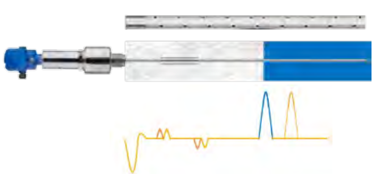
If it goes in the steam boiler ...



To measure the water level in steam boilers, TDR sensors are installed in a bypass pipe. Steam compensation helps to precisely determine the fill level even at an operating pressure of over 40 bar and a temperature of over 200°C



Steam leads to a delay in running time under extreme conditions. As a result, the echo signal appears too late and the measurement result becomes inaccurate



The runtime shift is compensated when using steam compensation. For this purpose, a reference signal is generated via an additional tube around the probe, which can be used to precisely calculate the level.

Typical applications in which the robust TDR sensors are used are steam boilers. Steam is generated here under extreme pressure and high temperatures. A constant water level is crucial for an optimal steam quality. TDR sensors fulfill this measuring task with the help of a special feature.

Steam Compensation

In the first part of this white paper, the effects of steam have already been discussed. While a steam is formed under standard conditions (standard in this case means process temperature <200°C (392°F) and process pressure <20 bar (290 psig) hardly affects a level determination with guided microwave, this changes however under more extreme conditions.

The measurement result in a steam boiler that is operated at 350°C (662°F) and 200 bar (2900 psig) is falsified by 76%. The reason for this is the strong influence of steam on the speed of propagation under these conditions. It is slowed down considerably, which results in this high measurement error. In order to compensate for this measurement error a reference rod is installed inside the coaxial tube. With the help of this reference path, a reference signal is determined during the factory calibration, with the help of which the steam-related delay time delay can be compensated. The longer the reference rod, the more precise the compensation. This enables measurement accuracies of +/- 3 mm (0.12 in) to be achieved even under these extreme conditions.

Accuracy of TDR sensors under varying process conditions

Gas phase	Temperature	Pressure				
		10 bar (145 psig)	50 bar (725 psig)	100 bar (1450 psig)	200 bar (2900 psig)	400 bar (5800 psig)
Air	20°C (68°F)	0.22%	1.2%	2.4%	4.9%	9.5%
	200°C (392°F)	0.13%	0.74%	1.5%	3.0%	6.0%
	400°C (752°F)	0.08%	0.52%	1.1%	2.1%	4.2%
Steam (saturated steam)	100°C (212°F)	..	..	..	..	..
	180°C (356°F)	2.1%	..	..	..	..
	264°C (507°F)	1.44%	9.2%	..	..	..
	366°C (691°F)	1.01%	5.7%	13.2%	76.0%	..

If the pressure or temperature increases, this has hardly any effect on the accuracy of TDR sensors. Even if additional steam is formed, the measurement accuracy remains high. Steam in combination with very high temperatures and pressures in turn has a noticeable effect on the accuracy of TDR sensors. In extreme cases, this deviates by up to 76%. With steam compensation, however, this inaccuracy can be compensated.

Exemplary application of the TDR in LQUIDS

NG 8000 in Maceration processes of wood processing

www.uwt.de/tdr-wood-application

Special Challenges:

- ✓ special installation conditions
- ✓ high temperatures
- ✓ steam and moisture
- ✓ fluctuating process pressure
- ✓ varying DK values

Conclusion

TDR sensors are extremely versatile, which is why they can be found in a wide variety of applications and industries. In addition to the technology-related advantages of radar, the user-friendliness of the sensors has also had a positive impact and is another reason for its widespread use. Quick commissioning wizards, which guide the user step by step through the setting options, have greatly simplified calibration. Diagnostic functions and the easy to interpret echo curves help with troubleshooting, which shortens system downtimes enormously.

Together with the other points in this white paper, it is clear that TDR sensors are a reliable method of level determination even under difficult process conditions.

UWT GmbH

Westendstr. 5
87488 Betzigau
Germany

Tel.: +49 (0) 831 57 123 0

Fax: +49 (0) 831 57 123 10

www.uwtgroup.com

info@uwtgroup.com

https://www.facebook.com/UWTde/

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WE ARE LOOKING FORWARD TO YOUR SENSOR CHALLENGE!

We are very happy to support you with our expertise in the multitude of challenges that you have to overcome in the field of level measurement technology.

Your Nikolas Oppenberger

Tel: +49 831 571 23 146

Email: nikolas.oppenberger@uwt.de