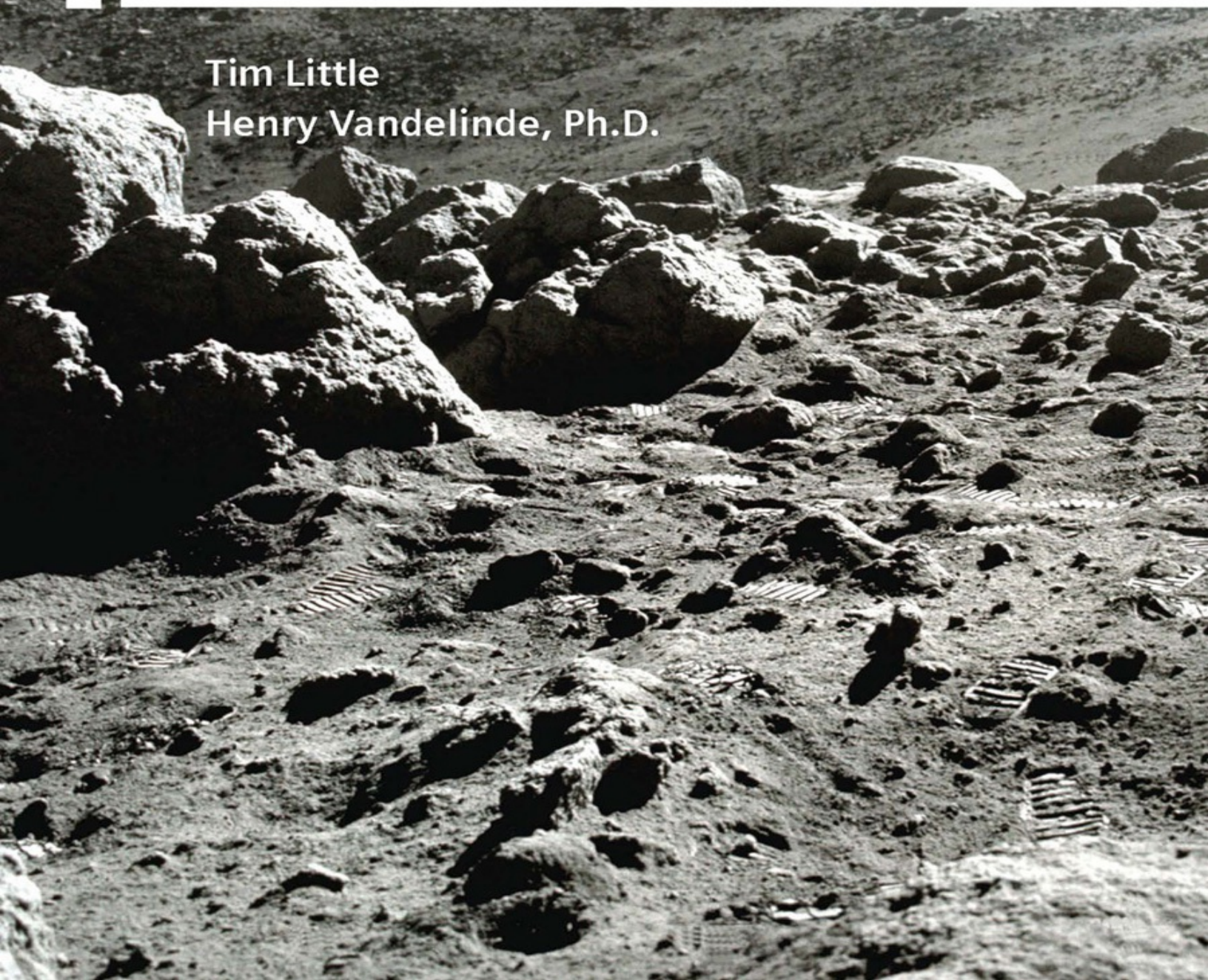
Going the Distance

Solids Level Measurement with Radar

SIEMENS

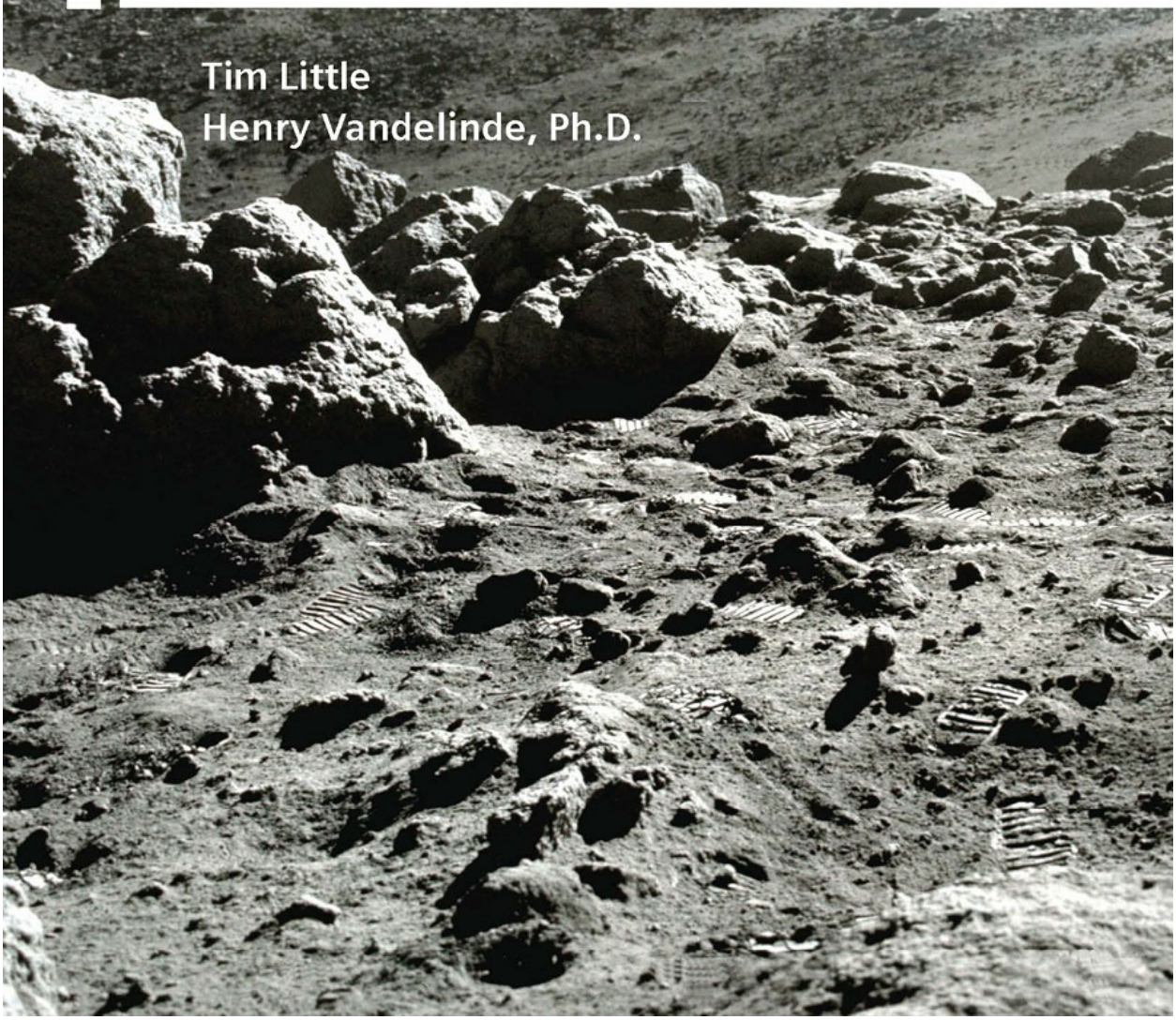


Tim Little
Henry Vandelinde, Ph.D.

Going the Distance

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Summary

Foreword

Siemens proudly presents this comprehensive guide to radar level measurement on solids media. From flour and coal to plastic pellets and cement powder, radar performs reliably on applications once considered too difficult, becoming the ideal technology for dusty solids measurement. Beginning with the SITRANS LR400, Siemens pioneered radar advances in the dusty solids market for the past decade, overcoming the challenging applications, installation difficulties, and high maintenance costs associated with solids level measurement.

From the days when ultrasonics first cut through the distance at the speed of sound to radar powering through dust so thick you could scoop it with a spoon, my whole professional life has been dedicated to this journey. I have been on silos and vessels all over the world and have dealt with the easy and the difficult, and I truly believe that the potential of radar in the level measurement market is only beginning to be realized.

Now Siemens takes another innovative leap in this forward path with the new 78 GHz SITRANS LR560. Its plug-and-play simplicity, long-range capacity, and measurement reliability position SITRANS radar technology as the only solution to your continuous solids level measurement requirements.

Tim Little, Product Marketing Manager

Acknowledgements

In the world of level measurement, radar is a fast growing and exciting technology, and we try to capture a bit of that thrill in these pages. The knowledge collected in this book is the sum of several decades of Siemens expertise, and we thank all those innovative and dedicated researchers, developers, engineers, application specialist, and marketers who recognized early on that Siemens radar had the potential to carve out a huge chunk of the solids level measurement market. It is their work that led to the SITRANS LR560, and it is our firm belief that this versatile and exciting product will be a milestone for radar technology. This book is a testament to that belief and to all those who pushed the technology into the new millennium and Siemens to the forefront in the solids level measurement market.

The authors in particular want to thank the SITRANS LR560 development team whose determination to build a plug-and-play, long-range solids radar brought us to this day. We salute your technical creativity and your ambitious vision. We also thank all those who contributed directly to the development of this book. Pete Froggatt who brings his inimitable creative style to the graphics from the practical to the playful, and Jamie Chepeka who coordinated the development from design to print. Her patience and resourcefulness are legendary, and we both owe you a debt of gratitude. We also thank the numerous reviewers who held us accountable and who put in many hours on the elusive typo hunt. The best of this book belongs to all of you, and the authors take full responsibility for any and all misses.

On a personal note, Tim sends an appreciative hug to his ladies – Wendy, Ashley, and Amy. Their love and encouragement meant a great deal in the writing process. Henry, as always, sends his thanks to his boys for their unwavering support.

Lastly, we thank SC PI 2 management for their continued support of the book project. This one is the third[1] in the Siemens SC PI 2 library, and a fourth on dynamic weighing and belt scales is in production. We will keep writing

them as long as you keep reading them.

1 See *Understanding Ultrasonic Level Measurement* by Stephen Milligan and Henry Vandelinde (2007) and *Catching the Process Fieldbus* by James Powell and Henry Vandelinde (2009).

Chapter One

Introduction – solids level measurement

In every phenomenon the beginning remains always the most notable moment.[1]

The late George Carlin[2] once said that the whole meaning of life is to try and find a place for your stuff. To take that a step further, the whole meaning of economy has to do with production, storage, and distribution of stuff; and to manage all this stuff successfully, it needs to be measured. This book is about how to measure stuff, specifically solid stuff, and how radar level measurement has developed into an accurate and reliable technology for industry to manage its stuff.

Topics

- Basics of level measurement
- Containers for level measurement
- Measuring solids level
- Point level
- Continuous level
- Level technologies

The basics



Knowing the level or volume of solids material has always been valued, whether it is confirming the stockpile of wood for the winter season or determining the quantity of ingredients required to produce a loaf of bread. The former means

survival through a cold Canadian winter while the latter determines dinner for the night. These visual methods are effective and people use them dozens of times throughout the day. How much water is left in the cooler? Is there enough sugar in the bowl for coffee time? Are there enough eggs for breakfast? Again and again, people measure quantity throughout the day.

Much of what is measured is possible because the quantity level can be observed. The water cooler and the glass measuring cup represent a visual sight-glass type of measurement principle – it is possible to see through the vessel to take the measurement. However, not all containers are transparent or open at the top. Content levels in sealed containers like silos are difficult to determine without the help of a measuring system of some sort, whether it be a knotted rope or a sophisticated electronic system. Knowing what the level is in these solids containers is crucial to managing the inventory properly, ensuring that there is always enough material to feed production or to be shipped to customers. Depending on the industry or the nature of the contents, accuracy demands will vary. Some customers are satisfied with approximations while others require specific and accurate knowledge of a vessel's contents.

Understanding the level of solids material is crucial for many businesses, although the precision of that measurement is dependent on the requirements of the business. So the measurement of accuracy for cement in a 50 meter silo can have a +/- error margin of one meter while a feeder hopper may only be out by a few centimeters to keep production flowing in a process that relies on the accurate addition of material for its success.

This book focuses on radar solids measurement and how it has become the most reliable, accurate, and cost effective technology for measuring solids level in industries like cement, mining, and food supply. While there are many manufacturers of radar instrumentation, Siemens has carved out a significant market share by inventing reliable radar solids measurement and has become a premier supplier of radar instrumentation to solids applications across the globe. From the ground breaking SITRANS LR400 and SITRANS LR460 to the inexpensive plug-and-play simplicity of the new SITRANS

LR560, Siemens is committed to providing accurate, reliable, easy to use radar instruments for all solids applications. So the next time you are asked about measuring a solids level application – the answer is Siemens.

Solids containers

Solids level measurement is mainly restricted to containers which hold a variety of materials, and their shapes and sizes reflect the content requirements:

- cement
- plastic pellets
- coal
- lime
- flour
- grain
- aggregates
- wood dust

Containers also come in different shapes and sizes depending on their functions.

Silos

Cylindrical storage vessels in either steel or concrete for bulk materials, typically 2 to 30 meters (6 to 90 feet) in diameter and 10 to 60 meters (30 to 197 ft) in height.



Hoppers or bins

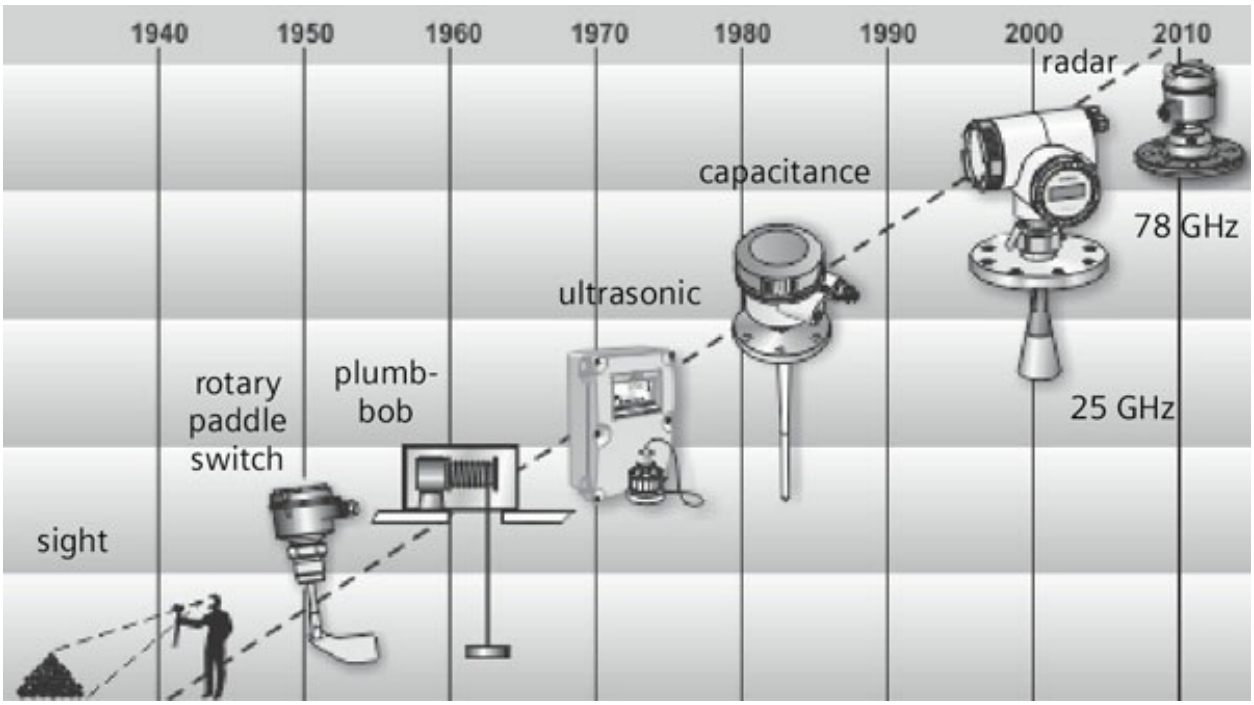
Smaller than silos, these containers are used as intermediate buffers between inventory and daily production. Similar to a chute but built larger to hold inventory, hoppers are temporary storage containers for dry solids, holding product for later use.

NOTE: The common challenge facing level measurement suppliers is that silos and hoppers were almost always designed without consideration for installing a continuous level measurement device. Thus the instrument has to be fit in where possible, rather than where preferable. This situation has been limiting for de-vices that cannot operate too close to the side walls or are too large for the point of access. However, now the SITRANS LR560 with its narrow beam is well suited for these applications.

Solids level measurement

Measuring a container’s contents uses techniques from the very basic to the high tech. Before instrument based measurement, content levels were often determined by mechanical means like lowering a measuring rope attached to a weight from the vessel’s top. Another popular technique requires striking the silo with a mallet or throwing rocks at its sides and determining level through pitch changes. These rudimentary measuring methods are labor intensive and generally inaccurate, but do provide basic level data for the user. Certain applications, where accuracy is not an issue and cost is, still rely on these methods. However, when measurement requires precision, level instrumentation with a variety of sophisticated technologies provides the accurate data.

Level measurement technology development



Solids level is measured in two distinct ways:

- point level – the content level is measured at a specific point in the container, often high and low to prevent overfill or inventory depletion. Point level measurement is generally done by switches that activate fill alarms.
- continuous level – a constant reading of the container's contents is made available by the instrument. Continuous level data is gradually becoming the measurement of choice as it allows for accurate inventory management and process control.

Radar has the highest growth rate in this market.

Point level

Level technology accuracy and reliability has significantly improved for the solids market in the last five decades. Point level switches were introduced in the 1940s and replaced many of the basic techniques such as ropes. Installed at the top, bottom, and occasionally the midsection of a silo, switches

generally provide relay points activated by material contact. Top level switches provide over-fill protection, avoiding costly clean up efforts and environmental damage. Low-level switches and mid-level switches are generally used for inventory management by giving set points that indicate usage trends or re-order points.



The SITRANS LPS200 paddle switch has a high integrity mechanical seal.

Point level switches require little setup, provide low cost measurement, and are available in several technologies including radio frequency, capacitance, and mechanical rotary paddles and tuning forks.

Note the following solids applications are suitable:

- dry material
- non-abrasive free-flowing type solids materials

Under these conditions, however, many contacting devices may experience problems:

- falling or heavy material can cause mechanical stress or damage the sensor element
- high moisture applications can lead to buildup, causing pre-mature switching or switching failure
- abrasive materials can deteriorate the sensor or damage the seals in some rotary paddles

A point level switch provides the level information at a specific level, so production planning and inventory management can be difficult, even with carefully spaced switches. By the time the low level point switch is activated and more material should be ordered, the silo may be empty and production stops until new material arrives. Mid-level switches at key points would help prevent this situation, but adding switches drives up the cost and the usage rates can still vary depending on production rates.



Think of the logistics involved with your automobile if you didn't have a fuel level gauge and only had the use of two level switches: a full level indicator and a near-empty indicator. You would then need a log book to track your distance and the rate of consumption related to your driving habits.

There will be many a day that you are standing at the side of the road with a gas can.

Continuous level

Requirement for higher accuracy and improved production and logistics management have thus created a demand for continuous level measurement technologies that provide constant level information over the full range of the vessel. The oldest continuous level measurement technology for solids materials is the static weight system. The silo or hopper sits directly on multiple load cells that put out a signal level directly proportional to the weight of the silo. Load cell technology is still available, but it is expensive and difficult to install.

Ultrasonic measurement devices arrived on the market in the 1970s and provided reliable continuous level measurement systems. Easy installation from the vessel's top and low maintenance made this non-contacting technology very appealing. Although restricted somewhat to shorter ranges and limited success in dusty environments, ultrasonic technology is still widely used for continuous level measurement. Other continuous technologies have since joined the market (see below), providing accurate and reliable level data.

Continuous level technologies

Numerous technologies are available for the continuous measurement of solids, each with its own advantages and limitations. While no single technology is suitable for all applications, non-contacting radar has the greatest applicability when considering all process variables, total cost of ownership, and ease of use. This suitability is confirmed by the greater and continuing growth rate of radar technology over other technologies in solids level measurement applications.

> In 2008, Siemens solids radar business growth exceeded 35%.

The following methods and technologies are found in the solids level market:

- consumption calculation
- rope measurement
- plumb bob
- laser
- load cell / strain guage
- capacitance
- ultrasonic
- guided wave radar
- radar

Consumption calculation

This common method calculates level by considering consumption and production rates. If, for example, the silo capacity is 150,000 kilos, and 5000 kilos of finished product is produced daily with a 5% scrap rate, then 52,500 kilos of material is consumed every ten days, leaving 97,500 kilos.

> When the silo is filled, a hi level switch or person on the top of the silo needs to confirm when the silo is full.

Advantages

- no capital investment

Disadvantages

- not accurate because of variances in the manufacturing process consumption. Silo must be manually checked regularly to confirm levels.
- time consuming
- errors in calculations lead to potential overfilling or a lack of material – both costly to clean up and/or in stalled production

Rope

A measured rope is dropped into the silo from the top until a change in resistance is felt, and the airspace distance is then subtracted from the silo's total height with the difference providing the material level.



Advantages

- cost effective and direct.

Disadvantages

- potentially unsafe
- the user has to climb to the top of the silo to take a measure-ment
- the user may be exposed to the hazards associated with an open silo — intense heat or dust. During filling the dust can be especially dense. If the material temperature is high, the rope must be able to withstand the heat. Since material surface temperatures can be significantly higher, dipping ropes or tapes can stretch or break and lose their weighted ends in the material.
- screw conveyors or other hazards near the bottom can entangle the rope

- accuracy is questionable. While the method should be accurate as it is a simple distance from the top to the material contact, the material profile needs to be considered. The angle of repose in a solids tank can be considerable, so depending on where the rope makes contact, the level accuracy can vary.

Angle of Repose is the internal angle between the surface of the pile and the horizontal surface of a granular solids pile.

Plumb bob



This automated mechanical rope technology is referred to by numerous names, including Yo-Yo®[3], plumb bob, or weight-and-cable. A weight and cable unwind from a motor operated drum until the weight reaches the material surface. When the cable is retracted, the length of the retracted portion of the cable is calculated using electrical pulses from an encoder assembly.

Advantages

- reasonably accurate
- suitable for very low bulk density materials (very low density materials require a weight with a large surface area)

Disadvantages

- the mechanical wearing on the moving parts leads to high maintenance costs
- failures occur when the cable collects dust or other debris
- cables get damaged or weights are lost in turbulent applications or materials with extremely high bulk densities
- systems are generally not operable during filling as the weight can become trapped under the filling material. Stopping the fill periodically to update the measurement is time consuming and difficult to manage.

Laser



High frequency electromagnetic waves operating at laser wavelengths (generally one micro-meter) measure the distance to the material using the time-of-flight principle. Laser technology has been used effectively for scanning the surface of solids and providing accurate volume measurement. Laser technology can be applied to industrial level measurement applications with minimal dust, but care must be taken to ensure the lens is kept clean. For most solids applications, this requires an air purge option.

Advantages

- narrow aim and accurate point measurement
- long range
- very fast update rates

Time of flight calculates distance by comparing the time taken to reach a destination to the speed of the flight.

Disadvantages

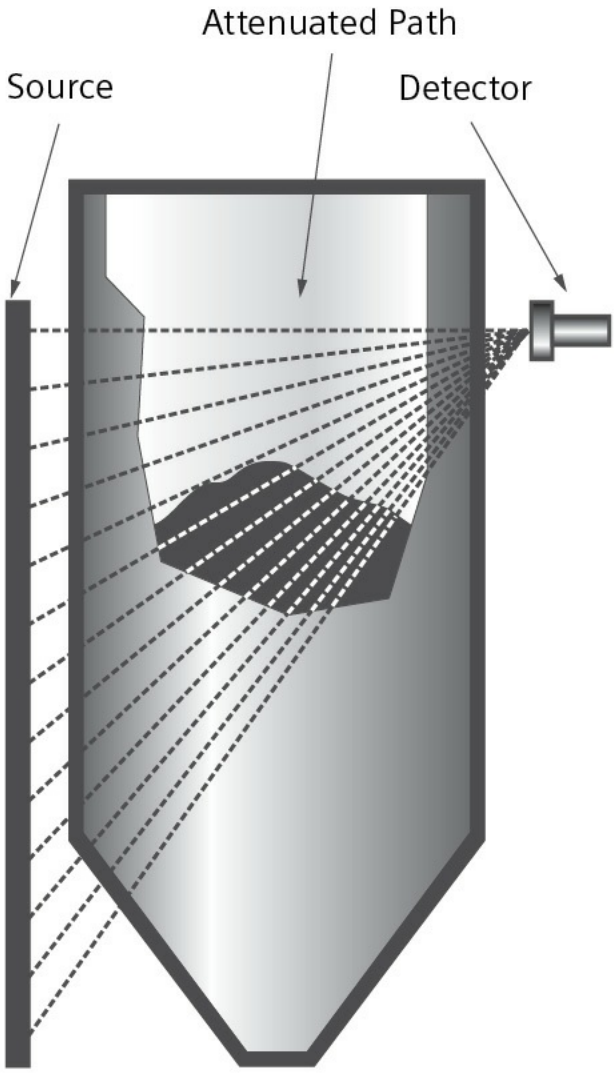
- high maintenance associated with cleaning
- poor performance in dusty applications because laser frequencies are absorbed by dust particles in the atmosphere, reducing the measurement range in higher dust intensity. Extremely dusty environments absorb the laser signal and there is no reflection from the surface. This is the fundamental difference between radar at lower electromagnetic frequencies and laser at very high electromagnetic frequencies – lower frequency radar is not attenuated by dust. Laser effectiveness is similar to ultrasonic technology considering the effect of dust and the resultant attenuation.

Nuclear

Nuclear radiation level measurement uses a radioactive material source like Cesium or Cobalt located on one side of a silo while the other side contains the electronic detector. The gamma radiation has much less transmissibility through the material than air, thus attenuation indicates its presence between the source and the detector. For continuous level measurement, either a long source or a long receiver section is used, and these must both be aligned to ensure the complete silo contents are measured.

Advantages

- non-invasive and mounted outside the silo walls
- impervious to the conditions within the silo



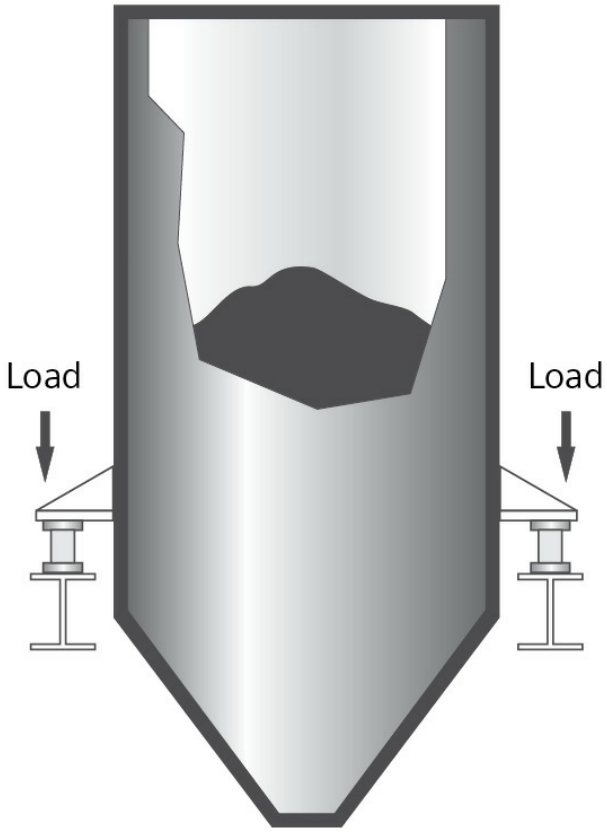
Disadvantages

- more expensive than other technologies
- installation sensitive
- a nuclear radiation source requires licensing, as well as a knowledgeable nuclear safety officer on site
- the source will deteriorate over time and need proper disposal and replacement, a very strict, costly, and formal process.

When there is no possible mounting place for another type of level technology or when the process environment is too extreme for conventional level measurement technologies, nuclear is sometimes the last resort for critical measurement.

Load cell/strain gauge

Load cells support the silo and its contents and directly report the mass within by providing an output voltage proportional to the load (voltage is calibrated for empty and full conditions).



Strain gauges operate in a similar fashion by reporting a varying voltage output with load; however, they are easier to install directly onto the support legs of the silo. The strain gauge measures the support structure compression under load, proportional to the weight in the silo.

Advantages

- accurately reports the mass of the silo contents

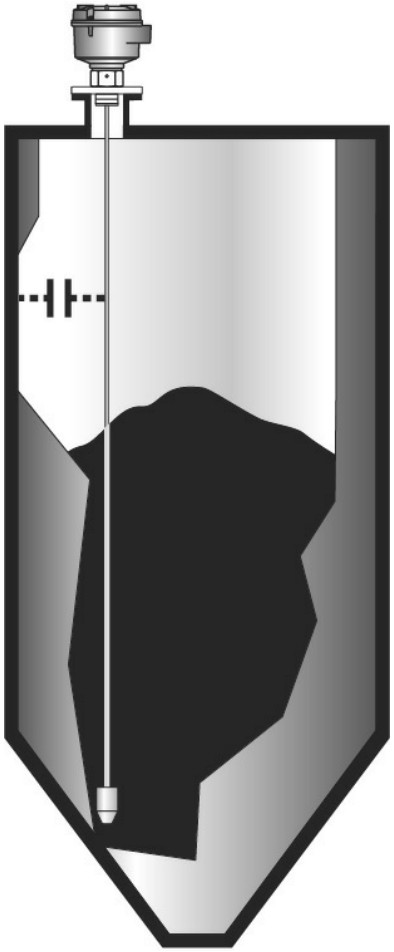
Disadvantages

- hysteresis effects from connector pipes or support members connecting the silo to the building structure and wind effects
- installation can be difficult and expensive if the silo must be completely lifted onto the cells
- calibration of this system may be challenging as the silo must be completely empty to produce a zero output condition and then must be filled to a known mass span. A full silo or hopper is required to obtain

the span output level as this will yield the highest accuracy. Acceptable accuracy can be achieved with a level greater than 50%. Coordinating this calibration zero and span with known values of weights can be a challenge.

This technology is widely used in very small hoppers and silos requiring critical mass measurements, high accuracy batching, or ratio applications.

Capacitance



With capacitance level technology, a capacitor stores an electrical charge and is made up of two parallel plates of a conductive material separated by a dielectric material (a non-conductive or insulating material). The amount of energy stored by this dielectric material is the measured capacitance, and the difference in capacitance between the material and the empty section marks the level.

A capacitance system uses an electronics transmitter with an non-insulated probe (or rope) and a ground (earth) reference. The ground reference can be a metallic tank or silo wall that is connected to electrical earth and the product to keep them at the same potential. The measured material makes up the dielectric material, and the cable and tank wall act as the two parallel plates. An increase in the material level results in a proportional change in the measured capacitance which is then converted by the transmitter to an output signal to indicate level.

Capacitance technology has been used for well over fifty years in a variety of industries.

Advantages

- used in a wide range of applications, good for adverse conditions including high temperature and high pressure
- has installation flexibility and can be mounted on the top of the vessel, but can also be mounted from the bottom or on the side of a silo

Disadvantages

- subject to mechanical damage from abrasion to signal problems due to material buildup
- readings may also vary with changes in the dielectric properties reacting to moisture or property changes of the solids

Ultrasonics[4]



Ultrasonic technology uses the time-of-flight principle, directing high frequency sound waves to the material by a transducer and measuring the time lapse of the return. Frequencies as low as 5 KHz are used for long range solids while higher frequencies at 44 KHz or above are used on shorter ranges, primarily liquid targets.

Distance ranges of up to 60 meters are promoted; however, this maximum range quickly deteriorates when there is intense dust in the silo.

Advantages

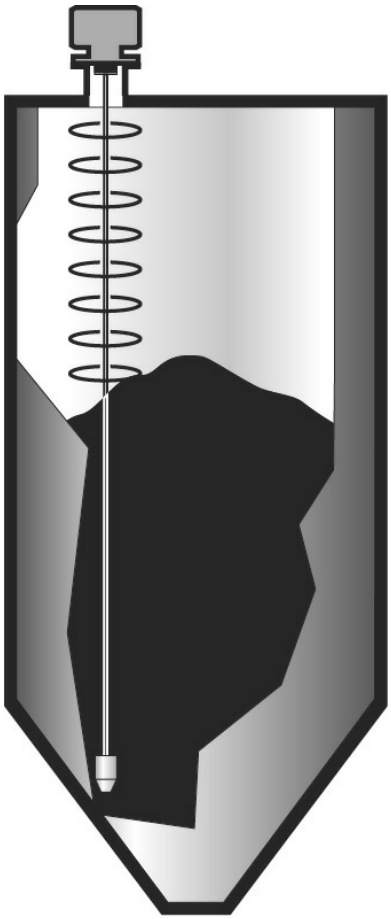
- low cost and reliable
- non-contacting
- sophisticated controllers capable of intelligent echo processing of the return echoes, differentiating between false echoes (ladders, material buildup, weld seams) and the material echo
- can be used without restriction in silos or hoppers which are completely open

- self cleaning sensors

Disadvantages

- dusty atmospheres may prevent a return signal to the sensor
- high temperature materials will also change the speed of transmission, leading to measurement error
- sloped surfaces may cause indirect reflection leading to weak and/or split echoes

Guided wave radar (a.k.a. TDR)



Also known as Time Domain Reflectometry, this technology sends an electromagnetic pulse down a guided conductor until it hits the tank contents and then returns. The level is then calculated using the time-of-flight measurement principle. This technology is generally limited to shorter ranges (20 meters or less) and materials that are not extremely heavy or abrasive.

Advantages

- relatively low cost
- easy to set up
- not affected by atmospheric conditions (temperature, pressure, dust)

Disadvantages

- shifting material and tensile forces make the instruments prone to broken or tangled cables that could interfere with the process and increase maintenance costs
- the bottom of the cable is sometimes anchored to ensure the cable does not move around during material draw down or shifting. If the cable touches the side of the silo, it will report false measurements.

- cables must also be sized properly for the silo to ensure they can withstand the huge tensile forces present; however, if the cable is too strong, it can damage the silo roof during material draw down
- when installing a cable system, the vessel must be completely empty before fastening the end of the cable to the bottom of the silo. Alternatively, weighted cables can be used, but the silo must first be empty to allow the cable to stretch out to its full length.

Radar



Radar (Radio Detection And Ranging) technology has been used successfully for liquid level measurement since the mid 1970s on large storage vessels, although the costs were initially high. Radar was used with only limited success until the late 1990s because of the high cost, large antenna/low frequency design, and low signal/noise ratio, all limiting its use as effective level measurement.

As cost decreased and the technology developed further, radar devices have been applied to a wider range of applications, including smaller liquid bulk storage as well as agitated process vessels. Just after the year 2000, a breakthrough occurred when Siemens introduced the SITRANS LR radar transmitter into the market. This 24 GHz unit[5] had an extremely high signal to noise ratio, and these features, coupled with Siemens Milltronics' advanced echo processing system, demonstrated immediate success in the difficult cement industry (long range dusty solids). Within a very short few years, 24 GHz radar quickly became the preferred measurement technology for all leading cement manufacturers.

Advantages

- cost effective
- works well in dusty environments
- effective for long range (up to 100 meters)
- high accuracy, one millimeter is possible on liquid applications

Disadvantages

- filling stream may intersect transmission beam, causing false readings
- very top and very bottom levels are not measureable due to blanking requirement. Minimum detection distance is usually 0.3 meters or greater, and the lowest areas of the cone in the silo can present a challenge due to multi-path reflections.

Summary

This brief outline of the solids level measurement field now turns the focus to radar technology and how it has become the dominant technology in the market. The following topics are discussed:

- History and types of radar (FMCW and Pulse)
- Frequency, performance, and the benefit of 78 GHz
- Antenna selection and properties
- Installation
- Configuration example
- Echo processing of solids
- Troubleshooting
- Markets and application examples

1 Carlyle, Thomas. Scottish philosopher, and author. 1795-1881
2 Carlin, George. American comic. 1937-2008.
3 ®Yo-Yo is a registered trademark of Bindicator.
4 For the definitive text on ultrasonic level measurement, see S. Milligan and H. Vandelinde, *Understanding Ultrasonic Level Measurement.* Siemens Milltronics, 2007.
5 24 GHz was the high frequency radar at the time.

Chapter Two

History of radar

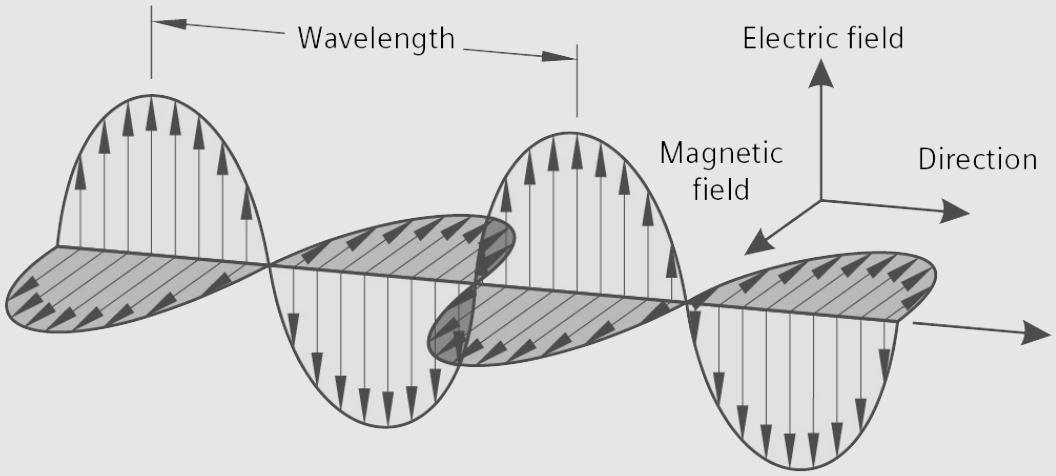
Learn from yesterday, live for today, hope for tomorrow. The important thing is to not stop questioning.[1]



Journalist and historian Robert Buderi claims the development of radar to be one of the seminal events in modern technology:

Radar has been the root of a wide range of achievements since the war [WW II], producing a veritable family tree of modern technologies. Because of radar, astronomers can map the contours of far-off planets, physicians can see images of internal organs, meteorologists can measure rain falling in distant places, air travel is hundreds of times safer than travel by road, long-distance telephone calls are cheaper than postage, computers have become ubiquitous and ordinary people can cook their daily dinners in the time between sitcoms, with what used to be called a radar range.[2]

The premise behind all these applications is actually rather simple: electromagnetic waves are harnessed and/or measured, resulting in heat, communications, measurements, sounds, and visuals.



First presented as a theory 175 years ago, radar technology now has numerous daily applications with more added regularly. In the last decade, radar technology has also been successfully applied to solids level measurement. The journey from theory to military death ray to solids measurement takes numerous turns as the technology grows, changes, and new possibilities are illuminated. As frequencies increase and components get smaller, new applications come to light. This chapter briefly outlines the journey from nineteenth-century mathematical theory to sophisticated level instrumentation.[3]

Topics

- History of radar
- Key thinkers and milestones
- Liquids to solids – a long shot
- Solids level market drivers
- Market opportunities

History of radar – speeding into a new sunrise[4]

The long distance communication requirements of the military took the fledgling radar technology out of its infant stage and pushed it into a rapidly evolving communication and measurement technology. Two key applications spurred the development:

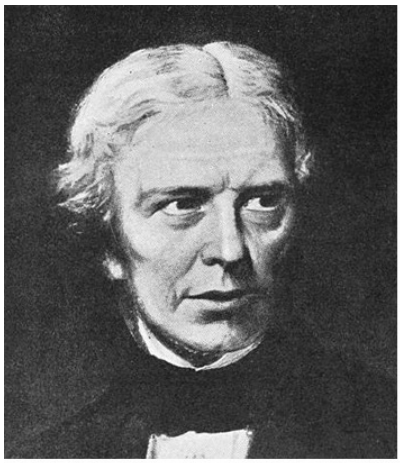
- long range communication: radio
- defense: detecting ships and aircraft

The practical employment of electromagnetic waves to these two applications illustrate the key characteristics that also make radar practical as a measurement technology:

- high speed: travels at the speed of light
- directional: can be pointed directly at a target to focus signal or to increase sensitivity. e.g. television antenna
- no carrier medium required: travels in full vacuum
- not impeded by media that hampers ultrasonic signals: e.g. rain drops, clouds, fog, temperature variations, dirt, to name just a few
- instruments can be small and low powered: e.g. SITRANS LR560, Bluetooth headset

Key thinkers and milestones[5]

The route from theory to military application and then to industrial use is a long and varied one for radar technology and rests in the mathematical models of Michael Faraday. A nineteenth-century English physicist and chemist, he is credited with developing the basis for the electromagnetic field concept in physics. In 1831, Faraday postulated the idea of electromagnetic induction, establishing that a changing magnetic field produces an electric field. This relationship became know as *Faraday's Law,* a mathematical model for electromagnetic fields developed from Faraday's ideas by Scottish theoretical physicist James Clerk Maxwell in 1865.



Michael Faraday
(1771–1857)



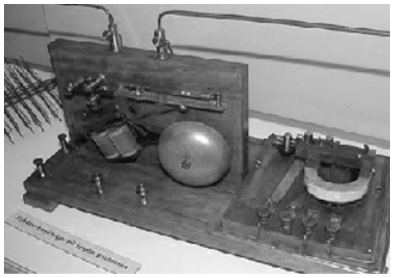
James Clerk Maxwell
(1831–1879)



Heinrich Hertz
(1857–1894)

Maxwell used Faraday's law as one of four equations in which he shows that magnetism, electricity, and light are all related and are part of an electromagnetic field. Using the four equations, he confirmed that all electromagnetic waves move at the same speed of light in space (300,000 kilometers per second). This conclusion is still considered to be one of the greatest advances in physical science. In 1936, Albert Einstein referred to Maxwell's work as the "most profound and the most fruitful that physics has experienced since the time of Newton."[6]

Maxwell's theories were then used by Heinrich Hertz to show that electromagnetic radio waves are remarkably similar to light. The German physicist's experiments proved that free space electromagnetic waves can travel over a distance as suggested by Maxwell and Faraday. By measuring Maxwell's waves, Hertz demonstrated that the velocity of radio waves was equal to the velocity of light when he transmitted and received radio waves in his lab.[7] Furthermore, he also measured electric field intensity and polarity.

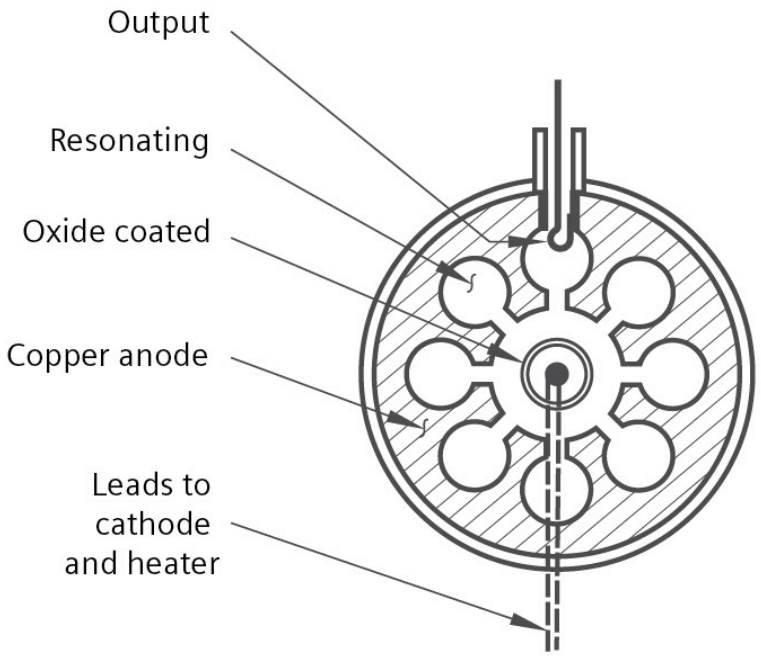


Using Hertz's experiments, German Engineer Christian Heulsmeyer developed the first working instrument that used electromagnetic waves. In 1904, he used the telemobiloscope[8] to locate a ship on the Rhine by bouncing signals from it. Although he couldn't determine the distance, he

did detect its presence. Over the next decade, numerous people, including Guglielmo Marconi the radio developer, worked with the technology for detecting metallic objects.

The oscilloscope is a test instrument that shows a two-dimensional electronic signal.

However, the first practical use for the infant technology was illustrated in the mid 1930s by both the Soviets and the British. In 1934 Soviet scientists used radio waves to detect a plane flying at 150 meters from 600 meters away, and in 1935 British scientist Robert Watson-Watt combined a BBC radio transmitter with an oscilloscope to detect aircraft as far away as 13 kilometers. Using Watson-Watt's continuous wave radar as inspiration, the British military eventually developed a radar safety net during WWII to detect incoming bombers and fighters. The development of the cavity magnetron in 1940 was important and helped the British and Americans develop powerful radar instruments that made night flying safer by allowing planes to ground map and by helping fighters find their targets in the dark sky.



The development of the cavity magnetron was a pivotal step; it not only increased power but narrowed the frequency, reducing ambient noise in the return signal for clearer detection of the target.

The Americans are also credited with coining the term *RADAR* (Radio Detection and Ranging) in 1941.[9] Radar became a staple in the defense arsenal on both sides as the war continued, and by the end of the war most of the countries involved used radar with varying degrees of success. The Allies, led by Britain and the Americans, operated the most advanced systems and many historians credit radar with shortening the war.[10] After the war ended, radar development continued and was used extensively by the Americans and Soviets to build early warning detection networks during the Cold War. As the accuracy increased and the costs came down, other practical uses for radar technology emerged.

Microwave oven



No discussion on the development of radar and microwaves would be complete without reference to the microwave oven which was discovered by accident in the early 1940s by an engineer at Raytheon, the American defense contractor. Percy Spencer was working on a radar experiment when the chocolate candy bar in his pocket melted. Intrigued, he fed microwave power into a metal box, creating a high density electromagnetic field, and placed food in the cavity. The first thing he cooked was popcorn and then an egg, which exploded all over one of the lab techs.[11]

From these early experiments, Raytheon developed a microwave oven called the Radarange®[12] in 1947. Almost two meters high and weighing a substantial 340 kilos, it sold for $5,000 (US). As the technology developed, the cost dropped and by 1954 a commercial model was available for $2,000 to 3,000 (US). By 1967, Raytheon was marketing a domestic countertop Radarange microwave for $495 (US), and smaller even less expensive units flood the market today, popping corn and exploding eggs in millions of kitchens.

The development of the microwave oven from a costly pantry sized appliance afforded by only a small market into the ubiquitous coffee warmer used the world over mirrors the common development path of any emerging

technology. It starts out large and expensive, and as market opportunities come to light and technological advances refine it, popularity increases. This is a self fulfilling prophesy as the bigger the market, the more the competition; and the greater the need for cheaper, faster, and smaller components.

This development model is also relevant for the use of radar as a solids level measurement technology. The shift from detecting aircraft and ships to radar level gauging is a natural one, and like the development of the microwave, it goes from the early large, expensive units in selective applications to the Siemens SITRANS LR560, the easiest, most reliable solids radar on the market today.

Aircraft and naval radar

Initially, radar was developed to detect aircraft and ships, but when the instruments became smaller and more accurate, aircraft began to use radar altimeters for height sensing by the late 1940s. By today's standards, the radar equipment was still bulky and expensive, but by the mid 1960s semiconductor components allowed for radar frequencies of 10,000 MHz to be generated by semiconductor components. Saab,[13] the Swedish aircraft manufacturer, saw potential and used the technology to develop early warning systems and altimeters on its fighter aircraft.

Saab also had a department developing ship electronics and when the tanker ship industry expanded in the 1960s and 1970s, Saab took advantage of its shipyard connections to develop and promote radar level gauging for oil cargo tankers. Existing mechanical float systems were far from reliable and were subject to clogging and breakdown. The need for a non-contacting technology was clear and Saab stepped in to fill the gap, dominating the early development of radar for tank measurement.

The application requirements were demanding and Saab's developers had to meet these criteria:

- high accuracy requirement compared to aircraft altimeters
- lower cost target

- mandatory requirement for electrical intrinsic safety (a safety requirement ensuring that the instrument will not spark an explosion)
- difficult tank conditions

It took a while, but Saab applied for a patent for a reliable working radar measurement unit by 1973 and delivered a functioning unit in 1975. It was installed on the Norwegian crude oil tanker, the M/S Havdrott, and according to Rosemount it is still in operation.[14] Even though the oil crisis of the 1970s greatly reduced the building of the tankers, the market for the radar units was in place and grew steadily until 1983, when Saab Marine Electronics AB was formed under Saab to market this product.[15]



Technology expansion 1980s and 1990s

In 1985, two new systems were launched from Saab Marine Electronics:

- the TRM (TankRadar®[16] Marine) – optimized for ships
- the TRL (TankRadar Land) – the original marine unit adapted for measurements on oil refineries with increased accuracy and a number of other features.

As the first radar level system to get custody transfer approval for accuracy, the TRL system was a trail blazer in the market. While similar in technology to the TRM and based on proven production quality, there were also some differences based on the application requirements:

- flameproof enclosure for use in refineries

- temperature sensors connected to the radar unit, refining measurement and increasing accuracy by compensating for fluid expansion and contraction over temperature
- the ability to measure level in existing still-pipes

Saab Marine launched the TRL/2 in 1991. Lighter and designed for precision measurement, it was marketed to refineries and storage plants and boasted other major improvements in radar technology:

- a changed microwave transfer process between the electronics and the antenna made it possible to use a variety of antennas on the same electronics. It also made installation easier by making it possible to install the unit closer to the wall because indirect wall echoes could be suppressed.
- pipe measurement in Liquified Propane Gas (LPG) tanks
- general improvements in signal processing improvements, and the rapid development of microprocessors reduced costs

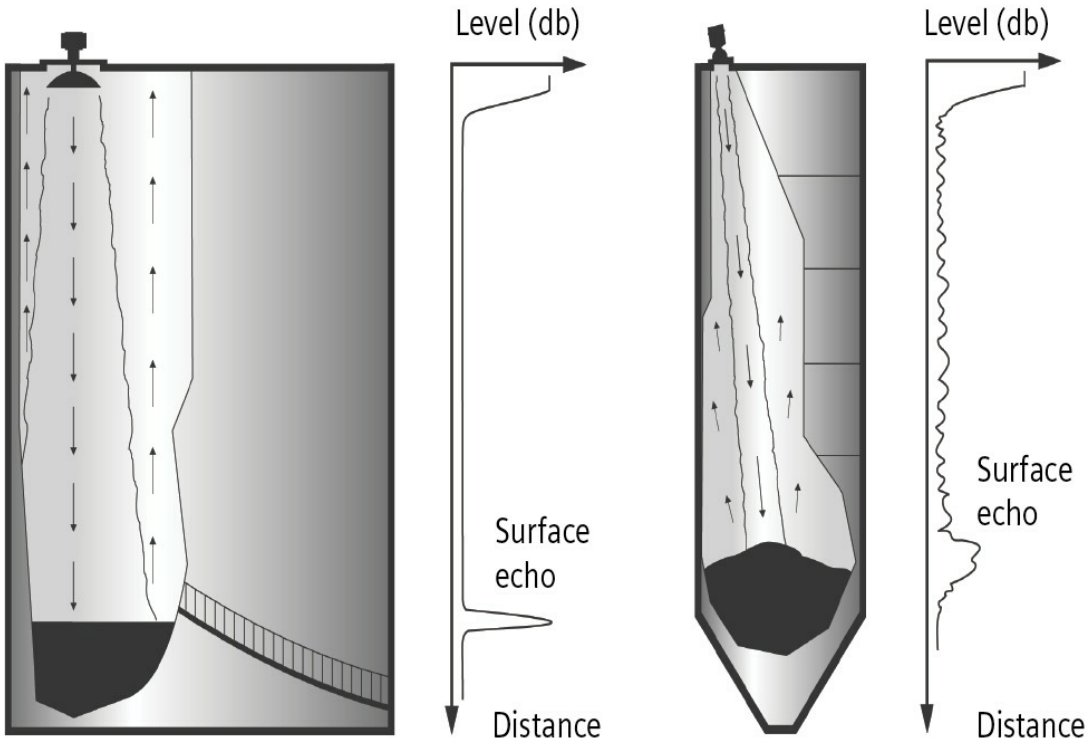
Liquids to solids – a long shot

Saab is the pioneer in the development of radar technology for tank measurement and can be credited with carving out the market for liquid level measurement on ships and large tanks. The liquids market was the natural one for the microwave technology (10 GHz FMCW[17]) because its limitations made solids measurement difficult. These included the antennas – the large dish antenna used in free-space applications is awkward to install in narrow silos while the smaller horn antenna was originally restricted to the stilling well tube. Flat liquid surfaces reflect just fine, but sloped, granular solids return signals too weak for the sensor to pick up.

Dielectric refers to the reflective properties of a material and how much of the signal it absorbs or returns.

However, Saab's success in the liquids market motivated other developers and industries to enter the market, and by 2000 radar was used successfully on many liquid applications including agitated process control vessels, but solids level measurement remained elusive on other than short range (<15 meter) flat surfaces.

Solids materials are significantly more challenging than liquids to measure because the dielectric properties are generally very low, and the surface is almost always sloped and/or irregular. This sloped and irregular surface causes the reflection to be much weaker than that from a flat surface, so the receiver design must be significantly more sensitive for these applications.



Sound waves travel at 340 m/sec at 15° Celsius.

Distance in solids measurement is the other factor that challenged radar. Solids silos tend to be higher than liquid applications (can be 50 meters or higher), and the liquids radar devices just did not have the power and/or sensitivity. Liquids radar was just a bad fit for solids, and the technology would have to be developed further if it were to be applied to the solids

market. Siemens accepted the challenge and started the new century by launching radar equipment specifically for the solids market and using the more sensitive components now available for the receiver designs.

When a signal is attenuated, it is absorbed by a medium, like X-rays and lead.

The advantages of radar as a level measurement technology were quickly realized in the early 1990s by companies like Milltronics[18], Endress & Hauser, Vega, and Krohne. Ultrasonics was the main non-contacting level measurement technology during this period, but was not suitable for the chemical and petrochemical industry. Applications with these materials contain vapors, are often under high pressure or in a vacuum, and can have extremely high temperature conditions. Because ultrasonic technology uses a compression/de-compression sound wave through air to propagate a signal, these conditions can adversely affect performance. When the vessel contains vapors other than air, the speed of sound changes and/or the signal is attenuated. In a vacuum, sound cannot travel at all, and temperature variations affect the speed of sound waves. If the speed is not constant, the calculation of distance is not accurate.

Radar, however, proved unaffected by these environmental influences, piquing the interests of level technology companies. While ultrasonic measurement dominated water/wastewater, aggregate, and other general applications where the atmosphere is regular (permitting measurable propagation), radar had the potential to measure the difficult applications. These applications included agitated vessels; vessels with foam, deposit, high dust, full vacuum, and fluctuating temperatures. Contact technology was the only technology available. However, contact has its own problems, especially where there are agitators or materials that clog a system or break a cable or rod. Furthermore, they are expensive, and technologies like capacitance had their own performance problems.[19] Thus, the market potential for a non-contacting measurement in these applications was significant and companies scrambled to bring solids radar to the market.

Radio waves travel at 300,000,000 meters per second regardless of temperature, pressure, or dust.

Solids level market drivers

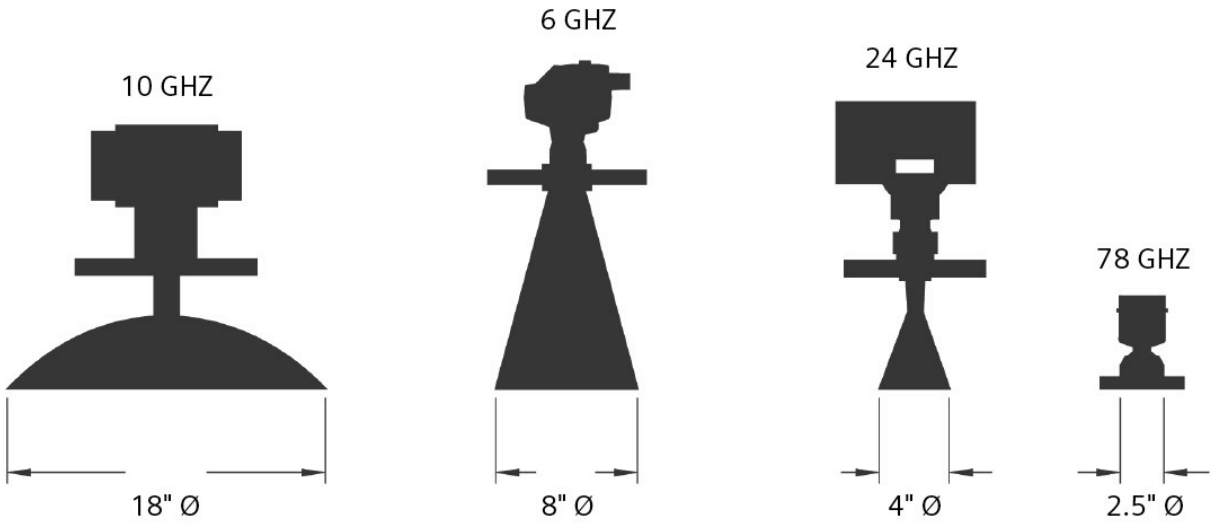
The market for radar solids level grew as a result of the combination of advancing technology and emerging market opportunities.

Technology advancement

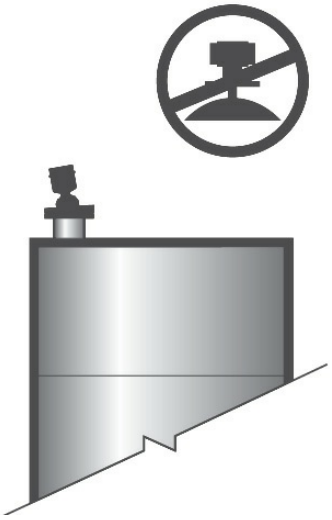
5.8 GHz (6.3 GHz USA) pulse radar technology[20] was introduced in 1981 as a lower cost circuit design over the 10 GHz FMCW designs in the market. The large dish or horn used on 10 GHz technology is not practical on the smaller vessels typically found in the chemical industry where vessel openings are typically 5 to 10 centimeters (2 to 4 inches) in diameter rather than the 45 centimeters (18 inches) required by the dish antenna.

> Costs also dropped and by the 1980s were a third of what they were a few years earlier.

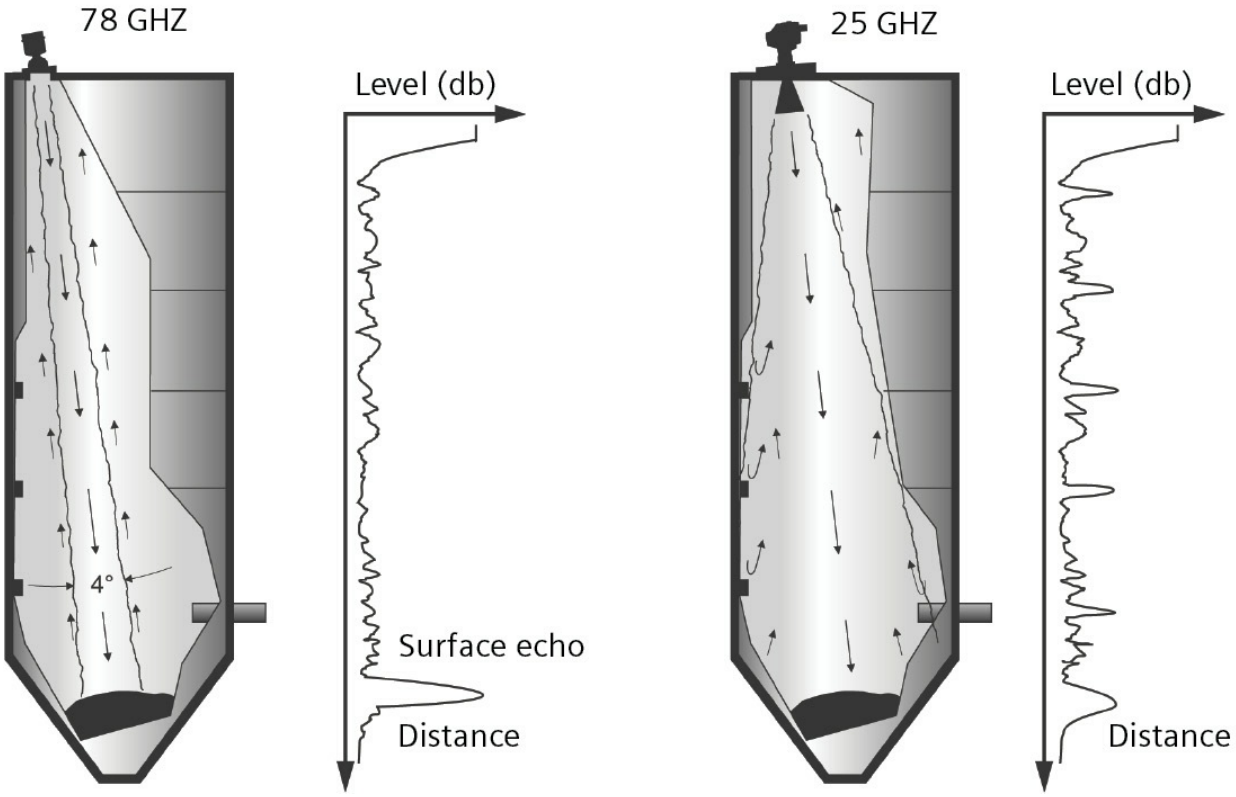
Pulse radar with 2-wire low power designs and the dielectric rod antennas that fit the narrow access connections opened up the liquids chemical market in the late 1990s. Furthermore, the increased sensitivity of the electronics and improved echo processing provided acceptable performance levels in chemical vessels, often containing internal agitator blades, baffles, and turbulence.



Frequency and the antenna



These advances in liquid radar brought to light opportunities for solids radar, and a significant driver was the increase in frequency capabilities – the higher the frequency, the smaller the antenna. Access openings into tanks can be kept small and that keeps installation costs low. Most silos do not have openings large enough to accommodate a large antenna and the cost of creating an opening large enough for the dish antenna (generally eight inches or greater) is prohibitive. Many silos would need to be completely emptied for this rework, perhaps scheduled during an annual production shutdown, delaying installation. Modern radar higher frequencies use a smaller antenna and can usually fit into existing openings in the silo. The antenna diameter for the 78 GHz Siemens SITRANS LR560 is less than three inches.



Frequency and the narrow beam

As frequency increases, the radar beam angle gets narrower, with three significant consequences:

1. Silos are generally tall and narrow, and the narrow signal ensures only minimal signal interference from hitting the side of the silo, preventing multi-path problems. Multi-path problems make it difficult for the unit to discern surface signals from wall bounce signals, leading to inaccurate and false level indication.
2. Transmitters with a narrow beam can be mounted inside standoff nozzles without worrying about interference from the installation nozzle. Lower frequency radar devices have a significant noise problem because the signal spreads as it leaves the antenna and intersects with the end of the standoff nozzle, causing noise throughout the complete measurement range. Installing a low frequency radar requires that the end of the antenna be exposed outside of the standoff nozzle to avoid this interference. This type of installation can be costly as the standoff nozzle may have to be altered or expensive antenna extensions are required. Higher frequency radar devices like the 78 GHz SITRANS LR560 can be mounted inside most existing standoff nozzles without any interference.

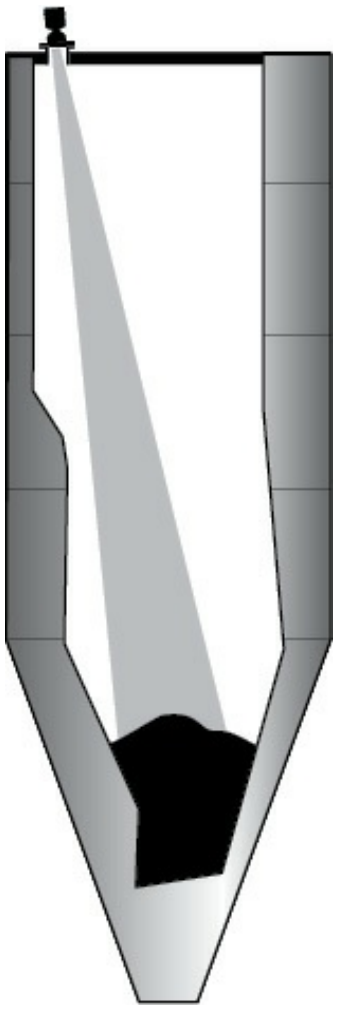


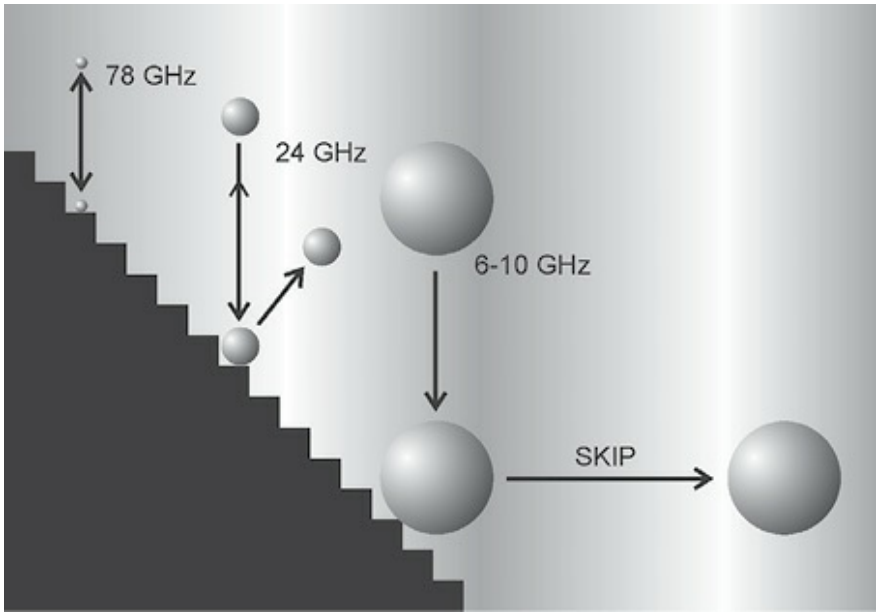
3. The narrow beam is more accurately aimed towards the center of the cone at the bottom of the silo, ensuring the material is measured well into the lowest level.

Frequency and reflection:

As the frequency increases, the wavelength of the signal gets smaller. Shorter wavelengths are needed to ensure direct reflection from sloped solids surfaces.

The wavelength at 5.8 GHz is 52 millimeters, so any solids particles equal or greater than half of this wavelength will be suitably reflected back to the source. However, most solids materials are smaller (plastic pellets, powders), which is the main reason why the earlier radar devices were not effective as the granular surface did not reflect adequately.




78 GHz
24 GHz
6-10 GHz
SKIP

Siemens brought 24 GHz radar[21] with a frequency wavelength of 13 millimeters to the solids level market in 2000, and while performance was very good, to this day the frequency still has limitations on sloped solids surfaces. Now, ten years later, Siemens introduces another breakthrough technology with the SITRANS LR560. This revolutionary system operates at 78 GHz with a wavelength of only four millimeters so that it performs on practically any sloped solids material.

Two-wire low power electronics

Early radar devices required line power (five Watts or more) to operate effectively, and wiring these older devices meant three wires for the power connection, two wires for the analog output signal, and then additional wires for the remote communication protocol. In the late 1990s, the first 2-wire loop powered radar transmitters hit the market, realizing an immediate installation cost advantage as communications and power are carried on the same two wires.

Since then, the availability of lower cost electronics components has also increased, and radar manufacturers wasted no time incorporating them into their designs.

The development of digital fieldbus communications networks like PROFIBUS PA[22] and Foundation Fieldbus further reduce costs by daisy chaining instruments together, minimizing wiring costs.

Increased electronics sensitivity

Prior to 2000, radar was only effective on solids with a relatively flat surface and with a comparatively short range (< 15 meters) such as finished cement and fly-ash. Most solids materials are significantly more challenging to measure because the dielectric properties are generally very low and the material surface is almost always sloped and/or irregular. Sloped and irregular surfaces cause the reflection to be much weaker than that from a flat surface so the receiver design must be significantly more sensitive for these applications.

Market opportunities

As frequencies increased, the antennae got smaller, the beams got narrower, and the installation costs shrank, more applications for radar became apparent. Traditional barriers to the technology fell by the roadside, and it became increasingly clear that solids applications would provide a significant market for radar. The emerging radar solids measurement would have several advantages over both ultrasonic measurement and contacting technologies.

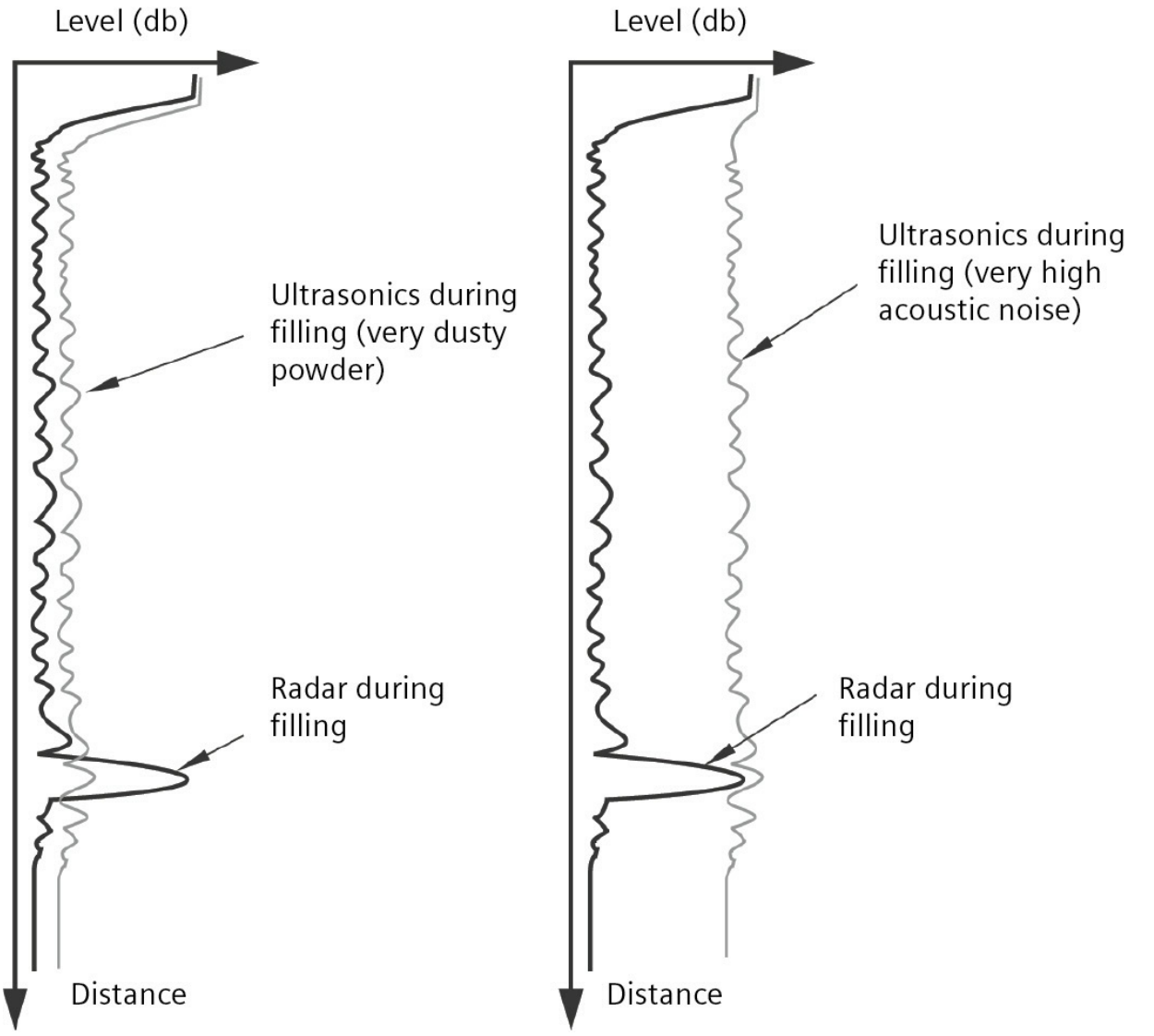
Performance in dusty environments

Electromagnetic waves propagate through dusty environments without any attenuation effects while ultrasonic sound waves can be drastically reduced or completely eliminated in a dusty atmosphere. Some applications are clear during static conditions when ultrasonic devices can work well, but they can easily lose signal during filling when dust and particles cloud the atmosphere. Ultrasonics is thus often rendered unreliable for process control applications or monitoring during filling.

Radar technology, however, provides a reliable signal during both filling and static conditions because the signal is not attenuated by dust. In many markets and applications such as the cement industry, the ability to provide a continuous level measurement signal was not possible before the year 2000.

Performance in noisy environments

Ultrasonic technology can also have difficulty during filling conditions due to the increase of the noise level. This filling noise causes the return signal to appear weaker. In fact, in some cases the signal may not be strong enough to overcome the noise. So aside from being attenuated by dusty conditions during filling, the additional sound/noise plays havoc with the signal.



Another noise source can be the long cable distances between the sensor and the controller (receiver) and the intrusion of capacitive or inductively coupled noise on the transducer cable. This electrical noise would affect the sensor as an elevated noise level similar to filling noise. Radar, which operates with electromagnetic waves at a very high GHz frequency, is not affected by these types of noise generators.

Safety

Solids silos are often high, and personnel need to climb ladders or access the rooftop to gain access to the top of the silo where wind, rain, snow, and ice are all serious environmental hazards. Safety is thus a big issue and the

potential for falling off (or into) the silo is a significant concern to manufacturers. As a result, going onsite often requires mandatory safety orientation training, proof of fall-arrest training, and confirmation of equipment use training.

It is not just the environmental conditions on top of the silo that need to be considered. Many silos use air pressure to pneumatically feed dusty solids into the silo, and opening it for a manual dip measurement during this time releases dust particles into the environment and exposes the operator at the same time. Other potential hazards like contact with sudden high temperatures, fumes, and mechanical devices like gate valves can make the top of the silo a dangerous place to send personnel. Remote measurement thus offers industry a secure alternative that is safe for personnel and will not disrupt the process, an event that incurs significant costs.



When I started my field service career in 1991, very few plants had a safety plan for employees or contractors to climb to the top of a silo. Sign in at the front door and up we go…

Nowadays most plants insist on fall arrest training certification and full body harness fall arrest equipment to ensure personnel safety. Thus the costs to venture to the top of silos has risen immensely.

In the United Kingdom, 13 individuals die yearly resulting from falls according to Health and Safety Executive. For individuals 45 years old or older, falling is the leading cause of death. Non-fatal fall injuries are frequent in the workplace, causing personal hardships and expense.

Summary

By the year 2000, both the market and the technology were ready for solids radar. The chocolate melting, corn popping death ray that opened up the night skies in WWII had proven itself as an effective and efficient industrial measuring system for liquids. Now it was ready for the leap to solids measurement and to open up new markets to coincide with the new millennium.

In 2000, Siemens purchased Milltronics,®[23] a global leader in ultrasonic technology. Like other level instrumentation companies, Milltronics had already started to develop radar technology with the IQ 160 and had experienced some success with 5.8 GHz radar devices on liquid applications. However, tests on solids were not successful.



IQ 160



SITRANS LR

Siemens had recently launched a 24 GHz FMCW radar level transmitter in the month prior to the acquisition of Milltronics. As Siemens Milltronics became the new Siemens global center of competence for level, this 24 GHz transmitter, the SITRANS LR, was brought into the level product portfolio. Field tests showed early on that this particular radar transmitter had promise in solids applications.

The SITRANS LR400 took the cement market by storm and within five years, 24 GHz FMCW radar became the standard for global cement producers worldwide. Siemens built on its success by enthusiastically expanding its radar portfolio.

SITRANS LR200 and SITRANS Probe LR 2-wire

Both are 6 GHz pulse radar level transmitters for continuous monitoring of liquids and slurries in storage vessels with pressure and high temperature to a range of 20 meters (66 feet).

SITRANS LR300

A 4-wire, 6 GHz pulse radar level transmitter for continuous monitoring of liquids and slurries in storage and process vessels including high temperature and pressure to a range of 20 meters (66 feet).



SITRANS LR200



SITRANS Probe LR 2-wire



SITRANS LR300



I remember reviewing the field trial data from sites in Germany right after the SITRANS LR was launched and a summary sheet identified a couple of successes on solids. I was skeptical but decided to test this new unit on the homogenization silo at the local cement plant where we had visited the year prior to test a new ultrasonic transducer. This 70 meter silo defied all measuring systems with its difficult measuring conditions:

- *continuous fill*
- *intense dust*



- *multiple air slides*
- *continuous aeration to keep the material inside homogenous*

It was so intensely dusty that when a trouble light was lowered from the top, it disappeared from sight after only two meters. Milltronics produced the most powerful ultrasonic sensors in the world, but even these lost signal after only five meters of measuring distance! The day we arrived on site to try the new LR400 there had been a recent test of a mechanical plumb-bob device and within one day the turbulence inside had torn the weight from the end of the stainless steel cable.

We dropped the SITRANS LR horn antenna into the existing four-inch hole where the plumb-bob had been mounted and immediately the radar transmitter read a 30 meter distance, backed up by the large spike at 30 meters on the signal profile. Impossible we proclaimed and dropped a rope to check the real distance. The rope confirmed the 30 meter distance and we were elated. We had arrived at a new era in measurement – reliable radar solids measurement.

SITRANS LR250

A 2-wire, 25 GHz pulse radar level transmitter for continuous monitoring of liquids and slurries in storage and process vessels including high temperature and pressure to a range of 20 meters (66 feet). Ideal for small vessels and low dielectric media.

SITRANS LR260

A 2-wire, 25 GHz pulse radar level transmitter for continuous monitoring of solids in storage vessels including extreme levels of dust and high temperatures, to a range of 30 meters (98.4 feet).



SITRANS LR250



SITRANS LR260

SITRANS LR400

A 4-wire, 24 GHz FMCW radar level transmitter with extremely high signal to noise ratio for continuous level monitoring of liquids up to 50 meters (164 feet). Ideal for very low dielectric media.

SITRANS LR460

A 4-wire, 24 GHz FMCW radar level transmitter with extremely high signal to noise ratio and advanced signal processing for continuous monitoring of solids up to 100 meters (328 feet). Ideal for measurement in extreme dust.



SITRANS LR400



SITRANS LR460

SITRANS LR560



All of the above transmitters are aimed at specific markets, including liquids, and Siemens continues to dominate the solids market with the robust SITRANS LR260 and the 100 meter SITRANS LR460. Never content to rest on its laurels, however, the Siemens radar group reached for the holy grail in radar solids measurement: a high intensity, plug-and-play unit easily installed into almost any solids application.

In 2010, ten years after the groundbreaking SITRANS LR400 cut through the dust and opened up the cement market, Siemens brings the SITRANS LR560 into the solids radar market. This high frequency, small, stainless steel transmitter uses a lens antenna so it fits into holes as small as seven centimeters, and can be placed almost anywhere on the silo because the high frequency beam eliminates both the need for aiming and for mitigating multi-path interference. At 78 GHz, it pinpoints the material surface with laser beam accuracy, even on difficult applications like fine sand and small pellets that are too steep for 24 GHz radar.

1 Einstein, Albert. *Relativity: The Special and the General Theory*. Penguin Classics, 2006.
2 Buderi, Robert. *The Invention that Changed the World*. Simon & Schuster, 1996.

3 The large radar is the Incoherent scatter radar antenna at Sondrestrom, Greenland and is used for ionospheric studies. This photo file is licensed under the Creative Commons Attribution ShareAlike 2.5.
4 Golden Earring. *Radar Love*, 1977. Please note, as tempting as it may be, that this will be the only reference to this song in the book.
5 The information in this chapter is meant to provide a context for the development of radar measurement only. We are not attempting a definitive historical treatise on radar, as there are many of those available written by people far more qualified than we are.
6 Einstein, Albert. (1879–1955) American scientist, physicist, philosopher.
7 Hertz was a full professor at the University of Karlsruhe when he discovered electromagnetic waves in 1885.
8 Photo courtesy of www.design-technology.info.
9 The term *Radar* is also a palindrome, a word or phrase that reads the same forward and backwards.
10 Air Chief Marshal Sir Hugh Dowding, Commander-in-Chief, RAF Fighter Command was asked if their only hope was to pray to God and trust in radar. He replied, "At this stage I would rather pray for radar, and trust in God." David E. Fisher, *Race on the Edge of Time: Radar — The Decisive Weapon of World War II*. 1987.
11 Just to be clear, there is no proof that this event is the origin of the phrase "getting egg all over your face" to indicate embarrassment.
12 "Radarange" is a now a registered trademark of Maytag Corporation (the current parent company of Amana Refrigeration).
13 The historical information on the development of Saab radar is courtesy of www.rosemount-tankradar.com.
14 The photo of the M/S Havdrott courtesy of www.rosemount-tankradar.com.
15 Radar tank measurement was the purview of the Saab Marine Electronics division. It was purchased by Emerson in 2001 to be part of its Rosemount division and eventually became known as *Rosemount Tank Radar AB.*
16 TankRadar® is a registered trademark of Rosemount Tank Radar AB.
17 FMCW: Frequency Modulated Continuous Wave Technology – See Chapter Three for a detailed discussion.
18 Milltronics was acquired by Siemens in 2000.
19 The Siemens capacitance line with its frequency based measurement technology has avoided the performance problems plaguing early capacitance instruments.
20 See Chapter Three for the comparison between FMCW and pulse radar technologies.
21 The SITRANS LR400.
22 For a comprehensive introduction to PROFIBUS and industrial communications, see J. Powell and H. Vandelinde, *Catching the Process Fieldbus*. Siemens, 2009.
23 ®Milltronics is a registered trademark owned by Siemens AG.

Chapter Three

Types of solids level radar

Catch a wave and you're sitting on top of the world.[1]



This chapter looks at how the two radar signal technologies, Frequency Modulated Continuous Wave (FMCW) and Pulse, work with the technical components like horn and rod antennas to produce specific application results. The object of the technology is to produce a signal profile so that the echo processing can work the data to provide a level output reading.

The antenna types focus the signal, depending on the application requirements, and there are numerous factors to consider when selecting an antenna. However, the revolutionary high frequency SITRANS LR560 uses a new antenna design – a lens – and it takes little space to install and does not protrude into the silo.

Getting an accurate and reliable radar signal on a solids application requires the perfect marriage of signal technology, antenna, and processing software.

Topics

- Signal technologies: FMCW and Pulse
- Antennas

Signal technologies

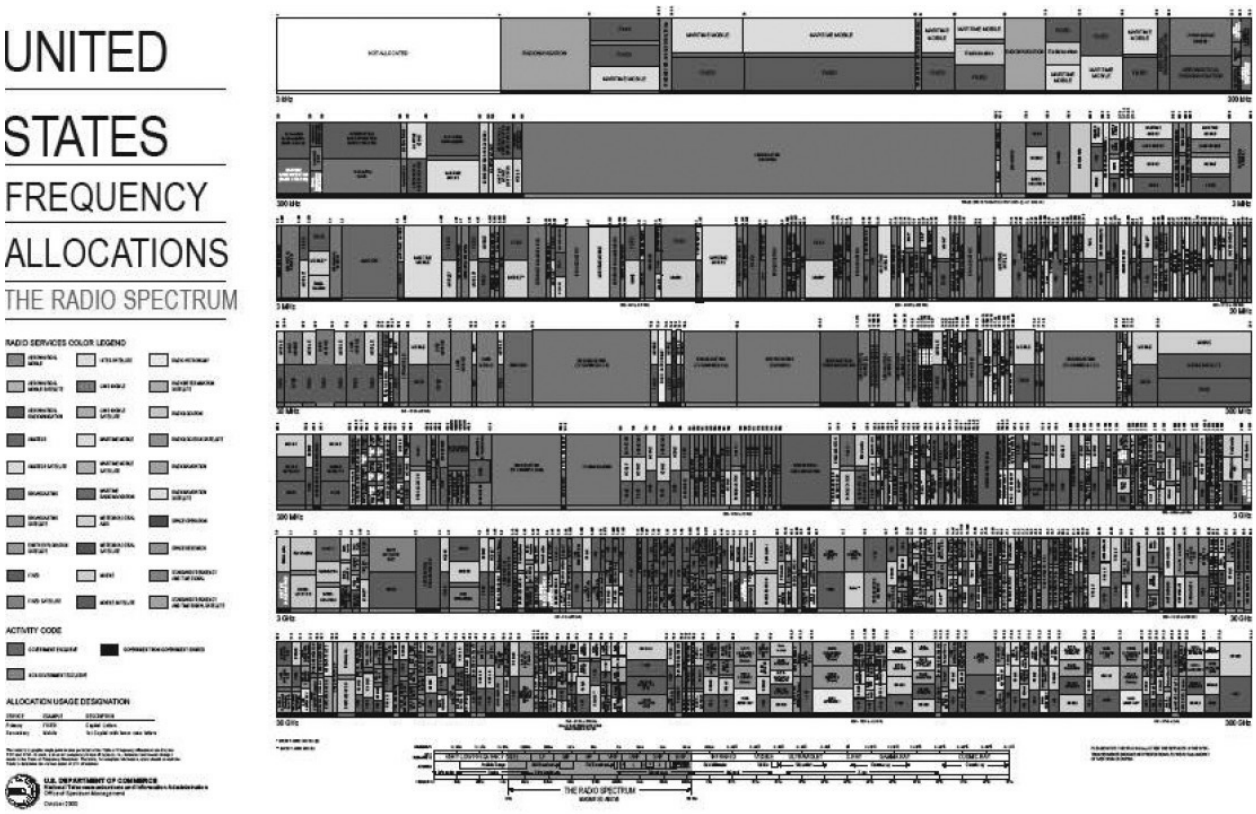
Radar instrumentation relies on two completely different technologies used to capture the raw signal profile from a silo: FMCW and Pulse radar. While the end user may not be able to discern the difference, after all performance is the only concern, radar manufacturers choose between the technologies for a variety of technical and economic reasons:

- FMCW makes precision measurement easier
- Pulse is easier to design and costs less to do so
- FMCW requires heavy math processing, making a 2-wire low power design more challenging than a pulse system

Radio approval for the defined frequency bands radar is required to operate within may also determine which signal technology is used, as the manufacturer may choose a specific design to fit within the approved band. FMCW radar can be designed to sweep precisely between a lower and upper frequency set point, while a pulse radar operates at a nominal fixed frequency; however, the bandwidth of the pulse radar frequency is wider and surrounding frequencies (say outside of 5.8 GHz) can spill into restricted areas.

In the USA, 5.8 GHz is not an acceptable frequency. At 5.8 GHz, there is an excess amount of signal transmitting from the main lobe in the restricted area of 5.46 GHz and lower. To avoid this, 6.3 GHz is used, offering a safety margin. Unfortunately for radar manufacturers, the radio spectrum is very busy and all users must compete for space. Since there are relatively few users of radar level measurement devices compared to television viewers or amateur radio users, it is very difficult to obtain an area of the spectrum which is dedicated to radar level measurement. However, this was obtained recently in Europe with the release of the new harmonized standard for radar level transmitters ETSI EN 302 372-1. This document defines specific frequency bands for level radar in closed vessels only; unrestricted free-air use of radar is still under discussion.

American radio bands



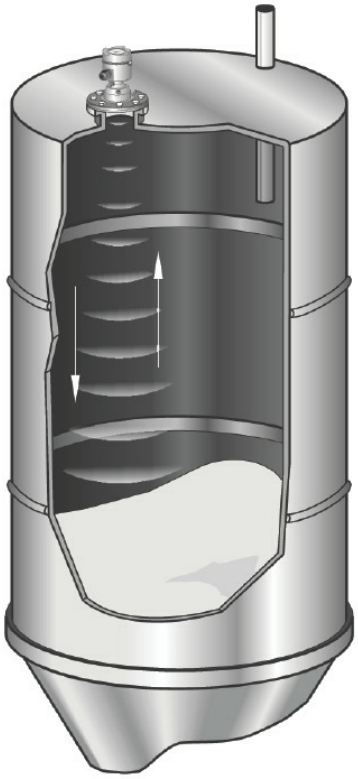
As illustrated above, the frequency spectrum for radio bands in the USA is very busy, and it requires careful control so that radar instruments can operate effectively in their areas.[2]

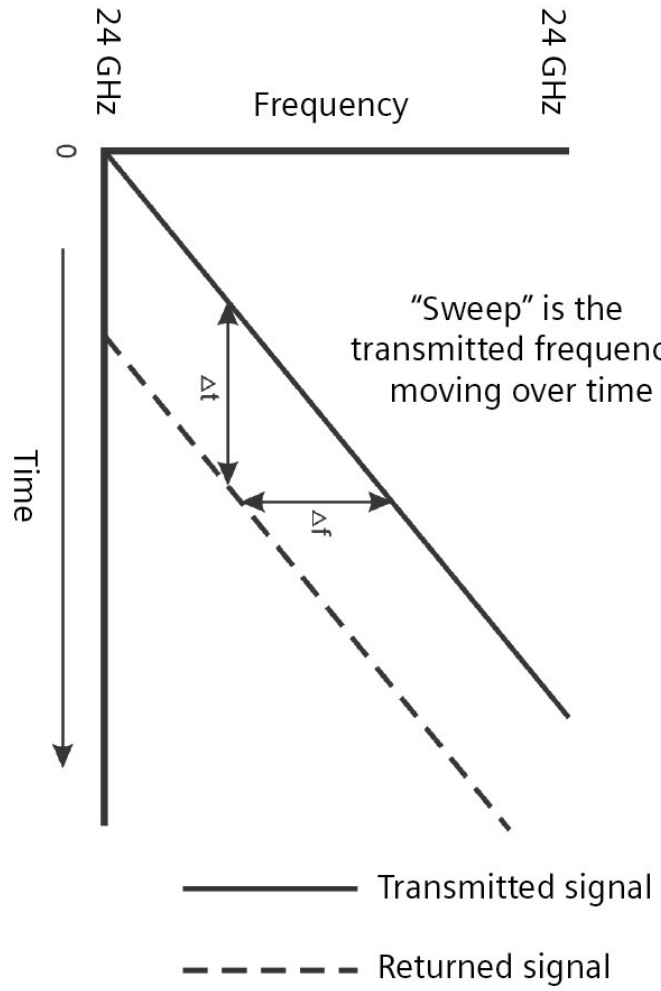
Frequency modulated continuous wave (FMCW)

FMCW technology was introduced to liquid level measurement in the 1970s. This technology uses a variable frequency transmitter that repeatedly sweeps over a specific frequency range. Simultaneously, the receiver circuitry continuously samples and compares the current transmitter frequency with the received frequency. The difference in frequency between the transmitter and receiver at any given moment is directly proportional to the distance due to the time delay to and from the target.

Imagine loudly singing a song from a mountain top (transmitting), and the resultant echoes coming back to your ears (receiver) are delayed depending on the distance to the reflective hill. There will also be a variety of echoes – strong echoes coming from the larger targets directly in front of you, and

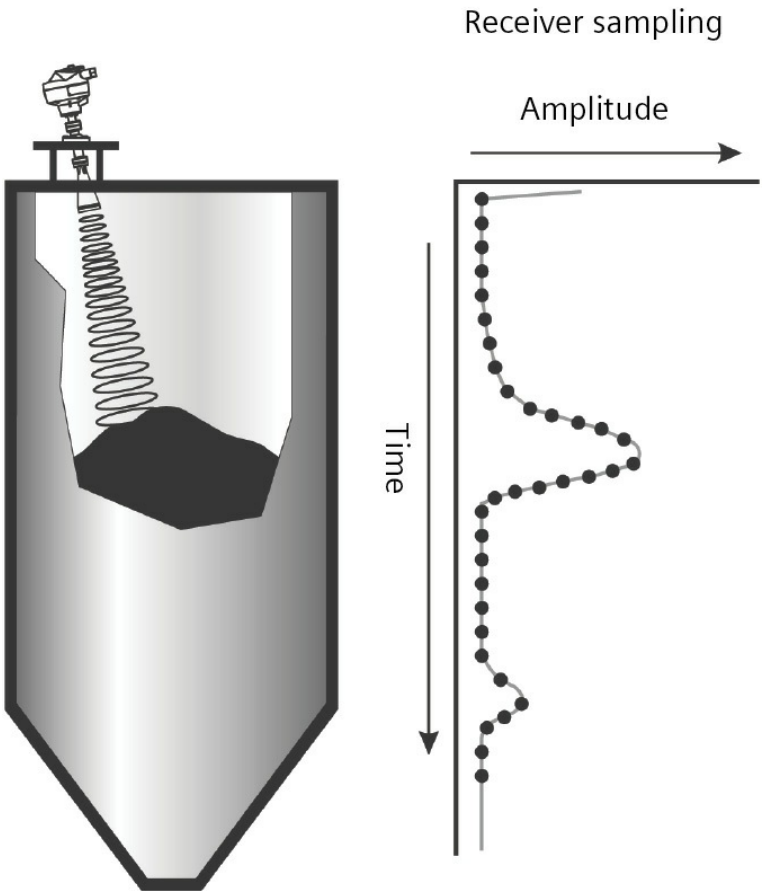
weaker delayed echoes for nearby objects like trees and large rocks. The echo processing software (Siemens Process Intelligence) then sorts the relevant echoes from the peripheral noise.





Pulse radar

Pulse radar was introduced in the 1980s in an effort to reduce the cost of the devices and accommodate the 2-wire design. Pulse radar uses fewer electronic components and uses less microprocessor power than FMCW. Pulse radar uses a fixed frequency transmitter and then uses time-of-flight measurement by calculating the time for the pulse to travel and return from the target.



For an ultrasonic transmitter it is a fairly simple calculation. Because the speed of sound is only 344 meters per second, a single burst into the silo and the return occur in real time, and a digital echo profile can be created from that one transmit cycle. However, electromagnetic waves travel at the speed of light, and it is impossible to calculate a silo signal profile with only one shot because electronic components are not fast enough to collect and sample the entire vessel at one time.

The calculation is only possible using a sampling technique. Pulse radar uses a very high transmit repetition rate (e.g. 500,000 times per second). For each transmit cycle, the receiver is triggered to measure the signal amplitude of the receiver at a very slight delay after the transmit pulse. For each subsequent pulse, the trigger for the receiver is delayed slightly more (measures the amplitude of the return echo signal) and repeats until the entire measurement

range has been scanned. The scan then sequentially steps further and further away from the radar device, and for every measurement, the silo is actually “scanned” in tens of thousands of small pieces.

Imagine travelling at the speed of light down a highway. The scenery all around would be blurry because the brain cannot absorb and decode all the information coming in from the eyes. Now close your eyes, turn your head to the right, and open your eyes for just a fraction of a second to capture the image you see. Repeat but wait just a moment longer before opening your eyes and capturing another image. This way, a clear panoramic picture is built one snapshot at a time. Pulse radar does the same thing. It captures specific reflections at intervals to build a complete reading of the level.

Antenna types

Since the inception of radar for solids level measurement, antennas evolved from large dishes to horns to small lenses. Many of the challenges of the past ten years have been addressed. Installation problem, such as small openings, tall nozzles, and material buildup have been overcome by advances in high frequency design and the development of the lens antenna. Antenna types used on solids have evolved from the parabolic dish to the horn, and now to the lens; and sizes have moved from 45-centimeter dishes to seven-centimeter lenses. However, all the antenna types are still in production and are often used where still applicable.

Four types of antenna are typically used for solids level measurement:

- parabolic dish antenna
- horn antenna
- dielectric rod antenna
- lens antenna

Parabolic dish antenna

The familiar parabolic dish antenna is widely used for data transmission and communication, weather detection, and satellite television reception. A parabolic reflector surface reflects the radar waves (aka “feed”) toward a focal point of this reflector. The dish acts like an upside down umbrella, collecting rain and gathering it in the center.



Advantages

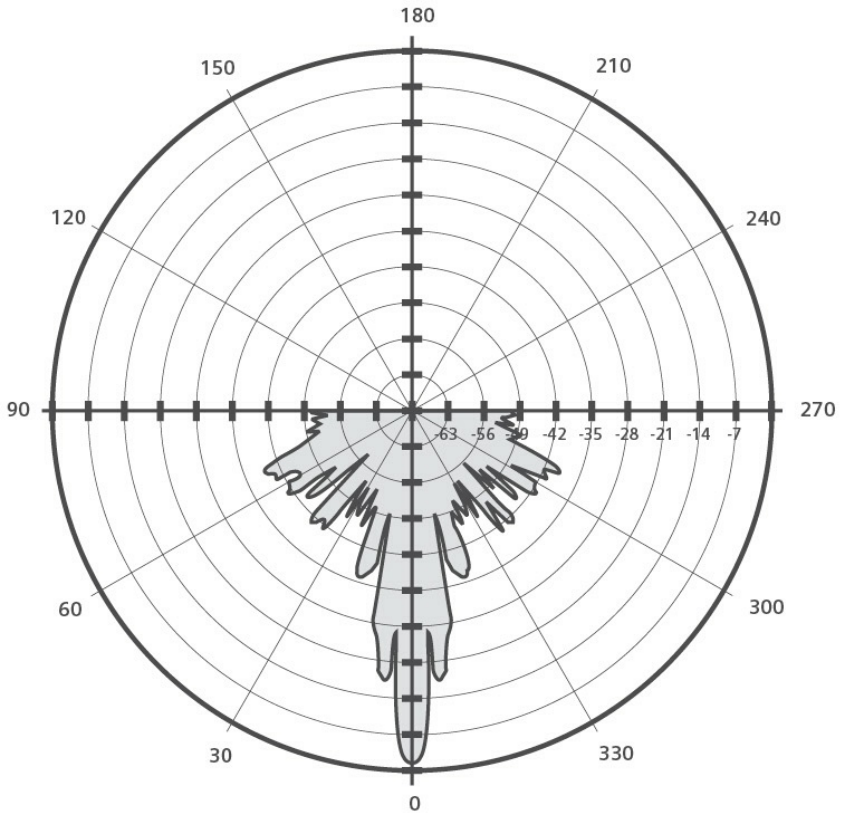
- high gain (stronger signal because energy is highly focused, narrow) with very large dish sizes, can detect very weak signals
- narrow focused beam

Disadvantages

- large size, most silos do not have an opening large enough to accommodate it
- feed transmitter casts a “dead zone” within the beam because the feed tube/pipe is directly in the beam
- feed transmitter is prone to dust build up because the emitter transmits upward toward the dish, causing signal deterioration

The parabolic antenna is generally made of metal or some other suitably high dielectric material. The greater the size of the dish, the larger the signal received, and the beam pattern is narrower with a larger dish. A dish antenna is also a cost effective way to increase the gain of the weak return signal as increasing the bowl size increases the capture area without having to redesign all the electronics.

A significant drawback to this antenna type is the significant area required to install it. Typical dish antenna systems for solids level applications range in diameter from 250 to 500 millimeters (10 to 18 inches), and most silos do not have any existing openings this large available. Installation that requires the creation of a large new access hole is quite costly, and while some of these antenna systems are still used on large cement silos, they number fewer all the time.



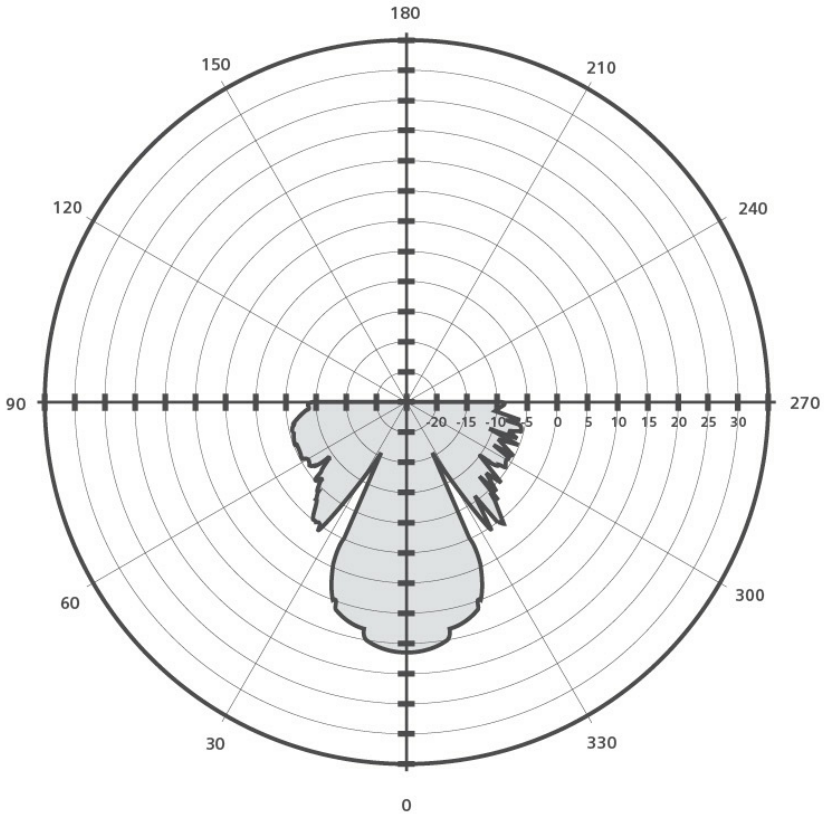


A 26 GHz dish antenna pattern has a strong, narrow main beam but can have side-lobes.

Dielectric rod antenna

The dielectric rod antenna was introduced to radar level measurement devices in the mid 1990s for liquid applications, as both a cost reduction initiative and because most liquid vessels rarely have an opening large enough to accommodate a large dish or horn antenna. The electromagnetic signal is fed into the upper end of the rod antenna, usually made of some low dielectric plastic material, allowing the microwaves to pass through into free air. The diameter and length of the rod is proportionally related to the frequency of the transmitter.





A 6 GHz rod antenna has a wide main beam and large side-lobes.

Advantages

- fits into small openings
- made of chemically resistant material, such as PTFE[3] or other chemically resistant material (such as polypropylene or polyethylene) making the rod antenna a good choice for highly corrosive liquids applications
- low cost

Disadvantages

- wide beam pattern, including large side-lobe signals that cause false reflections
- minimum detectable distances are longer than other antenna types
- does not offer the integrated purge/self-cleaning option available on other antenna types, so it is common on solids applications to require periodic cleaning of the antenna system
- quite long and intrusive into the vessel

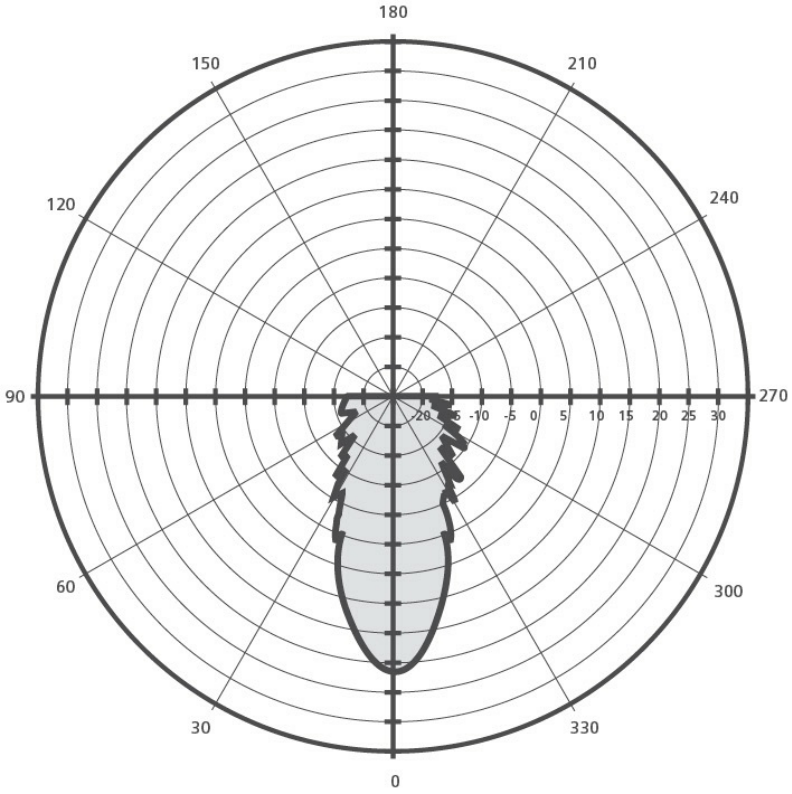
- the beam pattern contains relatively large side lobe signals – strong signal levels are transmitted at angles away from the main transmission lobe. On liquid applications this can cause many false echoes and large measurement errors.

Rod antenna systems are rarely found on solids applications. The larger openings generally more available on solids silos permit the use of the more accurate larger horn or dish antenna systems. Given that the rod antenna is intrusive and the active portion is directly exposed to the inside of the tank or silo, it is more sensitive to contamination and buildup than other types. The general rule for any radar level transmitter on liquids or solids is to avoid using the rod antenna unless highly corrosive applications make it necessary.

Horn antenna

The horn antenna was introduced into the market in the 1980s as a low cost alternative to the parabolic dish antenna. The horn is essentially a guided transition from a narrow tube to a wider opening; and the larger the antenna diameter, the narrower the beam pattern. The net result is a larger signal gain, and using the biggest horn size permitted by the size of the opening available will ensure the largest available signal.

Since 2000, when 24 GHz radar came in to the solids level measurement market, horn antennas have become widely accepted for most applications. Particularly in applications in the cement industry or other dry processing operations. As long as the solids media is dry and does not build up more than a simple dust layer on the antenna, the signal quality from the antenna is acceptable.





A 24 GHz horn antenna has a good main beam pattern and is free from side-lobes.

Advantages



- the emitting component is located way up inside the horn and thus relatively shielded from contamination.
- horns are made of metal and are very rugged – can be exposed to extremely high temperatures.
- extensions are available to elevate sensitive electronic components away from the heat source. Another benefit is to minimize unwanted reflections from the installation stand-pipe.
- can be fitted with a PTFE or similar cover to keep solids from building up inside the horn and deteriorating the signal.
- for extremely sticky solids, an integrated air purge connection is available for easy automated cleaning. Air purge is also sometimes used for cooling the antenna in extremely high temperature applications.

Disadvantages

- cleaning horn buildup requires additional parts (purging air lines, cover). Even mildly sticky solids materials like flour and lime powder (calcium carbonate) can pack the antenna over time so it will require periodic cleaning. A dust cover is a solution, but only if you are aware that the material will build up inside the antenna before the unit is installed. Periodic visual inspection of the horn will indicate if the cover or a purging system are required. If the unit is covered with a thick layer of buildup, the antenna will undoubtedly have a thicker layer. Buildup can also be a seasonal or a regional problem. Humid summer months leave material sticky, and a seaside plant will have buildup problems that a desert facility would not.

Use horn over rod when possible to provide a narrower more uniform beam.

- dust cover on a horn antenna may not seal properly. Clamps or screws hold the dust cover onto the horn, and if these are not tightened down sufficiently, moisture may enter and cause a poor signal.
- the dust cover also increases antenna diameter so it may not fit the opening.

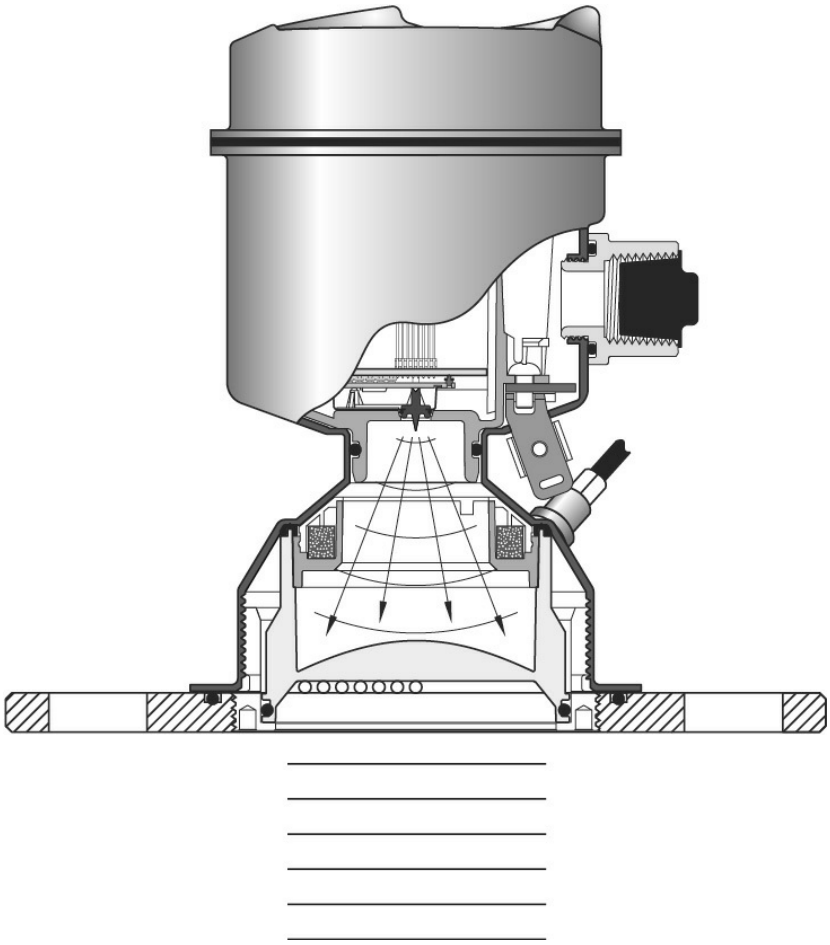
Lens antenna

The SITRANS LR560 solids radar uses a lens antenna. The sealed lens is a barrier, protecting the emitter from the many materials that can build up a very thick barrier to the radar transmission. The lens antenna uses an emitting radiator to “illuminate” the backside of the dielectric lens. The lens then shapes, enhances, and focuses the signal into a beam pattern free of side-lobes.

The lens has the following characteristics for success:

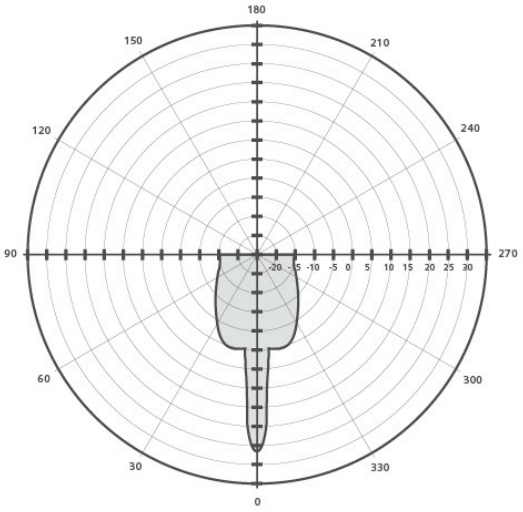
- low dielectric material so the radar signal can pass through
- proper location, thickness, and shape of the lens to minimize losses in gain

- robust lens material that allows for a wide range of temperatures



The SITRANS LR560 lens antenna design provides every single application with integrated dust protection as well as a built-in air purging feature designed to keep the face of the lens clean. The air purge feature is included in every LR560 and although most applications will not require it, it is there when needed. Retrofitting a horn antenna after purchase is now not necessary, nor do you need to purchase an optional dust cover in case it becomes necessary later.







A 78 GHz lens antenna has a strong, narrow beam and small side-lobes.

The air purge on a horn device also does a good job of cleaning the emitter, as the air pressure is highest at the emitter location. However, the air pressure and turbulence decreases as it moves towards the end of the horn; therefore, air purging is less efficient on a horn radar device as it is on a lens radar device where the entire antenna can be cleaned effectively.

Summary

Both FMCW and Pulse technologies have their benefits, and the requirements will determine which suits the application.

The application and the process connection can also determine the antenna required, but the ideal antenna system for solids level measurement is small, free from maintenance or easy to keep clean, has a strong narrow beam and very low side-lobes. The LR560 operating at 78 GHz with a lens antenna meets all the criteria. However, there is still plenty of opportunity for the rod antenna and horn antenna in the liquids markets.

1 The Beach Boys, “Catch A Wave.” *Surfer Girl,* 1963.
2 At the time of publication, no specific frequencies are allocated to radar level devices in the USA. Therefore, radar devices are currently restricted to in-tank usage to prevent emissions into the outside environment.
3 polytetrafluoroethylene: a synthetic fluorocarbon solid consisting wholly of carbon and fluorine. Retains its integrity in extreme temperatures as high as 260 °C (500 °F).

Chapter Four

Frequency and performance

What's the frequency Kenneth?[1]



In the past decade, radar level transmitters have employed a range of frequencies:

- 10 GHz
- 5.8 GHz
- 6.3 GHz
- 24 GHz
- 26 GHz
- 78 GHz (recently introduced)

The range of frequencies used is directly connected to three factors:

1. Design experience and capabilities
    - Specialized expensive equipment is required
2. Manufacturing capabilities
    - As frequency increases, component tolerances increase, including placement of components, circuit board track width, thickness, etc.
    - Application performance
    - Cost of manufacturing
3. Regulated use of specific frequency bands in various countries

The development of the frequency range[2] was (and still is) driven by the need for performance. As more applications are discovered by enterprising radar promoters, new impediments to performance need to be dealt with. Since performance and frequency are closely linked, improving frequency can often overcome obstacles in solids level measurement like high angle of repose, accuracy, and sensitivity to mounting locations and configurations.

Topics

- Frequency
- Properties of reflection
- Narrow beam
- Distance to the target
- Slope of material
- Radio approvals

Frequency



Ten GHz radar was introduced in the 1970s and used the latest in existing electronic components, including large through-hole resistors, capacitors, and discrete transistors. The next 20 years witnessed a fast paced evolution in electronics design and packaging as every electronic device from cellular phones and televisions to personal computers and toys underwent significant decreases in manufacturing costs and increases in performance – all contained in smaller packages.

Smaller integrated circuits (ICs) replaced large printed circuit boards with their array of components, making much of the size reduction possible and consuming far less power. Remember early cellular phones with their one hour of talk time limits and separate battery pack to carry around? Compare that to current mobile phones!

Radar technology developers enthusiastically adopted these electronic component advancements, greatly reducing both the size and costs of the radar transmitter. These advancements also opened up a wider range of applications by increasing the availability and performance of sensors. The compact SITRANS LR560 with its lens antenna embodies the latest in micro technology and is suitable for almost any solids application.

Higher frequency yields and the smaller antenna

The first radar level measurement devices used 10 GHz technology for liquid level measurement. Smaller antennas at a 10 GHz frequency had too small a signal amplitude with too wide a beam angle to be accurate. Proper signal quality required a large parabolic dish antenna to ensure sufficient signal return from the liquid surface. Furthermore, the large dish creates a narrow beam, minimizing the multipath influence from the tank sidewall, thus improving accuracy.

However, the large dish limited the instrument to tanks that had a very large opening (minimum 47 centimeters / 18 inches).

As other market opportunities for radar came to light, higher frequencies were explored for the majority of vessels that do not have large openings available. Higher frequencies use smaller antenna, ergo, more opportunity.

Signal strength and performance

The math

Signal amplification or strength is referred to as gain, and radar antenna gain is calculated using this formula:

$$G = \eta * (\pi \ D \ / \lambda)^2$$



KEY

G = gain
η = aperture efficiency
λ = wavelength in meters
c = speed of light 299 792 458 m/sec
f = frequency in Hz

For most practical antennas, **η** is approximately 0.7

There are practically only two ways to increase the signal from the antenna – make it bigger or decrease the wavelength. The former is not practical and the latter requires an increase in frequency.

Let’s do some calculation and see what is needed to reduce antenna size and increase performance.

Step one: calculate the wavelength by dividing the frequency by the speed of light.

6 GHz radar horn

- antenna is typically 150 millimeters in diameter
- wavelength of 0.050 meters

Wavelength is calculated:

$$\lambda = c / f$$

$$\Downarrow$$

$$\lambda = 299\ 792\ 458 / 6\ 000\ 000\ 000\ Hz$$
$$\lambda = 0.050\ meters$$

Antenna gain:

$$G = \eta^* (\pi D / \lambda)^2$$

$$\Downarrow$$

$$G = 0.7^* (3.14 * 0.150 / 0.050)^2$$
$$G = 62.1$$

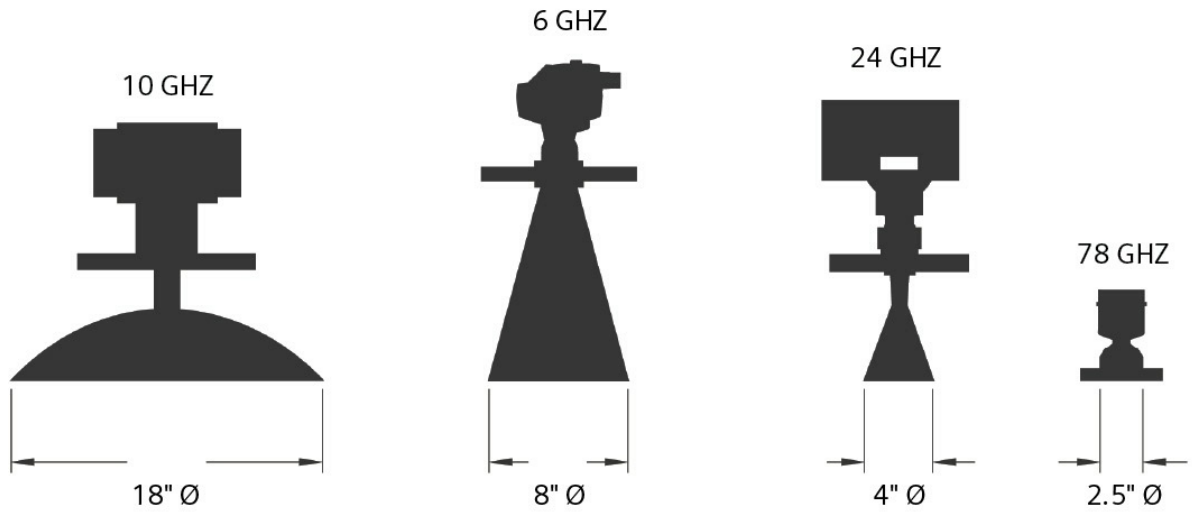
Step two: determine the antenna size required at 24 GHz to get the same gain.

- @ 24 GHz wavelength is 13 millimeters
- x represents the horn diameter required

$$62.1 = 0.7 * (3.14\ x / 0.013)^2$$
$$x = (0.013 / 3.14) * sqrt\ (62.1 / 0.7)$$
$$x = 39\ millimeter\ horn\ diameter\ @\ 24\ GHz$$

All else being equal, a 39 millimeter diameter horn at 24 GHz has about the same gain as a 150 millimeter diameter horn antenna at 6 GHz.

The wavelength at 78 GHz is only four millimeters, thus the antenna size required to achieve the same gain as the above example is only 12 millimeters in diameter!



The SITRANS LR560 uses a lens antenna with an effective diameter of 60 millimeters at a frequency of 78 GHz. A radar device operating at 24 GHz would need a horn diameter of 195 millimeters to achieve the same gain, and a 6 GHz radar device would need a horn diameter of 750 millimeters!

Conclusion:
Higher frequencies thus create larger signals from smaller antenna systems.

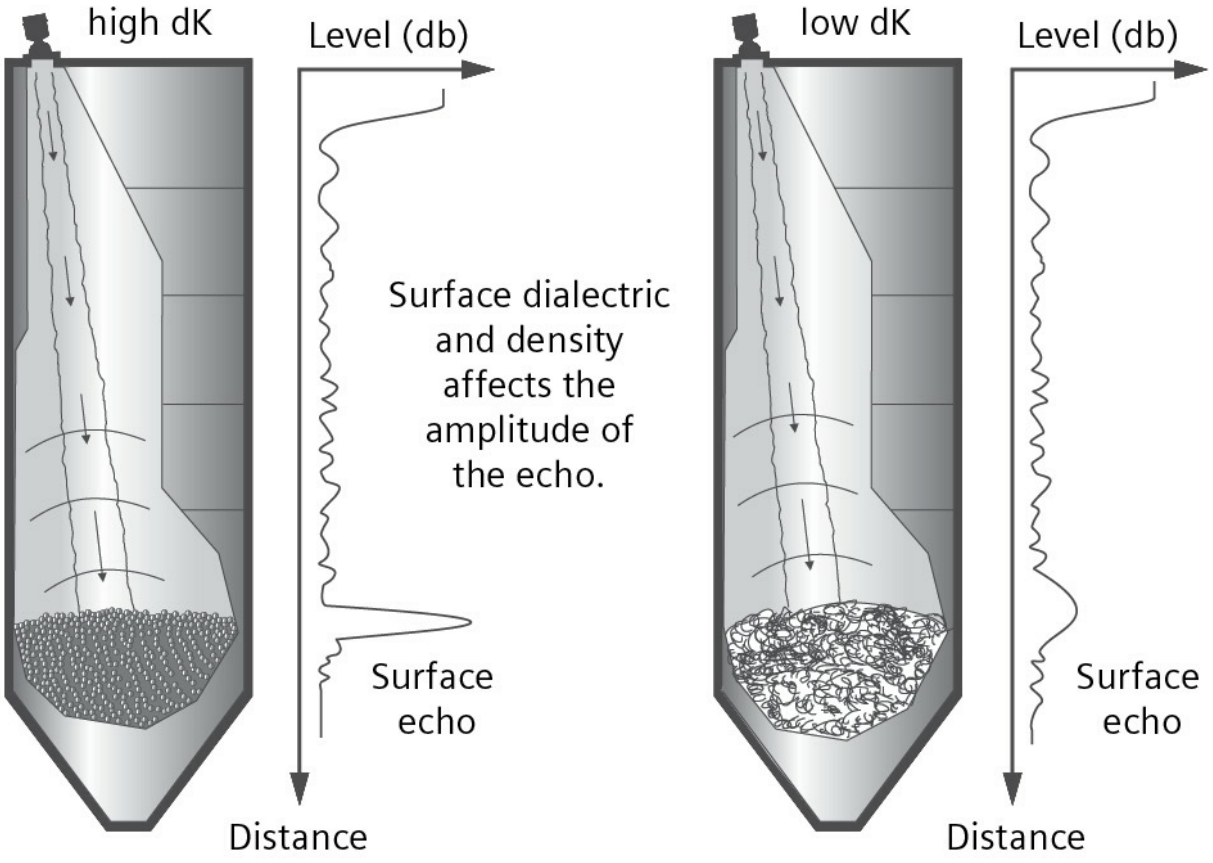
Properties of reflection

When a radar signal transmits to a material surface, the signal reflects back to the source, and the signal volume directly reflected and received by the antenna is mitigated by these variables:

- target dielectric
- target density
- target slope
- target particle size (surface roughness)
- target distance
- antenna focusing (beam angle)

Target dielectric

An electromagnetic wave is reflected when it meets an environment interface marking a difference in dielectric[3] properties between two media. Because the dielectric constant of air, most gases, and very dusty environments is about 1.0, a wave passes through them perfectly without loss until it hits another material, aka, the material surface. This surface does not completely reject the electric signal, rather it absorbs at a different rate than the previous material thus creating an interface point where a segment of the signal bounces back.



Dielectric constant refers to a property's ability to conduct electrical energy. The higher the dielectric, the less energy it absorbs and the more is reflected.

On surfaces with a high dielectric constant (dK)[4] like water or iron pellets, there is a high level of reflection from the interface. However, if the dielectric constant value is low, there is significantly less reflection and most of the transmitted signal will pass through. For most solids materials, the dielectric

value is very low and the reflected signal is therefore very weak as most of the signal is absorbed or travels through the material and reflects from the silo bottom. Traditionally, this made the measurement of solids problematic, but with the development of high frequency radar, low dielectrics no longer pose a problem because the narrower beam focuses the available signal.

A sample of materials and their dK

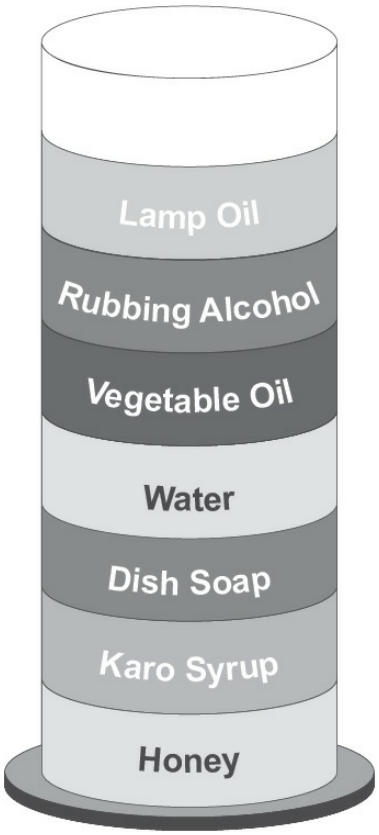
NOTE: These values apply to densely packed materials only.

ABS Pellets	2.0	Nylon	4.0
Air	1.0	Polyethylene pellet	1.5
Asphalt	2.7	Polypropylene pellet	1.5
Barley Flour	3.0	PVC powder	1.4
Calcium	3.0	Salt	3.0
Cement Powder	5	Sand	5.0
Cement Clinker	2.7	Soy Beans	2.8
Copper Oxide	18	Starch	3.0
Cotton	1.3	Sugar	2.0
Flour	2.5	Sulfur powder	3.0
Fly-ash	2.0	PTFE	2.0
Glass (Silica)	3.0	Water	80
Grain	3.0	Wood (Dry)	2.9
Lime	2.2		

Target density

The chart above lists typical dielectric values for densely packed materials. If the material is aerated, then the density of the material will be lower because it is diluted by the increased volume of air. Air, with its low dK of 1.0, is mixed with the material and causes the dK to be lower than the dK of the material without air and thus is more difficult to measure. Oat bran flour, for

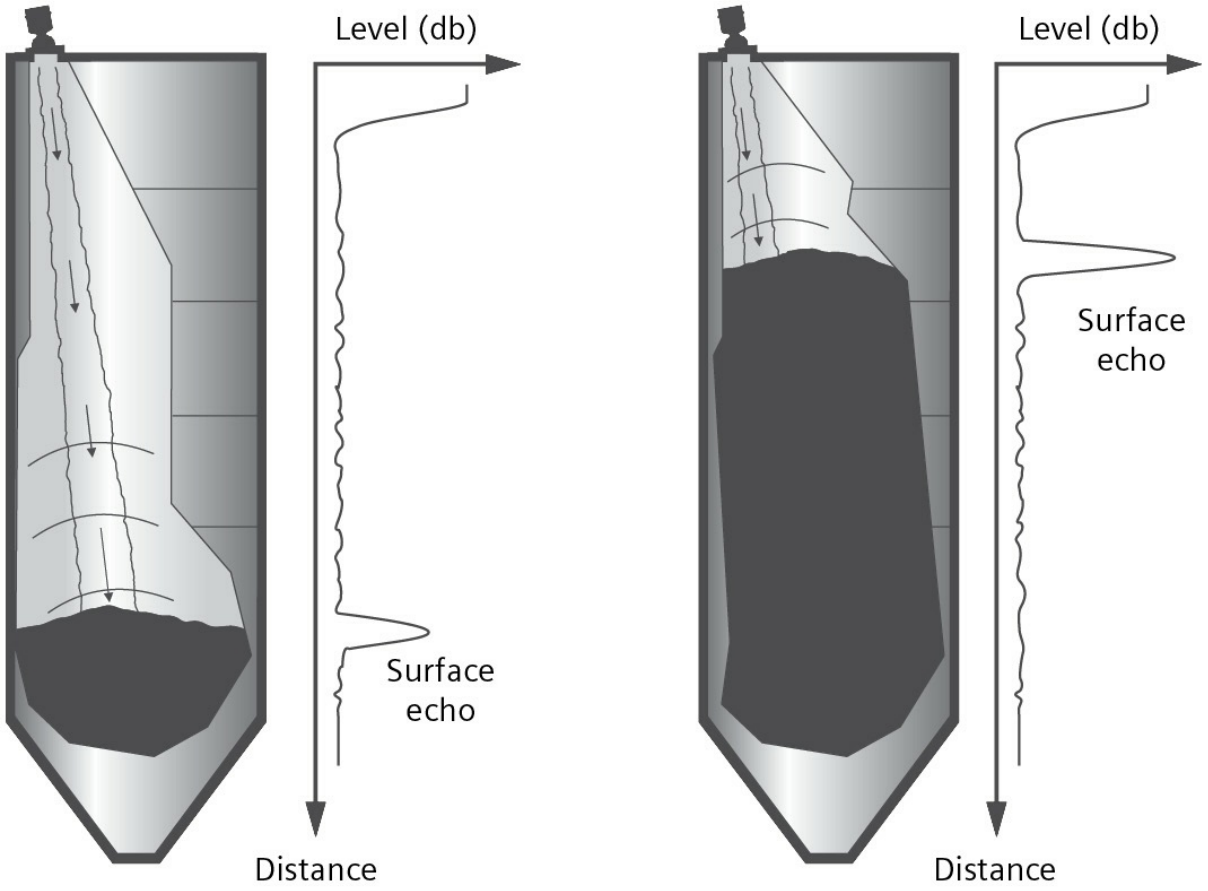
example, is 1.7 dK in its highly compressed state but less than 1.4 after it is shaken up and allowed to come to normal rest.



Target distance

Here is a physics lesson in the obvious: even though the signal travels at tremendous speed (the speed of light), the farther it has to go the weaker it gets because it starts to spread out and lose its focus.

The transmitted signal has a defined beam angle as it leaves the transmitter and that spreads wider as the distance increases. This widening causes the return echo to be weaker because the percentage of signal transmitted that returns directly back to the antenna becomes smaller with distance while the rest hits the silo roof. A return echo at five meters will be a lot stronger than a return echo at 30 meters.



The dK of the material is also a factor affecting distance. A material with a high dK that reflects strongly can be measured from a farther distance because it will reflect the signal far better than a low dK material which absorbs a lot of the energy and returns a weak signal.

Thus a radar device with a 60 meter specified range, may only operate well at 20 meters with lower dK material because the return signal is not strong enough to be detected. A more reflective material will return sufficient signal to measure to the full specified range.

Target slope

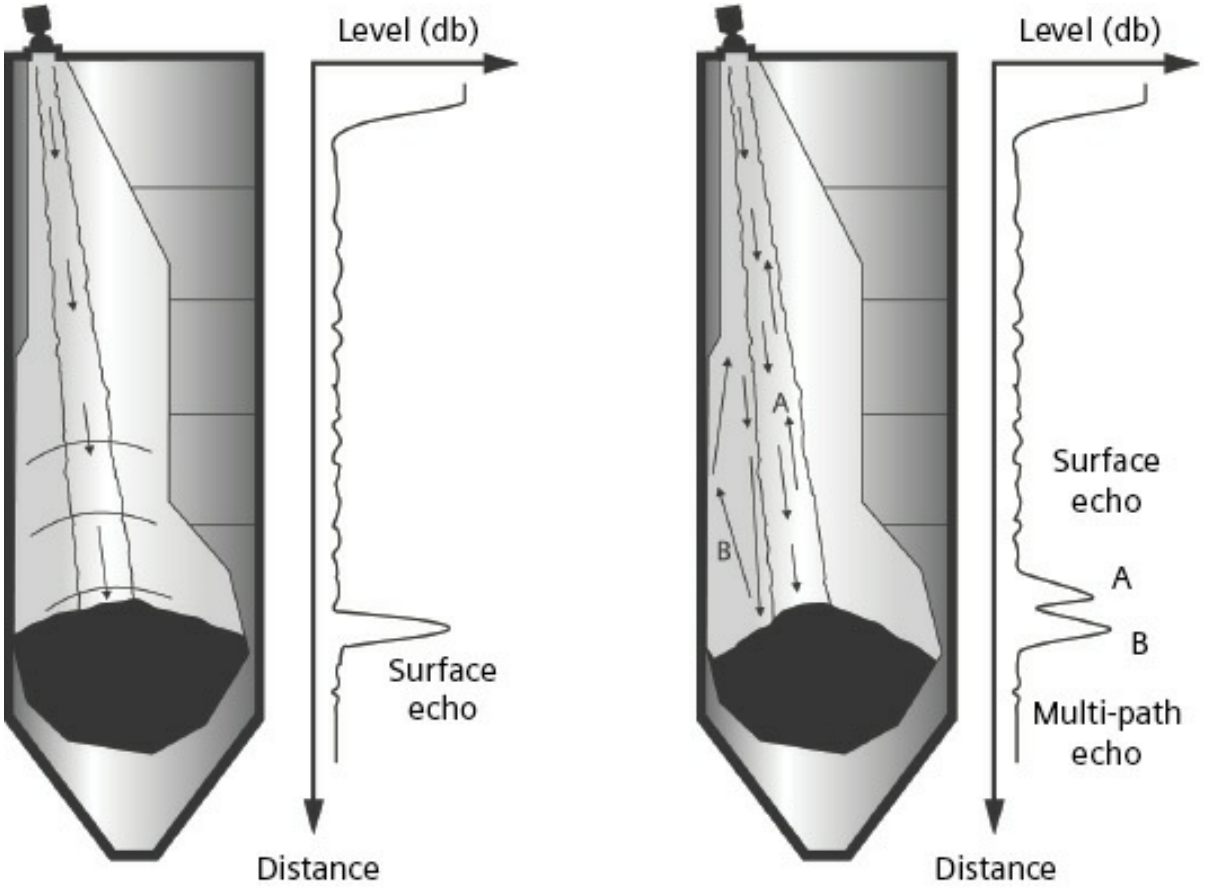
The material slope also affects signal strength. A flat surface will produce a strong reflection back to the source, assuming the surface is perpendicular to the transmitted beam. As the slope of the surface increases, however, the resultant signal amplitude decreases.

Most solids will have a surface slope or angle of repose because of their filling patterns. Silos are generally filled from the top, and like sand in an hourglass the highest part of the surface is where the material is directly deposited. Then, as is the nature of solids, the rest rolls towards the lowest point creating a slope.



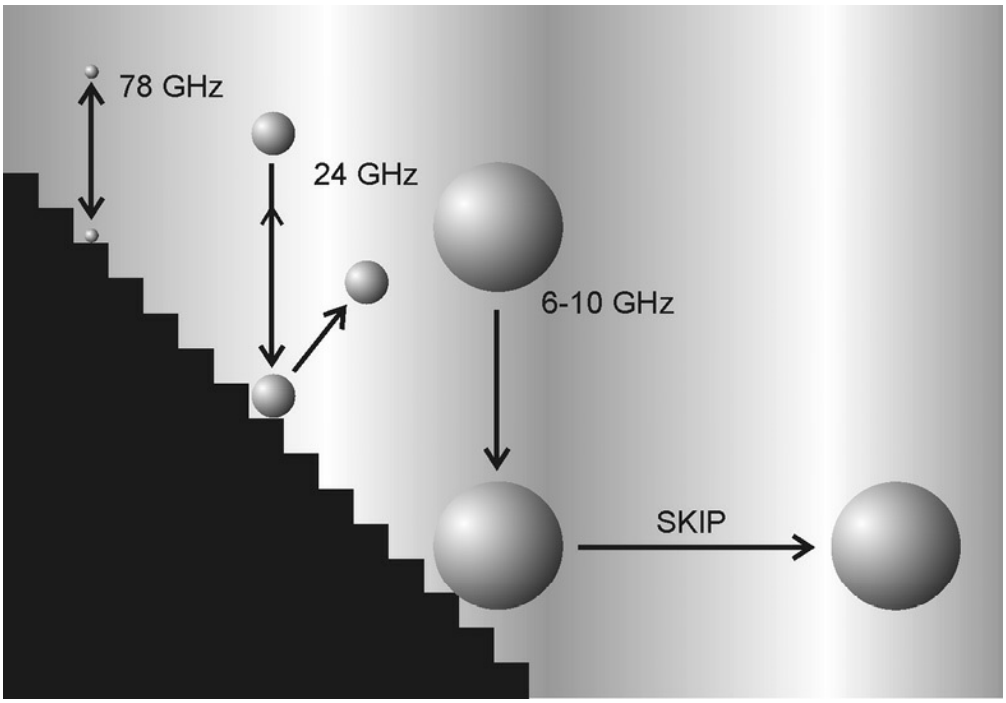
This slope is problematic to most non-contacting level measurement technologies for two reasons:

1. It reduces the amplitude of the return echo signal by altering the return path of the signal.
2. It causes the echo return to take an additional path back to the source (multipath). This multipath scenario can take one transmitted signal and split it into two separate return echoes of smaller amplitude.



The degree of signal splitting from the surface target is also affected by material roughness or particle size. There is a direct correlation between particle size and wavelength, and the amount of signal splitting. The larger the particle size, the stronger and more direct the return signal because there is a more direct surface to reflect from and splitting is minimized. The smaller the particle size, the more diffused the return signal as the slope is generally steeper with finer materials and there is less particle surface available to the wave. The most effective way to overcome the problems caused by small particle reflection is by increasing the frequency to reflect more signal from sloped solids surfaces.

Thus, while 6 GHz radar generally yields very poor performance on solids applications, 24 GHz is far more successful. However, on fine powder and granulated materials like sugar and sand even the 24 GHz struggles on sloped surfaces. Here is where the SITRANS LR560 operating at 78 GHz really shines because of its shorter wave length.



Antenna focusing: beam angle

The difficulty with measuring solids with radar has traditionally been the very low reflectivity of the surface to be measured. Solids are generally not good reflectors as most are dry materials with low dielectric constant values. Therefore, trying to get a reliable level is difficult because the return signal will be very weak, especially if the beam pattern is too wide. The amount of energy returning to the antenna from a wide beam pattern is considerably lower than if a narrow beam is employed because the narrow beam directs the energy back in a more constrained pattern.



Think about the spray nozzle from a garden hose. While the water volume and pressure are constant, varying the beam spread by changing the size of the nozzle produces either a wide weak spray or a narrow, more powerful stream. A narrow beam radar system works the same as a narrow water stream by focusing the available signal into a narrower path through either increasing the size of the antenna (not practical) or increasing the frequency.

Calculating a beam angle: The beam angle of the antenna is directly related to its size and frequency and is approximated by this formula:

Beam angle = 70° x λ / D

KEY

λ = wavelength
D = horn diameter



Example 1

- 6 GHz radar system
- 100 millimeter horn

Beam angle = 70° x 52 millimeters / 100 millimeters

⇩

Beam angle = 36.4°

Example 2

- 24 GHz radar system
- 100 millimeter horn

Beam angle = 70° x 13 millimeters / 100 millimeters

⇩

Beam angle = 9.1°

Example 3

- 78 GHz radar system
- 60 millimeter diameter lens

Beam angle = 70° x 4 millimeters / 60 millimeters

⇩

Beam angle = 4.7°

We recommend selecting the largest horn antenna size possible for the available opening.

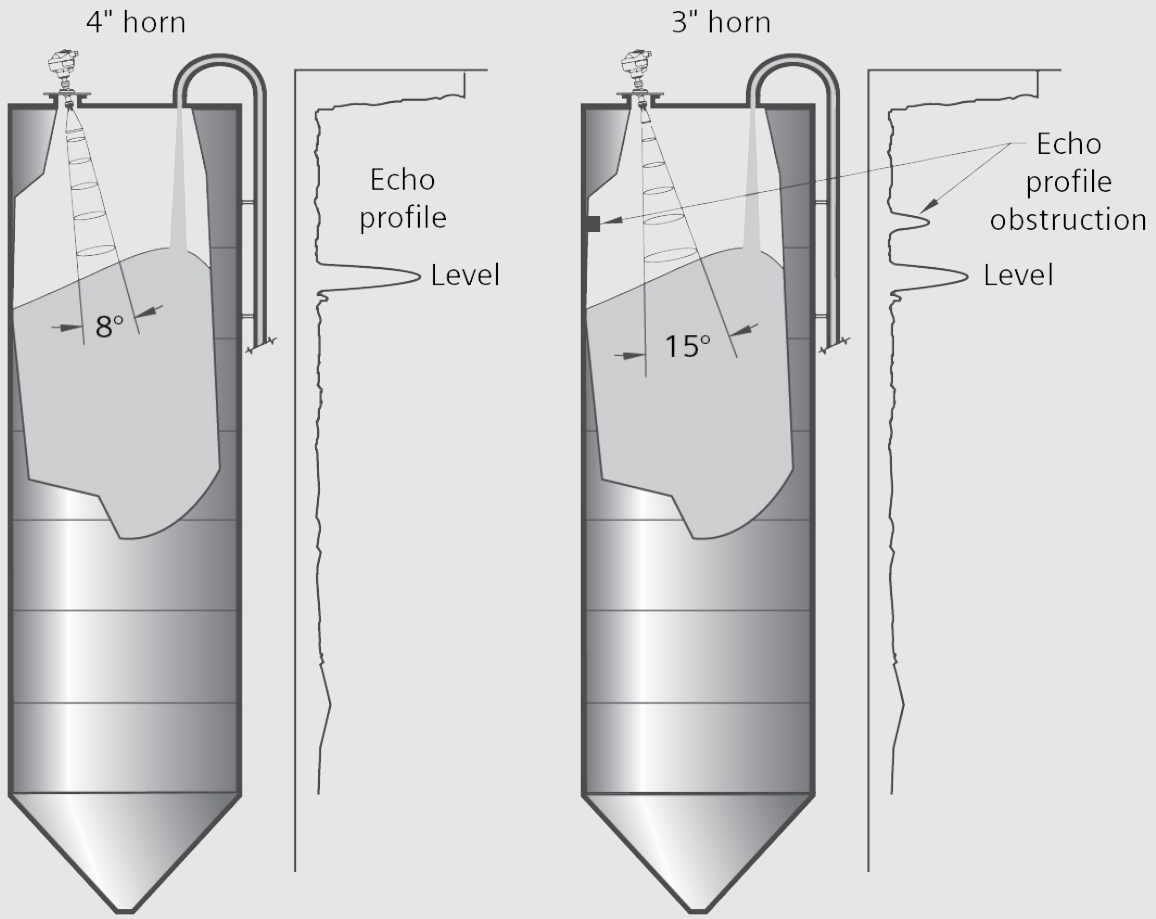
Therefore, for a specific signal quantity from an antenna system, a higher frequency signal has a significantly greater focusing affect, in turn producing a stronger received signal from the material surface. The bigger the horn, the smaller the beam angle and the stronger the return echo. Combine that with a higher frequency and the beam angle narrows even more.

Narrow beam also means less interference

Non-contacting technologies such as ultrasonic and radar transmit a signal beam that gets wider with distance travelled. The beam angle is usually specified as an inclusive angle at the -3 dB boundary, meaning that half of the energy from the antenna is within this defined beam angle. The other half of the energy is outside of this angle, and this rogue signal will also produce echoes, albeit false ones, as they pick up other reflections.

Example: SITRANS LR260 signal reflection

- beam angles as specified inthe manual
- no other obstructions in the silo
- an obstruction in the silo appears in the echo profile even though it’s outside of the beam angle



The beam angle is only approximately half of the energy from the antenna while the other half does not really have any specification. But it still returns to the transmitter. Therefore, the obstruction shows up in the profile even though the signal returned to the antenna is outside of its published beam angle.

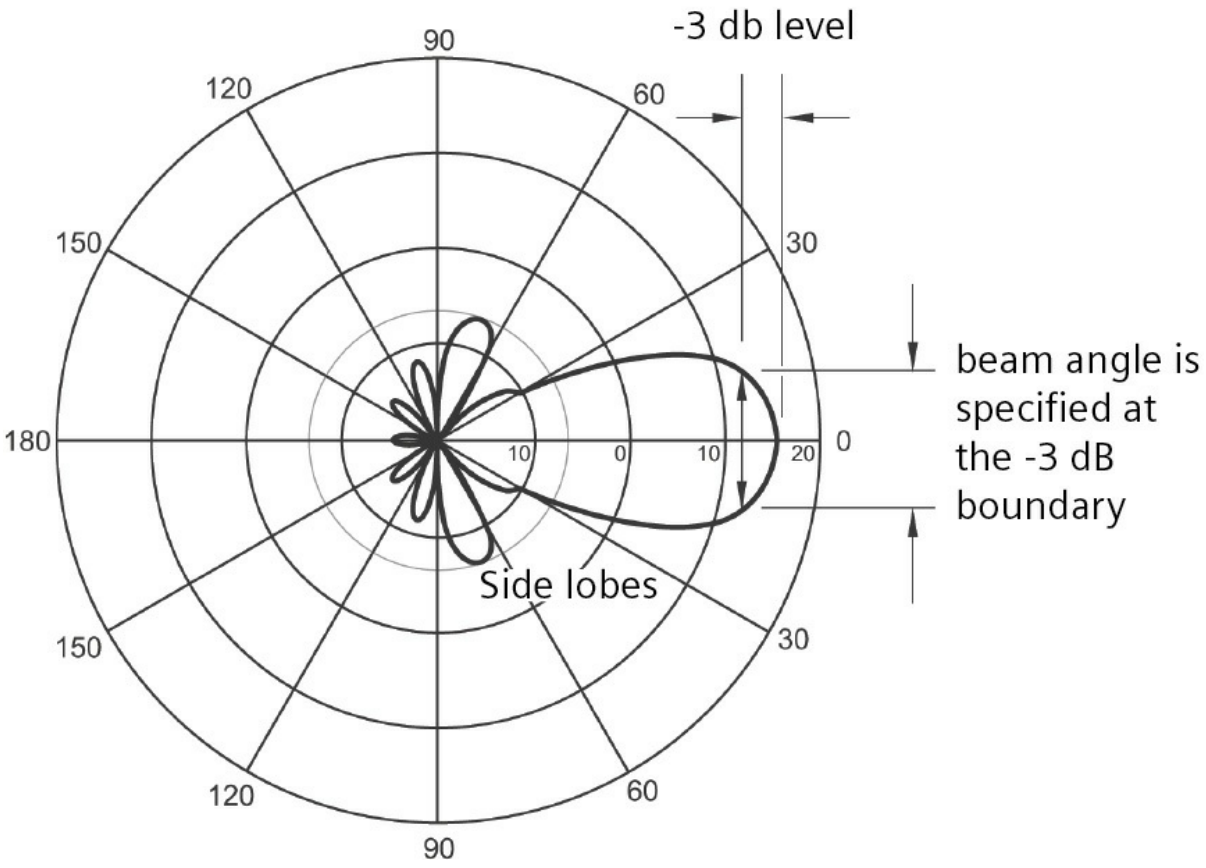


A flashlight has an intense beam when it is aimed at the ground immediately in front, and there is also some weak light surrounding this focused spot. However, when the flashlight is aimed at a target 100 feet away, the surroundings nearer to the flashlight are easier to see than the target 100 feet away because the light is diffused from the source and picks up objects closer to the source.

Radar measurement works the same way in a silo where the material echo will produce a much weaker signal than a false target that is much closer to the radar antenna. Even though the material surface is within the main beam and the false target is outside of the published beam angle, the radar waves outside of the main beam reflect back to the unit and register obstructions like wall seams, ladders, and ledges.

Manufacturers define their beam angles at the -3 dB half-power level. So one sensor could have a similar published specification as another but have completely different performance results because the energy dispersement outside of the specified beam can be very wide and vary according to manufacturer. The wider the pattern, the more false reflections and the worse the unit’s performance: how a unit handles its beam angle as a whole is crucial to its performance.

Here is a polar pattern from a radar transmitter in two dimensions. The antenna is directed to the 0 on the plot. By specification, only the width of the beam to a level of -3dB from the peak is defined. The rest of the signal is not defined by the beam angle specification. For this antenna, a metal target 70 degrees off-axis that is close to the antenna may appear stronger than a low dK target that is far away and directly in front of the antenna.

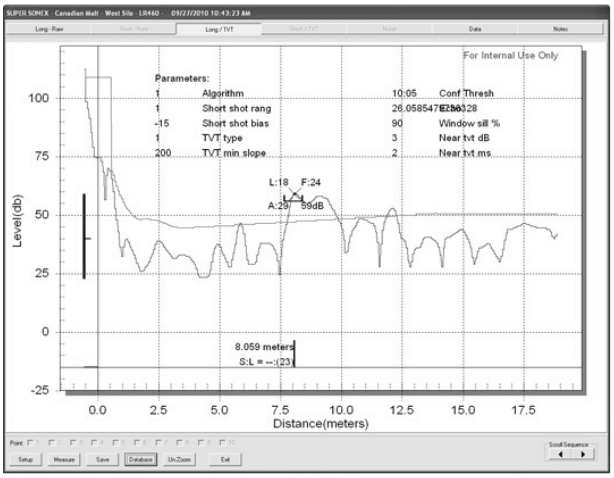


Narrow beam application

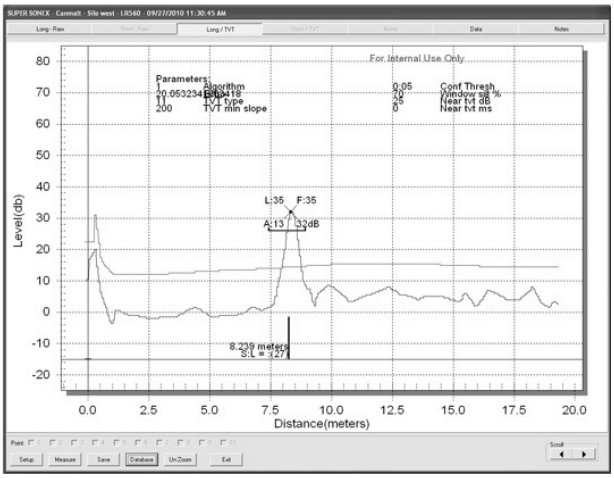


This application clearly demonstrates the benefit of 78 GHz/narrow beam over 25 GHz. The steel silo has internal seams that are detected by the wider beam of the 25 GHz radar. For the 25 GHz technology, the TVT needs to be shaped around these false echoes for reliable operation, and this simple procedure can only occur in a near empty silo (which is difficult to schedule). Even after the custom TVT is created, the level readings will not be very stable because the product echo mixes with the false echoes causing measurement drift.

25 GHz



78 GHz

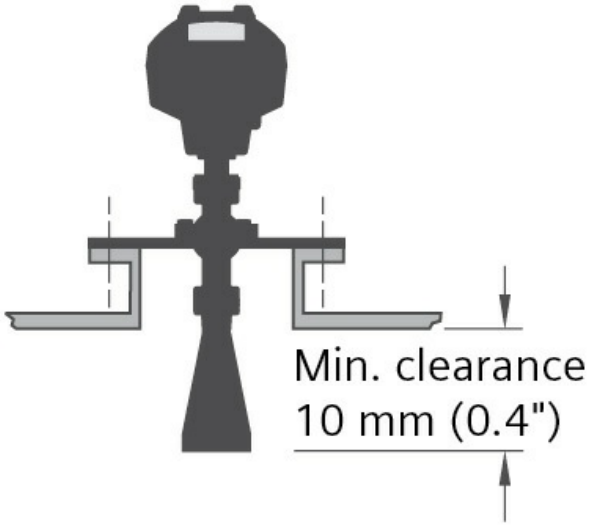


Installation and performance

Because false echoes are often generated from obstructions that are outside of the published beam angle, the installation location of the unit needs to be carefully planned to direct the beam away from the side of the silo where false targets are likely to be located.

Siemens provides the Easy Aimer, an integrated process connection that lets the unit swivel easily to the correct angle.

Improper installation on the mounting nozzle has been the greatest source of many radar failures. There is one basic rule that is the same for all radar installations, regardless of the manufacturer: the radiating part of the antenna MUST BE inside the tank or silo! Failing to do so may lead to unreliable results, regardless of frequencies, although the lower the frequency the more imperative it is to follow this rule.

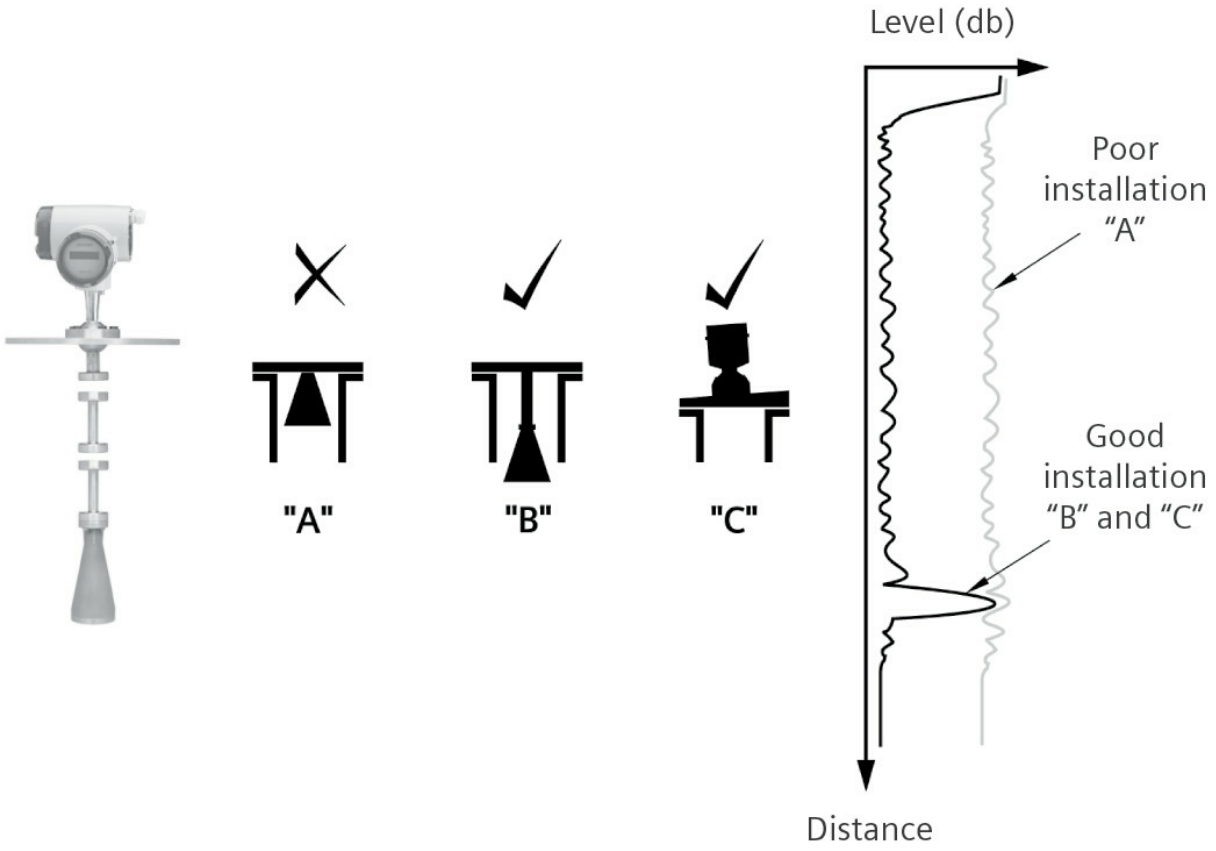


For a 6 GHz radar device this rule is absolutely mandatory because the low frequency makes for a wide beam. If the antenna is inside the nozzle, too much of the signal is reflected from the nozzle walls and not enough goes to the material surface. The excessive signal noise from nozzle echoes will then prevent the instrument from performing properly. For a 24 GHz radar device with a narrow beam, there can be some leeway with how far the antenna can be installed up inside the nozzle. The higher frequency of the narrow beam makes it far more focused and less likely to reflect from the nozzle walls. However, there are other factors that must be considered if the installation has the antenna inside the nozzle:

- material dielectric: the lower the material dielectric of the surface, the weaker the return signal and the more likely the nozzle noise will interfere with the level reading.
- surface quality inside the nozzle: if there is any material buildup, or if there are weld seams, the signal will reflect back from inside the nozzle creating noise.

Generally, 24 GHz radar is strong enough and focused enough to compensate for some inner nozzle installation noise while 6 GHz radar is generally not. The basic rule of a ten millimeter minimum distance protrusion of the horn should still be followed, regardless of frequency. If it is not practical to do so,

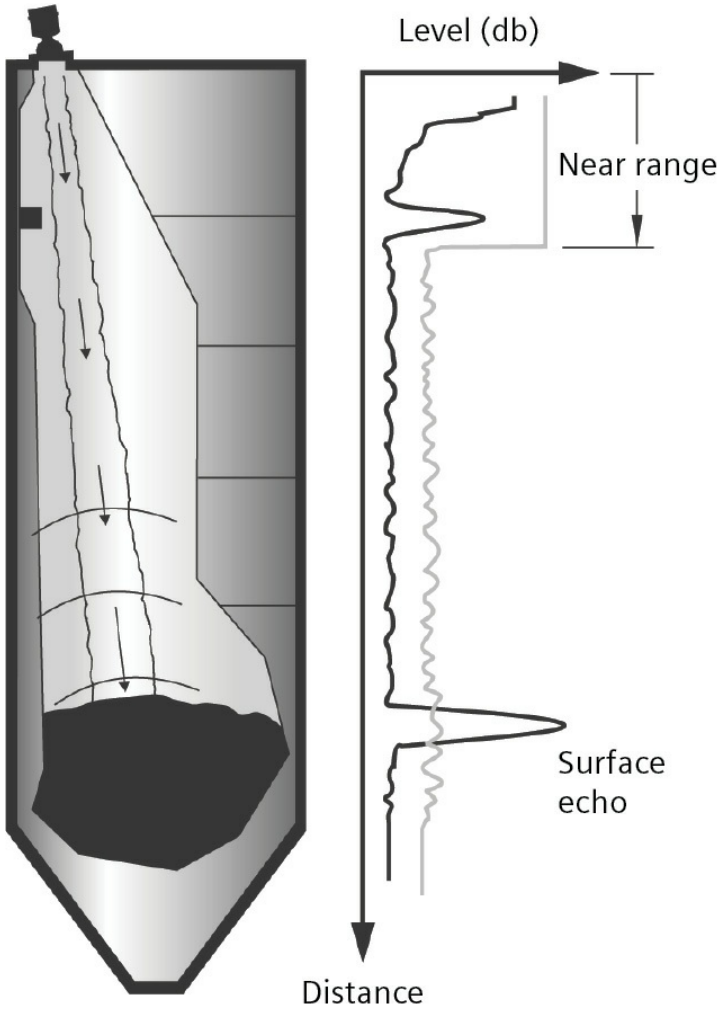
then keep the nozzle as short and as large in diameter as possible to minimize unwanted reflections. Another option is to install the unit with a horn extension that brings the antenna below the silo roof.



Blanking / Near range

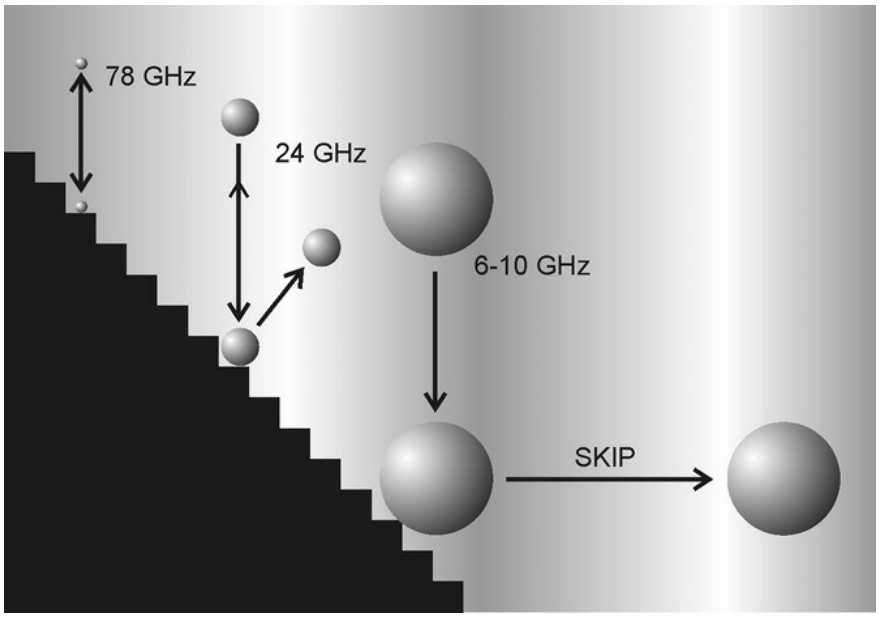
Blanking (aka near range or blocking distance) describes the adjustable zone immediately in front of the sensor that tells the sensor to ignore everything in this zone. When dealing with a false echo, it is sometimes a mistake to try to blank it out. Nonetheless, false echoes need to be managed as one false echo may cause many other false echoes, obscuring the actual level echo. Note from this profile graphic how a false echo is generated from a fixed obstruction near the antenna. Many repeated false echoes are generated from this type of obstruction, causing the entire noise floor to become elevated and the material echo very difficult to extract.

Twenty-four GHz radar works at least ten times[5] better in a nozzle than 6 GHz. SITRANS LR560, which operates at 78 GHz with a very narrow beam of only four degrees, works even better in a nozzle. Thus while it is still recommended that the antenna extend past the nozzle, the LR560 operates accurately and reliably inside most nozzles.



Frequency and sloped surfaces

If a beach ball is dropped on stairs, it skips away from the sloped surface every time. A dropped ping-pong ball, however, will bounce directly back to you nine times out of ten because it is smaller. The ping-pong ball is similar to the short wavelength of high frequency radar, while the beach ball is comparable to the long wavelength of low frequency radar.



Radio approvals

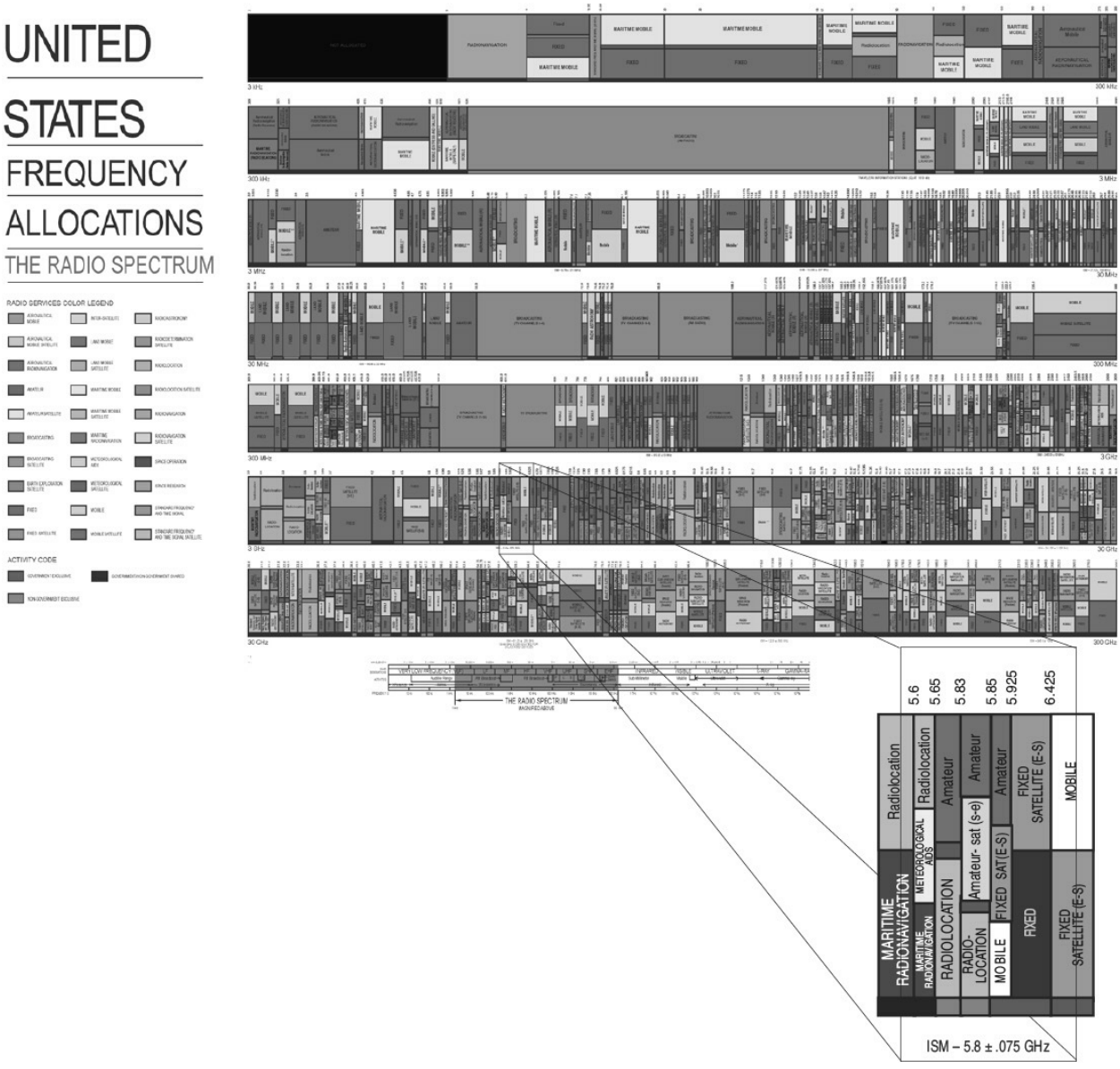
Electromagnetic waves of varying frequencies are pervasive in modern life; television, radio, cellular phone, and Wi-Fi all operate through electromagnetic waves. Each of these technologies uses a specific frequency allocated to the technology by the local governmental body. Until recently, however, no specific frequency bands were dedicated to radar level measurement transmitters. Note that the USA frequency allocation chart on the next page does not have a band for radar level measurement. The chart is highly detailed and is included only to show how densely populated the frequency bands are.

ISM bands are reserved for Industrial, Scientific and Medical usage. Used by microwaves and wireless phones.

In Europe, level radar devices are considered Radio and Telecommunications Terminal Equipment (R&TTE) and must comply with the R&TTE Directive 1999/5/EC, which describes the process required to place radio equipment on the market.

Frequency allocation chart

Until recently, there was no specific harmonized standard for level radar devices, although they were subject to the generic Short Range Device standard EN 300 440. Level radar devices available on the market are generally wide band (usually 1 GHz or more) and as such they do not fit into available frequency bands. However, radar devices have been allowed in Europe because emissions measured outside of a closed tank are below the spurious emission limit of –41.3 dBm / MHz. This compliance restricts the use of the radar device to closed tanks.



The Industrial, Scientific and Medical (ISM) band at 24 GHz is only 250 MHz wide.

Closed vessels

In 2008, a new harmonized standard for Level Radar devices (EN 302 372) defined clear requirements for the use of level radar devices installed in closed tanks, including power and operational frequency. European National Authorities have adopted this standard, making the process of obtaining radio approvals for closed tank use in Europe simpler.

Open vessels

Europe: The European Telecommunications Standards Institute (ETSI) is responsible for creating associated standards. The fully approved European standard EN 302 372 explicitly states that radar level transmitters must be installed in a closed tank. A draft standard EN 302 729 has been created which allows very low powered radar transmitters to be used outside of a closed tank. This standard is not expected to be fully approved for several years.

USA: While the regulations differ, the level radar frequency situation in the USA is similar to Europe in that the wide bandwidth renders them unsuitable for use within the ISM bands. Therefore, manufacturers have to show that device emissions do not exceed the very low spurious limits as defined in the FCC Part 15 regulations. Since that is not yet possible with the wide bandwidth and emission levels of current level radar devices, the device can only operate inside a closed tank.

Currently, a working group of radar manufacturers is trying to define standards for future open air use. This endeavor will take some time and effort as a strong business case is required to convince all the other users of the same air space (e.g. astronomers, air traffic control, communications) that no harm will come of it.

Summary

Frequency, antenna size, and beam angle all combine to give each radar unit a particular set of skills that work effectively for a defined range of solids applications, depending on contents, angle of repose, dK, and silo types and construction. The ideal device would operate on any combination of these conditions, and the SITRANS LR560 comes very close to that. With its lens antenna, narrow beam, and high frequency (78 GHz), it is a plug-and-play radar level device for most solids applications.

1 In 1986, American news anchor Dan Rather was mugged by two men in New York City. Between blows, the men are quoted as repeatedly asking “Kenneth, what is the frequency?“ The band REM immortalized the incident in their 1994 song *What’s the frequency, Kenneth?*

2 See frequency allocation chart at the end of this chapter.

3 William Whewell (1794 – 1866). English scientist and mathematician credited with coining the term.

4 *dK* is the reference contraction for dielectric constant.

5 This ratio is derived from field observations and performance comparisons. However, even though the 24 GHz‘s chances of performing in nozzles are better, it is always better to extend the antenna a minimum of ten millimeters past the nozzle if possible.

Chapter Five

Installing radar

If you're going to do something, do it right the first time.[1]



Installing a radar device properly, like any technical installation, is fundamental to its performance, and many a "should be simple" application quickly becomes a disaster when basic installation guidelines are not followed.[2] Some 'problems' are resolved very quickly by adjusting the installation and then become funny stories told later over a pint of beer, like the time a technician drove two hours to troubleshoot a defective system only to discover that the installer had forgotten to remove the shipping covers from the sensors. However, as amusing as these situations can be in retrospect, they can have serious negative side affects on a technology's reputation if the problem is allowed to linger.

Whether it be ultrasonic, radar, or laser measurement, the quality or reliability of the signal processing and the data transmission means little without a clear reading of the vessel's contents as provided by a quality signal. The installation is crucial to the optimal performance of the sensor because it ensures that the signal is of the highest quality possible. If the raw signal is tainted, the subsequent reading is unreliable, and the software programmer's adage of garbage in – garbage out certainly applies here because the level data will then be worthless.

Topics

- Installation history
- 6 GHz installation
- Rod antennas
- Location
- Conical bottom silos
- High temperature installation
- Nozzles
- Aiming



I’ve observed competitors’ radar devices that required weekly cleaning while the Siemens sensor worked flawlessly in the same conditions for over a year. The raw signal for both devices was the same, only the echo processing method was different.

Siemens Process Intelligence lies at the heart of the instrument, and is the collection of decades of development through Sonic Intelligence, data analysis, and innovation.

Installation history

The simple rule to remember during installation is that not all radar sensors are created equally nor installed in the same manner. Thus proper installation for that specific device is crucial to performance, and the instructions outlined in the manual must be followed to the letter. Think of it like baking a cake – substitutions or portion variations put the entire project at risk with no fault of either the instrument or the technology. Mess with the mix and it all falls flat.

Different radar technologies, frequencies, antenna types, and echo processing approaches all factor into the installation. While some devices will work flawlessly even when the manufacturer’s guidelines have not been completely met, others cannot tolerate even marginal deviation from the

installation requirements. In the early days of radar level measurement, improper installation practices contributed to a negative reputation that radar is still trying to overcome, and the main contributors to this image problem are the legacies of 6 GHz technology and rod antennas.

Six GHz installation

Six GHz (5.8 GHz or 6.3 GHz) technology was introduced in the 1980s as the beginning of low-cost, pulse radar technology and still has a place in extreme process conditions like foam or heavy tank build up. However, the rod antenna's 28-degree beam angle is very wide, making the installation requirements very stringent and unforgiving because of the noise from excessive side lobes.

Thus the installation rules for a 6 GHz radar are numerous:

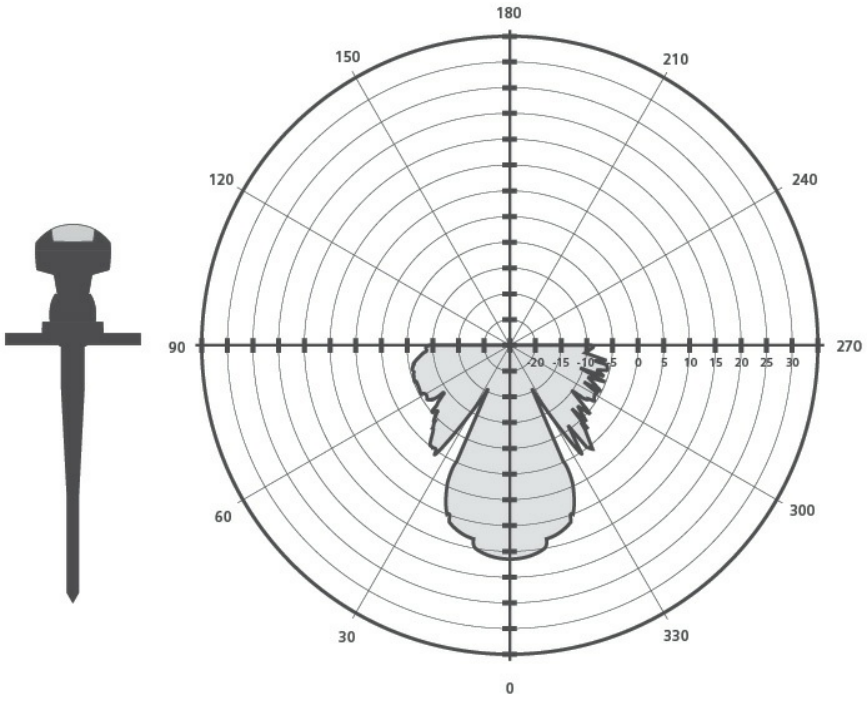
- never put a 6 GHz transmitter in the center of a vessel or silo
- do not place too close to the side
- do not install on tall standpipe nozzles
- stay away from narrow nozzles
- make sure the antenna is shielded
- avoid low dielectric media
- allow a long distance blanking zone
- stay away from very small vessels
- do not install on narrow, tall vessels (because of wide beam)

Get any one of these wrong and the level reading is problematic. The misplaced installation difficulties were further exacerbated by the introduction of the rod antenna in the 1990s as more applications were suddenly accessible. When 10 GHz was introduced, it used large diameter dish antennas, and when 6 GHz was first used for level measurement it employed large diameter horn antennas, none of which were installed if they would not fit the vessel. These large antennas required a very large opening

and were subjected to minimal influence from the installation nozzle; however, the introduction of the small antenna opened up other applications as access to them was easier.

Rod antenna

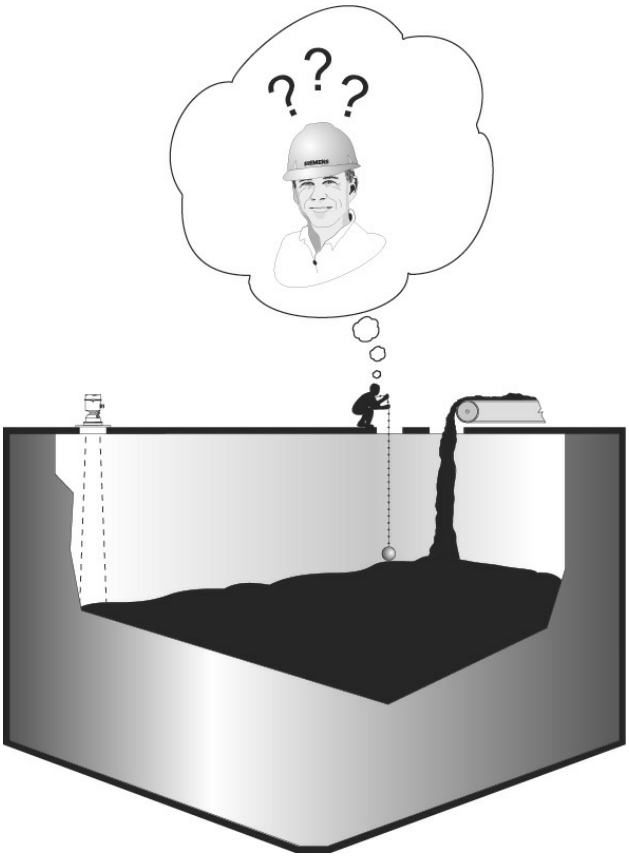
The narrow dielectric rod antenna made it possible to measure vast numbers of previously restricted applications (an estimated 95% of all liquid vessels worldwide) because it can be installed in a small opening. Furthermore, the rod antenna’s composition of PTFE or other plastic also provides high chemical compatibility, thus opening up more applications. However, during operation the rod antenna has excessive unpublished side-lobe signals that emit outward from the antenna and cause an excess of false echoes when installed in standpipe nozzles. Proper installation of the sensor requires the nozzle to be as short and wide as possible and/or use an integrated rod antenna shield to minimize this noise interference. This installation is detail oriented and requires that every installation nozzle be inspected for suitability before installation. Failure to do so often means a dysfunctional sensor and an arduous diagnostic process to determine if the unit or the installation is at fault.



Current high frequency radar, operating in the 24 to 26 GHz range and with a much narrower beam pattern, makes installation far more forgiving, so the majority of sensors will work fine even if some of the manufacturers' guidelines are ignored. Solids radar measurement actually started with 24/26 GHz technology, and does not have the stigma of installation difficulty associated with the 6 GHz liquid market. However, please note that while the installation requirements may not be as precise as with earlier liquids radar, the instructions must still be followed very carefully to avoid contributing another factor to a potential sensor failure.

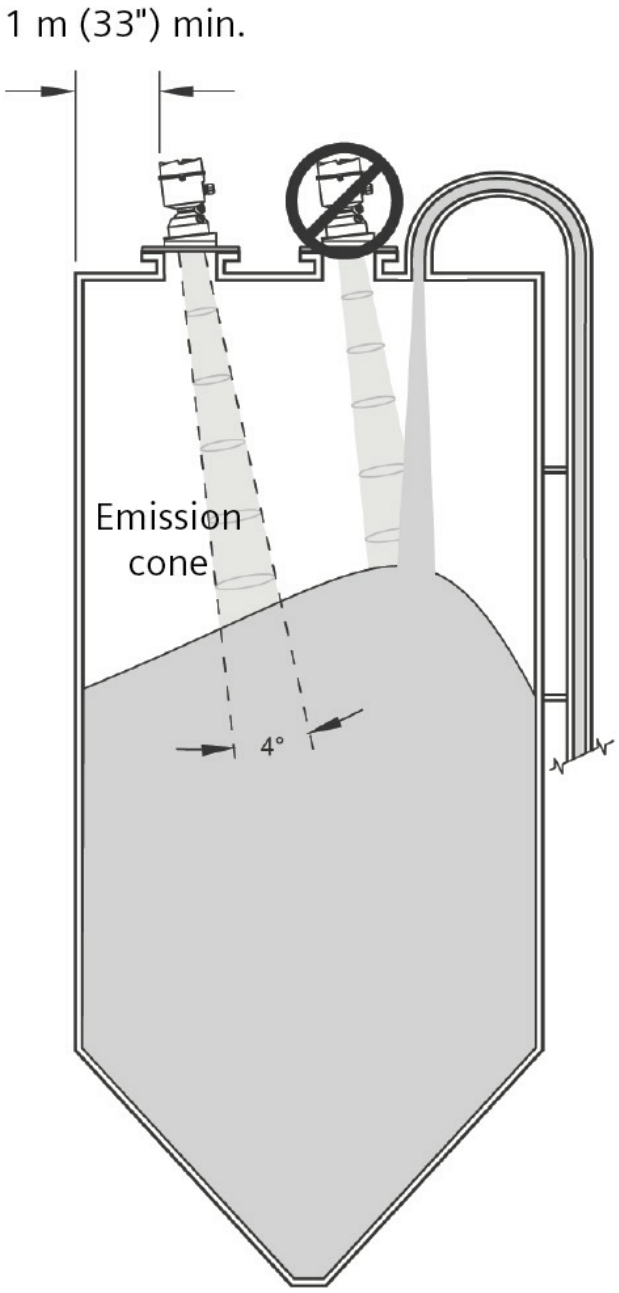
Location, location, location

This common real estate axiom expressing that location is crucial to success is particularly relevant to radar level device installation. Move any existing radar device to a different location on the vessel and a completely different reading is guaranteed. Some locations will yield improbable results while others provide accurate readings. The trick is to find the latter, especially when working with existing vessels where the optimum location may just not be available for sensor installation.



The accuracy of the sensor should always be compared with a manual dip rope. Make sure the dip rope is dropped as close to the sensor as possible.

Even brand new silos are generally not designed to include a radar device unless, as with OEM[3] accounts, the design specifies the sensor. Very large concrete silos, like those found in the cement, steel, or power generation industries, often have an existing man-cover or metal plate available at the silo top and a hole is cut in the plate for the sensor installation. However, the location of the access plate is predetermined by the existing design so the location may not be ideal for the sensor.

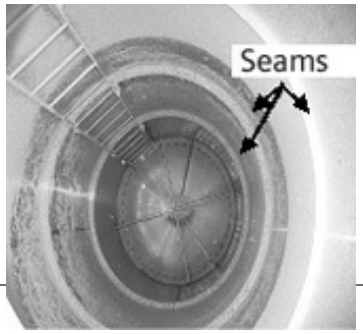


Typical steel silos, like those found in the plastics or food industries, may have several nozzle connections available. Thus each silo needs to be assessed for its best installation location so the sensor can operate at optimum capacity and provide reliable level readings over the full range of operation.

Example

Two potential locations for the sensor:

1. Too close to the filling point: filling streams will widen as they fall and it is impossible to measure through a filling stream. Although radar is not affected by acoustic noise or dust like an ultrasonic sensor, the particle stream will interfere in the reading as the sensor must be able to clearly see the surface it is measuring.
2. The proper location: one meter away from the side wall and with clear sightline to the material level. Nothing interferes with the beam, including ladders, agitators, and weld seams.



NOTE: if possible, bring a flashlight and look inside the silo when it's empty to really see what's in there. Most users have no idea what the inside of the silo looks like and assume it's wide open, but that may not be so and many silo interiors have the following:

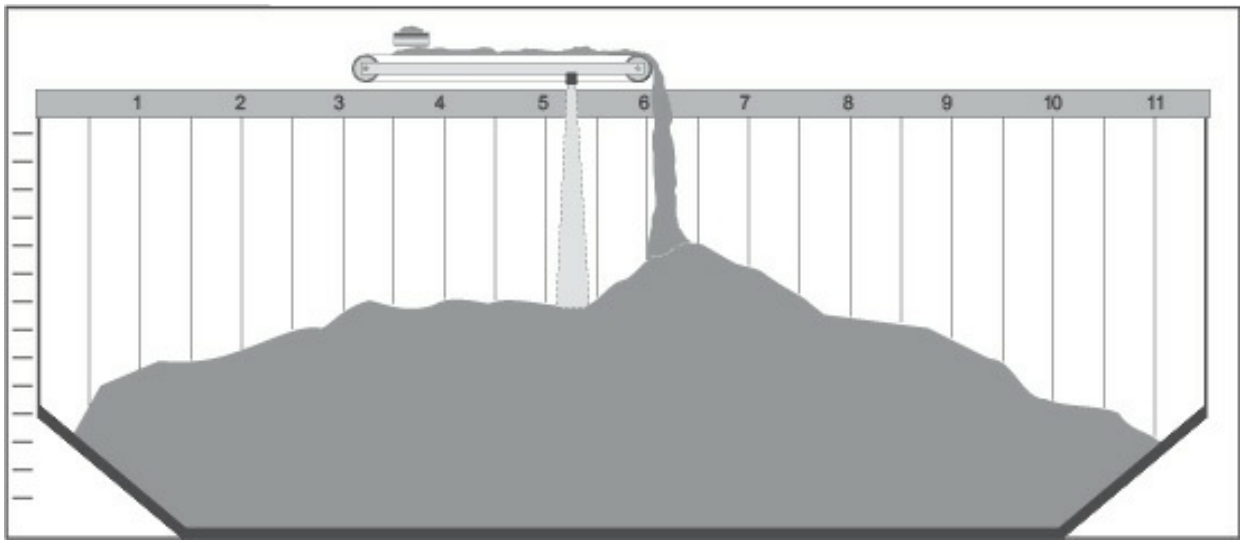
- weld seams or rings around the perimeter – silos are generally constructed from sheet stock in rings which are clamped together and welded. Frequently an internal lip at each seam is left to be cut off and ground smooth. However, occasionally, they are left as is or not ground down far enough, and the protrusion can send nasty reflections back to a radar sensor. If these are present, it is best to be as far away as possible to improve the signal quality.
- internal ladders – placed inside some silos to facilitate periodic maintenance. These can create false level signals or elevated noise levels on the signal profile. The sensor should be installed as far away as possible from the ladder or be pointed away from it.

Large diameter silos or halls

When faced with a very large diameter silo or hall with multiple feed points, the following needs to be determined before radar device installation:

- filling locations
- sensor locations

Some solids storage areas cover a large area. Therefore the transmit cone of the sensor hitting only a certain point rather than the whole area does not accurately represent the level. In an application using a moving tipper car to convey material over a large area, a narrow beam radar like the SITRANS LR560 can accurately scan the surface of the entire pile and provide a reliable reading.

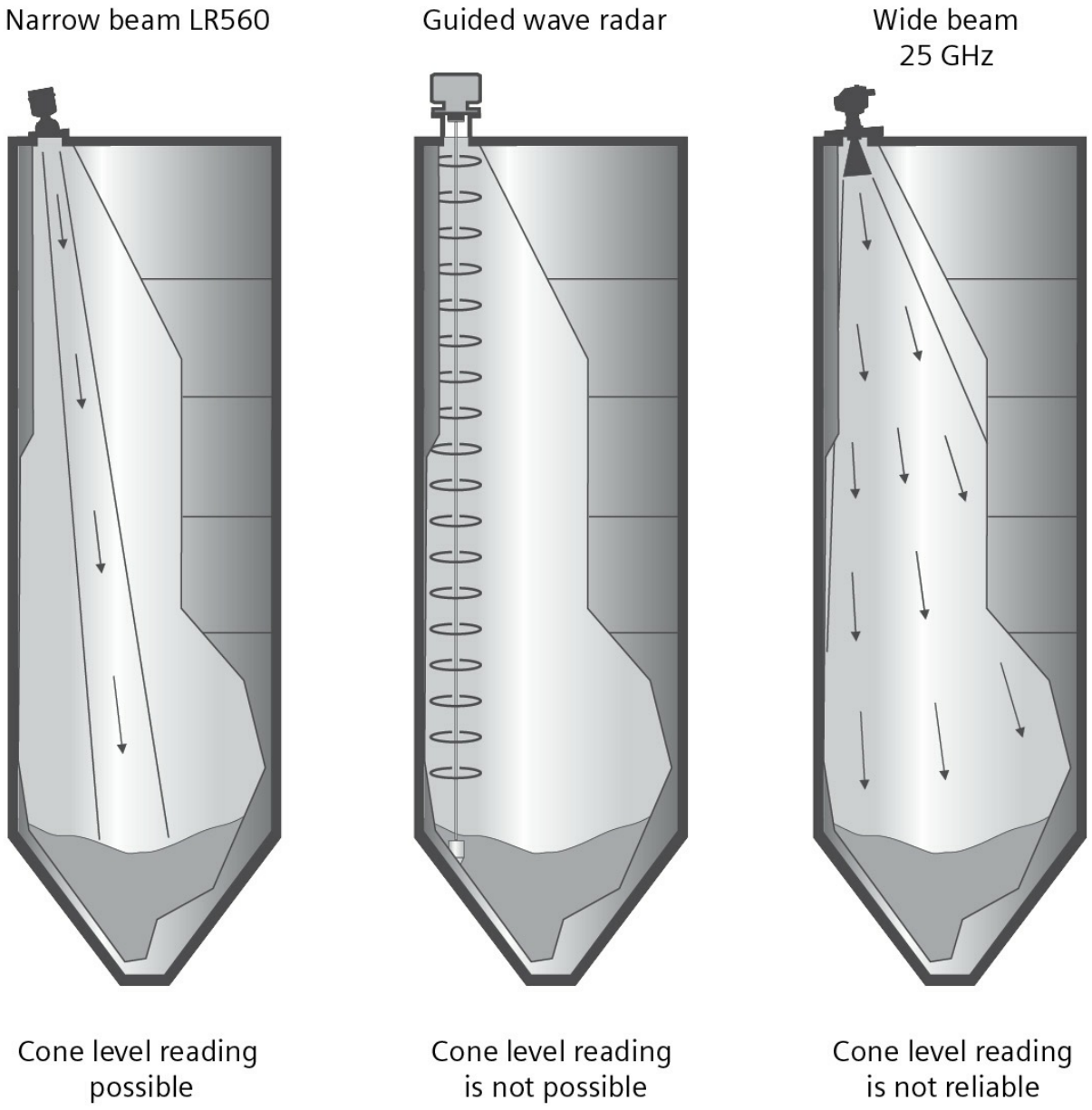


Multiple sensors may be implemented to achieve the necessary accuracy. In large silos, filling point location needs to be determined according to where the level reading is required. At the fill point, the angle of repose will give a dramatically different level reading than the sides of the container. All solids surfaces will have an angle of repose, and sometimes the surface of the level can vary by a few centimeters or a few meters.

Silo cone area

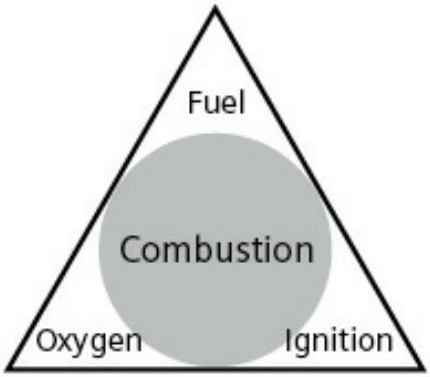
Typical storage silos have a conical bottom shape to facilitate material exit, and this conical area presents challenges for the level measurement technology during low level conditions:

- a rope dip is usually off center and will hit the side of the cone before it touches the material surface
- guided wave radar (aka TDR) is generally suspended with a weighted end and provides level measurement readings only as far as the measuring cable, again, somewhere at the side of the cone but rarely all the way to its bottom
- with traditional ultrasonic or radar technology, the signal beam width is fairly wide once it reaches the conical area and there is significant scattering, mixing, and stretching of the signal – leading to inaccuracy



However, the SITRANS LR560 with its narrow 78 GHz beam and standard aiming flange can be carefully pointed towards the conical area and then give a precise level measurement. This significant step forward in radar technology resolves the common problem of poor measurement in the conical region.

Hazardous area installations



Flammable and explosive substances in the form of gases, dusts, or fibers occur in many industrial sectors. There are many types of dust that are a potential risk to become explosive under the right conditions of dust concentration (fuel), air (oxygen), and a source of ignition. These three components form the triangle required to cause an explosion risk, and if any one of these components is removed an explosion cannot occur.

In this ignition triangle the dust is the fuel and the radar level transmitter and/or the electrical installation is the potential source of ignition.

Here are just a few of the common solids materials that are considered to be an explosion hazard:

- grain dust
- coal
- cotton
- some plastics
- titanium
- magnesium
- wood dust
- most food dusts (flour, sugar, coffee)

The users of material handling equipment are obliged by law to prevent the danger of explosion in the hazardous areas by providing protective measures. Where solids are handled or transferred, there is an opportunity to create dust and fuel for an explosion. Radar level measurement transmitters are designed and approved for hazardous dusty areas to make certain that they will never be the source of ignition. This state is accomplished by ensuring that the housing does not become hot during any fault condition and that the housing is dust tight to keep flammable dust from entering the enclosure. In addition to the transmitter being approved for the hazardous dust area, the customer must also install the installation wiring in accordance to the local electrical codes pertaining to hazardous dust.

Explosion protection is regulated by law in most industrial countries. The European Union has issued the ATEX (ATmospheres EXplosive) directive which stipulates the use of type-tested explosion-proof equipment. In the Americas, explosion protection is regulated by the National Electrical Code. In either system, the customer must first identify if the application where the transmitter will be installed is classified as hazardous or not.

Here is an example of the explosion requirements from a customer in the USA for a radar transmitter:

FM Class II Div. 1 Gr. G	
Class II	hazardous dust present
Div 1*	hazard is continuously present
Gr. G	dust types such as grain, flour, and wood

* Div. 2 suggests the hazard is only present during abnormal functioning, such as a filter bag breaking.

The approval option required by the transmitter is selected from the catalog sheet and will have the exact approval coding listed on the nameplate. As important as choosing the correct transmitter is completing the electrical

installation to the local code requirement for the level of hazardous area defined.

The coding determined by the ATEX directive is considerably different; here is an example for a dusty application:

ATEX II 1D	
II	surface installation (as opposed to below surface – mining)
1	hazard is continuously present
D	hazardous dust present

Again, the approval option required by the transmitter is selected from the catalog sheet and the exact approval coding is listed on the nameplate. Equally important to choosing the correct transmitter is completing the electrical installation to the local code requirement for the defined level of the hazardous area.

High temperature applications





Radar technology is proven effective on high temperature solids. The steel, cement clinker, and gypsum production industries all work with solids materials that are very high in temperature and often require special precautions.

The material temperature and air space temperature between the radar device and the material surface bears no influence on providing reliable measurement. It is the radar

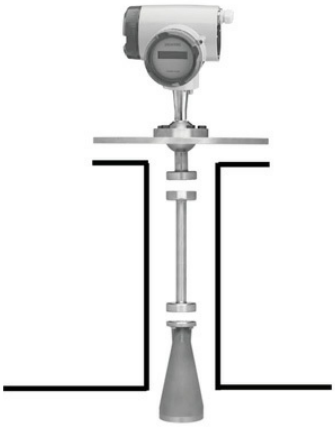
device itself that needs to be kept cool and the following considerations must be met to protect it from high temperatures:

1. The internal device electronics must be maintained below 80° C to avoid damaging the electronic components. Two-wire radar has an advantage in high temperature applications because the electronics consume fewer than 0.5 watts, thus generating very little internal heat. If the ambient temperature around the enclosure is 70° C, the electronics operate at close to 70° C. A 4-wire device, however, consumes more power, and the heat generated by the power supply-circuit dissipates inside the enclosure, making the internal housing typically 15 to 20° C hotter than the ambient conditions outside the enclosure. This difference in operational principle is why the 2-wire LR560 has an ambient temperature spec of 80° C, while the 4-wire LR460 ambient spec is at 65° C (compensating) for the internal temperature difference.
2. The radar antenna temperature must be kept cool enough to prevent damage. A steel antenna can be exposed to temperatures over 1000° C before sustaining damage that will affect the microwave properties. However, the radar emitter inside the steel antenna is usually made of PTFE[4]6 and will become softer at temperatures above 250° C. Therefore, the PTFE emitter is the primary source of the temperature rating, typically 200° C. Determining the process temperature specification must also account for the heat conducted through the antenna to the enclosure. If the electronics temperature is expected to get too hot, a simple remedy is to add height to the standoff nozzle and distance the electronics from the heat. An additional 30 centimeters (12 inches) can reduce the temperature at the electronics by more than 50° C.

NOTES:

- Elevating a 25 GHz radar usually means adding an antenna extension to keep the end of the horn inside the silo to minimize signal noise. While this retrofit can sometimes be done on site, it’s better done at

the factory. Note that a long antenna extension minimizes the adjustment angle of the radar antenna for materials with high angle of repose.

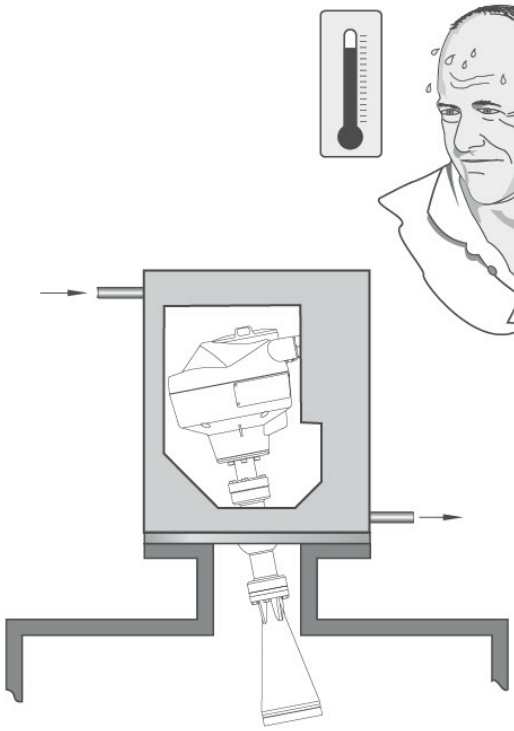


Very high temperature applications can be achieved with 25 GHz by using a long antenna extension and an elevated nozzle.

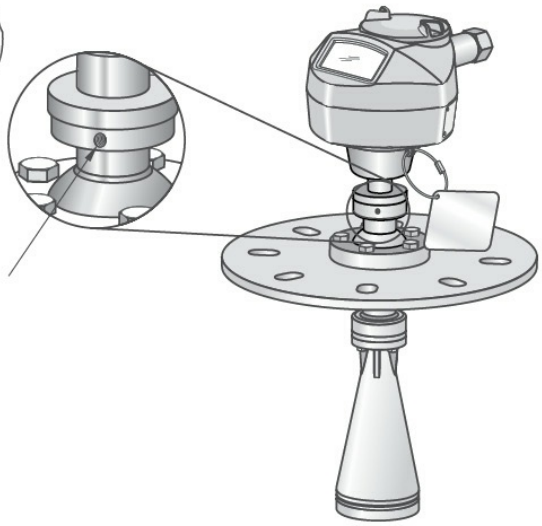
Elevating the 78 GHz LR560 the 30 centimeters will have very little effect on the signal quality because of the very narrow beam. The shorter wavelength at this frequency will also yield excellent reflection from a sloped solids surface. In the same conditions, the 25 GHz radar needs to be carefully aimed.

Air cooling

On extremely high temperature applications where a long nozzle is not possible for isolation, the antenna and electronics can be cooled with added air. Air cooling requires custom modifications to the site as air supply systems are connected to the installation nozzle to keep a constant supply of air moving around the antenna.



An external air source needs to be applied to the electronics if the ambient temperature exceeds specification.

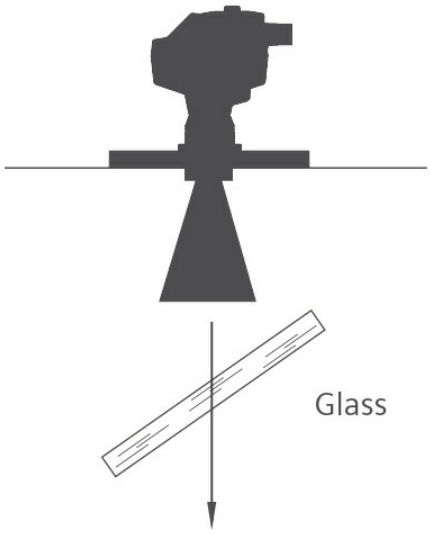


An external air source can be applied to the purge inlet to supply dry cooling air to the antenna.

Furthermore, adding a cover to the enclosure helps direct the cooling air supply to the device. Blast furnace applications in the steel industry have been measured effectively by keeping the radar transmitter cool.

Temperature isolation lens

Glass, ceramic, or any other low dielectric insulating type material can also be used as heat isolation material between the antenna and the application. However, use this option only when no others are possible. The reflection from this isolator causes noise to induce on the signal and while an isolation lens could be manufactured to be perfectly transparent, it is costly.



The thickness of the isolation lens is directly proportional to the lens dielectric value and the wavelength of the radar frequency, as per this formula:

$$\text{Optimum thickness} = \frac{\lambda}{2 * \sqrt{\varepsilon r}}$$

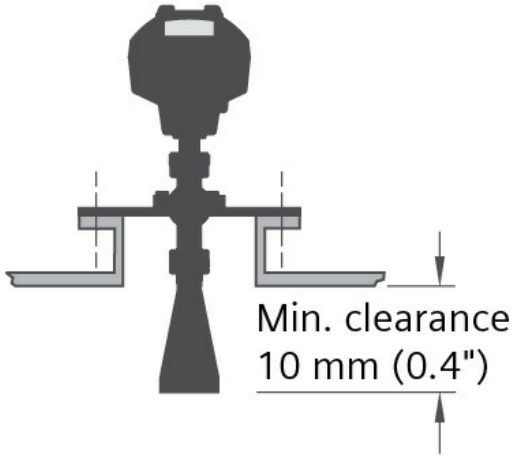
The PTFE dust cover for the LR460 is precisely 4.3 millimeters thick, and adds no noise to the signal.

For a 25 GHz radar device like the SITRANS LR460, the ideal thickness of a perfectly transparent lens made from PTFE is 4.3 millimeters. This size ensures that the wave reflecting from the front of the lens is 180° out of phase from the reflection off the back of the lens. If the thickness of the isolation lens is not tuned to the optimum amount, unwanted reflections appear and are generally viewed as a single echo and then ignored with the echo processing. However, it is possible for the signal to be very noisy into the measurement range, conflicting with the material echo. In this case an alternate lens material or thickness should be used.

The lens should be installed so it is at a 45° angle to the antenna direction. This angle also minimizes the reflection from the lens.

Very long and/or narrow nozzles

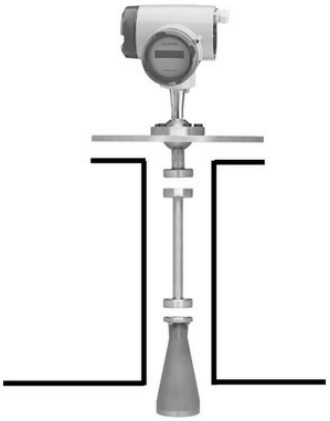
A general installation principle for radar devices is to keep the mounting nozzle as short as possible and as large in diameter as possible to minimize unwanted reflections. To eliminate any influence from the mounting nozzle, the active part of the antenna must be completely outside of the nozzle. For many silos, a 25 GHz radar device can be installed on an existing nozzle and the end of the horn will be outside of the nozzle.



The outside of the metallic horn is completely inactive so the nozzle shape and size is irrelevant for this basic application. However, if the nozzle is longer than the antenna, it should ideally be cut shorter. An alternative solution is to use an antenna extension (see High Temperature Application above).[5]

NOTES:

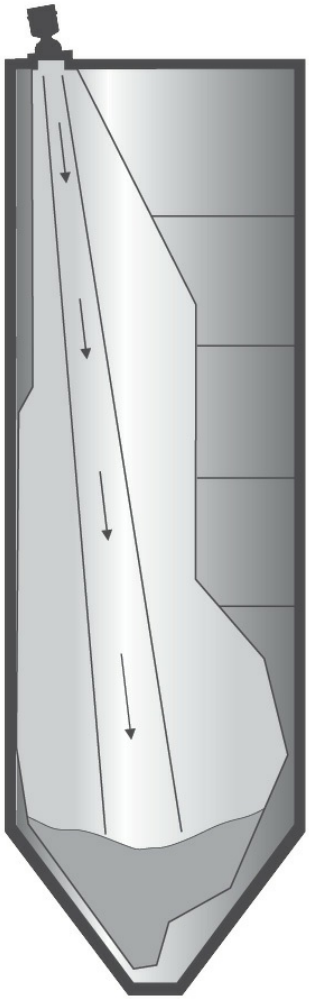
- 6 GHz devices installed in long nozzles have a 90% failure rate
- 25 GHz devices installed in long nozzles have a 90% success rate (the higher frequency provides a narrower beam less affected by nozzle interference)
- the new 78 GHz LR560 installed in a long nozzle has a 99% success rate because of its very narrow beam



Bolting in a radar device

Bolting a device in place needs to consider the following:

- use a suitable gasket in dusty applications to maintain a good seal from the radar flange to the mounting nozzle flange or plate (a silicone sealant can be used, although any attempt to remove the sensor later will be more difficult)
- note the orientation of the local display for convenient viewing
- ensure wiring ports are accessible



Aiming the antenna

A radar device designed for solids measurement requires a means to steer the antenna for any of these reasons:

- improve reflection on sloped solids

- direct beam away from sidewall where silo seams, buildup, ladders, and other obstructions may be present
- improved measurement in the low cone area

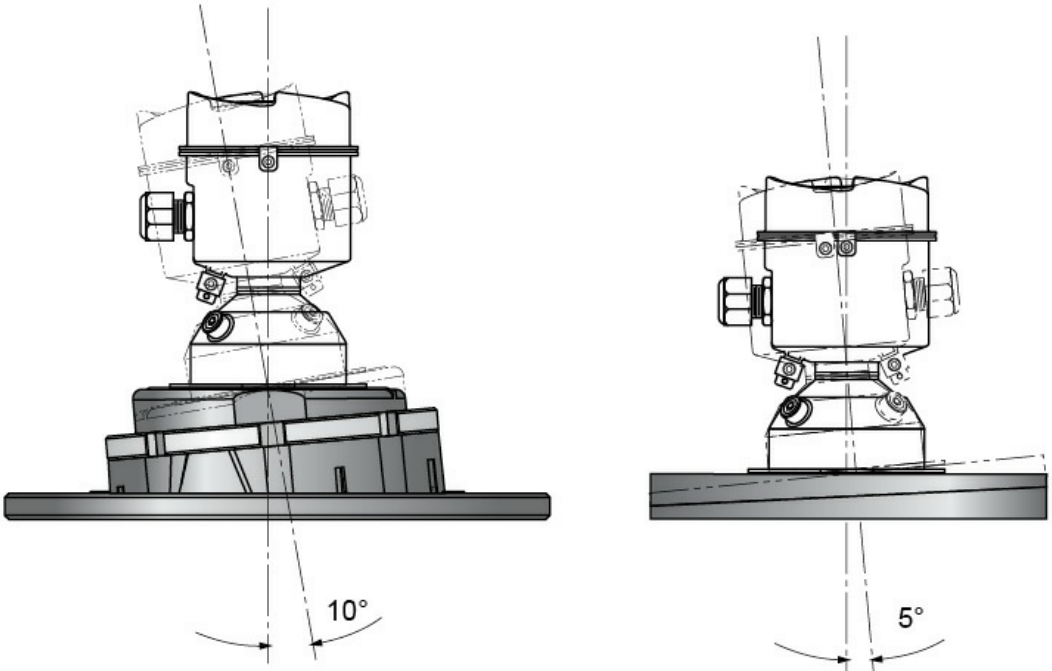
When aiming the LR560, direct the 78 GHz beam towards the bottom exit point of the silo. A few degrees off vertical is sufficient.

Example silo

- diameter: 4 meters
- height: 15 meters
- device installation: 1 meter from the side of the silo

A slight angle of only 3.8° (1/15 INV/SIN) is required to aim the beam to the bottom center of the silo. Just unlock the aiming flange and rotate the sensor to the required angle.

If the silo is near empty, the signal profile can be viewed on the radar's local display or on a PC running SIMATIC PDM.[6] Adjust the radar until the noise level is lowest and the signal strength is strongest from the material. If the silo is completely empty, the return signal from the bottom of the conical area will be unreliable and so the antenna will have to be aimed at the approximate location.



4" and 6" Flange

3" Flange

NOTES:

- After adjustment, tighten down the aiming mechanism
- For reference, use a permanent marker to note the position on the aiming mechanism. Then, if the unit is moved later, it is easily returned to its correct position.

Summary

Installing a radar device on a solids application requires awareness of all the conditions that can interfere with performance. The lower the frequency, the more installation requirements like location, nozzle length, silo obstructions, angle of repose, and cone design matter. For the LR560, however, with its narrow high frequency beam, installation is dead simple. The lens antenna is small and easily installed on any opening, including long nozzles. The narrow beam almost completely eliminates the need for fine tuning the threshold

curve (TVT) to ignore false echoes and obstructions. Furthermore, the narrow beam permits readings in the conical area; something not possible with other technologies.

1 Mike Holmes. Host of *Holmes on Homes*. HGTV, 2004 -.
2 Tim Little has personally commissioned and diagnosed ultrasonic and radar installations for over 20 years, and he confesses that it is one of his favorite topics during late night tavern discussions with colleagues.
3 OEM refers *Original Equipment Manufacturer* and to companies that sell solutions comprising components made by other companies.
4 PTFE (polytetrafluoroethylene) is a synthetic fluoroplymer of tetrafluoroethylene best know by the DuPont brand name *Teflon*.®
5 Long extensions limit aiming for solids applications with a high angle of repose. Antenna extension lengths are limited and some mounting nozzles may be too long for the longest antenna extension length available. The nozzle then needs to be cut shorter.
6 SIMATIC PDM (Process Device Manager) is the Siemens software for configuration, diagnostics, and asset management.

Chapter Six

Connections and basic setup

Four legs good, two legs better.[1]

Once the physical installation details are worked out on the vessel and the optimal connection site is determined, it is time to look at the electrical feed and the device requirements. Radar devices have either a two or four-wire connection.



Topics

- Power
- Connections: 4 and 2 wire
- Communications: HART and PROFIBUS
- Installation
- Basic setup

Power

The two types of radar transmitters are defined by how they are powered:

- 4 wire – high power
- 2 wire / loop powered – low power

Until the late 1990s, all radar transmitters were 4-wire type, and for a number of years after the introduction of 2-wire devices, customers had to choose between 2-wire transmitter economy and 4-wire accuracy, stronger signal, and quicker response times. However, rapid advances in low power, highly

sensitive, fast electronic components soon made 2-wire technology equal to 4-wire in accuracy, signal strength and response speed. Nonetheless, 4-wire devices are still found in the market, primarily in tank gauging where very high accuracy and additional input variables such as temperature and pressure are required.

Connections: 4 and 2 wire

Four-wire devices

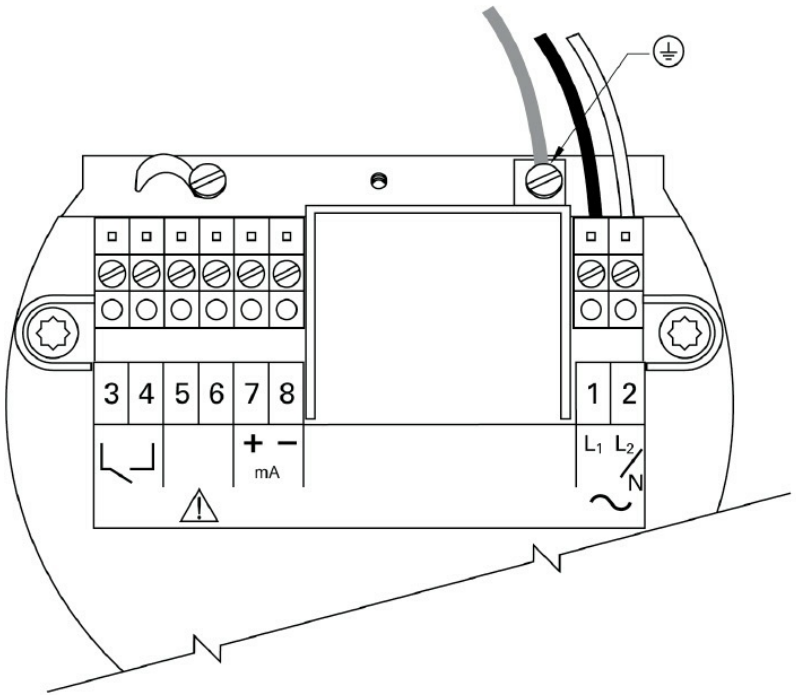
A 4-wire radar device uses a minimum of four wires to operate and to transmit level output readings. The power supply connection takes at least two wires and is completely independent from the output channel which uses two separate wires. Furthermore, there may be additional wires and connections to the transmitter for communications or for diagnostic use.

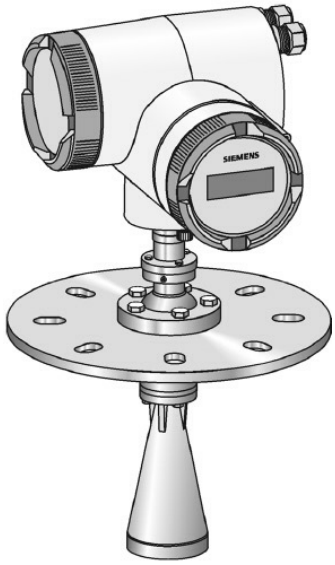
> 4-wire transmitters may be AC or DC and usually consume five to ten watts of power.

Radar transmitters were initially designed as 4-wire systems because the early electronic devices needed the robust power supply to power discreet components. This supply needs to provide the devices with both a strong signal and a very fast response rate, and must also have enough power left over for signal processing, communications, and a backlit display.

For a 4-wire radar device, the power consumption specification needs to be checked to ensure the power supply used is sufficient for the sum of the transmitters to be connected.

Example: 4-wire transmitter connection and specification





Power Supply

- 100 to 230 V AC, 15%, 50/60 Hz, 6 W

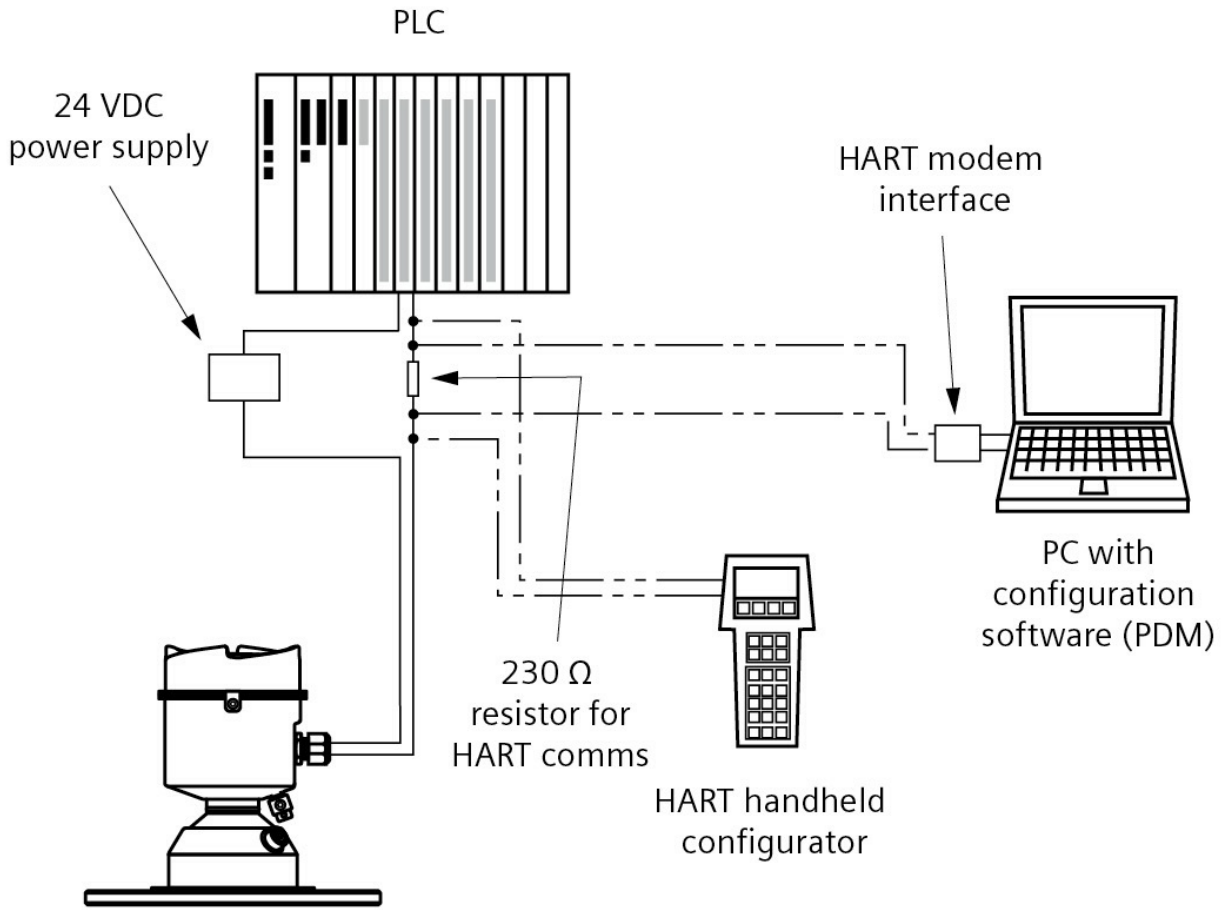
NOTE: In a 4-wire installation, the power supply wires must be kept physically separate from the output signal wires to prevent noise or interference.

Installing a 4-wire radar device, with its multiple wires on the input and output plus additional conduit or other means for separation, can thus be costly with installation costs often exceeding the radar transmitter costs. However, for very high accuracy requirements (one millimeter), radar transmitters often rely on input from pressure and temperature variables which use additional power not available in a 2-wire installation. Added communications requirements like providing RS485 or other high speed digital data also can require more power than a 2-wire device can provide.

The wiring cost of 2-wire compared with the 4-wire system is at least half, depending on the configuration.

Two-wire devices

A 2-wire transmitter uses the same two wires to deliver the power, a signal output, and communications. The most common design uses the 4-20 mA loop control signal with 24 VDC as the power supply. A constant voltage is applied to the loop and then the transmitter draws current from 4 to 20 mA based on the level measurement reading. Generally, 4 mA represents 0% level and 20 mA represents 100% level. The 24 VDC supply to the loop may be separate or be integrated with a PLC input channel as shown here:



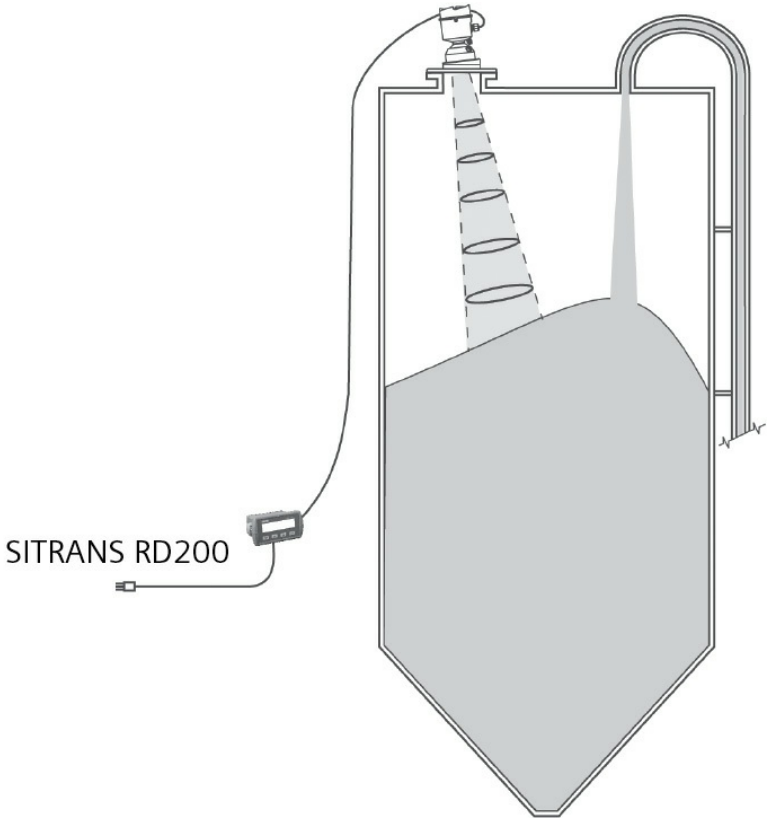
Other equipment may be in the same loop such as remote displays or chart recorders, and these devices also reduce the operating voltage available to the transmitter. The transmitter thus has a minimum operating voltage specification and a maximum loop resistance specification. The design of the

loop must consider all the devices on the loop as well as the total wire length to ensure that the loop resistance is not exceeded. If so, the transmitter will not function.[2]

A 2-wire transmitter consumes minimal power. At its lowest, it may be as little as 50 mW; at its highest, it may consume 0.6 watts, depending on the level of current being drawn. The device design must accommodate the lowest power available and yet maintain a strong signal and provide an acceptable response rate.

Siemens engineer Ian Van Zyl[3] was granted a patent in 1995 for a radar design where a loop powered transmitter can operate at an average current in excess of the minimum value of current that flows in the loop. The microprocessor is temporarily turned off while the transmitter fires to the sensor, and then the transmitter is stopped while the microprocessor operates. This sequencing of power allows the device to function efficiently with the limited power available, a breakthrough design which is used in most 2-wire, loop-powered transmitters today.

Two-wire loop powered transmitters have many advantages over 4-wire as only a single shielded twisted pair cable feeds power and sends data to determine the level and perform diagnostics. A basic stand alone silo system might use a simple remote display with integral 24 VDC power supply.



Furthermore, many existing analog wires can be reused for the new radar transmitter. There may be an existing point level switch at the top of the silo that feeds a level indication to the control system, and this same wire can often be re-used for the radar transmitter, saving significantly on the total cost of the installation.

Communications: HART and PROFIBUS

HART communication

Highway Addressable Remote Transducer (HART)[4] is a communications protocol for connecting field devices to control systems. A 2-wire, 4-20 mA loop powered transmitter may simply be connected to a remote display or be used as an input to the PLC. However, the device needs to be configured for the application and scaled so that 4 mA corresponds to a specific distance from the sensor (usually empty) while 20 mA corresponds to the opposite distance (usually full).

Scaling is the term for matching the output (digital or analog) with an actual measurement reading.

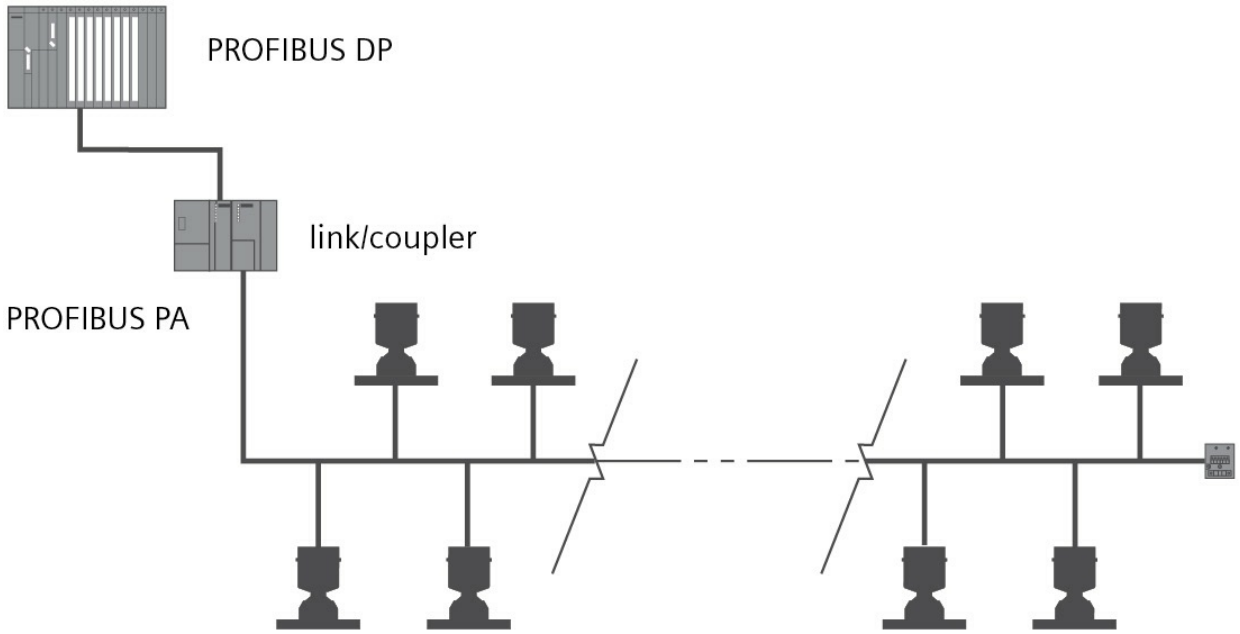
This scaling can be done several ways:

- at the transmitter using local pushbuttons
- using a proprietary handheld communicator such as the Siemens Milltronics infrared handheld programmer
- via remote HART communication using a personal computer or a handheld HART communicator

The advantage of remote HART communication is that programming, scaling, and diagnostics of the radar transmitter are possible anywhere on the current loop. It is not necessary to climb the silo to perform these tasks, a benefit in nasty weather. The communication access can be done safely on the ground or in a control room.

PROFIBUS

PROFIBUS is a two-way fieldbus communications system that integrates devices into a unified system. Thus elaborate installations including multiple silos use a PROFIBUS Network to link the devices together, gathering all the application data from the devices and providing configuration access.



PROFIBUS is a primary communications protocol for process industries, and this fieldbus network brings a number of advantages to any multiple device installation:

- configuring and commissioning from one control location
- data management for full inventory control
- diagnostic checks and warning with preventative maintenance
- asset management

The SITRANS LR560 can thus be added to a complete control loop where it will provide full level control as part of the communications network.

Installation guidelines

Local electrical codes

The electrical safety and installation requirements vary from region to region. It is the responsibility of the customer or installer to ensure that the local requirements are met, not the manufacturer. Manufacturers clearly state this in the instruction manual.

Hazardous areas

Many dusty environments can be very explosive under the right concentrations and with the right trigger. Therefore, they are classified as safety hazards and must be handled accordingly. Local electrical safety codes provide instructions on suitable handling and installation requirements.

The customer is responsible for determining the area classification where the radar transmitter will be installed and to match this requirement with the device.

Example of two different approval classifications for the SITRANS LR560:

1. CSA/FM Class I, Div. 2, Gr. A,B,C,D
2. ATEX II 1 D, 2D, 1/2D, 3G

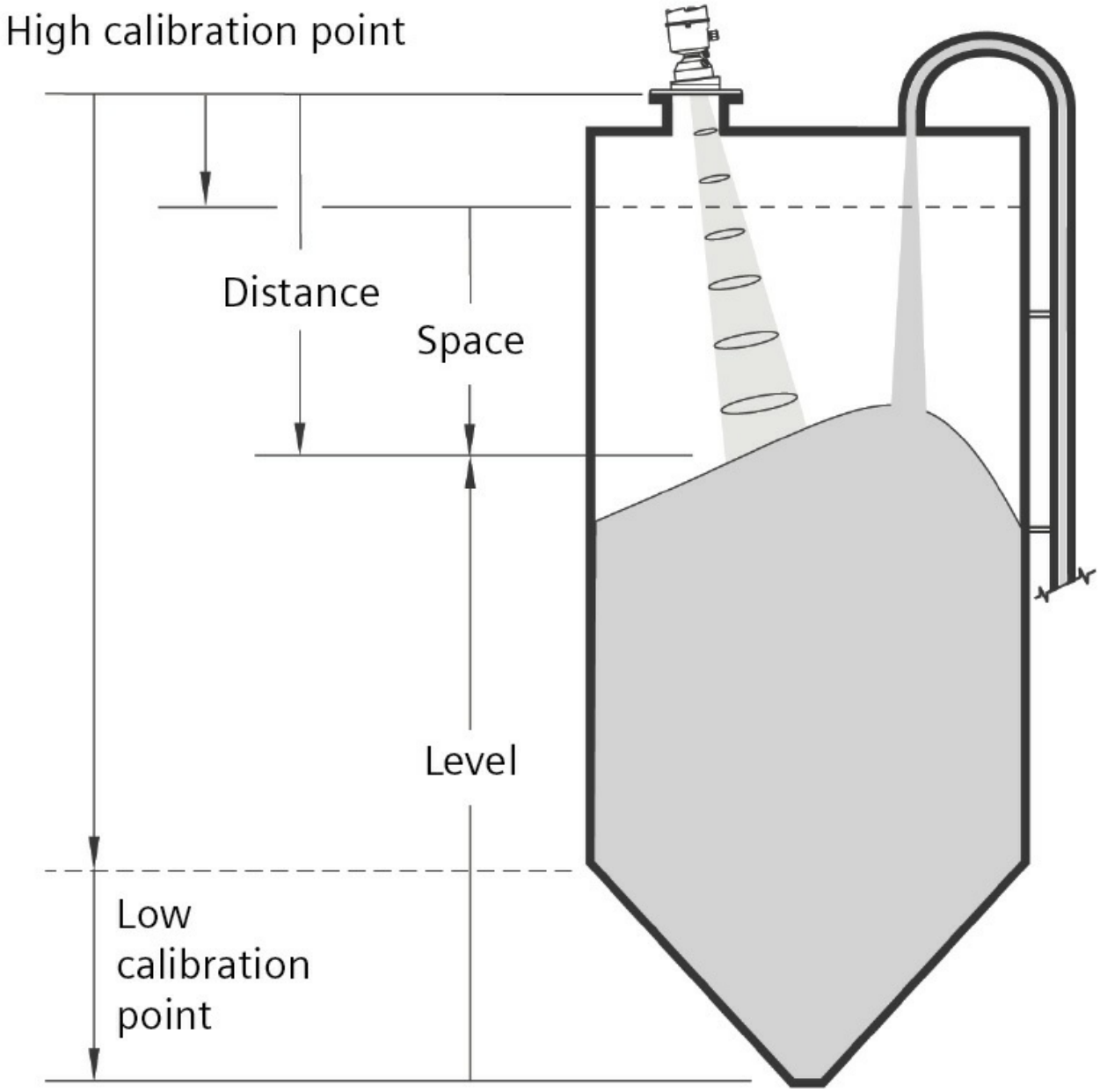
Before installing the transmitter, be sure to check the device nameplate to ensure its approval for the intended application.[5] For more information, please see Chapter Five.

Basic setup and programming

Now that the radar transmitter is correctly installed and wired in, the next step is basic programming to calibrate it to the application. When radar first came onto the market, this was an arduous process and often required bringing someone in from the manufacturer to set up and fine tune the complicated instrument. It often took several days, plus a little black magic to make the device work. Now, however, programming is a great deal simpler and most end users are able to set up the radar device on their own.

Calibrating 0% and 100%

The first step in the commissioning process is to get physical measurements of the silo, and there are two critical measurements:



- the distance from the transmitter reference point to the zero percent level. Note that the bottom of the silo is not always zero. With large heavy material such as coarse ore, a layer of stock is often kept at the bottom to prevent damage as it drops in. In other cases, a safety stock level is maintained, locating the zero percent reference higher than the bottom.
- the distance from the transmitter reference point to the 100% level. Note that the top of the silo is not necessarily 100%. There may already be a pre-determined 100% somewhere else, for inventory management

reasons or for operational safety (often the case with hot material).

Startup wizard



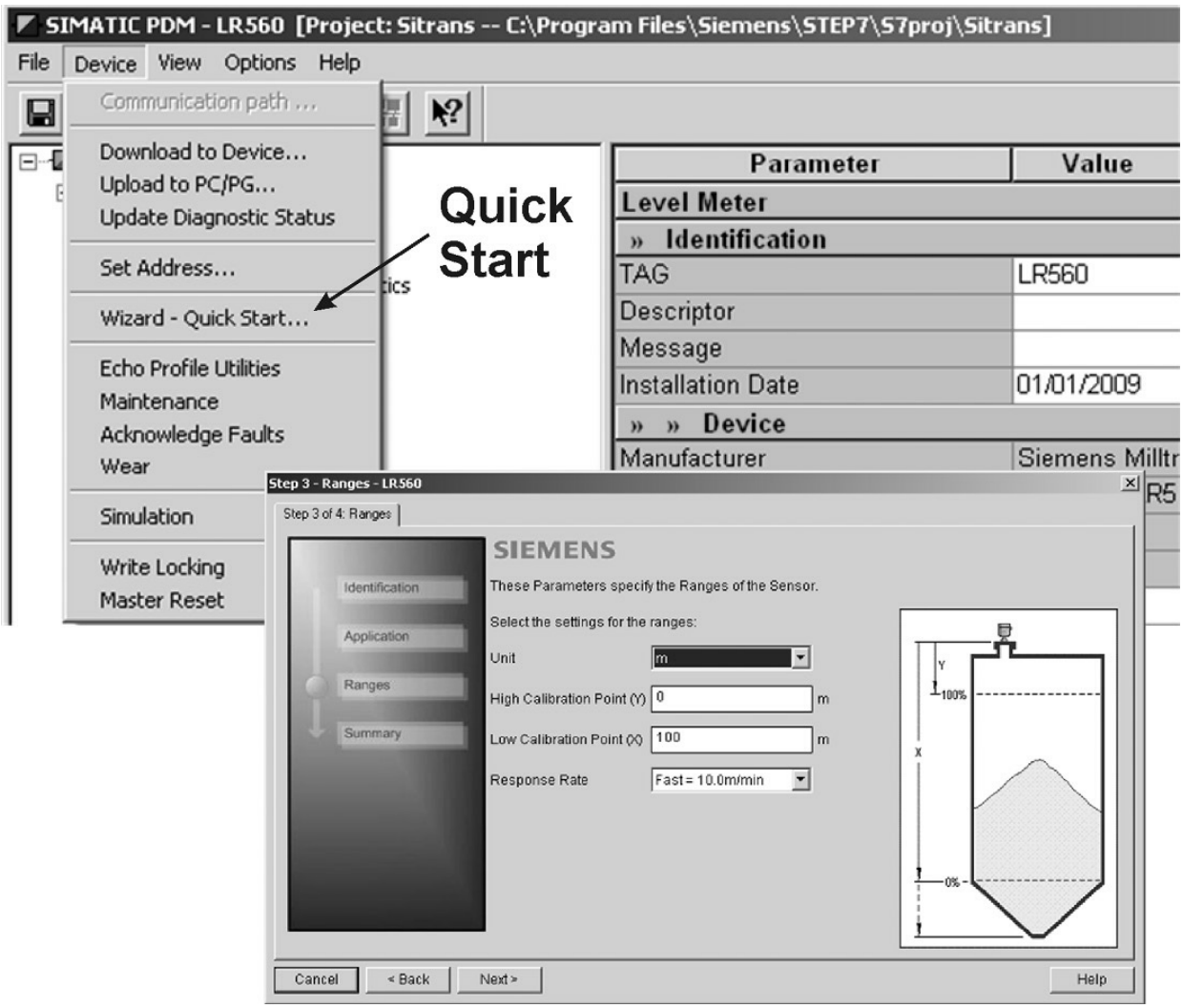
The SITRANS LR560 startup wizard accesses the basic programming steps right at the device, using either the optional infra-red handheld programmer or the four-button local display to configure the following:

- language
- measurement units
- level/space/distance values
- low calibration point
- hi calibration point

This simple and quick setup ensures that 95% of all applications will function effectively if the correct data is entered. Remote access to this startup wizard is also provided by the Siemens configuration software SIMATIC PDM (Process Device Manager).

The full parameter set is also accessible by programmer or access buttons; however, SIMATIC PDM offers remote communications for programming, diagnostics, and asset management through either HART or PROFIBUS protocols.

Once SIMATIC PDM is installed and configured, access the quick start wizard from the drop down *Device* menu.



Using the quick start wizard, simply enter the values pertaining to the application and then transfer them to the transmitter.

Response rate: Always select the slowest speed setting allowable for the application:

- slower speed settings use more samples for measurements, leading to a smoother echo profile
- slower speed settings use a smart window discriminator function, leading to more stable readings
- the output signal will be smoother because of higher damping values and less signal drifting of the signal. Solids surfaces are sloped and sometimes there will be shifting on the surface during filling and

emptying, and a slower speed setting will provide a smoother trend for the operations.

The LR560 has three response rate settings:

- slow: 0.1 meters per minute
- medium: 1.0 meters per minute
- fast: 10 meters per minute
  The slow setting defines a response rate of 100 millimeters (4 inches) per minute maximum, and because most solids silos are filled and emptied at slow rates, this setting usually works just fine.

Example:

- 15 meter silo
- plastic pellets
- eight hour fill time
- one week content consumption

Because the filling rate is 3.125 millimeters per minute, the slow setting of 100 millimeters per minute is perfectly acceptable.

Verification

After the basic set up, the radar transmitter should be reporting the material level in the units defined. However, the reading should be confirmed by dipping the silo. Lower a measured rope or tape measure to the material surface and check the distance against the reading of the device, making sure of the following:

- the reference point for the distance measurement is correlated to the flange of the radar transmitter
- the dip is performed as close to the radar transmitter as possible to minimize errors caused by the slope of the surface

If your accuracy is off, turn to Chapter Seven: right away.

Acceptable accuracy depends on the media measured. Typical accuracy for both ultrasonic and radar technologies is the greater of either 1.0% of the distance to the material or 150 millimeters, thus:

- if the distance to the target is five meters, accuracy should be within 150 millimeters (six inches), not five centimeters
- if the distance to the target is 50 meters, accuracy should be within 0.5 meters (20 inches), not 150 millimeters

Solids materials without a slope are excepted from this because the echo is very strong, narrow, and sharp; similar to a liquid signal reflection.

The following verifications are recommended, but not mandatory:[6]

- Confirm the 4-20 mA loop scaling on the remote indicator or control system. Programming the transmitter with the dimensions of the silo will correctly scale the output. However, if the transmitter is fed as an input to a PLC, and the PLC programmer has converted this 4-20 mA signal into other values (for example 0 to 50 tons or 0 to 30 feet), these are the values displayed on the process control screen. Just confirm that the device and the PLC are talking the same language.
  For a basic setup with remote indicator, power supply, and radar transmitter make sure the remote indicator reads in the required units rather than the factory set 0 to 100% or 4-20 mA. Check the remote indicator manual to adjust these settings. Remote indicators like the SITRANS RD200 from Siemens include software for this step.



- Once the control system has been scaled or the remote indicator has been adjusted, the radar transmitter needs to be manually adjusted to read 4 mA. This could be done locally at the transmitter, or remotely via HART communications using SIMATIC PDM software. Once the transmitter reads a fixed value of 4 mA, verify that the remote indicator or control system display value reads exactly 0.0. If not, there is probably an error in the scaling somewhere between the radar transmitter and the remote display.

For example: the device provides 4-20 mA input to the PLC, which the programmer then scales. Thus 4 mA equals 0% and 20 mA equals 100% or maybe 4 mA equals 10 centimeters while 20 mA equals 20 meters. If the 20 meters does not match the device's Hi cal point setting, then there is a scaling error. Errors can even include complete reverse reading with backwards scaling and the device will read empty while the customer reads full.

Now set the transmitter to read 20 mA (full scale) and adjust the scaling of the remote system until it reads the required 100% value in the selected units. Once the scaling of the transmitter is aligned with the remote system, the transmitter can be switched from manual mode to normal.

NOTE: Do not try to adjust the radar transmitter mA calibration. Its 4-20 mA settings are calibrated at the factory traceable to national standards.

- Take an echo profile of the signal from the transmitter. During commissioning, the echo profile can be retrieved, and this can be saved with the SIMATIC PDM project for future reference. This step is to confirm that the initial signal quality is good at time of commissioning and will measure reliably over the full silo range. This profile will also be useful as a future reference. If there are application difficulties, the original profile can be compared to the current one.

Parameter list

Parameter	Value	Unit	Status
Level Meter			
» Identification			
Long TAG	560_8_66		
TAG			
Descriptor			
Message			
Date			
» » Device			
Manufacturer	Siemens AG		
Product Name	SITRANS LR560		
Order Number			
Range Mode	100 Meters		
Hardware Revision	1.00.00-00		
Firmware Revision	00.00.08-66		
Loader Revision	00.00.00-00		
EDD Version	01.00.00-00		
Date of Manufacturing			
» Setup			
» » Sensor			
Units	m		
Sensor Mode	Level		
Damping filter	10	s	
Unit	m		
» » Calibration			
Low Calibration Point	7.090	m	
High Calibration Point	1.000	m	
Sensor Offset	0.000	m	
» » Rate			
Response Rate	Slow		
Fill Rate per Minute	0.100	m	
Empty Rate per Minute	0.100	m	
» » Fail-Safe			
Material Level	Hold		
Timer	100	s	
Level	3.56	mA	
» » Analog Output Scaling			
Current Output Function	Level		
Start of Scale (=4 mA)	0.000	m	
Full Scale (=20 mA)	9.000	m	
Control Range: Lower Limit	3.8	mA	
Control Range: Upper Limit	20.5	mA	
» » Signal Processing			
Near Range	0.278	m	
Far Range	15.000	m	
» » » Echo Select			
Algorithm	First Echo		
Echo Threshold	5	dB	
Position Detect	Rising		
CLEF Range	0.000	m	
Echo Marker	70	%	
Application Type	Steel Silo		**Initial value**
» » » Sampling			
Echo Lock	Material Agitator		
Sampling Up	5		
Sampling Down	2		
Echo Lock Window	0.000	m	
» » » Filtering			
Narrow Echo Filter	0		
Reform Echo	10		

The majority of SITRANS LR560 applications will require only the quick start wizard, and the final step of the commissioning is to record these basic parameters for future reference:

- use a daily log book
- write them down in the instruction manual
- use SIMATIC PDM to save every single parameter setting to the PC. PDM also prints the list of settings in a table format:

Summary

The radar device, whether 2-wire or 4-wire, needs to be installed according to the existing electrical codes and as specified in the instruction manual.

Once installed, the quick start parameters (accessed through the wizard on the unit, HART, or PROFIBUS) set up the installation quickly and effectively.

Verifying the settings remains crucial to accurate performance.

1 Orwell, George. *Animal Farm.* Signet Classic, 1956.
2 For more on designing communications networks, refer to *Catching the Process Fieldbus* by James Powell and Henry Vandelinde.
3 Ian Van Zyl, a long time Siemens engineer and R&D Manager, has been instrumental in developing radar technology, first for Milltronics and now for Siemens.
4 HART was developed in the 1980s by Rosemount and then turned into an open protocol in 1993.
5 For further details on hazardous area installations, go to https://www.automation.siemens.com/w1/efiles/spmirror/2929/brochures/Brochures%20PSPA/Explosionprotection_en.
6 These steps are generally included as part of a professionally contracted commissioning.

Chapter 7

Process intelligence and troubleshooting

Dreams are often most profound when they seem the most crazy[1]

Using the same technology powering Siemens Sonic Intelligence, Siemens radar transmitters use Process Intelligence to parse the signals and determine the level. With the visual representation of the signal, known as a profile, the radar performance can be viewed and analyzed. The profile is the main tool for setting up the transmitter and for troubleshooting, and Siemens Process Intelligence is equipped with numerous features that make analyzing and refining a signal quick and easy.



Topics

- Early echo protection
- Digital echo processing
- Echo profiles
- Troubleshooting with profiles
- Troubleshooting parameters

Early echo detection (1970s)

The origin of radar signal profiling lies in ultrasonic level measurement. Sonic signals were first analyzed by an experienced technician with an oscilloscope over many days (could even take months).

The service engineers often camped out at the plant with the instrument technicians as it took some time to set up. Not as much fun without the campfires.

Echo processing

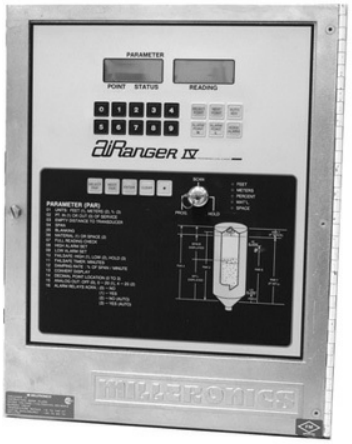
Ultrasonic return echo signals are very weak, ranging from only a few mV to 100 mV in amplitude, so a simple threshold scheme was used to select the first echo above a specified value (e.g. 50 mV). Since signals get smaller with distance, a time variable threshold (TVT) can also be used where the threshold at close ranges can be higher than the threshold at longer ranges. This TVT was typically set with a resistor/capacitor (RC) circuit and could be adjusted by changing the components with a soldering iron or by turning a potentiometer to get the threshold curve to match the signal profile. This process was very time consuming.

Digital echo processing (1984)

In 1984, Siemens Milltronics became the first level measurement company to imbed a microprocessor inside a level controller platform: AirRanger IV, a scanning system for dry solids level measurement. Milltronics had a lot of experience in dry solids handling processes in cement, grain, mining, and aggregates; and this experience culminated in Sonic Intelligence, a patented echo processing architecture for reliable level measurement. The ultrasonic transmitter analog signals were digitized and then stored into memory where the digital echo profile was analyzed by the Sonic Intelligence software. The software uses algorithms to extract the correct echo from the noise echoes.

MultiRanger – the first multi-pump controller with microprocessor (1986)

This processor provided multiple functions for alarm levels and pumping operations for liquid level measurement. Echo processing for liquid level measurement has traditionally been an easy task for Siemens Milltronics' sophisticated sensor systems.[2]



AiRanger IV



MultiRanger Plus

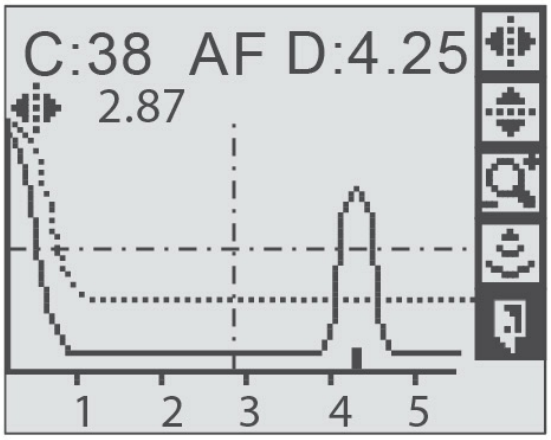
The well designed Siemens Milltronics sensors have narrow beams, sending a very strong signal that is reflected from the liquid surface. The echo processing is simple: pick the first echo over a dynamic threshold.

Numerous features and functionalities have been added to Sonic Intelligence since then, adapting it for both sonic and radio wave processing:

- quick start wizard for setup in minutes
- auto false echo suppression for easy nullification of false echoes
- improved first echo detection routine for radar
- narrow and reform filtering for narrow false echoes or for sloped solids materials
- advanced window discrimination features for improved stability of measurement
- CLEF algorithm for improved performance on low dK media

Echo profiles

An echo profile shows the signal obtained from the silo following the transmit and receive period of the radar device. It shows exactly what the radar device sees and how it processes the information received.



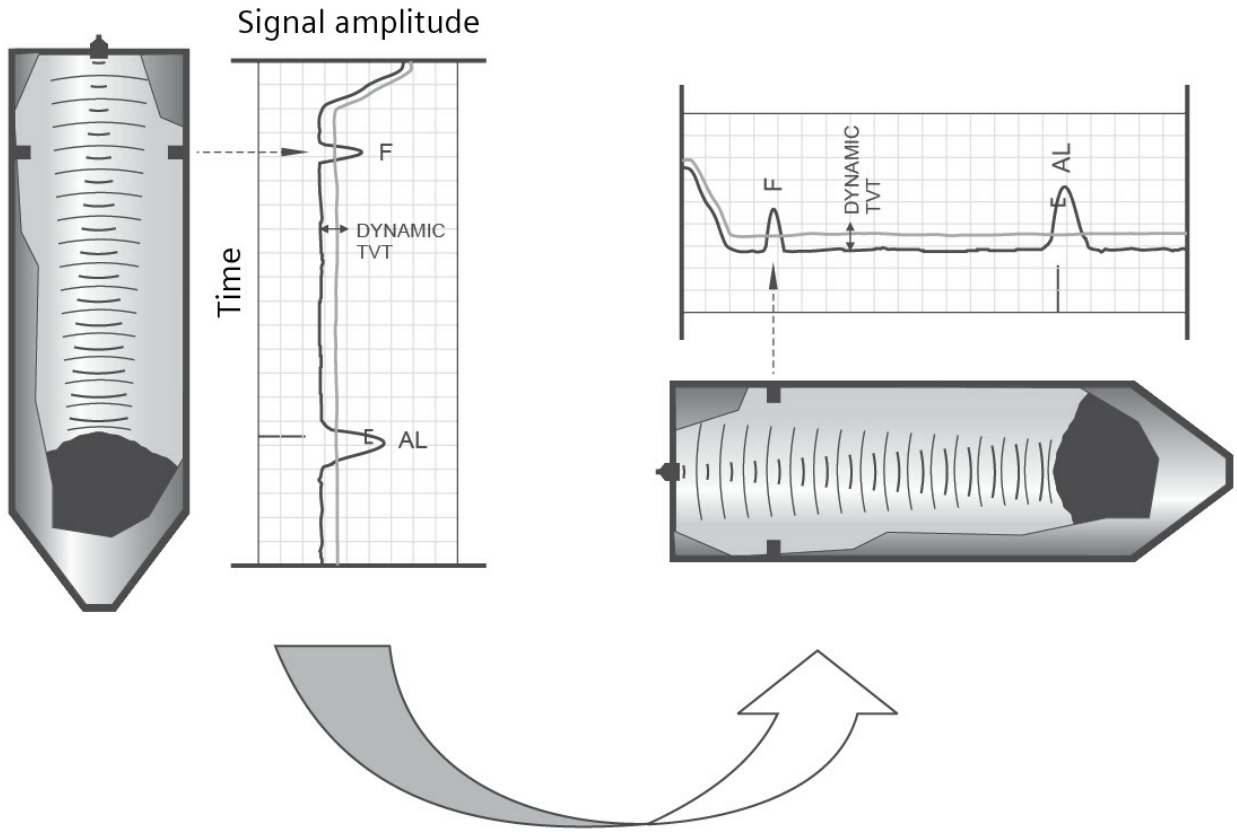
LEGEND

C: confidence
A: algorithm – first echo
D: distance to material

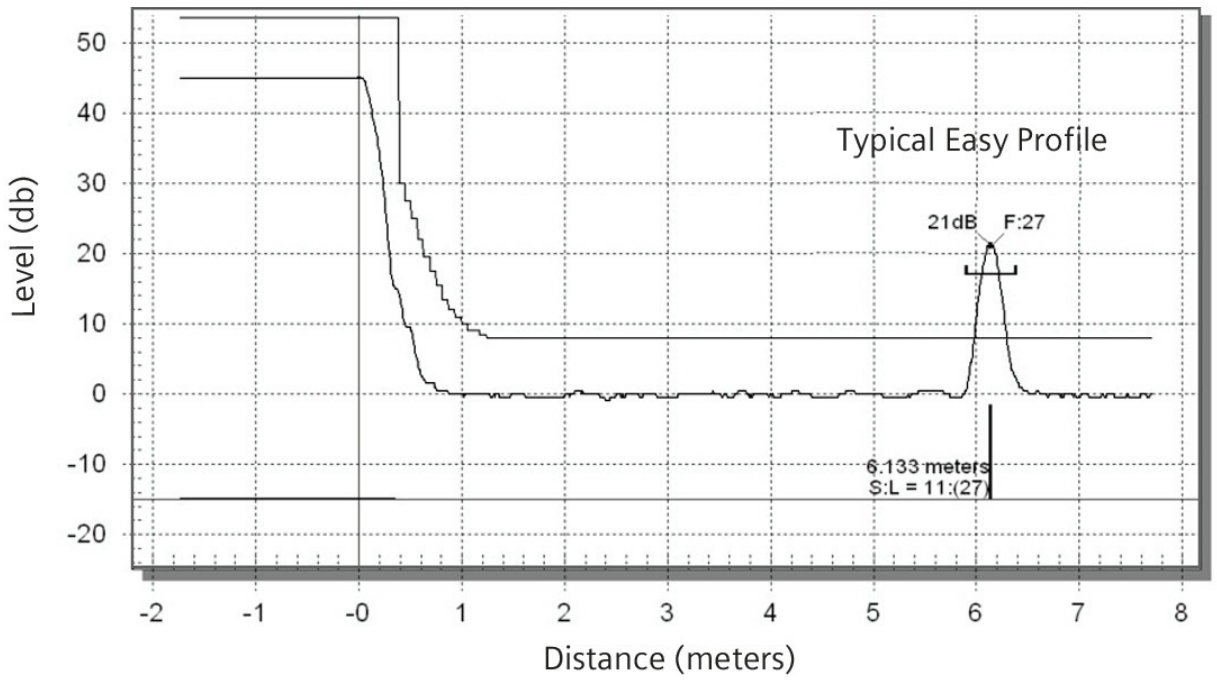
Echo profiles could initially only be viewed on an oscilloscope connected to the controller's electronics. Technology has since advanced significantly, and the units can now generate the echo profile right on a PC screen running dedicated software and with the device transmitting the echo profile over HART, PROFIBUS, or some other communication protocol. Many SITRANS radar devices also show profiles right on their display.[3]

The echo profile indicates what the radar transmitter is seeing and how the Process Intelligence processing responds to the signal.

Characteristics: echo profiles are generally viewed horizontally:

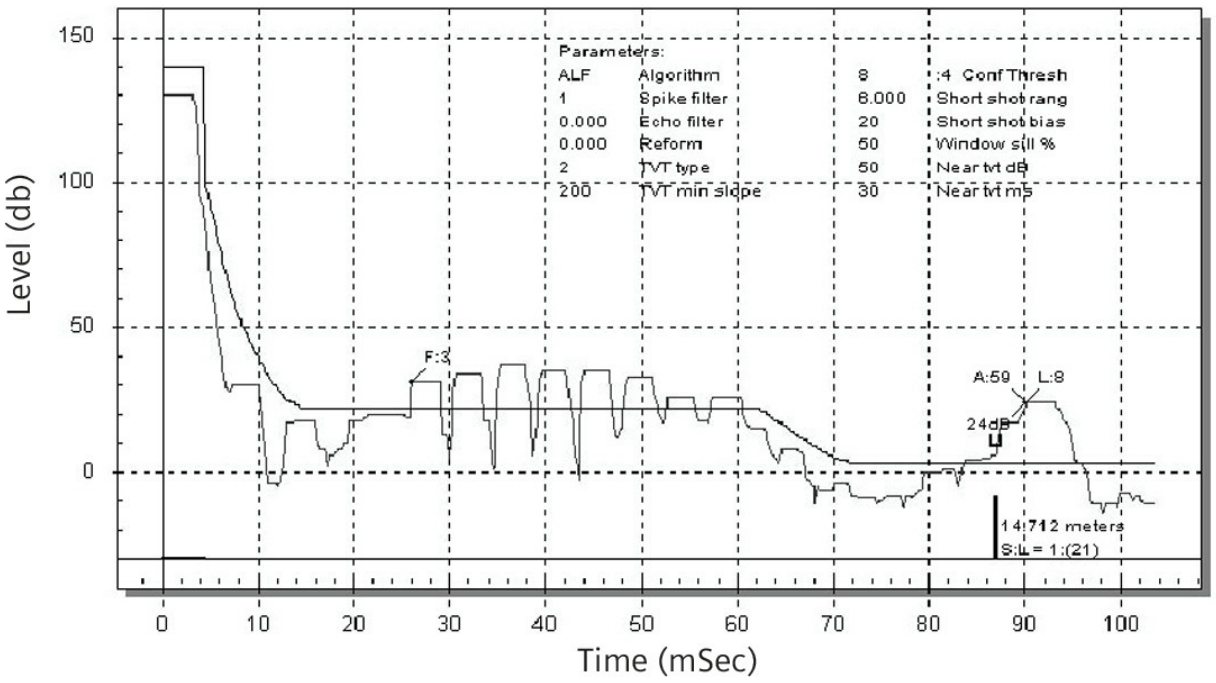


Simple profile: when the raw signal from the sensor looks this good, as in most liquid applications, echo processing is an easy task. The level is clearly marked with a strong signal peak, and there are no other noise/interference blips to confuse the transmitter. Liquid applications tend to have smooth surfaces, and the signal is much stronger as a result.



Complex profile: complex signals in solids applications with variable surface contours and silo obstructions are far more difficult to process. In applications like this solids bin, with its crisscrossed support struts, process intelligence echo processing is imperative. Note the many interferences (reflections from the struts) sending echoes back. The processing software has to know where the interferences end and the true level begins.



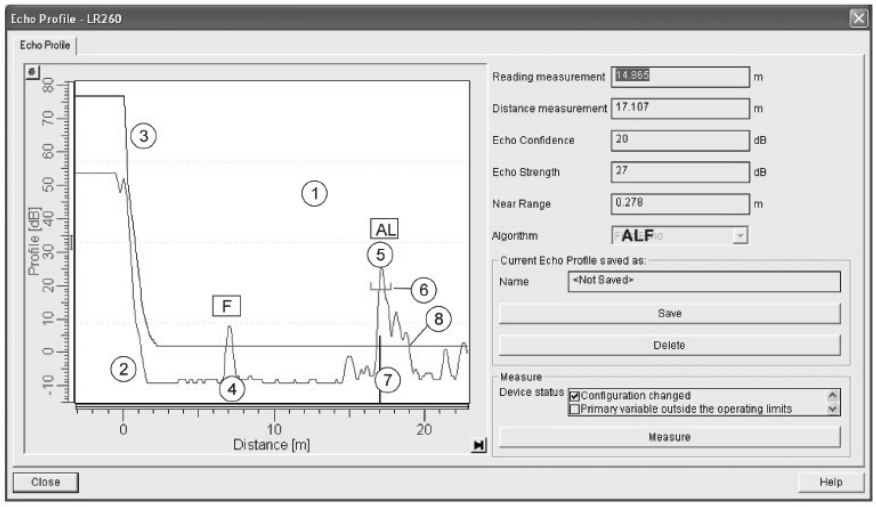


ALF algorithm identifies the correct material echo from the noise.

The echo profile for the SITRANS LR560 is viewed on the local display under the DIAGNOSTICS menu. The profile can also be viewed using SIMATIC PDM[4], DTM, or AMS programs.

SIMATIC PDM profile

1. profile screen
2. echo profile
3. time varying threshold (TVT)
4. false echo (First)
5. selected echo
6. window discriminator
7. echo marker
8. multipath echoes



Reading a profile

Process Intelligence analyses the signal to extract the true level from the noise. Siemens Process Intelligence employs a number of patented features designed to maximize the successful level reading and illustrates the process with a graphical representation known as a *profile:*

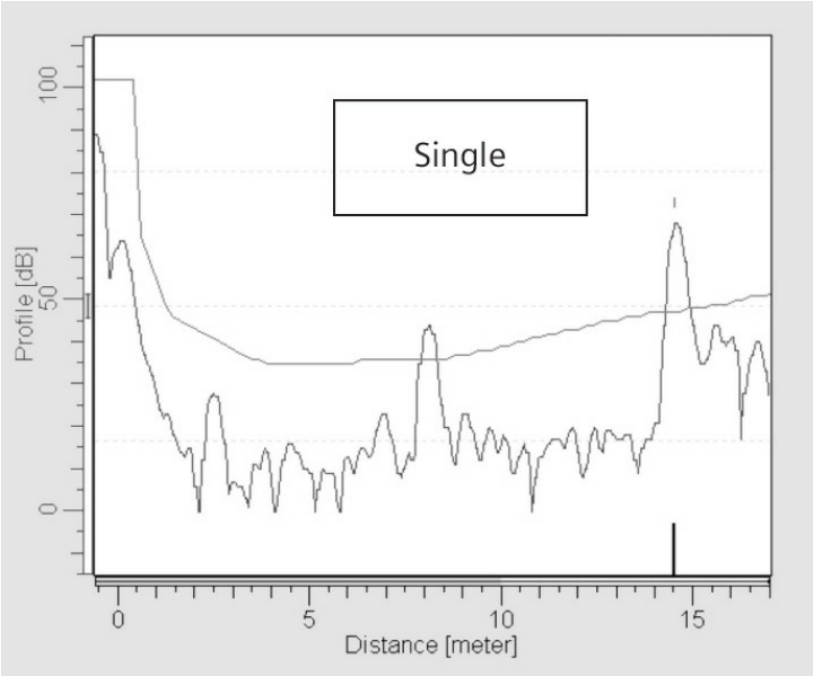
1. profile: a graphical representation of the true echoes from the vessel. Shown horizontally where the 0 on the X axis represents the sensor reference point.
2. returned / reflected signal: the actual signals reflected from the vessel — can include the end of the antenna (ring down), false echoes, and the material echo.
3. time varying threshold (TVT): an adjustable reference line in the profile. All echoes below this line are ignored. Those above the line are included in the algorithm calculation. This dynamic feature can be moved around false echoes as they appear, providing the opportunity to customize each profile reading as required. (See profile examples below.)
4. false echo: an echo from a source other than the material level
5. algorithms (ALF): the processing software weighs three factors to determine the true level:

    a. Area: area of the echo
    b. Largest: the largest amplitude reflection
    c. First: the first echo to cross the TVT
    d. window discriminator: An echo inside the window is immediately accepted. A better echo outside of this window is not accepted right away.
6. echo marker: identifies the distance to the selected echo.
7. multipath echo: an echo that takes its path off the side of the vessel (not direct)

Other features

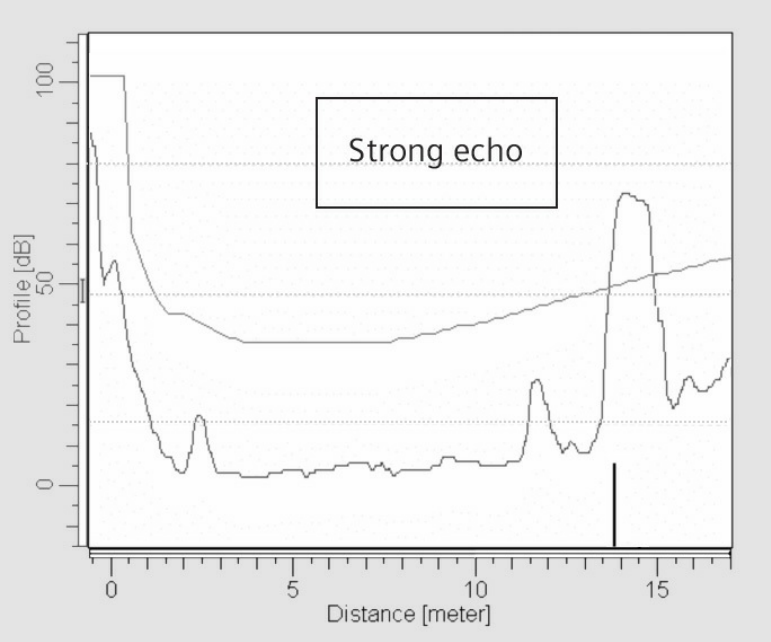
Process Intelligence also employs these behind-the-scene features:

- Averaging (many profiles summed together)
  The radar transmitter has a base noise level that is random in nature. A single echo profile can appear noisy as a result of the radar base noise so single profiles are stored and averaged together by the processing software and the resultant averaged profile is used for processing.

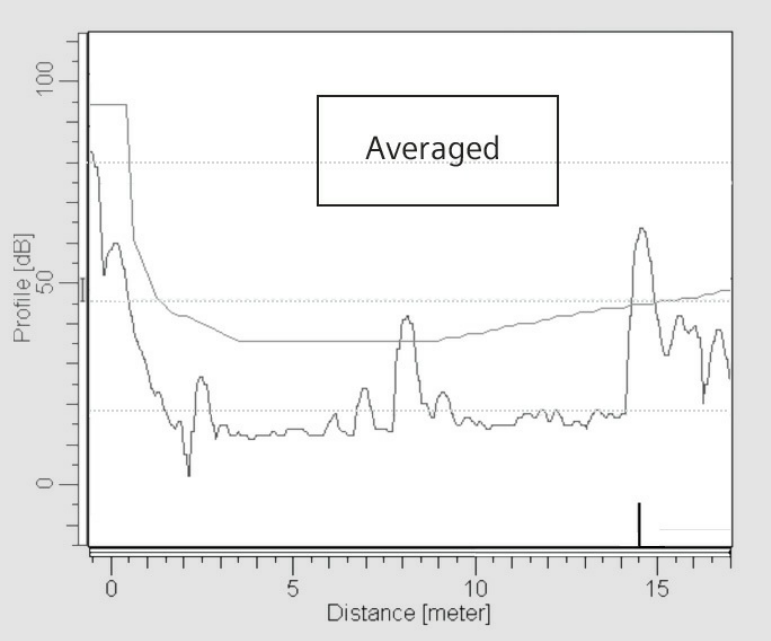


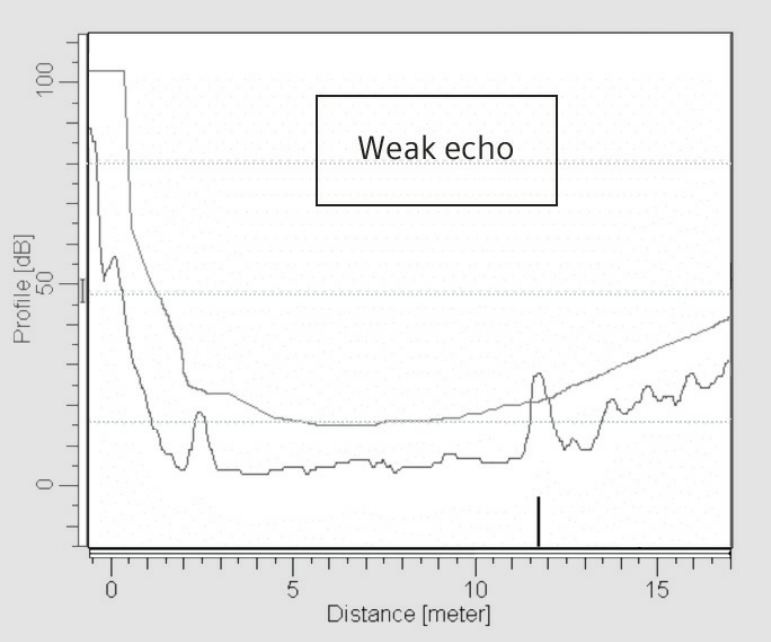
  Averaged noise levels are always smoother and lower in amplitude than peak noise levels, and by using the averaged noise level the resultant signal quality is immediately improved.

- Dynamic TVT
  The time varying threshold (TVT) is automatically placed and adjusted by Process Intelligence. The curviness of the TVT is derived from the echo profile signal and the height of the TVT above the profile is derived from the strongest echo in the profile. When there is a strong echo, the TVT is high so the weaker false echoes fall under the TVT and are therefore not considered by the echo processing. The high TVT level is considered to have low sensitivity with the advantage of rejecting weaker false echoes.

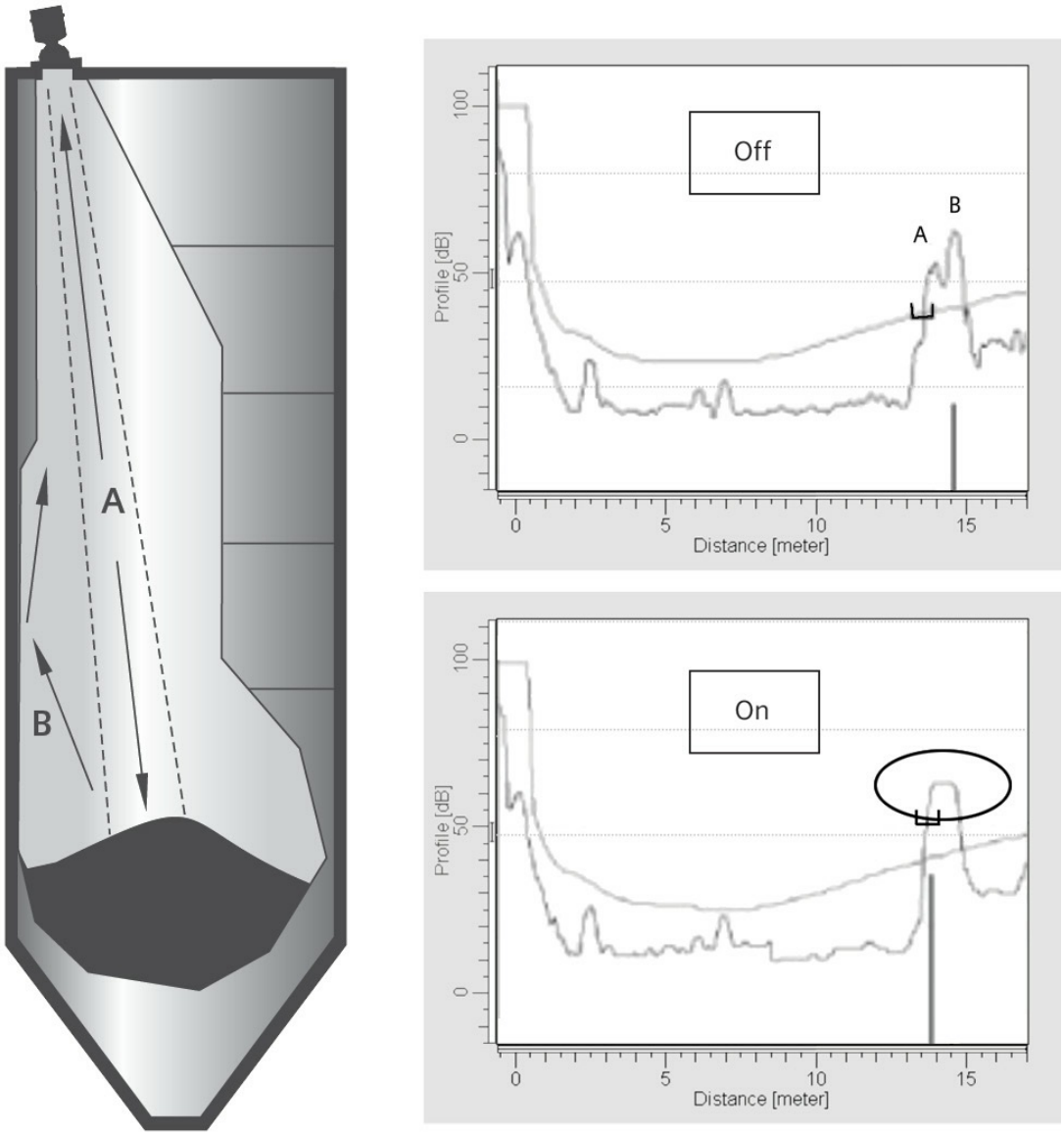


When the echo is weaker, the TVT is automatically adjusted lower, driven again by the largest echo in the profile. A higher sensitivity is created. The only danger here is that weaker false echoes could be detected and Auto-False-Echo-Suppression should be used to prevent these false echoes from being selected.





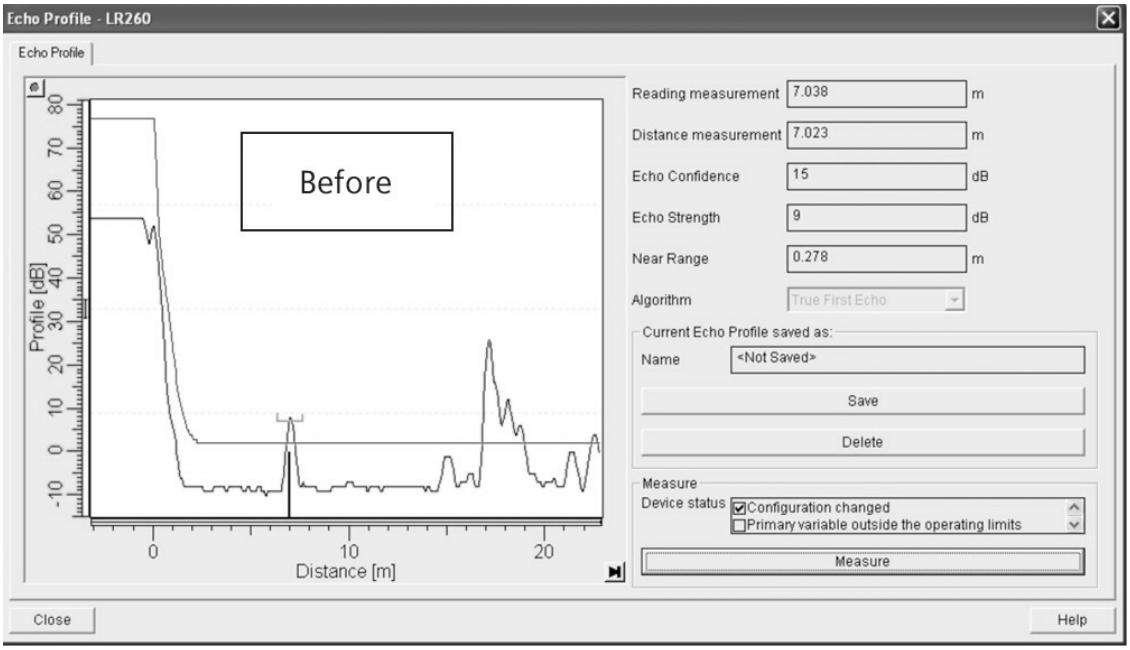
- Reform echo filter
  Echo reform is a time based parameter for smoothing jagged shaped echoes, typical in solids applications where the material surface is often uneven. While the multi-peak echo may be an accurate surface reflection, it can cause the level reading to jitter as the device locks onto different points of the jagged curve.

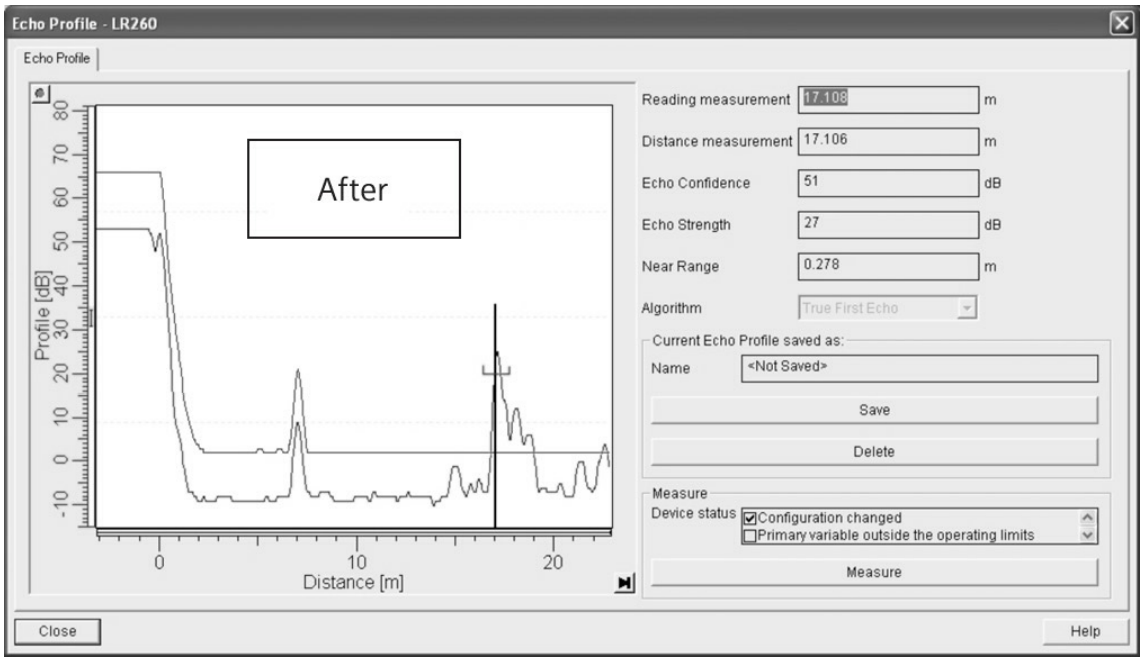


This variation can generate a saw toothed trend. For example, during a filling cycle the level can intermittently decrease even though material is continuously being added to the tank and the general trend increases. The device is selecting different points of the jagged echo profile, some lower than the actual fill point. By increasing the Echo Reform setting, the user smoothens the jagged, multi-peak surface of the echo profile to form a single, smooth shape that the device to lock onto consistently.

This filter is the software equivalent to physically flattening the surface of the material being measured.

- Auto false echo suppression
  If an obstruction causes a large echo before the material level echo, that echo will rise above the default TVT curve and may be incorrectly selected as the true echo.
  Auto False-Echo Suppression modifies the TVT curve so that the false echo remains below the TVT curve.
  With Auto False Echo Suppression, the device first learns the echo profile at that moment. A learned TVT curve follows the echo profile and rises above the false echo.
  Set the Auto Suppression Range so that the learned profile replaces the default TVT curve to a point past the obstruction. From that point on, the default TVT curve is used. The material level echo rises above this and is selected as the true echo.
  This can be performed at the local display or remotely with the PC.





Troubleshooting solids radar

The profile is a valuable tool for troubleshooting should there be problems with the application. The Siemens Milltronics technical support groups handle numerous queries to assist customers with troubleshooting in the field. The following is a typical list of questions designed to diagnose the problem:

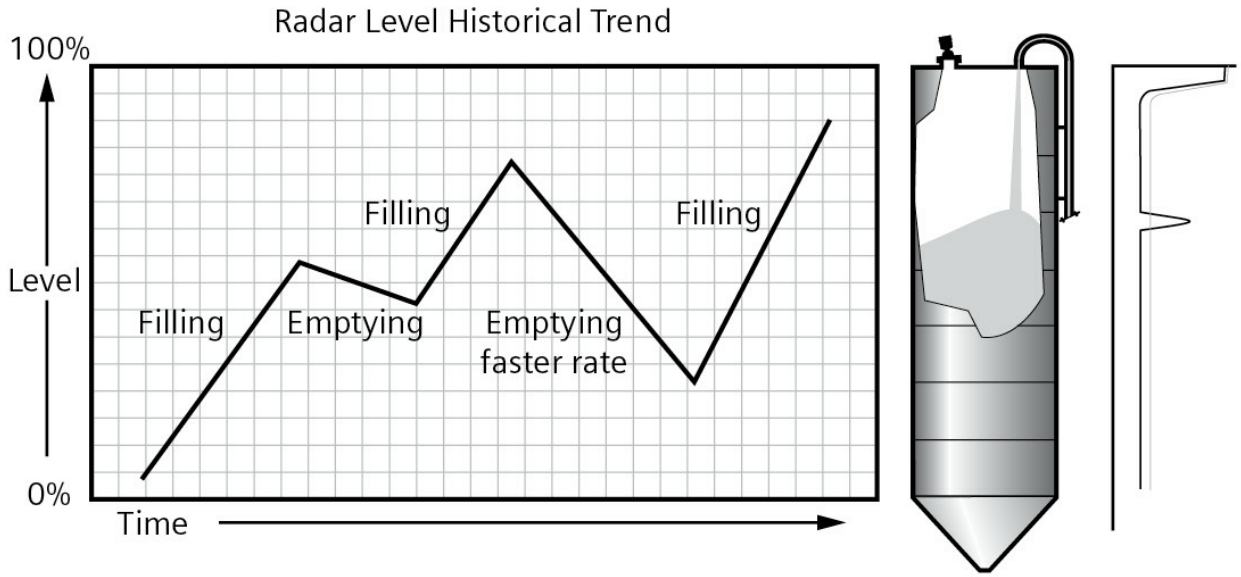
- what sensor type is it?
- what version is it? (firmware, serial number, part number)
- what is it connected to and from? (power, wiring, PLC)
- sketches are very useful
- what does the silo look like?
- nozzle size, location
- feed type, location, and rate if known
- what are the parameter settings?
- is there a trend available?
- can you provide an echo profile? (with PC or photo of LCD)
- what is meant by “it doesn’t read correctly?”

Effective troubleshooting requires understanding the problem from all sides, including the source of the complaint as different departments/people in the organization have varying needs and requirements from the reading.

Devices are often purchased for safety reasons so personnel does not have to climb silos every day to take rope measurements. At the point of sale, the agreed upon accuracy requirements are set (for example: 30 centimeters) and are acceptable for the needs at that time. However, requirements change, and if at a future date the level signals in the control system were converted to kilograms to compare the silo readings with actual production consumed, there will be a discrepancy because of the 30 centimeter error which is typical of most solids level applications. Communication about the expectations of the level measuring equipment across the organization is important at the commissioning phase and in the years following as well.

Trending

A trend display of the radar device's output signal over a specific time is an extremely valuable troubleshooting tool. Most production facilities record output trends over the past days, weeks, or months. Signal trending can be configured in the control system and collected over a fill/empty cycle.



Trending analysis must also be properly applied in non-contacting solids level applications. When trending was done manually, for example, and level values were recorded daily in a log book, there were few fluctuations other than the expected operational level changes. Any spikes or non-linearity in the readings would essentially go unnoticed.

> Many customers are not aware of this level fluctuation because they are not roping the silo every minute of every day.

Minor spikes and non-linear readings are natural occurrences in solids level measurements because the level is rarely even,[5] often dusty (problematic for ultrasonic devices), and can have material interference from filing/emptying. A trend provides a recorded value of the output over the complete empty to full span of the silo and any little non-linear trend or blip may be interpreted as a problem. Consistent trending is far more likely in liquids measurement where the surface is generally even; trending is an example of a “perfect” level measurement system. This perfect trend is possible on liquid applications but is very rare on a solids level measuring system because the sloped surface of the solids change over time.

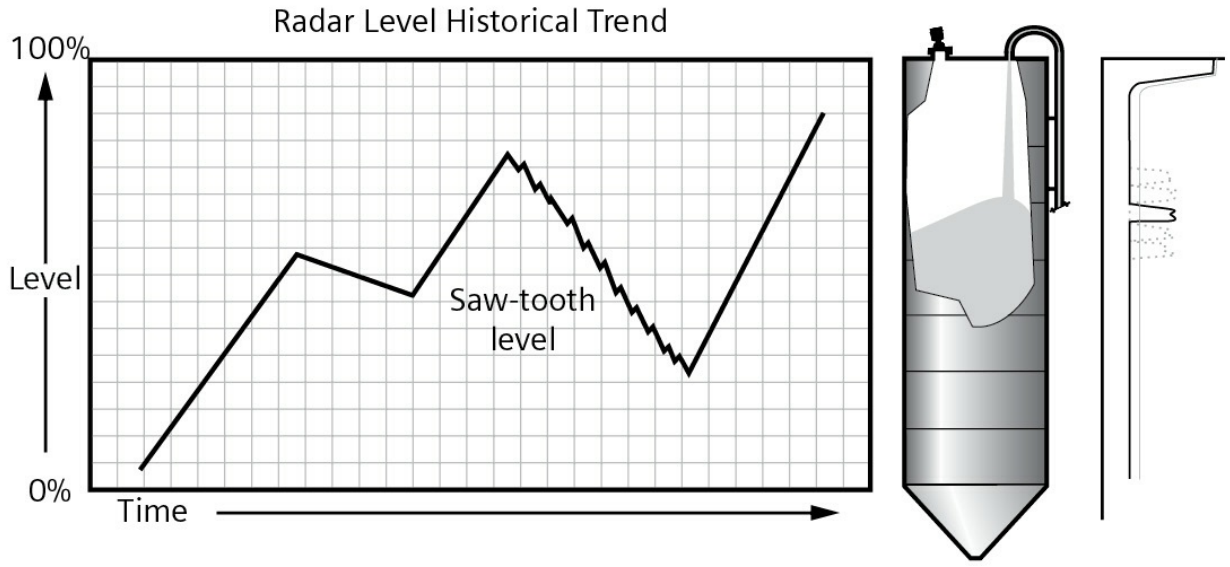
Trend with saw-tooth pattern

This typical solids level trend reflects surface activity during emptying/filling. It is caused by the sides of the cone of material falling down towards the center and causing a short duration rise in level. Or the top surface may drop down in little steps as sections of material overcome static resistance to move and fall from the wall and down the silo, suddenly changing the level. An hourglass offers a perfect illustration as it empties, the top surface doesn’t draw down linearly but rather in little steps.



Smoothening this trend requires increasing the reform parameter and/or increasing the damping to the transmitter's signal output. Transmitter output damping is generally time-constant based and then defined in minutes.

For example, with the LR560 a five-minute value means that the output will track to 63% of the new value in five minutes. Thirty-minute values are not unusual for very large silos that take a very long time to fill or empty. This damping provides a smooth process trend in the control room.





I went on a service call to a plastics manufacturer who was complaining that the level in the silo suddenly increased by 1.5 meters without any filling or discharge from the silo. Closer examination showed that significant material had been clinging to the walls of the silo before suddenly collapsing into the center and causing a level measurement increase.

A rope measurement would have yielded the same level reading.

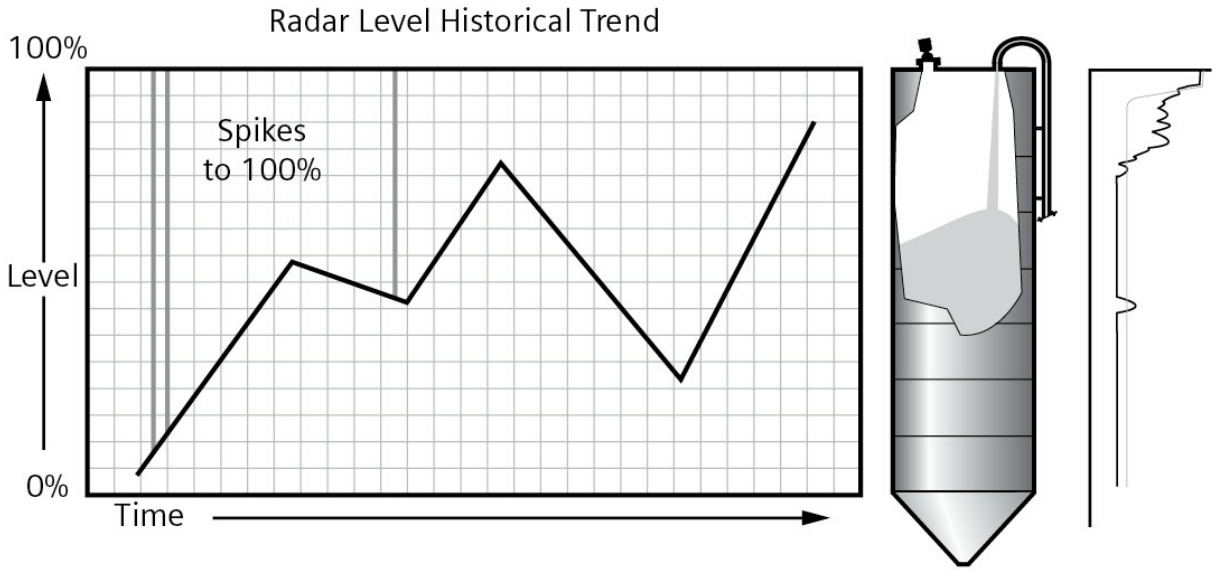
Common troubleshooting scenarios

Troubleshooting a radar application successfully is often a matter of asking the right questions and reviewing the proper data. Trending data plays an important role in troubleshooting:

1. Device does not power up:
    - confirm correct power supply is applied (i.e. 115 VAC or 24 VDC)
    - confirm voltage at the radar device terminals with a multimeter
        - check specification for radar and identify minimum voltage requirement
        - check for voltage drop. For loop powered devices, check radar specification for loop load resistance and confirm the loop is within specifications. If the loop has numerous loads like a PLC input, HART resistor, remote display, and others, the available voltage remaining for the radar transmitter may be too low. Also, the wire itself for the current loop may be too long and/or the gauge too small and be producing a voltage drop.
        - if voltage at the radar device is OK, then insert a 4-20 mA current meter in the loop (loop powered devices only!) and measure the current consumed. Is it somewhere between 4 and 20 mA?
        - if the wiring seems fine and the voltage at the terminals of the radar device is within specifications, then the device should power up. If not, it may be defective. Take the device to the instrument shop and power it up with a separate power supply. If it still fails, it most likely needs repair.
2. Doesn’t read correctly: this common complaint is too vague to diagnose – thus further queries are necessary for clarification:
    - does it always read Full?
    - does it always read Empty?
    - is it stuck at one level between Full and Empty?
    - does the reading lag behind the actual reading?
    - did it ever read OK?
    - when was it installed?

- how long has this problem been going on?
- does it read a little high or low all the time?
  - does the reading jump to Full sometimes?
  - does the reading jump to Empty sometimes?
  - does the problem occur only during filling? Only during emptying?
  - is the reading wandering around?
  - is the accuracy not as expected?

3. Spikes to 100%: there are several possible causes for this reading.



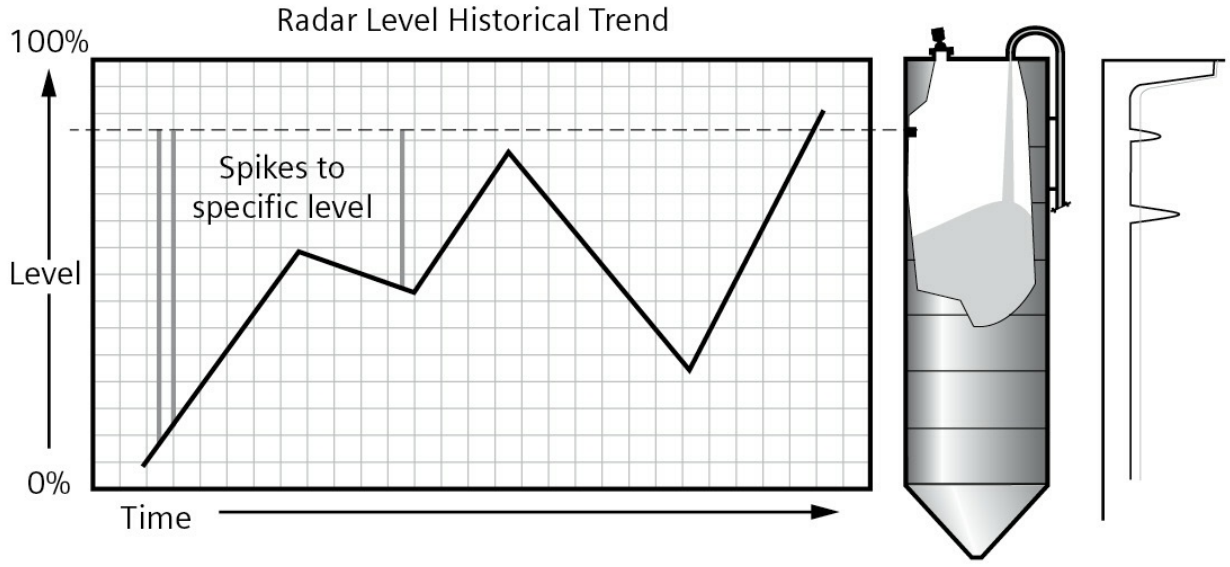
I. Material buildup on the sensor:
   - inspect and clean if necessary
     - add a dust cover (horn antenna devices)
     - integrate an air purge, self-cleaning system
   - process Intelligence can deal with minor buildup that doesn't increase over time. Determine from the echo profile if there is sufficient signal from the material. If minor buildup on the antenna causes a false echo, use Auto-False-Echo-Suppression while the antenna is slightly dirty. This should prevent the TVT from clipping the false echo at the antenna.

II. Loss of Echo (LOE) and Failsafe Hi

- there are many causes of LOE. Make parameter changes as required to prevent LOE condition
- failsafe Hi is generally not recommended for continuous level transmitters because some measurements are invariably invalid. Rather, use the failsafe HOLD setting of the radar transmitter and also use a level switch[6] as part of the safety shutdown mechanism.

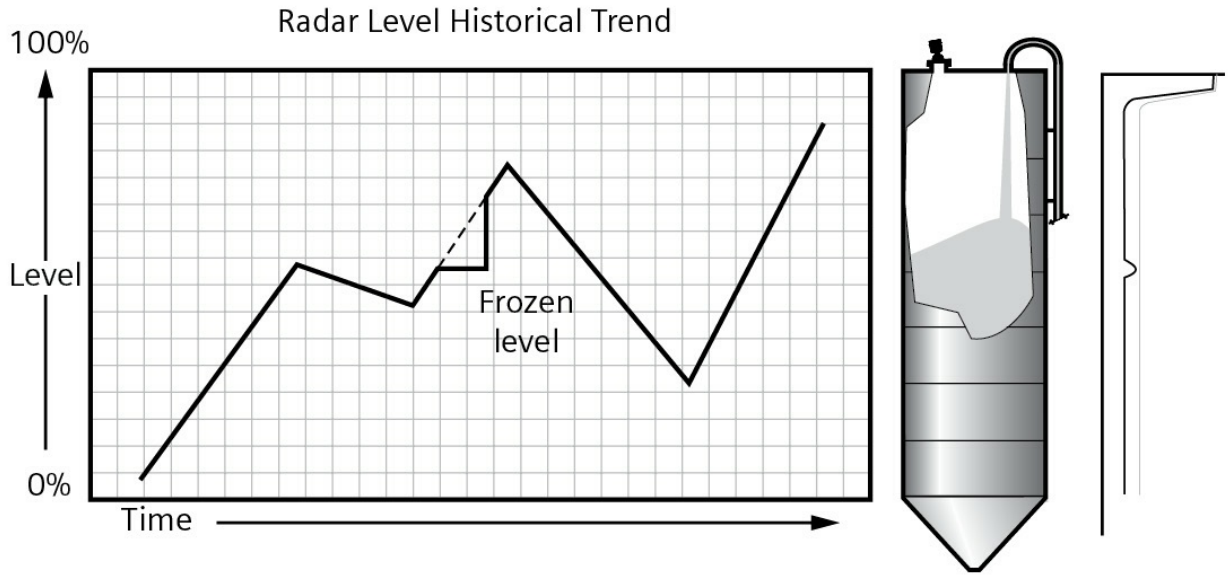
III. Installation problem:
- a signal very near the antenna is strong and being detected because it is within the transmitted beam.
  - review the instruction manual regarding installation and confirm the manufacturer's guidelines are being followed.

4. Spikes to the same level, higher than material: the unit may be picking up false echoes.
   - perform Auto-False-Echo-Suppression to create a custom TVT around false echoes.

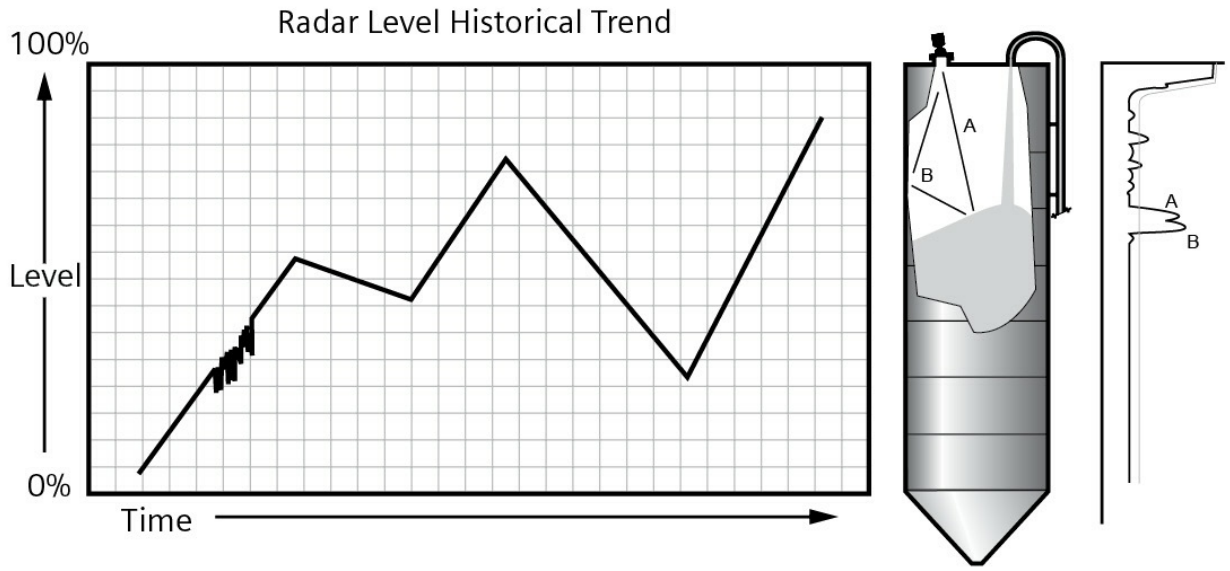


5. Reading is stuck or frozen temporarily: usually this indicates the transmitter was in LOE (loss of echo) for a period of time. If this occurs more frequently, it suggests that the sensor is getting contaminated with material. Highly sloped surfaces can cause a weak return signal and

aiming the sensor towards the angle of repose of the material can improve the signal strength. Always view the echo profile first before taking actions for improvement. This problem is common to taking ultrasonic level measurement on solids due to loss of signal during very dusty conditions.



6. Reading wanders between actual value and slightly less: this trend is usually the result of a sloped solids surface and competing echoes from the direct and indirect path. A common issue with 24-26 GHz radar devices, this condition has been significantly improved by the 78 GHz LR560.



Increase the reform filter parameter to join close echoes for improved stability of measurement and provide a smoother trend. Ensure that rising edge position parameter is used.

Parameters and troubleshooting

When troubleshooting, the parameter settings need to be considered as they affect the measurement value and reliability, even if the unit has already been configured. A new radar transmitter is shipped with the parameters factory-set to specific values. Parameter settings should be documented at the time of commissioning (as well as subsequent changes) so the unit can be returned to previous settings if new settings are not suitable. Many basic parameters suffice for generic applications; however, additional parameters may be accessed that can disrupt the performance and affect the accuracy or reliability of the transmitter:

Sensitivity set too high or low: if the TVT is too low, any little nuisance signal is detected and may cause output fluctuations or instability. Occasionally technicians play with a transmitter in the instrument shop, adjust the TVT around an object, and then later install the radar transmitter

without resetting the TVT back to factory value. This causes a loss of echo condition when the material echo is under the learned TVT level set in the shop.

Echo algorithms: a complex profile may have three or more echoes to choose from and selecting the F (first) or L (largest amplitude) or A (largest area) could all yield different results. Pick the one most suitable for the application.

NOTE: Lock it out! Once a radar transmitter is programmed and working well, set the user lock parameter to restrict operators from making changes.



Limited troubleshooting is possible without viewing the profile, but troubleshooting a radar without an echo profile is like a mechanic fixing a car without a diagnostic computer. It is possible but it will take longer and may not be as effective. Some of the parameters (reform, A-F-E-S, algorithm changes) can assist with troubleshooting without an echo profile as will a trial-and-error testing method. However, having a profile is your quickest, safest, and most reliable method.

Summary

Process Intelligence makes life with radar effective and productive. For most applications, these advanced parameters are not needed as they are preset by the factory. Setup is quick and easy as the silo's interferences can be shaped around using TVT. Troubleshooting is a step by step process and uses the

echo profile and trending to guide you to improving the reliability and overall success of the radar system. For the SITRANS LR560 with its high frequency and narrow beam, most applications are plug and play.

1 Freud, Sigmund. *The Interpretation of Dreams*, 1900.
2 In poorly designed ultrasonic sensors, the beam is often very wide, producing a lot of false echoes. Thus the echo processing component is strained when trying to extract the correct signal from the incorrect ones.
3 SITRANS LR560, SITRANS LR200, SITRANS LR250, SITRANS LR260, SITRANS LR460
4 SIMATIC PDM is the Siemens instrument configuration software.
5 One exception would be a homogenization or finished cement silo where the material surface is reasonably flat.
6 Siemens has a full line of capacitance, paddle, and vibrating fork switches for HI and LO failsafe protection.

Chapter Eight

Radar applications

By nature, all men love newfangleness.[1]



The applications suitable for a solids radar device are plentiful, and the material properties particular to many applications are so similar that success on one material type is easily transferred to success on another. Thus a radar sensor's performance on aggregate is similar to pet food bits because the particle size is comparable, as are the dielectric constant and the angle of repose. The filling noise and dust density differences do not apply because radar is not affected by either noise or dust.

New solids material types are released to the market every year, and these often contain a variety of characteristics. However, while there may be variances in the characteristics, the particles generally appear the same to the radar unit. For example, there are currently more than twenty different grades of hot mix asphalt with varying types and concentrations of additives depending on the surface application (i.e. a driveway in northern Canada versus a highway in southern Texas). To the SITRANS LR560, however, they all look the same and it can be installed with confidence on all of them.

The following application examples illustrate where Siemens radar transmitters are used successfully. Each application is representative of a whole group where the characteristics are similar, providing more opportunity for radar measurement.

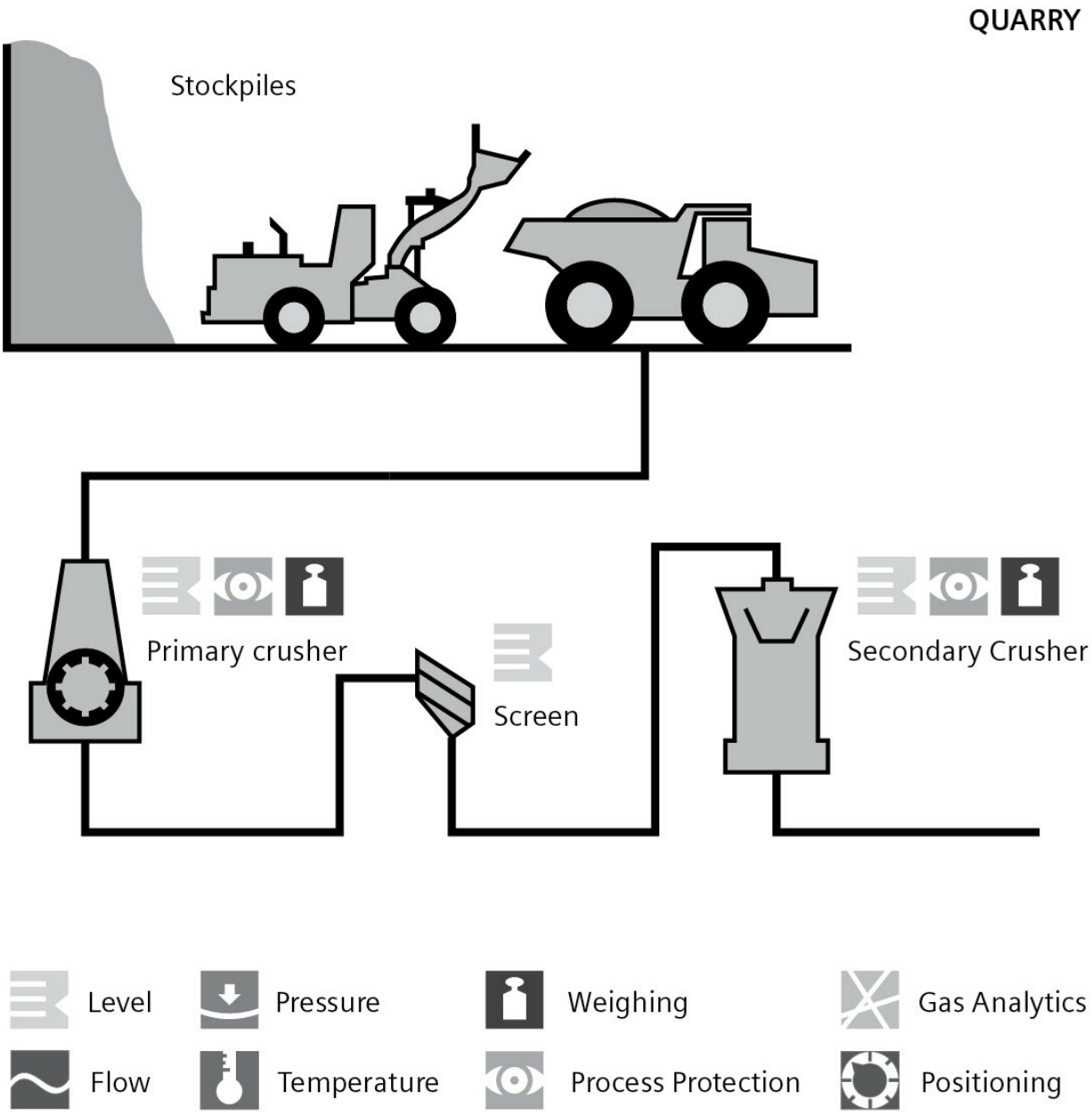
Topics

- Cement
- Power generation
- Petrochemical / plastics
- Food and beverage
- Metals
- Aggregates

Cement: production and terminals

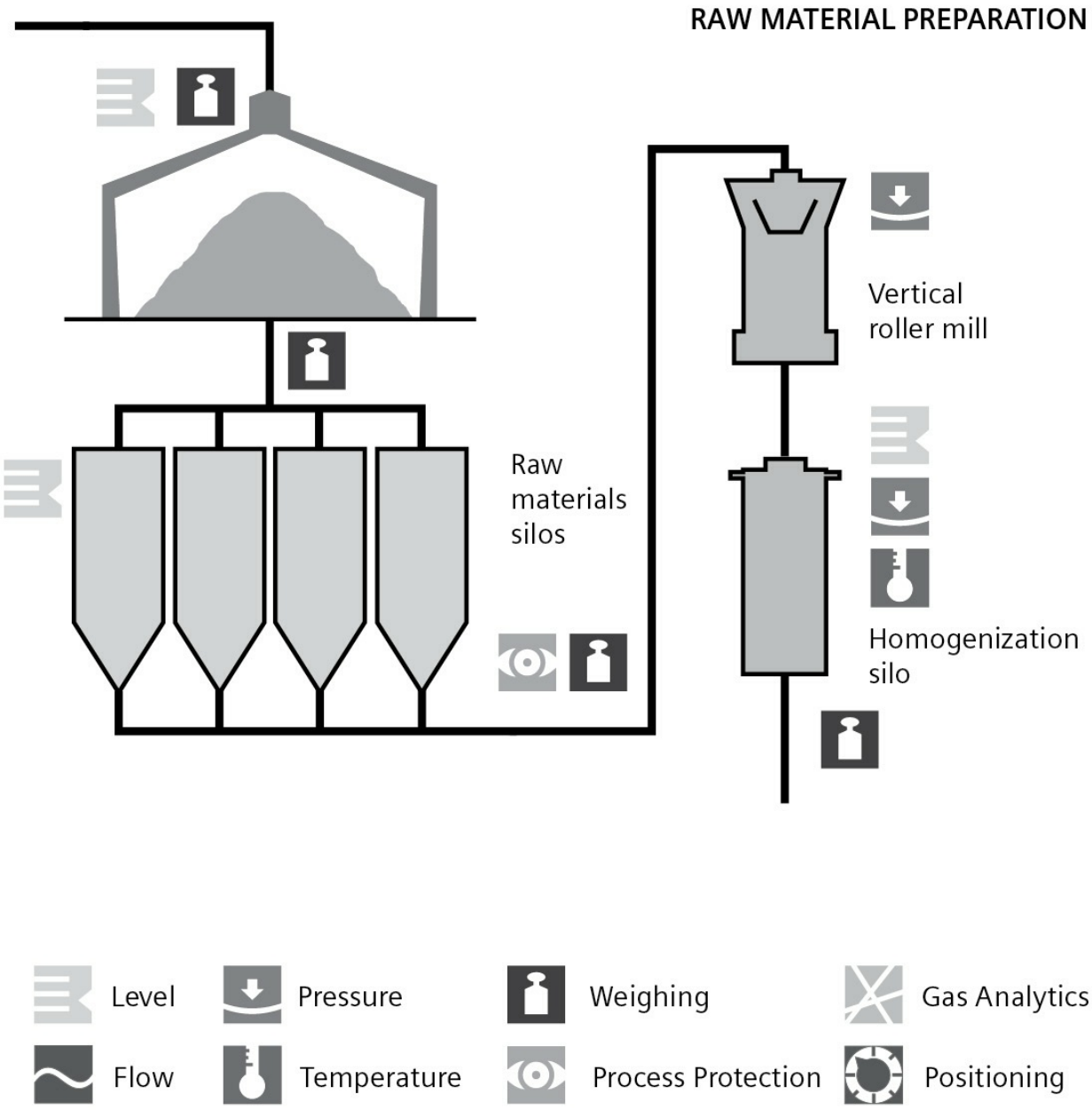
Siemens continues to be the market leader in automation systems and process instrumentation for the cement industry, and pioneered level measurement with its radar devices. As a result of Siemens technology, radar now is the standard level measurement technology in this long range dusty solids market segment, and Siemens leads the pack.

Achieving this position was the culmination of many trials and performance evaluations during the 2000s. All the key cement producers confirmed the reliable performance of radar in applications that were traditionally very difficult to measure with non-contacting ultrasonic technology. Radar quickly built a reputation for reliable and accurate measurement and is now accepted by most global cement producers as the standard level technology for new plants or plant upgrade projects.



Primary crusher: where large rocks of raw material, typically limestone, are crushed down to smaller sizes that can be conveyed uniformly and reliably to a secondary crusher where these smaller stones are then crushed into a powder. Generally an open environment, ultrasonic technology has been used effectively here in measuring the level above and below the crusher.

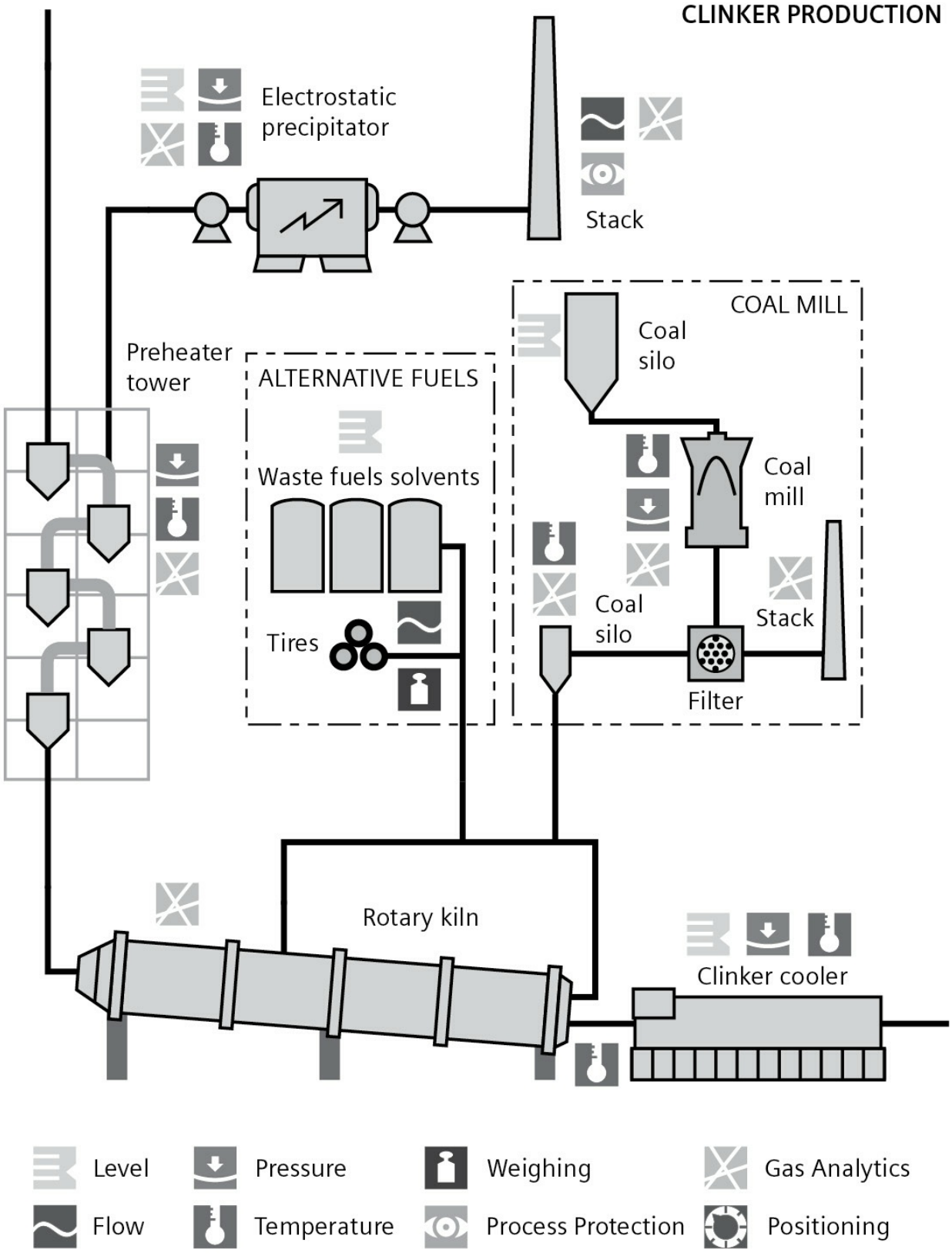
Secondary crusher: where raw material, typically limestone in small stones, is crushed into a powder. The crushed material may be stored in a small silo and can be measured with radar or moved directly into a blending hall or homogenization silo.



Pre-blending hall: a large room where the raw material from the quarry is distributed around and mixed to minimize the day-to-day variation in raw material that affects the consistency of the finished cement. One or more level transmitters can be used to measure the raw material level.

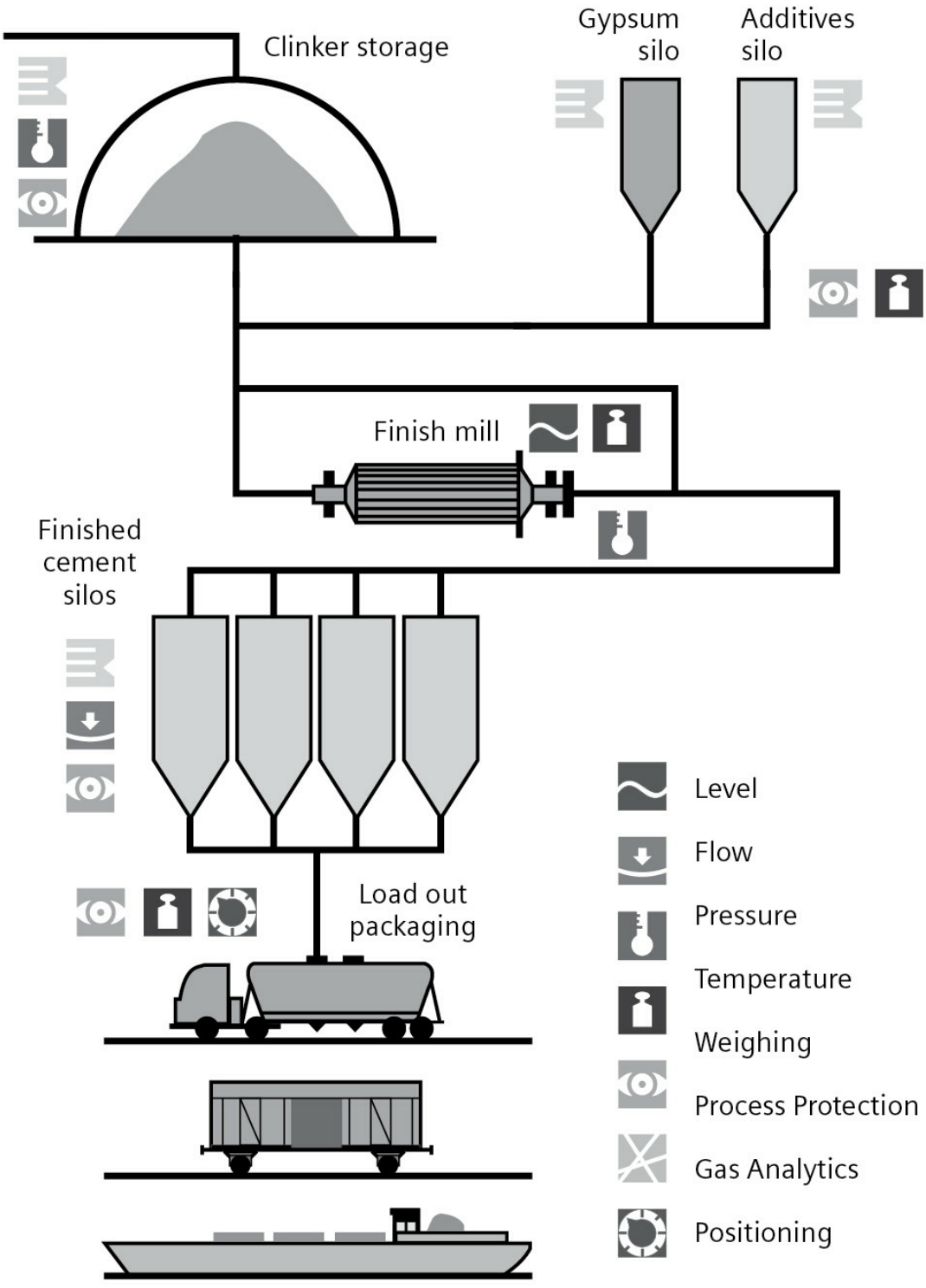
Raw material silos: depending on the chemical composition of the raw material, various other raw materials such as clay, iron ore, or bauxite may be used to combine with the raw material from the quarry. These are stored in silos and are measured effectively with radar.

Homogenization silo: similar to the process in the pre-blending hall, the homogenization process mixes large volumes of raw material in a large silo by aeration and multiple feed locations. Usually there is a continuous feed of raw material delivered to this silo, causing an incredibly dusty atmosphere. Radar measures level effectively on this application.


CLINKER PRODUCTION
Electrostatic precipitator
Stack
COAL MILL
Coal silo
Preheater tower
ALTERNATIVE FUELS
Waste fuels solvents
Coal mill
Tires
Coal silo
Stack
Filter
Rotary kiln
Clinker cooler
Level
Pressure
Weighing
Gas Analytics
Flow
Temperature
Process Protection
Positioning

Clinker cooler: the homogeneous mixture of raw materials are pre-heated and delivered into the rotary kiln that tumbles the mixture at very high temperatures. A succession of chemical reactions take place as the material moves along the sloped kiln and finally exits as “clinker” stones at temperatures of approximately 1400° C. The clinker is cooled first on a metallic grate conveyor where the most effective and efficient cooling air temperature is determined by measuring the clinker level on the conveyor. Radar works well for this belt level application. Once the clinker is sufficiently cooled it is moved onto conventional rubber belts.

FINISHING MILL/PACKING AND SHIPPING



Fuel vessels: various fuels like coal, petroleum coke, waste solvents which are used to heat the kiln are stored here. These are ideal for radar level measurement.

Additives silos: gypsum, normally added to the finished cement during the grinding process to improve the settling properties of the cement, is effectively measured with radar.

Finished cement silos: hold finished ground cement powder ready for transport by truck, rail, or ship. The cement powder is easily measured with radar transmitters despite the extremely dusty conditions.

Summary of radar level applications in cement

- raw material silos
  - calcite
  - sand
  - shale
  - iron
  - lime
  - gypsum
  - fly ash
- process silos/applications
  - pre-blending hall
  - homogenization silo
  - clinker cooler
  - waste kiln dust
- fuels
  - petroleum coke
  - coal
  - pulverized coal
- finished materials
  - clinker
  - finished cement



Common applications

The applications listed below are derived from actual radar field applications. Furthermore, the conditions under which the units operate are similar to those of other applications, and the principles can be applied across the industry.

Cement



Dust and distance are two major challenges to level measurement in the cement industry.

Application one: measuring level in a homogenization vessel.
This high vessel with lots of turbulence inside caused a yo-yo cable to break, so non-contact measurement was required. While the ultrasonic systems are used effectively on other vessels, they could not penetrate the extreme dust created by the powdery materials being mixed and aerated throughout the homogenizing process. This vessel directly feeds production so maintaining inventory is crucial to operation.

Conditions

- eighty-meter homogenizing vessel
- produces approximately 1.8 million tons of clinker
- produces 1.2 million tons of Portland cement[2] per year.
- turbulent surface during fill cycle
- extremely dusty

Solution

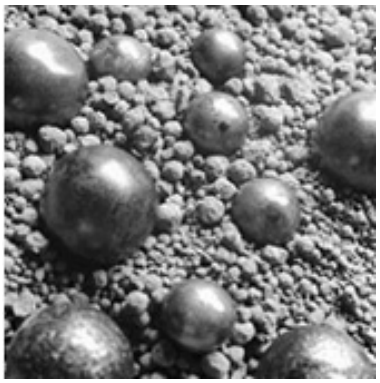
Siemens installed a SITRANS LR560 simply by bolting it on top of an existing manhole cover, and commissioning was easy using the infrared handheld programming interface.[3] The *Process Intelligence* signal-processing

software reliably extracted the material surface echo from other false echoes in the silo and cut through the dust. The Quick Start wizard made setup quick and easy.

Benefits

The non-contacting instrument makes installation easy and there is no risk of cables or weights breaking off and falling into the process. Neither the dust nor the distance present a problem and once installed there is no maintenance required. The site manager is delighted that Siemens solved one of their most difficult level measurement challenges.

Application two: measuring level in transmitters on the homogenizing, clinker storage, kiln dust, and finished cement silos. The new plant was looking for multiple measurement points in a highly productive, pollutant free plant in central Asia.



Conditions

- output of 2,000 tons a day and annual production of 600,000 tons
- uses the more efficient and cleaner dry-process production technique
- measuring on these vessels:
- homogenizing
- clinker storage
- kiln dust
- finished cement silos

The dry-process technique, however, does raise a lot of dust, and the plant needed level instruments that could measure reliably in the intense dust of cement silos. The designers wanted to optimize plant efficiency and minimize staff and maintenance costs.

Solution

Siemens installed a SITRANS LR radar transmitter as the level measurement solution for all silos with dust.

Benefits

Reliable measurement in the dusty environment.

Power[4]



Coal fired power plants are another example of where radar has quickly become the standard level measuring device for the solids level measurement applications. Key applications include raw coal, pulverized coal, and fly-ash silos.

Application one: fly-ash

Fly ash is a residue from coal combustion and is captured and disposed rather than released into the atmosphere. It is also used as a supplement for Portland cement in concrete production. At this site, a coal-fired power station providing 3,600 megawatts of power had difficulty obtaining level measurement of fly-ash. In several decades of operation, the plant had searched unsuccessfully for a reliable level measurement solution.

Conditions

- three 45-meter silos
- pneumatically fed from the top
- aerated from the bottom

The aeration creates a tremendous amount of swirling dust which, when combined with the low dielectric of fly ash, makes it difficult to measure the silo level accurately.

Solution

Siemens installed the SITRANS LR radar instrument on the first silo for a three-month period. After looking for a solution for so long, the staff was initially skeptical but was impressed with the easy installation and startup,

especially when the unit immediately produced accurate readings. When connected to a recorder, the instrument captured the filling and emptying trends, exactly the data they required.

Benefits

The plant supervisor and technician reported the Siemens SITRANS LR is extremely accurate and the trends show no sign of drift or deviation. After a trial period, they were satisfied with the results and purchased additional instruments to complete the three silos.

Application two: coal bunkers



Coal bunkers feed the turbines that generate electricity, and ensuring a constant supply of coal in the bunkers is crucial to avoid interrupting generation and disrupting service. The raw coal is treated with sodium powder and then pulverized into a very fine powder to fuel the plant. Maintaining a constant supply of coal in the bunkers has proven to be a challenge. High level mechanical switches often control the fill but leave no data between full and empty. Other plants still rely on rope-and-weight measurement, which is again unreliable, and bunkers often run empty causing a disruption in power generation.

Without continuous level data, it is difficult to manage the supply to the bunkers.

Conditions

- the bunkers are filled by a tripper car system – a large conveyor belt with two chutes for unloading near the top of the bunkers on a rail track. The tripper cars move along a rail track dispensing the coal into each bunker. When the high level switch is touched, the material stops unloading and the tripper car moves to the next bunker for unloading.
- coal passes through grates filtering out any last coal chunks

- when the bunker fills, the rail car automatically moves to the next bunker and begins the process again.

Solution

Siemens installed SITRANS LR460 radar level transmitters on the coal bunkers to provide continuous level monitoring and control the movement of the tripper car from one bunker to the next.

Benefits

Continuous level measurement of the coal levels in the bunkers has automated the tripper car system. Processing of the coal is more accurate, more efficient, and uses up the entire storage capacity of the bunkers. Maintenance and operations staff can now track the true level of the coal even through the thick dust, ensuring that there is always sufficient quantities of coal in the bunkers to fuel the burners.

Petro-chemical / plastics



Most standard plastic materials have already been successfully measured with radar, including polyethylene, polypropylene, polycarbonate, and polyvinyl chloride. In pellet form, the level measurement task has traditionally been quite an easy one with ultrasonic or radar technology. In fine powder form, however, the measurement has been more difficult with the lower frequency radar (6 GHz to 26 GHz) not quite up to the job. That all changed with the introduction of 78 GHz technology, and radar is now measuring these powder applications very successfully.

Application: plastic pellets

The facility produces extrusion grade nylon #6 as well as other polymeric (plastic) materials in a powder and pellet formation. A part of the stock is made from reprocessed nylon used almost exclusively in injection molded applications because of the typical color and reduced physical properties.

Film, wire and cable, monofilament, stock shapes, and blow molded applications account for about 55% of all nylon #6 sold. The remaining 45% is injection molded with half of that going into automotive applications, primarily air intake manifolds and fasteners. The non-automotive half is divided among power tools, consumer house wares, industrial components, electrical connectors, and miscellaneous uses.

Reliable level measurement of the material in the holding bins is critical to production because if a bin runs empty, production has to stop and wait until more Nylon #6 is produced and transferred to the holding bin. If too much material overfills the bin, the company experiences loss of product plus the cost of clean up.

Conditions

- Nylon #6 extruded into long strands, cooled, chipped, then conveyed to a holding bin
- storage silos ranging in height from 2 to 12 meters (6 to 40 feet)
- overfill bins store Nylon #6 after production. These bins are constantly being filled and emptied throughout the day as material is sent to large 1.2 x 1.2 meters (4 x 4 feet) bags for shipping.
- product level in the silos and bins are constantly changing

Providing reliable level measurement in the holding bins can be challenging because of the acoustic noise during the filling cycle, the material's extreme angle of repose, and the extreme dust. While ultrasonic devices cannot cope with these conditions, radar operates very effectively as long as it is properly installed.

Solution

Siemens installed a SITRANS LR460 radar level transmitter on a primary silo containing Nylon #6 pellets as a control device, using a 4-20 mA signal sent to a central control room. The control room generated several fill and empty cycles throughout the day as they pneumatically conveyed this low dK plastic into the silo. The airspace was very dusty and the angle of repose on the material surface was 20 degrees, but the unit performed flawlessly.

Benefits

The customer was delighted that the SITRANS LR460 level transmitter is easier to configure and more reliable than any other technology tried in the past. It is immune to acoustic noise and works well during filling and emptying cycles experienced in the metal storage silos. The customer is so pleased with the performance of the SITRANS LR460 level transmitter in the storage silo that an additional two units were purchased for the other critical silo and the two meter surge bin.

Food and beverage



This category comprises numerous materials, including grains, flour, sugar, starch, cereal, and pet foods.

Application: brewery malted barley silos
Malt extract is a vacuum concentrated sweetener made from high quality malted barley. Malted barley is stored in outdoor silos where it is drawn from the silo, crushed, and blended with water yielding a slurry called “mash.”

Conditions



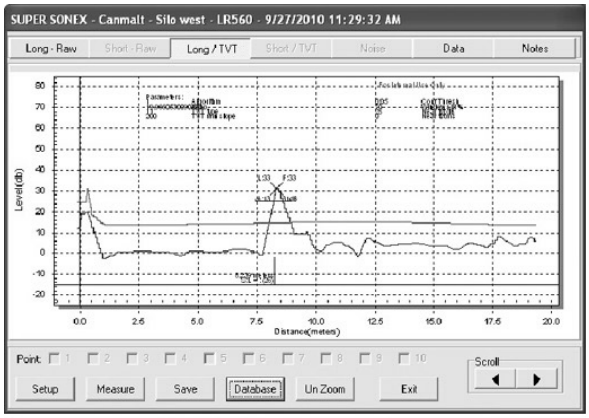
- barley stored in 15-meter (approximately 50 feet) steel silos
- silos have internal weld seams
- barley is received by rail car or truck and the pneumatic transfer into the silo creates a significant amount of dust
- accurate level measurement in the cone area required

The company used mechanical level measuring devices including a rotary paddle Hi level switch and a plumb-bob system for level monitoring, both

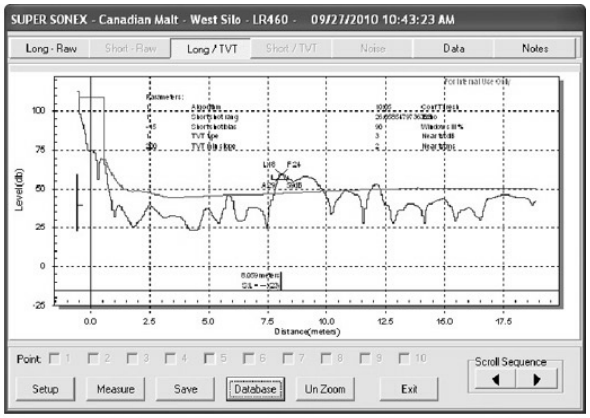
prone to costly maintenance and failures. The high cost of maintaining these mechanical systems combined with a mistrust of the level readings put severe stress on operations, motivating management to seek a new technology offering high reliability and zero maintenance costs. Operators wanted two additional benefits: local display inside the building indicating reliable level, and the ability to monitor the filling cycle so the transfer could be stopped before the silo was completely full.

Solution

Through the local distributor, Siemens installed a stainless steel SITRANS LR560 radar transmitter on a silo. With its high frequency of 78 GHz and a unique lens antenna providing a narrow four-degree beam, the compact unit worked right away. Its local display interface presents a user-friendly and graphical quick-start wizard, allowing the SITRANS LR560 to be set up in only minutes with no additional fine tuning. The four-degree beam makes for pin point accuracy and the internal seams of the silo were not seen by the SITRANS LR560.



Four degree narrow beam offered by 78 GHz SITRANS LR560 provides plug and play performance.



Eight degree wider beam offered by the 25 GHz SITRANS LR460 required fine tuning of the signal processing

Benefits

Since the new SITRANS LR560 has been installed, plant operators have noticed very stable readings from the transmitter throughout the cycle, from completely empty in the cone to a full silo. During filling, the operators simply keep an eye on the remote display, monitor the filling cycle, and shut

the transfer system off if the level approaches the top of the silo. There has been zero maintenance on the SITRANS LR560 since its installation and no maintenance is expected for years to come. The yearly maintenance cost associated with the previous mechanical level system has been eliminated. In fact, the cost of the new equipment is recovered within the first year of operation.

Ferrous and non-ferrous metals

The production of metals and smelting offers many opportunities for radar measurement, even in traditionally difficult applications like finished alumina powder in an aluminum plant. Just a few years ago this was considered a difficult application because of the severe angle of repose.

The steel industry also has many applications for radar measurement, from raw materials in pellet or powder form to high temperature molten steel where the temperatures are well over 1000° C. Virtually any material can be measured regardless of the temperature of the material or the air temperature above the material. The main consideration is to keep the electronics and the antenna system cool, and this can be accomplished by moving the sensor farther away (longer standoff nozzles) and/or cooling air supply.

Application: iron foundry



This facility produces castings for machining into large and heavy components into European industry. The application is to measure the level of the molten iron as it is poured into an outlet nozzle feeding the mold. The fill rate has to be precise to produce quality castings so the level of liquid iron in the nozzle needs to be carefully controlled. Furthermore, accurate readings optimize the processing speed, improving production rates.

Previously, laser technology was monitoring the level of liquid iron in the nozzle. However, lasers have a limited measurement range and were not using the complete volume of the outlet nozzle. This means the pot does not

completely empty each time as it returns to the horizontal position between filling the molds.

Conditions

- A large pot tilts and pours liquid iron (1450° C / 2642° F)
- outlet nozzle is 0.80 x 0.40 meters and 0.5 meters deep (2.6 x 1.3 x .6 feet)
- heavy vapors above the outlet nozzle

Solution

Siemens installed a SITRANS LR radar transmitter 1400 millimeters (55 inches) above the outlet nozzle. A cooling enclosure, created by the customer, protects the transmitter from the extremely high temperature of the liquid iron. The temperature at the antenna is approximately 200° C (392° F). A purging kit cleans and cools the unit.

The SITRANS LR was programmed remotely using SIMATIC PDM, and the characteristics of 24 GHz and high signal-to-noise ratio contribute to exceptional signal reflection, regardless of the dielectric value of the medium. It also features advanced echo processing algorithms for reliable operation on difficult applications.

Benefits

The SITRANS LR provides high accuracy reading through the whole range of the nozzle, so it can be fully used. The fast signal return time means accurate iron level readings so that the pot can stay slightly tilted after filling rather than returning to the complete horizontal position. This time saving greatly increased production rates.

The SITRANS LR also requires far less maintenance than the laser system it replaced.

Aggregates

Aggregates offer a lot of opportunity for radar level measurement within closed containers. Open aggregate measurement is still ideal for ultrasonic measurement because it is low cost and effective, but within closed vessels the dust and noise can prove problematic for ultrasonics.



Other aggregate applications for radar lie in the additive containers where compounds are added to materials.

Application: asphalt load-out silos

Hot mix asphalt is produced by combining liquid asphalt cement to dry aggregate materials, resulting in a hot solids mixture ready to be transferred to trucks for delivery to construction sites or road developers. This hot, smoky, and steamy material with a severe angle of repose is measured effectively with a radar transmitter.

Point level switches do not provide continuous monitoring, so the plant operator has no idea where the level is making inventory management difficult. Near the end of a shift (with five trucks waiting in line for asphalt), this could leave the last truck without product or leave excess product in the silo. Various grades for different purposes are produced on different days, so leftovers are not desirable. Unreliable level measurement leads to inefficiencies and headaches.

Conditions

- aggregates mixed with liquid asphalt cement (AC) in a ratio of approximately 5% AC to 95% solids and stored in temporary load-out silos
- level measurement in these silos is extremely difficult. Material buildup and destructive forces of aggregate material cause problems for contacting probes.
- intense heat creates temperature stratification, causing errors for ultrasonic systems

Solution

Siemens installed the SITRANS LR560 radar level transmitter on the asphalt load-out silos. It mounts easily on the existing nozzle and the 2-wire loop-powered wiring configuration is economical and easy to set up, connecting the transmitter automatically with the control room. The signal profile and diagnostic information is displayed on the LUI display and is confirmed in the control room using Siemens SIMATIC PDM via HART protocol.

SITRANS LR560 uses 78 GHz pulse radar technology and is suitable for silos up to 100 meters (328 ft) high. It is unaffected by high temperatures or applications with extreme levels of dust, as it is virtually unaffected by vapor, steam, dust, or temperature.

Benefits

This site had been using 25 GHz technology which was reliable over the silo range, with the exception of the cone area at the bottom. Now that the 78 GHz SITRANS LR560 is in place, its narrow beam provides reliable readings in the cone area.

Reliable continuous level measurement over the full range and operation of the silo allows operators to continuously monitor the asphalt level in the comfort of the control room. Inventory management is now possible, ensuring that trucks are properly filled and optimizing the facility's operation. The non-contacting technology means virtually no maintenance or cleaning is necessary. Site management was delighted that the unit was easy to install and configure. Significantly improving the plant's efficiency meant a very short payback period for the instrument.

Other applications

Wood processing/production

A lot of furniture is now made of medium density fiberboard (MDF). MDF is produced using epoxy resins and wood fibers pressed and cured together. The raw materials and dust from the sanding operations can be measured

effectively with radar level measurement.

The production of pellet fuels offers another market for radar measurement as it too requires bin storage of both finished material and raw materials like wood fiber and chemical binding agents.

Water/wastewater

In the w/ww industry, there are two common materials measured reliably with radar: lime and charcoal filter material. Lime has traditionally been hard to measure. Ultrasonic transmitters have difficulty with the dust while contacting technologies run into problems with buildup.

Chemical

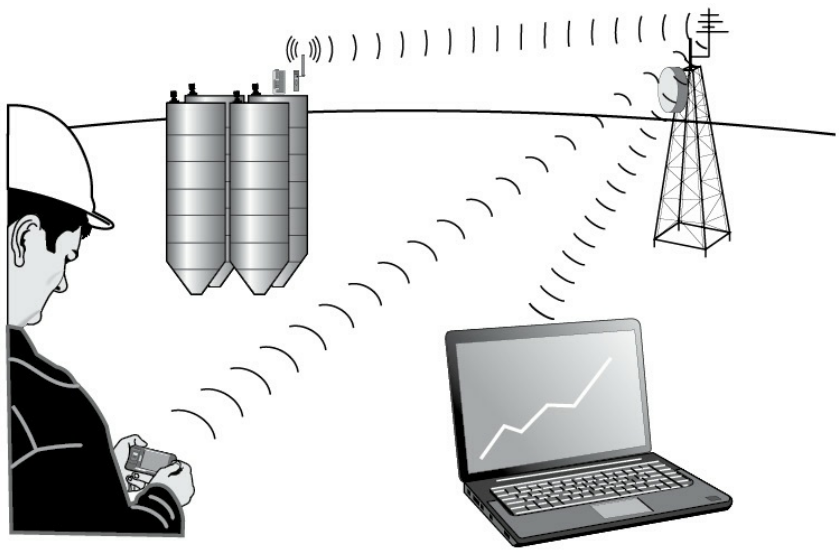
There are limitless formulations of chemical powders, both in raw materials and as finished products. Carbon black manufacturing is one example of a market segment where radar has been applied successfully. Carbon black powder is manufactured to many different specifications, usually defined by the particle size and density, and radar operates successfully because of its ability to pick up varying reflections. However, carbon black tends to build up on the antenna and its high dielectric properties can then cause false readings. To avoid this problem, periodic air purging is recommended to keep the antenna clean. Many SITRANS radar units have the air purge feature built in.

Other chemical powders measured effectively:

- soda ash
- zinc oxide
- titanium dioxide
- iron oxide
- talcum
- dolomite

Summary

The versatility of radar technology combined with the innovative Siemens designs makes radar the leading level measurement sensor for solids. The Siemens product line offers a great number of possibilities for measuring most solids applications. From the standard high-tech work horse SITRANS LR460 to the sleek and versatile SITRANS LR560, Siemens radar will tackle the tough stuff and will offer quick, reliable, and cost effective measurement of the easy applications.





SITRANS RD500

All of the SITRANS radars can be wired into a site's industrial communications network so the transmitter can be configured and monitored application data can be collected. Furthermore, you can check the data remotely over the internet using the SITRANS RD500 for inventory monitoring and trending. Hi or low level alarms can be directed to your mobile phone. With SITRANS radar level technology, you can take your site with you where ever you go.

1 Chaucer, Geoffrey. "The Squire's Tale."
2 Portland cement (often referred to as OPC, from *Ordinary Portland Cement*) is the most common type of cement in general use around the world, because it is a basic ingredient of concrete, mortar, stucco and most non-specialty grout. It is a fine powder produced by grinding Portland cement clinker (more than 90%), a limited amount of calcium sulfate which controls the set time, and up to 5% minor constituents.
3 Alternatively, it can be configured remotely with Siemens SIMATIC® PDM using HART® or PROFIBUS-PA.

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ISBN-10: ISBN 9782495-2-6

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