Measuring Level and Volume of Solid Materials
1.0 Solids measurement characteristics

Solids have different characteristics to liquids and there are a few things that need to be considered. This Technical Note outlines the most important areas for consideration when measuring solids.

1.1 Uneven surface

Most technologies for measuring level and/or volume of solid materials are top down measurements and depend on a signal reflecting from the surface back to the device.

Guided wave radar is less affected by uneven surfaces since the microwave signal is more compact and guided by the probe.

Non-contacting radar is affected by an uneven surface since much of the signal is not reflected directly back and instead may be re-directed away from the device. The device gathers several smaller echoes concentrated in an area and then merges them into a single echo that represents an average of the measured area.

The acoustic phased-array technology is not affected by an uneven surface since it measures over wide surface areas and calculates an average level and volume.

1.2 Dielectrics and bulk density

The dielectric constant of many solids is fairly low. For the radar technology, this is a key indicator of the amount of signal that will be reflected back to the gauge and thereby the possible measuring range. Technologies based on radar devices are not affected by bulk density.

The acoustic technology is not affected by dielectric properties but by bulk density. The acoustic signal can be absorbed in the material if the bulk density is extremely low.
1.3 Filling

The mounting location in relation to the filling location is important for most measuring technologies. The closer the device is mounted to the filling point, the larger the risk the device will be affected.

There are also cases where the material is blown into a silo thru a pneumatic process. Due to the nature of the acoustic technology, measurements can be affected during such filling but the effect decreases with increased silo size.

Dust and the actual stream from the filling can disturb the measurement to a large extent. It is recommended to locate the devices in accordance with best practices presented later in this technical note.

1.4 Dust

There is often a lot of dust during the fill cycle. The amount of dust depends on the type of filling and the material.

Radar and acoustic technologies can handle dust in the vapor space fairly well without being disturbed. Other technologies like ultrasonic and laser devices are less suitable since their signal is significantly impacted affected by dust.

A heavy layer of dust on the antenna can block the signal. With non-contacting radar, an air purge system may be required. With guided wave radar, the natural flexing of the probe can knock off excessive dust build-up. With the acoustic phased-array technology, the natural vibrations created by the acoustic signal can prevent dry dust build-up from occurring.

In applications where the dust is especially sticky, other alternatives such as non-stick antenna materials may be necessary.

1.5 Condensation

In many solids applications, condensation is present. Since the silo ceiling is normally the coldest spot, the condensation is present there. Unfortunately this coincides with the location of top-down measurement devices. Condensation can also tie up dust and create a layer on the wetted parts which may cause problems if no action is taken. Guided wave radar is not affected by condensation and is a good choice for extreme condensation. Non-contacting radars may need air purging to cope with condensation related issues, see “Tank connection” on page 11 for more information. The acoustic phased-array technology include self-cleaning functionality which reduces the need for maintenance. Using a PTFE antenna reduces maintenance needs even further.
1.6 Open air applications

Open air applications include measurements on piles and distance control between conveyor belts and the pile. These types of applications have different properties compared to standard silo applications. There are no walls or roof to install instruments on so the biggest challenge in these types of applications is to find an installation point. Protection from external factors like wind and rain can also be a challenge. Non-contacting radar or acoustic phased-array is recommended in these types of applications. Non-contacting radar devices are not affected by outdoor conditions. The acoustic phased-array will not be affected if the wind speed is less than 18.5 mph (30 km/h).

1.7 Noise

Many solids applications are in noisy environments. The noise can be generated by running engines, conveyor belts or during filling/emptying depending on method. Sound has no effect on radar based devices. Acoustic devices are impacted by noise around the following frequencies: 2.7 kHz, 3.4 kHz and 7 kHz. However, it is rare that all three frequencies are disturbed at the same time and an acoustic phased-array device can work even if two frequencies are compromised. The effect can often be mitigated with a different location of the device or possibly a different configuration.

1.8 Level or volume?

When selecting a measuring device it is important to understand the purpose of the measurement. Whether volume or level is the desired primary measurement, this will impact the selection of the technology. Using products outside of its main function could result in less than satisfactory measurement.

**Solids level measurement**

The main benefit of a continuous level measurement is that it can be used to control a process or make sure that there is material available. In level measurement there are often relatively fast level changes which put demand on the device to react quickly. Radar based devices are generally good at this and therefore recommended on level applications. For long ranges or on medias with very low dielectric constant, the Rosemount 5708L 3D Solids Scanner for level measurements can be a good alternative as well.
Solids volume measurement

Volume measurement is often related to a demand for inventory control, sometimes directly connected to an Enterprise Resource Planning (ERP) system. The demand for accurate volume readings is therefore high.

Measuring volume on solids is often a challenge due to material properties. There can be high peaks and deep holes and the surface is generally quite uneven. Multiple point measurement is therefore recommended and Rosemount 5708V is a good fit for small to medium sized silos. The Rosemount 5708S is recommended for medium to large silos where several Rosemount 5708S units can be connected together and give one combined volume output.

In exceptional cases where the Rosemount 5708V or 5708S cannot be used, an alternative is to install several radar devices where an average between the units is used as volume measurement.

Using only a single device suitable for level measurement can often mean less accurate results and an inferred volume reading, since the volume will be based on the level reading from a small portion of the surface.
2.0 Selection best practices

The following guide provides basic information on the different technologies and products in the Emerson™ product portfolio for solids measurement.

Table 1-1. Technology Selection

<table>
<thead>
<tr>
<th>Technology</th>
<th>Measuring footprint</th>
<th>Min mounting requirements</th>
<th>Advantages</th>
<th>Limitations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Guided wave radar</td>
<td>Rosemount 5303</td>
<td>1”</td>
<td>• Low DC, Probe End Projection&lt;br&gt;• Small silo intrusion&lt;br&gt;• Internal obstructions&lt;br&gt;• 2-wire</td>
<td>• Pull force dependent&lt;br&gt;• Wear on probe&lt;br&gt;• Inferred volume</td>
</tr>
<tr>
<td>Non-contacting radar</td>
<td>Rosemount 5402, Rosemount 5600</td>
<td></td>
<td>• Narrow beam&lt;br&gt;• Small silo intrusion&lt;br&gt;• Internal obstructions&lt;br&gt;• 2-wire (Rosemount 5402)</td>
<td>• May need purging (Rosemount 5402) or PTFE bag (Rosemount 5600)&lt;br&gt;• Inferred volume&lt;br&gt;• 4-wire, 24 to 240 Vdc or ac (Rosemount 5600)</td>
</tr>
<tr>
<td>Acoustic Phased-Array - level and volume</td>
<td>Rosemount 5708L, Rosemount 5708V</td>
<td>8” (4’ with neck extension)</td>
<td>• Self-cleaning antenna&lt;br&gt;• Long range&lt;br&gt;• DC independent&lt;br&gt;• Inventory (Rosemount 5708V)</td>
<td>• Not suitable for narrow silos&lt;br&gt;• No configuration via AMS™, Field Communicator, DTM™, DD&lt;br&gt;• Requires dedicated software&lt;br&gt;• 4-wire, 18 to 32 Vdc</td>
</tr>
<tr>
<td>Acoustic Phased-Array - visualization</td>
<td></td>
<td></td>
<td>• Inventory applications&lt;br&gt;• 3D visualization&lt;br&gt;• Multiple Rosemount 5708S can be connected together for large silos</td>
<td>• Not suitable for narrow silos&lt;br&gt;• No configuration via AMS, Field Communicator, DTM, DD&lt;br&gt;• Requires dedicated software&lt;br&gt;• Requires separate server for multi-scanner systems&lt;br&gt;• 4-wire, 18 to 32 Vdc</td>
</tr>
</tbody>
</table>
### Table 1-2. Product Selection

<table>
<thead>
<tr>
<th>Model</th>
<th>Silo height</th>
<th>Silo width</th>
<th>Power</th>
<th>Material restrictions</th>
<th>Protocol</th>
<th>Primary output</th>
<th>Features</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rosemount 5303</td>
<td>3-98 ft (1-30 m)</td>
<td>Unlimited</td>
<td>2-wire</td>
<td>DC &gt; 1.1 up to 39 ft (12 m) with Probe End Projection activated DC &gt; 1.4</td>
<td>4-20 mA, HART®, FOUNDATION™ Fieldbus, Modbus®, WirelessHART®</td>
<td>Level</td>
<td>Probe End Projection, Signal Quality Metrics</td>
</tr>
<tr>
<td>Rosemount 5402</td>
<td>Parabolic: 3-105 ft (1-32 m)</td>
<td>Unlimited</td>
<td>2-wire</td>
<td>Parabolic: DC &gt; 1.5 up to 52 ft (16 m), DC &gt; 2.0 up to 105 ft (32 m) Cone: DC &gt; 1.5 up to 33 ft (10 m), DC &gt; 2.0 up to 66 ft (20 m)</td>
<td>4-20 mA, HART, FOUNDATION Fieldbus, Modbus, WirelessHART</td>
<td>Level</td>
<td>Solids signal processing, air purging</td>
</tr>
<tr>
<td>Rosemount 5600</td>
<td>66-98 ft (20-30 m)</td>
<td>Unlimited</td>
<td>4-wire</td>
<td>DC &gt; 1.9</td>
<td>4-20 mA, HART, Modbus, WirelessHART</td>
<td>Level</td>
<td>Two 4-20 mA outputs</td>
</tr>
<tr>
<td>Rosemount 5708L</td>
<td>19-229 ft (6-70 m)</td>
<td>Min: 7 ft (2 m) Max: Unlimited</td>
<td>4-wire</td>
<td>Material density &gt; 12.5 lb/ft³ (200 kg/m³)</td>
<td>4-20 mA, Modbus(3), WirelessHART(1)</td>
<td>Average level</td>
<td>DC independent level measurement</td>
</tr>
<tr>
<td>Rosemount 5708V</td>
<td>19-229 ft (6-70 m)</td>
<td>Min: 9 ft (3 m) Max: 39 ft (12 m)</td>
<td>4-wire</td>
<td>Material density &gt; 12.5 lb/ft³ (200 kg/m³)</td>
<td>4-20 mA, Modbus(3), WirelessHART(1)</td>
<td>Volume</td>
<td>True volume measurement, multiple point measurement</td>
</tr>
<tr>
<td>Rosemount 5708S</td>
<td>19-229 ft (6-70 m)</td>
<td>Min: 16 ft (5 m) Max: Unlimited</td>
<td>4-wire</td>
<td>Material density &gt; 12.5 lb/ft³ (200 kg/m³)</td>
<td>4-20 mA, Modbus(3), WirelessHART(1)</td>
<td>Volume</td>
<td>3D Visualization, multiple devices can be connected together</td>
</tr>
</tbody>
</table>

1. The Rosemount 5708 with the Emerson Smart Wireless THUM™ Adapter enables wireless access to the following parameters: 4-20mA current, Distance, Percentage, Temperature and SNR. Diagnostics and configuration are available through wired connection.
2. Use Rosemount 5708S if \( \frac{\text{silo height}}{\text{silo width}} < 3 \). For more information, see section “Determining number of Rosemount 5708s” on page 15.
3. Ethernet capable.
3.0 Guided wave radar

Guided wave radar is used in many different applications. It is especially well suited for smaller vessels with diameter <33 ft (10 m) containing powders and small granular materials and where the installation area is restricted. As vessel height increases, wear on the probe becomes more of a factor in the suitability of its use.

3.1 Mounting considerations

Always install the probe in an empty silo and regularly inspect the probe for damage. For silos taller than 98 ft (30 m), consult your Emerson representative.

Position

Mount the probe as far away as possible from filling and emptying ports. This will minimize load and wear and will help to avoid disturbances from the incoming product.

Installing the probe at about \( \frac{1}{3} \) to \( \frac{1}{2} \) of the silo radius is recommended to compensate for measurement errors caused by cone shaped surface formation during centered filling. The minimum recommended probe distance to tank wall or disturbing objects is 20 in. (50 cm), unless the wall is comprised of smooth metal, then the distance is 4 in. (10 cm). In any case, the probe should not be able to touch the wall of the tank during operation.

Nozzle

A short nozzle is recommended. The maximum recommended nozzle height is nozzle diameter + 4 in. (100 mm). When nozzles are more than 4 in. (100 mm) in height, a long stud is recommended to prevent the probe from contacting the nozzle. Avoid 10 in. (250 mm)/DN250 or larger diameter nozzles, especially in applications with low dielectric constants.

Special silos

In case of non-metallic silos, a guided wave radar should be mounted with a metal plate of at least 14 in. (350 mm) in diameter. Use metal shielding for the conduit connections.

In the case of bunkers with a concrete roof, a Rosemount 5303 should be installed flush with the inner roof surface or in a nozzle insert.
3.2 Probe anchoring

The best practice is to have a free hanging probe but an anchored probe is sometimes needed for application reasons. The probe end should not be fixed for 98 ft (30 m) or longer probes. The probe must be slack when anchoring the probe to reduce the risk of probe breakage. Select a probe longer than the required measuring range so there is a sag in the middle of the probe greater than or equal to 1.5 in. per 10 ft (1 cm per m) of the probe length.

Electrostatic discharges

In some applications, such as plastic pellets, electrostatic charges can build up and eventually discharge. While the Rosemount 5303 electronics can tolerate some static charge, providing a good earth ground for the electronics by anchoring the end of the probe to the vessel will create ground paths for discharge away from the electronics. If the product can build up static electricity, the probe should be properly grounded (R < 1 Ohm).

3.3 Probe End Projection

Probe End Projection is a function in the Rosemount 5303 that allows for measurements when the surface pulse is too weak to be detected. This commonly occurs when the material dielectric constant is very low, especially in combination with a long distance to the surface, or electromagnetic interference. The method is based on the fact that microwaves propagate slower through product media than through air. By using the product dielectric constant and the probe end echo, the surface position is calculated when the surface echo is unavailable.

This function is recommended for solids with a dielectric constant less than or equal to two (e.g. perlite at 1.7, plastic pellets at 1.2).

The maximum measuring range with Probe End Projection is calculated by dividing the difference of 50 - the air gap to the material surface with the square root of the material dielectric constant.

Probe End Projection is easily configured by using the guided setup in either Rosemount Radar Master, AMS, or the Field Communicator. For best performance, complete the Guided Probe End Projection Setup with an empty tank and then a second time with a filled tank, but do not overwrite the empty tank calibration.
3.4 **Pull force**

The flexible single lead probe is recommended for solids. It is available in two versions to handle different loads and lengths. Yield strength is the amount of force the probe can withstand before any deformation occurs.

It is important to keep the following in mind when planning for installation:

- The silo roof must be able to withstand maximum probe tensile load.
- The tensile load depends on the silo size, material density, and the friction coefficient. Forces increase with the buried length, the vessel width and probe diameter.
- Forces on probes are generally increased two to ten times when probes are anchored to the vessel.

### Table 1-3. Tensile Load for Unanchored 0.16 in. (4 mm) Flexible Single Lead Probe, lb (kN)

<table>
<thead>
<tr>
<th>Material</th>
<th>Probe length 49 ft (15 m)</th>
<th>Probe length 115 ft (35 m)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Tank Ø = 10 ft (3 m)</td>
<td>Tank Ø = 39 ft (12 m)</td>
</tr>
<tr>
<td>Wheat</td>
<td>670 (3)</td>
<td>1120 (5)</td>
</tr>
<tr>
<td>Plastic pellets</td>
<td>340 (1.5)</td>
<td>670 (3)</td>
</tr>
<tr>
<td>Fly ash</td>
<td>770 (3.4)</td>
<td>1690 (7.5)</td>
</tr>
<tr>
<td>Coal dust</td>
<td>540 (2.4)</td>
<td>1190 (5.3)</td>
</tr>
<tr>
<td>Cement</td>
<td>900 (4)</td>
<td>2020 (9)</td>
</tr>
</tbody>
</table>

1. Exceeds the yield strength limit of 6519 lb (29 kN).

### Table 1-4. Tensile Load for Unanchored 0.24 in. (6 mm) Flexible Single Lead Probe, lb (kN)

<table>
<thead>
<tr>
<th>Material</th>
<th>Probe length 49 ft (15 m)</th>
<th>Probe length 115 ft (35 m)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Tank Ø = 10 ft (3 m)</td>
<td>Tank Ø = 39 ft (12 m)</td>
</tr>
<tr>
<td>Wheat</td>
<td>900 (4)</td>
<td>1690 (7.5)</td>
</tr>
<tr>
<td>Plastic pellets</td>
<td>450 (2)</td>
<td>920 (4.1)</td>
</tr>
<tr>
<td>Fly ash</td>
<td>1130 (5)</td>
<td>2520 (11.2)</td>
</tr>
<tr>
<td>Coal dust</td>
<td>790 (3.5)</td>
<td>1780 (7.9)</td>
</tr>
<tr>
<td>Cement</td>
<td>1350 (6)</td>
<td>2920 (13)</td>
</tr>
</tbody>
</table>

1. Exceeds the yield strength limit of 6519 lb (29 kN).
4.0 **Non-contacting radar**

Non-contacting radar is used on a large variety of applications. It has no restrictions with respect to the weight of the material so it can be used in applications where guided wave radar may not be appropriate due to probe breakage.

Non-contacting radar can be a more precise measurement over a smaller surface area and can react quickly to fast level changes over a wide range.

4.1 **Mounting considerations**

**Position**

The radar signal must never be shaded by the inlet nor the injected product. A non-contacting radar should not be mounted in the center of the silo or very close to the tank wall. General best practice is to mount the non-contacting radar at \(\frac{2}{3}\) tank radius from tank wall.
The cone antenna is fixed and there is no need to put it in a certain angle. The parabolic antenna inclination is adjustable. General best practice is to initially align the parabolic antenna vertically to the ground. Refer to the Rosemount 5400 Level Transmitter Reference Manual for further information.

If the signal is dampened by heavy condensation at the antenna, it often helps to insulate the nozzle. This minimizes the temperature disparity between the internal and ambient temperature. Installing the antenna so it is inside the vessel helps reduce the chance of condensation.

**Dust management**

Dust is often present in solids applications and even if the non-contacting radar is not affected by the dust in the vapor space, dust can be sticky and create a layer on the antenna. If this layer becomes too thick, it may affect the measurement. This is best managed by using air purging (Rosemount 5402) or a PTFE bag (Rosemount 5600).

The easiest way to determine if air purging or a PTFE bag is needed is to open the manhole hatch and see if there is a thick layer of dust on it. If so, air purging or PTFE bag is most likely needed.

4.2 **Software setup**

Follow a standard configuration and check the “solids” check box in the tank environment window to activate the special solids mode. Solids applications are generally difficult and thus Emerson has developed a special solids mode in the device database. Additional adjustments are generally not needed but are in some cases. Consult your Emerson representative for further details on how to proceed if additional adjustments are needed.
5.0 Acoustic phased-array

Acoustic phased-array devices can be used on a large variety of applications but are especially suitable for bulk storage materials. These applications tend to be very large vessels with slow changes in surface movement.

5.1 Mounting considerations

Acoustic phased-array devices measure volume and level in silos, warehouses, and domes. Correct location and mounting are key to achieving the most accurate volume measurements. Fill in the Application Evaluation Form (AEF) carefully with your Emerson representative to determine the optimal location. The AEF is used to evaluate the installation for suitability of use with the Rosemount 5708 and to determine optimal position(s).

Position

The Rosemount 5708 should always be mounted perpendicular to the ground to ensure highest accuracy. It is also important to mount the device at a height that leaves at least 0.4 in. (10 mm) below the standpipe for the antenna end to protrude. Since the Rosemount 5708 measures in three dimensions, it is also important to set the antenna at a correct angle in relation to the center. The notch on the top of the thread must be directed toward the center of the silo as shown in the illustration below.

Distance to wall and inlet

To get the highest accuracy from the Rosemount 5708, it is important to make sure the distance to walls and filling points are at least 24 in. (600 mm). This is to prevent false readings and ensure trouble-free operation.
Obstacle avoidance

It is important to know the location of any obstacles in the silo. Some obstacles may affect the measurement and this would impact the suitable device location. The following obstacles are common and important to identify before deciding on Rosemount 5708 location:

- Inlets
- Internal structures
- Ladders
- Support beams
- Thick roofs (for example in concrete silos)

If obstacle can’t be avoided by relocating the device, a neck extension can be used to extend the antenna past the obstacle.

Handling moving obstacles

Moving obstacles like augers and mixers must be taken into consideration when the Rosemount 5708 is installed.

The best practice to handle bottom mixers and augers is to exclude them from the measurement area. This is done during the commissioning phase where the silo dimensions are used as normal but “zero level” is set above the auger or mixer. The area under “zero level” will be the end of measurement.

Nozzle proximity to wall

Sometimes the recommended installation location cannot be applied to a silo or vessel. To handle a less optimal location of the device, a separate angle adapter can be used. This adapter should only be used if there are no other alternatives. Consult your Emerson representative for further details as needed.
5.2 Determining number of Rosemount 5708s'

For a very large silo or open bin, it may be necessary to install more than one Rosemount 5708 to cover the complete surface. Information from the AEF will determine how many devices are needed. The combination of vessel height and diameter are the primary factors along with the maximum fill height.

The Rosemount 5708s’ are daisy-chained with a RS-485 linked to a Rosemount System Controller. Data from all devices is then synchronized and sent to the control room.

It is important to input the exact location of each Rosemount 5708 during configuration for the devices to cooperate in an optimal way. Accurate location information will ensure better measurement accuracy.

5.3 3D visualization

The 3D visualization constructed in the Rosemount 3DVision/Rosemount 3DMultiVision™ software is based on multiple points collected by the Rosemount 5708 and represents the material surface the device(s) can see. This allows the user to get the best representative surface measurement. It also provides information on material formations within the vessels such as material that may be stuck to the walls.