Level measurement of liquids and solids in storage bins, process vessels, stockpiles, and channels provides information to ensure that raw materials are on hand, processes are at optimum conditions and that employees and the environment are kept safe and clean.

There are many different technologies available for measuring the level of a material:

- **Radar**: Microwaves travel the distance from the instrument to the material and back.
- **Ultrasonic**: Sound waves travel the distance from the instrument to the material and back.
- **Guided wave radar**: Microwaves travel along a probe that contacts the material and back.
- **Capacitance**: Material level between two conductors creates a change in the ability to store an electrical charge and is proportional to the material level.
- **Gravimetric**: Load cells deflect under the weight of a vessel’s contents.
- **Hydrostatic**: Material level creates a change in pressure.
- **Vibrating fork**: Vibration frequency changes from material contact.
- **Rotating paddle**: Paddle rotates until material contact stops the paddle.

In process industries the measurement of flow, temperature, weight, pressure, and level are critical to ensure a safe and efficient business as well as a quality end product.

Whether you are making gasoline, pasta, or cement, the use of these instruments is crucial to ensure the highest quality.
• **Nucleonics:** Detects changes in gamma rays as they pass through the material.

• **Magnorestrictive:** A magnet-equipped float changes position based on level height.

• **Conductive:** Resistance is changed when material contacts the probe.

• **Thermal:** Material contact causes a temperature change against a reference.

• **Laser:** Light waves travel the distance from the instrument to the material and back.

• **Float:** A buoyant probe changes position based on level height.

• **Displacer:** Weighted spring changes tension as it is submerged by the material.

• **Plumbob:** A weight travels the distance from the instrument to the material and back.

• **Bubblers:** Material level creates a change in air pressure at the bottom of the vessel.

The above technologies can also be divided into subcategories of continuous level and point level measurement, and further into contact and non-contact. It is also important to note that some of these technologies can only be used for solids or liquids, rather than both.

Of all the technologies listed here, one stands above the rest in terms of lack of understanding, but is still a very popular solution: capacitance.

Capacitance level technology can be used with liquids, solids, and slurries, and in interface applications (two different liquids which don’t mix). However, measuring the ability of a material to store a charge seems like a potentially dangerous and difficult means to do something as simple as measuring level... or does it?

Before you go running out to your tank farm to rip off the capacitance products you have, let’s review how these actually work and what the benefits are from using them. One last thing – before we get into some nuts and bolts, I promise that we won’t show you any mathematical equations when we describe capacitance!

**Back to basics**

A capacitor is created when a current flows between two parallel or concentric cylindrical surfaces. It is a passive electronic component that stores energy in an electric field between two conductors. As a low-voltage, high-frequency signal is applied to the capacitance probe, a minute current flow is created from the probe to the ground plane.

To store energy, the capacitor must have a differential voltage applied across first two conductors. As the level of the material changes, it changes the capacitance measurement between the probe and the ground plane.

All materials have a dielectric constant (dK). The dielectric constant is the ratio of the permittivity of a substance to the permittivity of free space. It is the ability of a substance to store electrical energy in an electric field, and is the electrical equivalent of relative magnetic permeability. Figure 1 shows some examples of popular materials and their dK values.

It is important to note that in some cases, material dielectric values can change with temperature.

Capacitance is measured in farads. One farad is defined as the capacitance of a capacitor across which, when charged with one coulomb of electricity, there is a potential difference of one volt. Conversely, it is the capacitance which,...

<table>
<thead>
<tr>
<th>Media with different dielectric constants</th>
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<tbody>
<tr>
<td><strong>Liquids</strong></td>
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<td>Alcohol</td>
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<td>Petrol</td>
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<td>Chloroform</td>
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<tr>
<td>Desmophen 5100</td>
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<tr>
<td>Deuterium</td>
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<tr>
<td>Chlorine (liquid gas)</td>
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<tr>
<td>Air -140 °C (liquid gas)</td>
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<td>Butane (liquid gas)</td>
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<td>Propane (liquid gas)</td>
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<td>Glycerin</td>
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<td>Fuel oil</td>
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<td>Petroleum</td>
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<td>Water</td>
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SITRANS LC300 and SITRANS LC500 continuous capacitance level transmitters provide reliable and accurate monitoring. SITRANS CLS300 level switch provides high and low level alarming. Figure 1: Capacitance is a very versatile measurement which can provide a solution for all of the materials listed.
when charged to a potential difference of one volt, carries a charge of one coulomb. A coulomb is equal to the amount of charge (electrons) produced by a current of one ampere flowing for one second.

For example, the voltage across the two terminals of a two-farad capacitor will increase linearly by one volt when a current of two amperes flows through it for one second. The amount of capacitance measured for level applications is considerably lower than a full farad; in fact, it is one trillionth of a farad, called a picofarad. The amount of capacitance is dependent on several factors, including:

1. Electrode surface area
2. Distance between electrodes
3. Dielectric constant
4. Probe length

The measurement cycle for an inverse frequency shift capacitance probe is as follows: Charge the probe electrode up to 10 VDC and then discharge the probe electrode.

Capacitance can be measured by taking advantage of the charge/discharge times. One way to do this is to create an oscillator using a comparator. The output of the oscillator will be a square wave with a period equal to the time it takes to charge the capacitor plus the time it takes to discharge the capacitor.

Figures 2 through 4 show the important waveforms in the circuit. Voltage V+ is a square wave changing between the voltages. Finally, the output of the oscillator is a square wave with a period proportional to the capacitance in the measurement.

The output period of the oscillator circuit described above is proportional to the capacitance charging and discharging. If the other values remain constant, then as the capacitance changes, the period of the signal changes.

A microcontroller measures the period of the oscillator output signal and with a simple conversion determines the capacitance.

Inverse frequency shift measurements look at the period of a square wave which is proportional to the capacitance measurement, or measuring shifts in period. The mathematical inverse of period is frequency, hence inverse frequency shift measurement. Other capacitance technologies are measuring some type of frequency/period, or measuring the amplitude of a signal with a static frequency, so they are not as accurate.

The probe of the capacitance instrument is one of these conductive surfaces that make up the capacitor. The other plane can be the tank wall, provided the material is non-conductive. In applications with a conductive material, the material itself acts as the other surface for the capacitor.

In special circumstances, the tank may be non-conductive (plastic) and the material also non-conductive. For example, a stilling well supplied with the instrument can act as the second capacitor plane here. Conductive materials will usually have a dK of 20 or more.

As the measurement is based on the shape and size of the vessel, operators will need to perform a calibration with the instrument in place. When the tank is empty (usually required for installation) the unit must be “zeroed”. This creates the empty reference point of capacitance measurement for the device.

Capacitance probes can be ordered in several different configurations for continuous level measurement. Rod probes lined with PFA ensure that materials don’t stick and also help protect the probe from corrosion in nasty applications. Rod probes are generally used in liquid or interface applications.

Stainless steel braided cable and PFA cable versions are
also available. Normally used in solids applications, the cable version probes can be as long as 35 meters. Stilling well designs are also ideal for non-linear tank shapes such as spherical or horizontal. If the reference plane is not parallel to the primary capacitor plane an offset will occur similar to the graphic at Figure 5.

With any level technology, buildup can be a concern or a complete detriment to the measurement. Siemens active shield design allows for a customer-orderable section of the probe to be covered without affecting the measurement of the level. This area is a “dead” zone for the measurement and therefore is not susceptible to buildup.

**Capacitance limitations and successes**

Capacitance level measurement in critical processes or in high-accuracy applications should not be used if changes to the dielectric constant occur.

Changes can come from temperature (generally 0.1 percent change per one degree Celsius), moisture content, chemical or physical composition, and packing density. In these applications, a different level measurement solution would be better suited, such as radar or guided wave radar.

Capacitance is ideal for applications with high pressure and high temperature ratings. Guided wave radar is as well, but where capacitance excels is with interface measurements, especially in emulsion applications where the separation of the two materials is not as “clean” as with oil and water, for example.

Because capacitance is measuring the change in the ability to store a charge, and not a reflection echo based on a dielectric change, capacitance can be the instrument of choice. Foam, vapors and dust have no effect on capacitance measurement. Capacitance can be mounted on the bottom of the vessel as well as on the side with cable versions.

**Summing it all up**

Capacitance level measurement is a proven technology in the field of industrial automation. Measurement devices available today offer many characteristics that allow for level measurement in tough applications by providing:

- Functionality in extreme pressures and temperatures
- The ability to remote mount electronics to keep sensitive circuitry away from harsh conditions from the process
- Flexibility in tank mounting—probes can be mounted from the bottom, top, or side of a vessel

An understanding of the basic principles of capacitance allows these devices to be installed in a multitude of processes and provide repeatable and reliable continuous level measurements.

So, capacitance is not quite the black magic it may have seemed before—just a clever way to make the life of an instrument technician better.