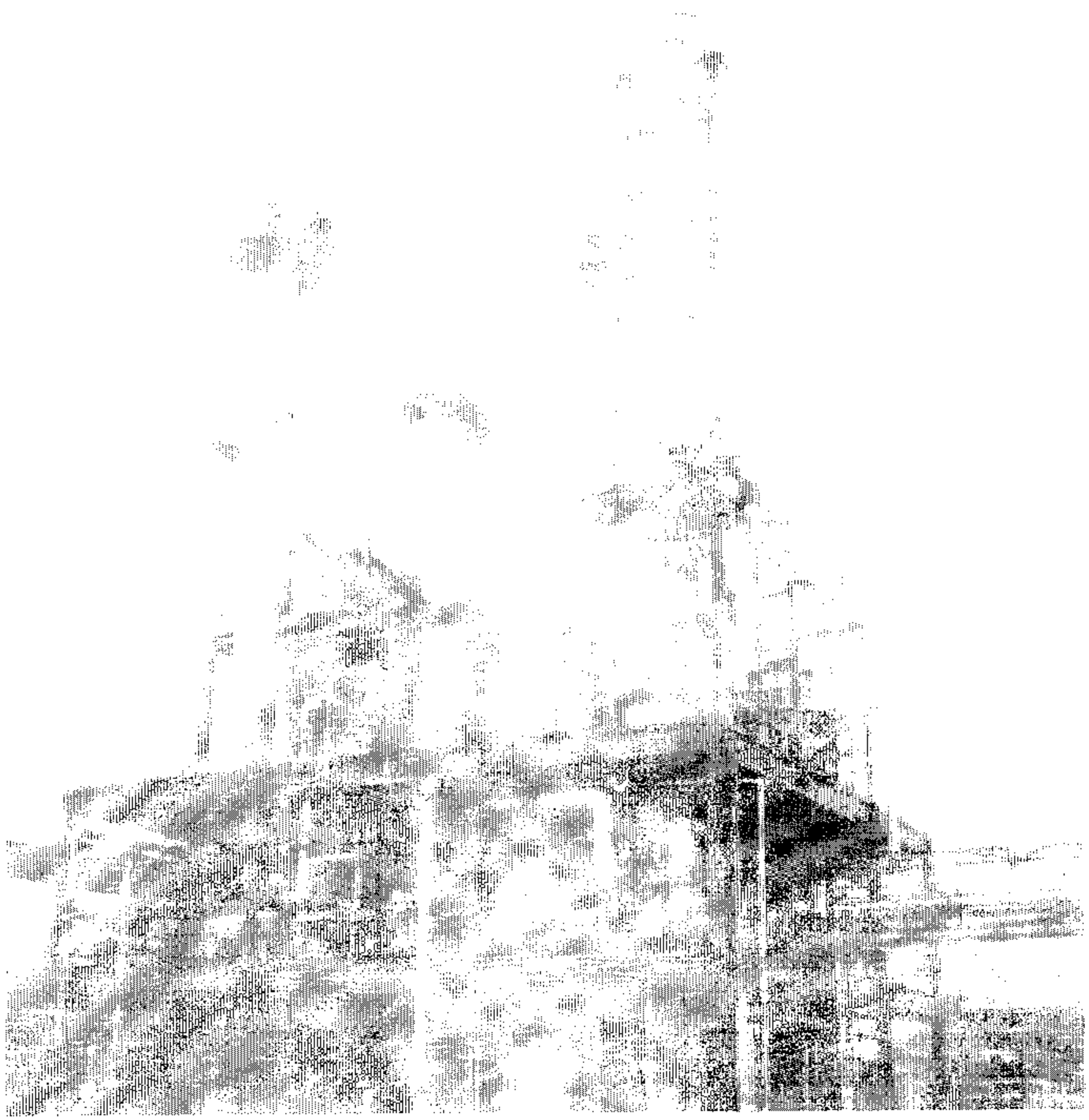
AMETEK®
DREXELBROOK

A Practical Guide to Radio Frequency Level Controls

by
Edward Schuler



About the author . . .

Edward L. Schuler was Service Department Manager, RF Continuous Product Manager, and Regional Sales Manager for Drexelbrook Engineering Co. for 37 years before retiring in 2000. His many years and vast experience with RF Admittance products make him an expert in the application, installation and servicing of level control products using this technology. In addition to this reference book, Ed has also authored various articles for national trade publications on the topic of level sensing and RF Admittance technology.

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1.0 INTRODUCTION

1.1 How to Use This Book

This book is intended as a practical, but not-too-technical guide to understand and get the most out of your radio frequency level measuring equipment.

The format permits use as both an instructional text and a reference manual. To use as an instructional text, the table of contents is organized to make learning easiest when the book is read from beginning to end. As a reference manual, the index in the back should aid in locating the desired information.

Information contained here is not all-inclusive nor intended to replace the specific instruction manual supplied with the equipment. Practically all reference to the application of the equipment has been left for another text.

Although some data is equally applicable to equipment manufactured by others, much information is limited to that manufactured by Drexelbrook Engineering Company, Horsham, Pennsylvania, U.S.A.

1.2 One Level Technology for Your Plant

Like temperature, pressure, and flow, LEVEL is one of the most important process measurements. To make the best choice for level instrumentation, the specifier should be familiar with over twenty distinctly different technologies that are commonly used in industry today. Few of us have the time or inclination to become experts in all of the technologies. Therefore, we tend to zero in one one or two that "look good". This may work if one is fortunate enough to initially make the right choice. Since most companies do take a random approach to the application of instrumentation, a solution is usually found to meet the requirements of that particular job.

Taking an analytical approach to the application of instrumentation will produce huge long term benefits. These benefits include lowered installation costs, less maintenance, reduced personnel training, and decreased plant downtime. In the case of level measurement, these savings can be achieved with a single, multi-faceted technology.

There is a universal level measuring technology which has proven reliable and is uniquely suited for extremes in process conditions as well as ambient environments.

It provides both POINT LEVEL and CONTINUOUS LEVEL measurement.

It measures all four material types: LIQUIDS, GRANULARS, SLURRIES, and INTERFACES.

It performs these tasks under process conditions ranging from vacuum to 10,000 PSI, and temperatures of -300°F to +1000°F.

It makes the measurement independent of variations in DENSITY, CHEMICAL COMPOSITION, and ELECTRICAL PROPERTIES.

It is safe, proven, easy to specify, and cost competitive. *THIS TECHNOLOGY IS RADIO FREQUENCY ADMITTANCE*

It is important not to confuse RADIO FREQUENCY ***ADMITTANCE*** with its "look alike" ***CAPACITANCE*** level measurement, which is similar to comparing calculators to PCs. Both a calculator and a PC will do the easy jobs, but only the PC, properly programmed, will provide an efficient solution to a complex problem. Similarly, only RF ADMITTANCE will calculate the real level measurement in the presence of undefined and uncontrolled variables. Despite coating buildups, or changes in density, or electrical properties, the RF level measurement will not be affected, even if all are acting at the same time.

WHAT MAKES A LEVEL TECHNOLOGY UNIVERSAL?

To qualify as a universal level technology, there are a number of important criteria which must be met. The first test is the ability to measure both *point level (on/off)* and *continuous level (analog, typically 4-20 mA).*

POINT LEVEL measurements, as the name suggests, are those which indicate whether the material level has risen or fallen to some predetermined point in the vessel. Some typical examples of these measurements are "over-fill" protection, pump cavitation protection, pump start and stop control, and "plugged chute" detection. Historically, the output mode of a point level control has been one or more pairs of DPDT dry relay contacts. However, the trend is continually moving in the direction of a switched change between high and low current in the 4-20 mA range. This current change is then transmitted to a receiver in the control room which may be a process controller, PLC, or other similar device. The receiver then converts the current signal to an alarm or control action. A universal point level device should be able to provide either output mode.

CONTINUOUS LEVEL measurements, on the other hand, provide a continuous reading of the actual material level in a vessel. The output mode of a continuous level measurement is typically a 4-20 mA signal that is proportional to the level. Because users frequently want the information in their units of choice, the continuous level signal should indicate how many feet of level or gallons (volume) or pounds (weight) are present. Obviously, a successful level technology will be able to provide the answers in the most useful form. While a 4-20 mA signal is still the most common format for this class of instrumentation, other forms such as the digital formats of RS-232 and 422 and the not yet finalized Fieldbus, are gaining acceptance as we move toward increased automation.

MATERIAL TYPES

The second test of universality is the ability of the technology to measure all four types of materials found in industry today. The four types of materials are: *liquids, granulars, slurries, and interface.*

PROCESS CONDITIONS

The third test of universality is the ability to measure level under the wide range of process conditions commonly found in industry. The conditions of most concern are: temperature, pressure, agitation, corrosion (chemical compatibility), foaming, explosion hazards, and potentially lethal materials.

PHYSICAL AND CHEMICAL PROPERTIES

The fourth test of universality is making a measurement independent of changes in material density, chemical composition, build-up, viscosity, or electrical properties. Certain technologies depend on some of these specific properties to make their measurements and are, therefore, sensitive to changes in them.

WHAT IS RF ADMITTANCE? WHY IS IT A UNIVERSAL TECHNOLOGY?

RF ADMITTANCE is a universal technology because when measuring level it is measuring something common to everything in the universe. All things, even a vacuum, have an electrical property called DIELECTRIC CONSTANT (k). The other electrical property is conductivity (g) which is the nemesis of CAPACITANCE level measurement.

RADIO FREQUENCY ADMITTANCE is a technology that takes both properties into account when computing the level. The measurement is made at a predetermined radio frequency rate. That frequency is usually between 15 Khz and 400 Khz. Hence the name RADIO FREQUENCY ADMITTANCE.

For information on how more materials affect the measurement, see the section on "Properties of Materials".

2.0 THEORY OF OPERATION: POINT LEVEL (ON/OFF)

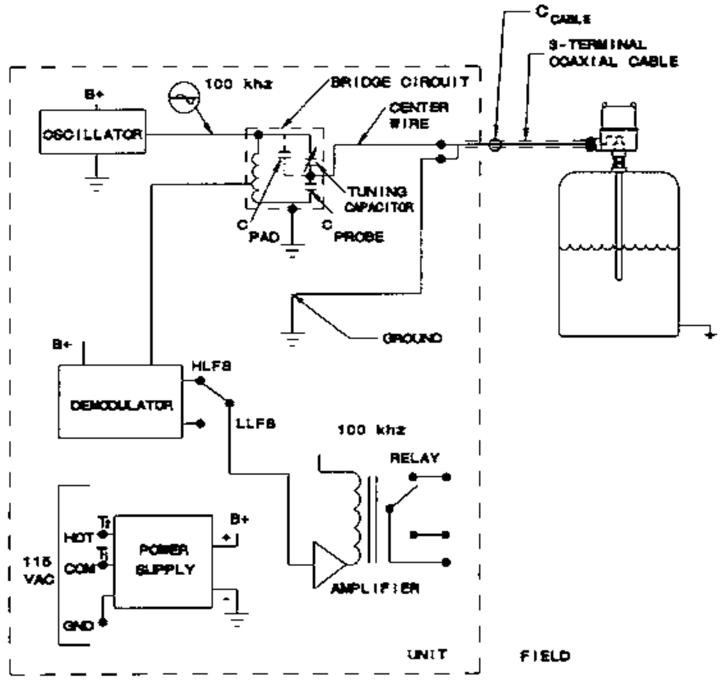


Figure 2-1A ***Simple Two-Terminal On/Off Capacitance Level Control***

2.1 Two-Terminal Capacitance Point Level Controls

A discussion of the operating theory of an on/off level control should begin with the two-terminal capacitance-type system. Please refer to Fig. 2-1A which shows a block diagram of a typical two-terminal on/off capacitance level control and the connecting cable and sensing element that make it a level control system.

The level control is typically powered by a 120-volt 60 Hertz power source, although 50-cycle and 230-volt are available as options. Internally, there is a power supply that converts ac to 24 Vdc in order to run various parts of the circuit. The oscillator circuit generates a sinusoidal radio frequency wave form of about 100 khz, and is connected to a bridge circuit. The bridge circuit contains the tuning adjustment which balances out the capacitance of the probe shown on Cprobe. The bridge circuit is connected directly to the sensing element (probe) via a connecting coaxial cable. The shield of the coaxial cable is connected to ground which is one side of the measurement. The sensing element end of the cable has its shield connected to the condulet, protecting the terminations of the sensing element. Because the condulet and probe body are threaded into the vessel, the vessel is also grounded through this connection.

During the calibration procedure, the capacitance of the probe in the vessel is balanced out by the tuning capacitor and bridge balance is obtained. When the coaxial cables are more than a few feet long, it is also necessary to add a capacitance equal to the effect of the capacitance of the coaxial cable itself. This capacitance is shown on the drawing as Cpad. In the tuning process, the capacitance of the cable and the probe are balanced out, and out put to the demodulator is essentially 0 volts. When the level in the vessel rises, a greater capacitance occurs. This causes a change in the signal being sent to the demodulator, where it is converted to a dc voltage proportional to the unbalance.

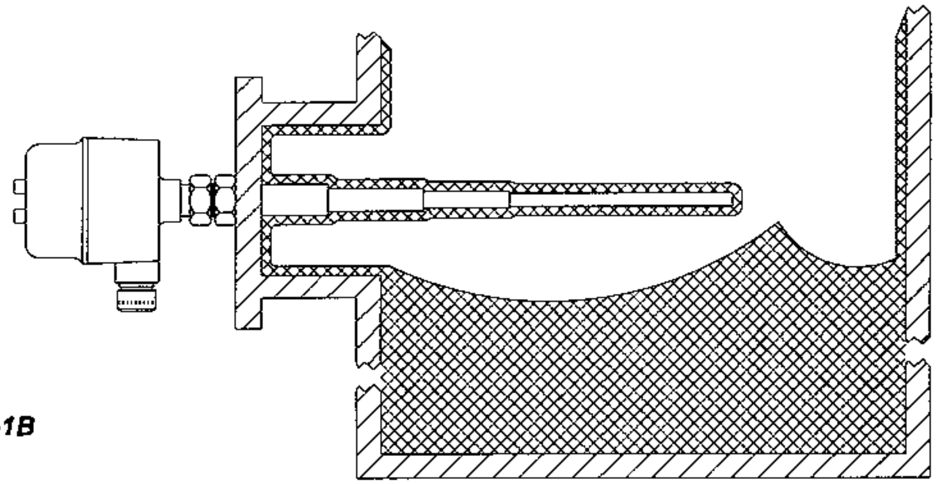


Figure 2-1B

This change in signal, caused by the increase in level, is amplified and used to energize the relay shown in the diagram. The relay contacts are then used to sound an alarm or activate the appropriate control.The simple capacitance level control system has several drawbacks and has been almost completely phased out in favor of the three-terminal or Cote-Shield™ type level control systems. The main drawback of simple capacitance is illustrated in Fig. 2-1B. After the level has once covered the probe and then fallen away, there may be a coating left on the probe that can cause the instrument to react as though the level was still on the probe. A problem usually occurs when the material leaves a conductive coating that goes all the way to the mounting threads. In general, coating problems are less severe with insulating materials. If there is a problem, it can sometimes be avoided by mounting the probe vertically, so that the coating never reaches the mounting threads. In this case, even if the material leaves a conductive coating, the operate point will be at the tip of the probe.

The second drawback to the two-terminal capacitance system is that the connecting cable acts as a large capacitor which is not stable with temperature. Changes in cable capacitance will appear to be the same as changes in vessel level. When this happens, there can be considerable errors in applications involving low dielectric materials. The errors and shortcomings found in two-terminal capacitance systems have been overcome by the use of three-terminal or Cote-Shield systems.

2.2 Three-Terminal Cote-Shield Point Level Controls

In comparing Fig. 2-2 with Fig. 2-1A, the major difference between the two circuits is the presence of a Cote-Shield amplifier in the three-terminal system. This amplifier is designed to have a gain of exactly "1", with its output being of voltage and phase identical to the input, but at a very low impedance, "Z". The output is connected to the shield of the coaxial cable and then to a shield ring on the probe that is called the Cote-Shield element. Ground is carried along the same cable, as a separate wire, and connects the chassis ground of the electronics to the vessel. This causes the outside of the vessel to be ground.

Observing the waveform diagrams in this figure, both the center wire and the shield wire of the coaxial cable are at exactly the same voltage and phase at all times. Since they are always at the same potential, there can be no current flow through the insulation capacitance of the cable. Thus there is no change in calibration due to the temperature

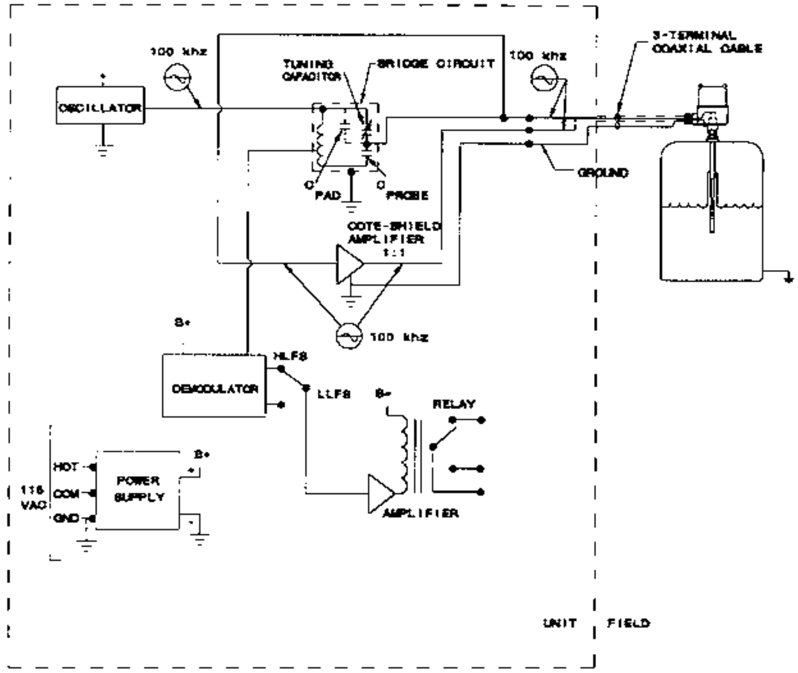


Figure 2-2
Three-Terminal On/Off
Cote-Shield Level Control

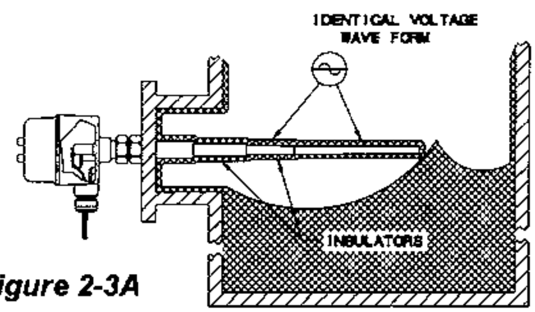


Figure 2-3A

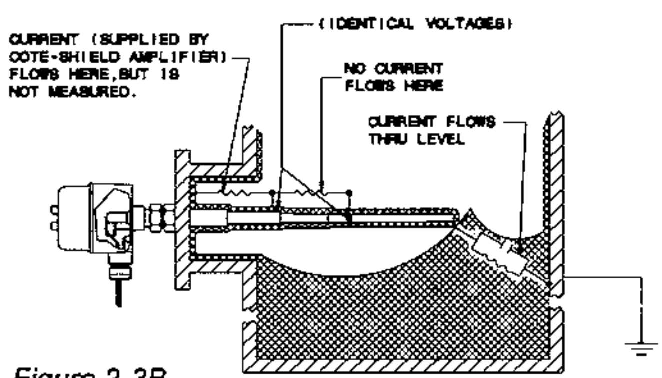


Figure 2-3B

effects of the cable. This makes it possible to lengthen or shorten the cable connecting the probe to the electronics without changing the original calibration. This is not true with two-terminal capacitance systems.

Fig. 2-3A shows an exaggerated view of how a coating may look in a level control system. Fig. 2-3B shows an electrical equivalent circuit of this coating left on the probe. The center wire of the coax is connected to the center rod of the probe, and the shield of the coax is connected to the middle element of the probe, called the Cote-Shield element. The ground wire of the cable is connected to the condulet and, therefore, to the vessel body. As in the case of the coax, since there is no difference in voltage between the probe element and the Cote-Shield element, there can be no current flow through any resistance due to the coating that may exist on the insulator.

The electronic instrument measures only the current that travels from the probe or sensing element center wire to ground, and this can only occur through the actual material being measured. There will be a current flowing from the Cote-Shield element to the vessel wall because of the potential difference that exists there.

However, this current is not measured, and will not cause the instrument to indicate high level. When the level in the vessel does rise and touch the center rod of the sensing element, it causes a current to flow that is sensed by the demodulator and causes the relay to change states.

2.3 Three-Terminal, Two-Wire Cote-Shield Point Level Controls (LCT™ Level Control Transmitter)

The next logical development in on/off level controls is the three-terminal control which transmits data by means of the classic two wire loop. Theory of operation is very similar to the three-terminal control described earlier, except the power supply and output portions of the circuit are remotely mounted in the control room where they are normally used. This is particularly true when the LCT is used as an alarm system for overfill/ high level protection. See Fig. 2-4.

Although the field-mounted unit functions much like the line-powered unit described earlier, there are some unique differences. The two wires carrying the 24-volt power to the electronic unit in the field also indicate whether the level is above or below the sensing element set point. The receiver system measures the current drawn by the transmitter. For instance, when the current is 15-20 mA, the transmitter is in the "normal" condition. When the "alarm" condition occurs at the sensing element, the current drops to 4-10 mA and the receiver system signals "alarm".

If the current being drawn by the transmitter is other than the normal or alarm range, there is a loop malfunction. There are two basic types of receivers. One is the simple line fail-safe type. It provides continuous self-checking diagnostics with a common output for both alarm and loop malfunction conditions. The other type, known as "line-monitoring", has an additional status output which differentiates a fault condition (instrument failure or signal loop malfunction) from an alarm condition.

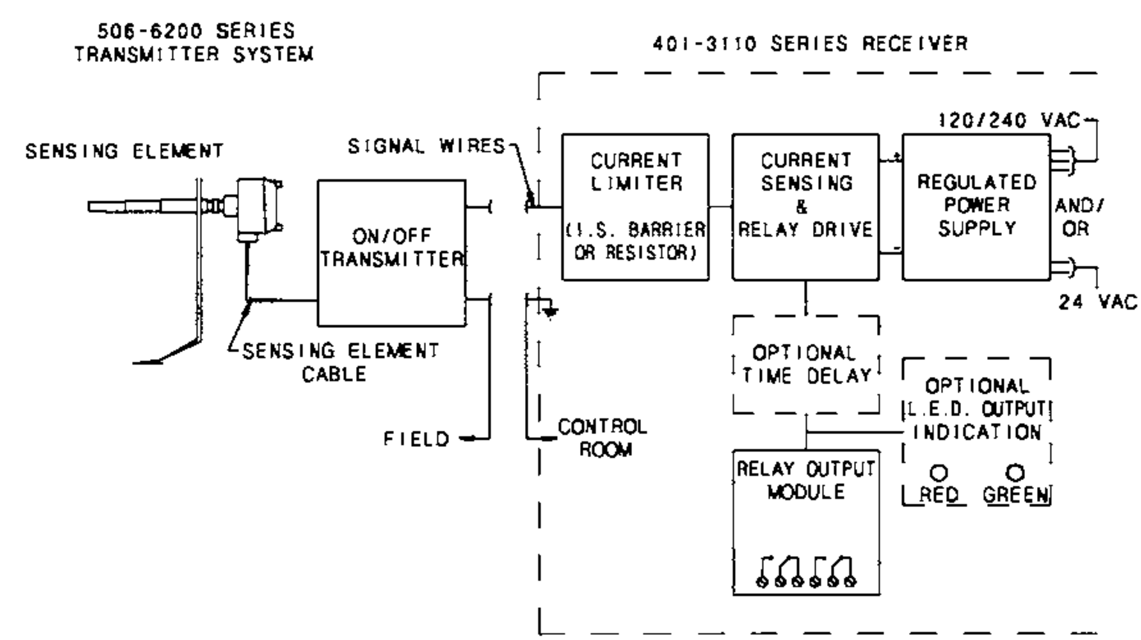


Figure 2-4

There are a number of important benefits to this three-terminal two-wire approach.

2.3.1 Intrinsic Safety

The transmitter and signal wires are intrinsically safe with or without separate barriers, and need not be in rigid conduit.

2.3.2 Remotely Mounted Relay Contact Outputs

Usually the alarm outputs are needed in the control room to actuate alarms and annunciators. With this system, the outputs are already in the control room.

2.3.3 Greater Personnel Safety

There is greater personnel safety because only 24 volts dc is present in the field mounted transmitter. It can be checked safely when powered ("hot").

2.3.4 Self Checking/Diagnostics

The LCT two-wire system has self checking diagnostic capabilities and will set off an alarm if there is a loop or instrument malfunction.

2.3.5 Push-button Calibration and Level Verification

Some models of the LCT two-wire point level control are available with digital, remote calibration and level verification for maximum calibration security and operator convenience. See Section 5.5.

2.3.6 Verify™ System Function Validation Circuit

In theory, a high level alarm system is installed in a vessel to indicate when material has reached a given point The intent is for the system to prevent dangerous overfill conditions.

In practice, however, a vessel may go for months or even years without ever experiencing a high level condition. It is imperative that the high level alarm actually function when called upon to do so.

The Verify switch offered by Drexelbrook Engineering simulates the effects of a high material level by imposing a calibrated amount of capacitance to the level sensor. By actuating the switch, the entire control loop is checked and verified. If any part of the system is non-functional, the Verify circuit will no indicate an alarm condition.

When comparing system check features offered by different manufacturers, it is important to understand exactly what is being offered. Many companies offer "self-check" or "system function validation" options which only check the function of the transmitter. This type of test does nothing to insure the integrity of the sensing element, wire connections, or calibration. The Verify circuit offered by Drexelbrook Engineering meets or exceeds the following regulations:

- NFPA 30, section 10.2
- NJ uniform fire code, NJAC 5:18-1 et seq
- EPA oil pollution prevention act of 1990
- EPA storm water run off requirement
- EPA spill prevention control & countermeasure (SPCC) plan
- Superfund amendment & reauthorization act (SARA) section 313
- OSHA process safety management of highly hazardous chemicals

All of the above advantages lead to the single great advantage of lower installed cost. In the not-too-distant future, most point level controls will probably be of the three-terminal, two-wire type.

2.4 Three Terminal Cote-Shield Multipoint Level Controls

The Multipoint Series electronic unit is designed for use with a two-terminal sensing element and three-terminal coaxial cable.

On/Off Theory

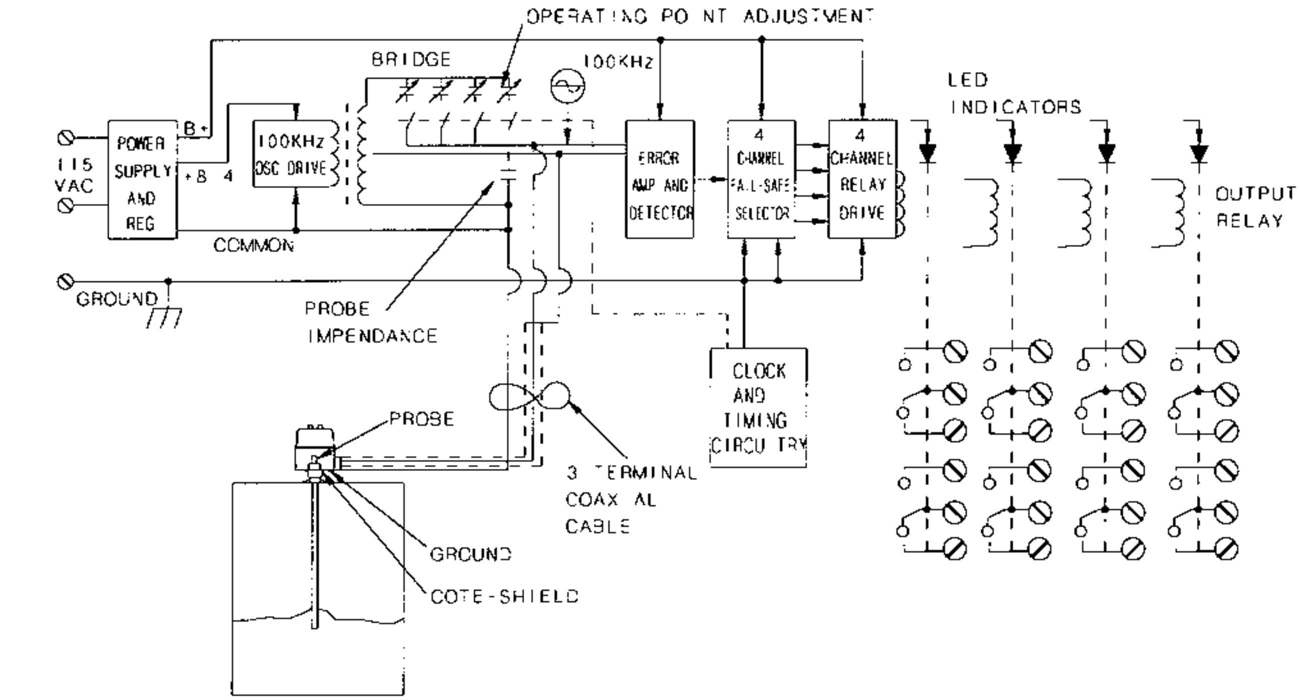


Figure 2-5

The electronic unit accepts 120 Vac (optional 230 Vac field changeable) and the internal power supply circuit provides a suitable voltage to operate the rest of the circuitry. See Figure 2-5.

The bridge circuit converts the sensing element admittance (determined by material level) into an ac error signal. The bridge is energized by a 100 KHz RF voltage from the oscillator.

The transformer side of the bridge contains a tape which serves as the bridge reference.

The capacitance side of the bridge circuit contains both the RF admittance information measured at the sensing element, and the operating point adjustment capacitor. The adjustment capacitor is set by the user so that the electronic unit switches states at a preset admittance level, determined by material between the sensing element and ground.

The change in admittance measured by the electronic unit is provided by the sensing element. The sensing element is mounted vertically from the top of the vessel.

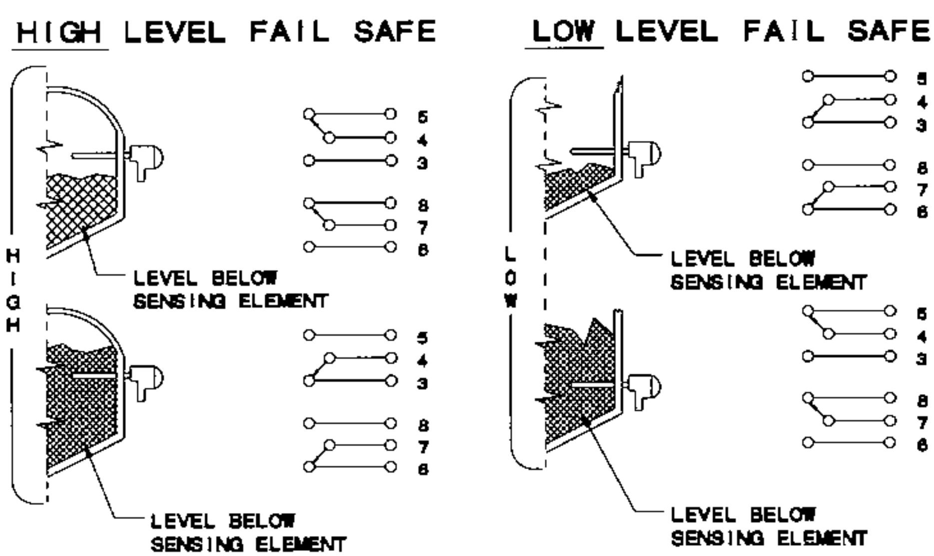
This unit uses a three-terminal coaxial cable to connect the sensing element to the electronic unit. The center wire of the cable carries the admittance information from the probe to the electronic unit, while the coaxial shield (Cote-Shield) is driven at the same potential. This prevents any current from flowing through the insulation of the cable. Because there is no current flow through the cable capacitance, any change in capacitance due to temperature or change of length in the cable will not change the original calibration.

2.5 Fail-Safe

In each of the examples in Fig. 2-6, the demodulator, which changes the ac voltage coming from the bridge circuit to a dc voltage, has a circuit to make the instrument either high-level fail-safe or low-level fail-safe. This means that the relay will de-energize with high level if the unit is in high-level fail-safe, and will de-energize with low-level if the unit is in low-level fail-safe. It is important to remember that, if the fail-safe link is changed, the meaning of the contacts changes with it. That is, a different set of contacts is closed with high level. Generally speaking, high-level fail-safe connection is used when the sensing element is intended to sense a high level, and low-level fail-safe connection is used when the sensing element is used to sense a low level. Always check the specific instrument instruction manual to verify which contacts are closed with intended level.

In the case of the two-wire control, low-level fail-safe (LLFS) produces a 4-10 mA signal with the probe uncovered. High-level fail-safe (HLFS) produces a 4-10 mA signal with the probe covered. As stated before, a change of fail-safe changes the alarm contacts in the receiver.

Typical Relay Connections vs. Level
Fig. 2-6

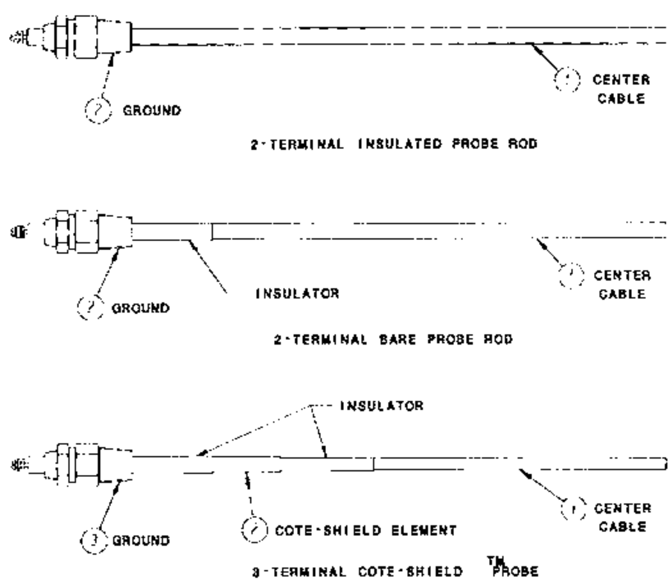


3.0 SENSING ELEMENTS (PROBES)

3.1 Theory (On/Off)

The sensing element used with RF level controls is nothing more than a conductive rod or plate that changes electrical impedance to ground when the material to be measured changes level on or near the sensing element. As discussed in Section 2.0, theory of point level controls, there are two major types of probes: two-terminal and three-terminal.

Two-terminal sensing elements may have an insulated or uninsulated center rod. Most three-terminal sensing elements have uninsulated center rods. See Fig. 3-1.



Typical On/Off Probe Styles
Figure 3-1

The simple capacitance instrument can be used only with two-terminal sensing elements. The more advanced three-terminal Cote-Shield electronic units can be used with either two- or three-terminal sensing elements. However, they are most often used with three-terminal sensing elements. See section 2.2 for electrical advantages of three-terminal systems.

3.1.1 Two-Terminal Sensing Elements

The only advantage of the two-terminal bare probe may be a slightly lower cost. [Bare metal probes (Fig. 3-2B) should be used only to measure materials that are known to be insulating.] If the material is insulating, the capacitance between the sensing element and ground increases as the level increases.

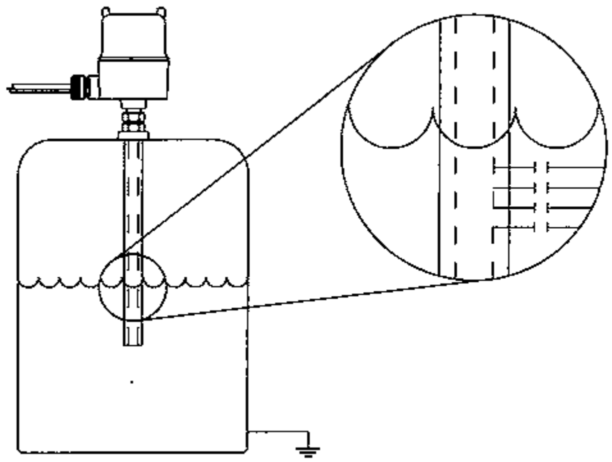
On the other hand, if the material is conductive, the probe will be shorted to ground. The system may or may not work, depending on design of the electronic unit. At best, the operate point will be at the tip of the probe and cannot be adjusted.

With the insulated probe, whether the material being measured is insulating or conductive, the sensing element will see an increasing capacitance with increasing level. In other words, a two-terminal insulated probe works with insulating or conductive materials, and the operate point can be adjusted over the entire probe.

3.1.2 Three-Terminal Sensing Element

Three-terminal Cote-Shield sensing elements should always be used in applications where the material being measured is conducting and leaves a coating on the probe. In such applications, the sensing element is mounted either horizontally at the desired level or vertically with the insertion length stopping at the desired level. For conducting materials, the operate point will be the lowest point on the active sensing element. Refer to Section 5.0 CALIBRATION for more detailed explanation of what happens electrically at the probe.

Figure 3-2A
Two-Terminal Insulated Probe



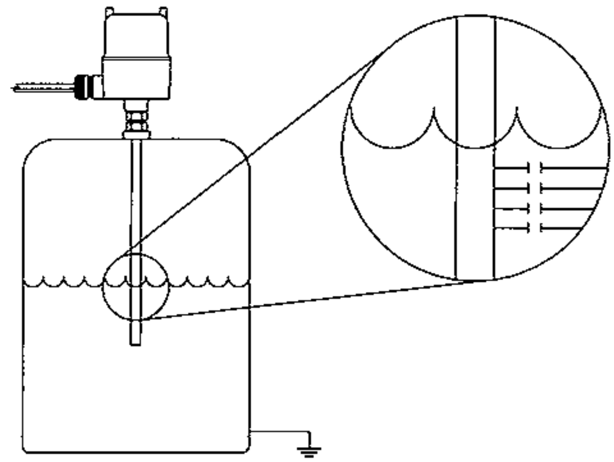


Figure 3-2B
Three-Terminal Bare Probe

For insulating materials, a vertically mounted three-terminal sensing element may have the operating point adjusted over the entire active length of the rod (between the Cote-Shield length and the insertion length [see Fig. 3-3]).

A horizontally mounted probe has the advantage of much greater capacitance change per inch, but will always operate within a fraction of an inch of its lowest active point.

3.1.3 The Vapor Stage

Many people are concerned that the effect of gases, vapors, steam, or just humidity in the vapor stage above the level will cause inaccurate readings. This is almost never a problem. The dielectric constants and conductivities of all gases, vapors, etc., are so minute as to closely resemble a vacuum. The only exception encountered thus far has been the vapor of an organic material compressed to several thousand psi, which squeezes more molecules into the available space. Even in this example, the error was relatively small and could be zeroed out by the instrument.

3.2 Mechanical Considerations (On/Off)

3.2.1 Temperature

Each sensing element is rated for a specific maximum temperature which is usually tied to a pressure rating. For example, 400°F at 10 psi, 300°F at 100 psi. This maximum takes into consideration the temperature ratings of the insulating elements, and their ability to maintain a pressure seal at those temperatures.

3.2.2 Pressure

The pressure rating of a sensing element refers to the maximum tested pressure at which the pressure seal is known to be satisfactory. Based on proven experience, it is not necessarily the maximum pressure rating for a particular sensing element.

Occasionally, a sensing element will leak at a pressure lower than the pressure rating. If that is the case, leaking is most often caused by a "cycling" of applied pressure and temperature. This malfunction can generally be corrected by retorquing the compression plug with a torque

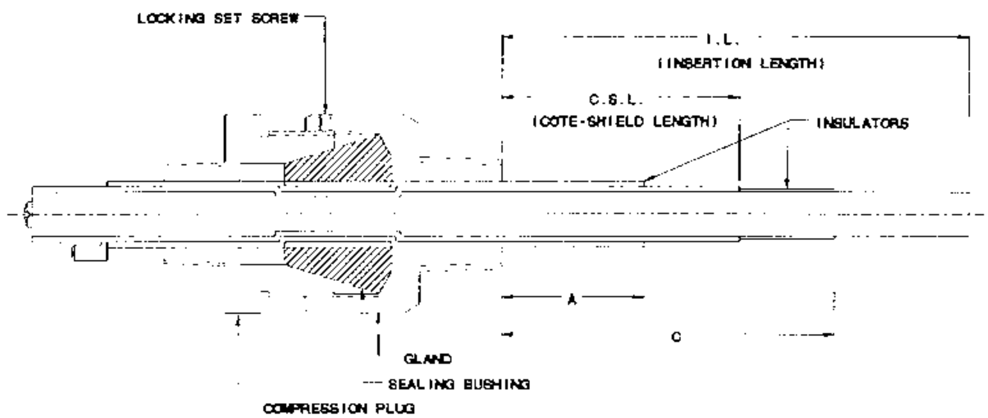


Figure 3-3
Three-Terminal Cote-Shield Probe
(Typical Construction)

wrench (Fig. 3-3). Consult the factory for specific torque values and procedures for each probe model. It is important to be sure this loosening is not caused by pressure/temperature combinations which exceed the probe rating under some conditions. (See Sections 3.6 and 3.7 for hermetically sealed Seal Tyte™ and Perm-A-Seal™ sensor designs.)

3.2.3 Mechanical Strength

Sensing elements are available in a variety of designs to suit most application requirements involving material forces, such as those created by an agitator in a vessel or material falling on the sensing element. In many cases, a probe may be safely shortened to reduce bending movement caused by these forces.

3.2.4 Compatibility of Materials

Sensing elements may be fabricated from a variety of materials. Among the metals are 304 stainless steel (the standard), 316 SS, carbon steel, Hastelloy B & C, titanium, tantalum, and others.

Among the insulators are Teflon* (the standard), ceramic, glass, polyethylene, rubber, and others.

Sensing element descriptions generally indicate standard materials of construction, and should be checked for compatibility with the process material(s), against chemical attack.

3.2.5 Mounting

Most sensing elements come with a male threaded connection as the standard mounting method; for example 3/4" NPT. However, most are available with a wide variety of standard and special flange mounts. Consult the factory for your particular requirements.

3.3 Options and Accessories

The following options and accessories are available for use with many of the available sensing elements:

A. Various threaded and flanged mountings, including 3A approved sanitary fittings.
B. Cooling extensions
C. Ground rods
D. Rear mountings
E. Multiple probes on a flange**
F. Inactive sections
G. Probe removable under pressure
H. Secondary seals
I. Specifically bent probe rods
J. Probe support bushings

K. Anchors and weights for flexible probes
L. Condulets
  a. With corrosion-resistant coating
  b. Condulet sealing kits
  c. Condulet-mounted spark protector
  d. Condulets close-coupled to the electronics
M. Variety of general-purpose and high-temperature cables
  a. Self-recoiling hose for cables
  b. Quick-disconnects for cables
  c. Junction condulets to splice cables
  d. Cable termination kits

* Teflon trademark of the DuPont Company
** Special precautions must be taken to avoid crosstalk

3.4 Theory (Continuous Probes)

Sensing elements used to make analog measurements of level are mostly of the two-terminal insulated type (Fig. 3-4A). Bare probe rods (Fig. 3-4B) may be used when the material being measured is known to be insulating, as in asphalt at 400°F.

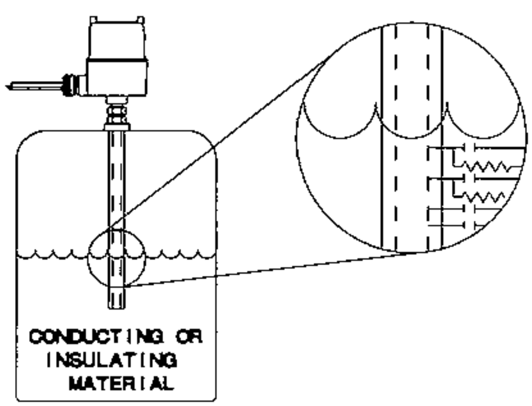
A three-terminal probe should be used where large temperature changes and low span capacitance could cause significant drift.

The insulated sensing element may be used whether the material is conductive or insulating. In a continuous level application, the sensing element must provide a change in capacitance that is proportional to the change in level being measured.

For a detailed discussion of how continuous or analog systems work, refer to Section 7.0 THEORYOF OPERATION.

The two-terminal insulated sensing element always presents a capacitance to the electronic unit, although there is a resistance effect. When the material being measured is insulating, there are two capacitances in series. The first is that of the insulation; the second is due to the dielectric constant of the material being measured. The first is called the saturation capacitance. This may be calculated by using the log of the ratio of the diameter of the insulation (D2) to the diameter of the metal rod (D1) and the dielectric constant of the insulation. The formula for the saturation capacitance, with a sample calculation, is found in Fig. 3-5.

Figure 3-4A
Two-Terminal Insulated Probe



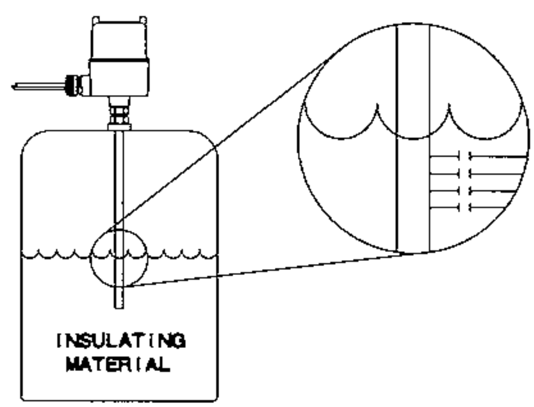
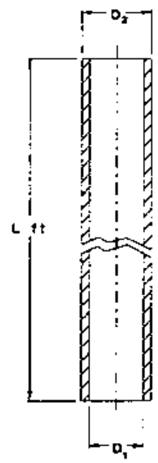


Figure 3-4B
Three-Terminal Bare Probe



$$\text{SATURATION CAPACITANCE IN PICO FARADS PER FOOT} = \frac{7.37\ (K)}{\text{LOG}\ \frac{D_2}{D_1}}$$

ASSUME: A 1-FOOT-LONG TEFLON INSULATED SENSING ELEMENT K=DIELECTRIC CONSTANT OF TEFLON=2

$D_2 = .75$ INCHES
$D_1 = .50$ INCHES

$$\text{SAT.CAP.} = \frac{7.37\ (2)}{\text{LOG}_{10}\ \frac{.75}{.50}} = \frac{14.74}{.176}$$

SAT.CAP. = 83.75 PICO FARADS/FOOT

Figure 3-5
Calculation of Saturation Capacity

3.4.1 Measuring Insulating Materials

The capacitance caused by the material being measured is determined the same way, using the insulation diameter of the probe and the inside diameter of the vessel (assuming the sensing element is mounted in the center of the vessel). The two capacitances, saturation and material, are in series and may be solved by the formula:

$$\text{Capacitance total} = \frac{(C_{sat}) \times (C\text{material})}{(C\text{sat}) + (C\text{material})}$$

Mathematically, it can be shown that the resultant capacitance is always less than the saturation capacitance. If the sensing element is mounted off center in the vessel, it is necessary to calculate the equivalent diameter of the vessel.

If the vessel is a horizontal cylinder, a sphere, or any irregular shape, the capacitance will be nonlinear with level when measuring an insulating material. In that case, some ground reference such as a concentric shield or ground rods should be used so that the sensing element sees a consistent ground reference. Be sure the concentric shield or stilling well has vent holes at the top.

3.4.2 Measuring Conductive Materials

When the material being measured is high in conductivity, compared to the capacitive reactance (Xc) of the sensing element saturation capacitance, the electronic unit sees only the saturation capacity—just as if ground were moved right to the outside diameter of the probe insulation. The output of the sensing element will be linear regardless of vessel shape or diameter. Conductive materials that leave a coating on the sensing element present a complex impedance that is not pure capacitance. This can cause a reading error and is discussed in detail in Section 7.0.

3.5 Mechanical Considerations (Continuous)

In addition to the mechanical considerations outlined in this chapter under on/off theory, there are other considerations for continuous level installations. Sensing elements used for continuous indi cation must be mounted vertically, and be long enough to extend the length of measurement. Forces on these sensing elements are sometimes very great and require special treatments. The distance from the sensing element to the vessel wall must be held fairly constant. Sometimes this may require extra-heavy-duty construction, a bottom anchor, or some sort of support. Contact the factory for specific recommendations for any long sensing element installation. In many cases, side supports are the least desirable solution, electrically, and mechanically.

3.6 Seal Tyte™ Hermetically Sealed Probes

Standard sensing elements are typically sealed through the use of a gland, seal bushing, and compression plug. The seal is accomplished by the compression plug compressing the sealing bushing into the gland and prohibiting any process material from leaking through the gland (packing) area (see Fig. 3-3). This method of sealing is standard throughout the industry and has proved highly

successful. However, recent technology gains in the plastics field have enabled Drexelbrook to develop a method of sealing which is far superior to the standard method described above. Sensing elements employing this new sealing technology are trade named Seal-Tyte™. This new method of sealing uses a hermetic seal between the probe insulation and either a flange face, or NPT gland mounting arrangement (see Fig. 3-6).
The advantages of this hermetic seal are obvious. There are no crevices for material to penetrate; therefore, there is virtually no possibility of leakage. Seal-Tyte™ sensing elements are especially useful for hazardous, corrosive, and osmotic-type materials (materials that have the ability to seep through the smallest crevice).

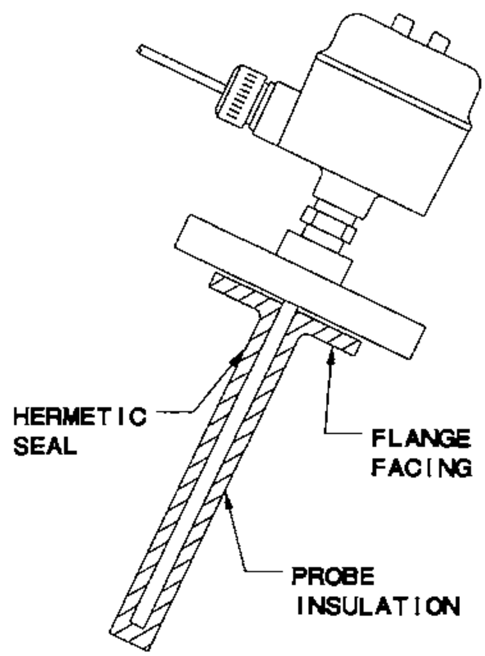


Figure 3-6
Seal-Tyte Sensing Element

3.7 Perm-A-Seal™ Injection Molded Point Level Sensing Element

Standard RF sensing elements are typically sealed through the use of a gland, seal bushing, and compression plug. The seal is accomplished by the compression plug compressing the sealing bushing into the gland which prohibits any process material from leaking through the gland (packing) area (see figure 3.3). This method of sealing is standard throughout the industry and has been very successful. Occasionally, however, sealing integrity can be lost due to temperature cycling (see section 3.2.2) or accidental loosening of the packing gland. To combat these situations, Drexelbrook Engineering has introduced a sensing element which has a patented injection molded design. This design totally eliminates the compression type packing gland. The Perm-A-Seal sensing element does not lose integrity when subjected to temperature cycling and, since there is no packing gland, it can not be accidentally loosened. The Perm-A-Seal sensor is particularly well suited to preventing fugitive emissions, hazardous materials, or wherever the utmost in sealing integrity is desired.

4.0 INSTALLATION OF RF LEVEL INSTRUMENTS

Often the success or failure of a level control application is determined by one or more installation considerations. The following section deals with some of the more important points to consider.

4.1 Enclosure

There are a variety of enclosures available for both the electronic unit and the sensing elements. The basic function is protection, which may take various forms.

4.1.1 Protection of Electronics or Sensing Element

Enclosures protect the electronics and sensing element from:

1. Weather
2. Corrosive atmosphere
3. Dirt and dusts
4. Washdowns during cleanup operations
5. Mechanical damage

4.1.2 Protection of the Plant

Enclosures also protect the plant from explosion or fire caused by ignition of gases or dusts by the electrical energy within the enclosure.

Probably the most common form of enclosure is the weatherproof type. Although its chief function is to protect against the weather, it also does a good job of protecting against dirt and dusts. The weatherproof enclosure may be made of a variety of materials including sheet metal, cast metal, and various molded plastic compounds. It can protect against a corrosive atmosphere if proper seals, and possibly air purging, are employed. Air purging is meant to keep the air pressure inside the enclosure greater than the outside, so that corrosive gases don't enter the enclosure. In a corrosive atmosphere, it is important that the construction material not be affected. Special corrosion resistant materials such as epoxy paint, stainless steel, and fiberglass are among the choices available.

To protect against washdowns where a high pressure hose is used, the weatherproof housing is generally not suitable, and a NEMA 4 type housing should be used. NEMA 4 housings typically have better gaskets and cover clamping mechanisms.

Tampering may be prevented by a variety of locks available for sheet metal housings.

4.2 Mounting Locations

Electronic equipment should be mounted where it is convenient and safe for instrument personnel to work on it. It should be mounted in an area away from excessive temperature, vibration, and corrosive atmospheres.

4.2.1 Temperature

Temperatures in excess of 140°F (45°C) are usually hazardous to electronics, as well as to personnel that work on the equipment. If a man can stand the temperature, so can the equipment.

4.2.2 Vibration

Vibration can be an enemy of long-term reliability. Although a properly designed electronic unit can stand a great deal of vibration, it is best to seek a location where the vibration is held to a minimum. If this is not possible, specify a unit that has been 'ruggedized'. This simply means that the components that have the greatest mass are specially supported so that vibration won't cause a premature fatigue failure.

4.2.3 Corrosive Atmospheres

Corrosive atmospheres are all too common in many industrial environments. First, mount the electronics where corrosive fumes are at a minimum.

Second, select a housing with the best sealing provision; this is often a NEMA 4 type housing. Then, consider air purging with a clean, dry noncorrosive air. Another option for electronic units is sometimes called 'tropicalizing', which is basically spraying the electronics with a fungus proof varnish that keeps the corrosive gases and moisture away from the electronic components.

As far as sensing elements are concerned, the condulet may be potted with a noncorrosive silicone rubber or paraffin wax. The outer surface of the condulet may be protected from corrosion by a coating of epoxy-paint or a heavy-duty PVC coating called Drexelcote™.

4.2.4 Electronics-In-Head Installations

Sometimes the worst of all conditions exists when the electronic unit is mounted in the same condulet as the probe head. In this type of installation, the electronic unit is frequently less handy and may not be as safe to work on as separated units. In addition, if the process is hot or contains corrosive materials, both electronics and personnel may be subjected to a potentially harmful environment. Electronics-in-head installation should be limited to measurements where temperature, vibration, and corrosive atmosphere are at a safe level. Usually, the benefits of electronics-in-head are a lower purchase price, lower installation costs, and more convenient installation.

4.3 Interconnections

Methods of interconnection between the sensing element, electronics, and control room and/or power source are determined by a number of factors:

1. Technical
2. Practical
3. Local and national codes
4. Plant standards

4.3.1 Technical

There are few technical requirements for the interconnections of RF level controls. For instance, there is no technical reason why the coaxial sensing element cables or 4-20 mA signal cables need be put into conduit. Three-terminal coaxial cable may be shortened without running into problems. However, two-terminal cables should be kept at their original length unless the correct compensation methods are used. Shielding is not needed for 4-20 mA signal leads, but is recommended for runs over 500 feet (150 meters), especially when the run is in close proximity to other wiring.

Ground loop problems are seldom encountered with the 4-20 mA signal leads. Most problems occur at much lower signal levels. Most RF level instrumentation has a maximum recommended coaxial cable length (between the probe and transmitter). **Do not** lengthen cable runs or substitute other cable types without consulting the factory that supplied the equipment. If cables are shortened, be sure to use special termination kits available for that purpose.

For troubleshooting purposes, it is often handy to have excess cable, a little longer than the sensing element insertion length, coiled up next to the sensing element condulet. With this arrangement, it may be possible to raise the sensing element out of the vessel without disconnection.

4.3.2 Practical

The practical considerations of interconnecting wiring are really common sense. Make sure connections are carefully made with some sort of strain relief provided. Protect the wiring from mechanical damage, and seal all housings from fume and moisture damage. Breather drains are commercially available to allow accumulated water to drain out of the enclosure. (See Fig. 4-1).

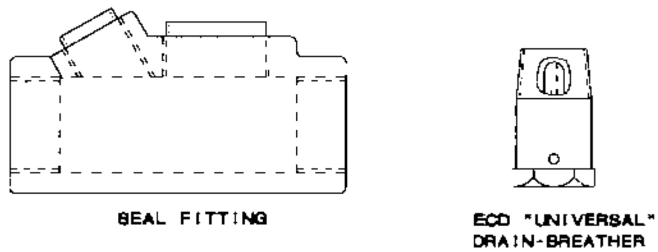


Figure 4-1
Conduit Seal Fitting

Also, keep in mind that many coaxial cables are hollow and may act as a conduit for moisture or corrosive vapors. In this case, potting the probe condulet is a practical defense.

If the temperature anywhere along the coax run can exceed 140F (60°C), high-temperature coax should be specified. Also, be sure the signal wire is correctly rated for temperature.

4.3.3 Local and National Codes

National codes vary throughout the world. Generally, the voltage applied to the wire determines the classification of the installation. Low voltage signal wiring generally has different requirements from power wiring. Consult the governing rules for each area.

4.3.4 Plant Standards

Plant standards generally follow local and national codes closely, but occasionally add a few requirements that rarely interfere with the expected operation of equipment.

4.4 Sensing Element Installation

First, a few general words about the proper installation of probes are in order. The most important thing is to protect the insulation on the sensing element against cuts and scrapes during installation. Very often, rough handling while lowering a large sensing element into its nozzle has caused permanent damage. Once the sensing element has been installed and tightened down, connect the spark protection, if supplied, and then connect the cable. After the system has been checked out and calibrated, it may be desirable to pot the condulet and apply some antiseize material to the threads of the condulet lid. Also see Section 8.5.2 for a discussion on spark protection.

4.4.1 Mounting Location

The mounting location is often determined by placement of nozzles or openings in the vessel. The sensing element should not be placed in a fill stream. When there is no suitable location inside a vessel, an external sidearm or a float cage should be considered.

4.4.1.1 Insulating Liquids

Location of the sensing element and vessel geometry are extremely important. For maximum linearity and accuracy of continuous level measurement, the sensing element must be parallel to a grounded reference point. Concentric shielded probes, cage probes, and ground rods can be used to accomplish this. See Fig. 4-2. However, none of these ground elements is required with on/off systems.

Figure 4-2

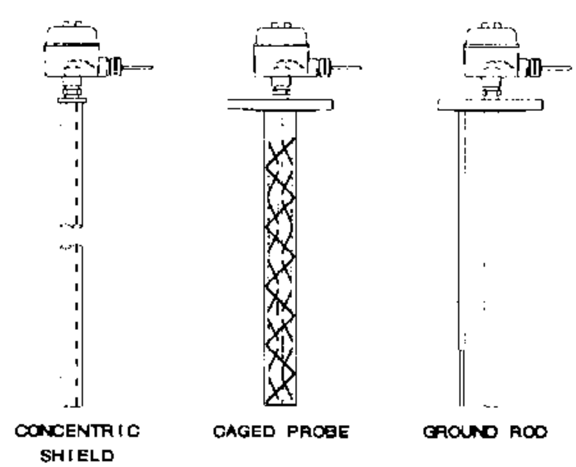
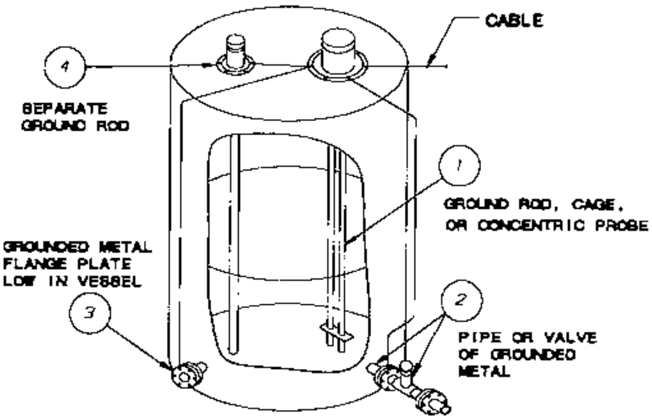


Figure 4-3
Four Ways to Ground a Nonmettalic Vessel



4.4.1.2 Conductive Liquids in Ungrounded Vessels

Mostly highly conductive liquids, particularly corrosives such as acids and caustics, are frequently stored in fiberglass or other nonmetallic ungrounded vessels. If the application calls for continuous indication, the sensing elements normally selected for these liquids are of high-capacitance-per-foot design. This makes the ungrounded vessel still more difficult to work with. In these applications, a sensing element with an integral ground element would normally be recommended. These ground elements are available in alloys and insulators which will withstand most corrosive liquids. Glass-lined vessels generally do not require ground rods.

Occasionally there may be a metal unlined pipe or other metal surface near the bottom of the vessel that can be attached to a ground.

In some cases, it is possible to provide an insulated ground rod if metals are unacceptable to the process (consult factory). Calibration after installing the ground rod is the same as for any level application. On/Off sensing elements rarely require ground rods.

If ever in doubt whether an application requires a ground rod, do the following:

Calibrate the system without the ground rod. Next, temporarily lower a grounded metal rod into the liquid. If the reading stays the same, you don't need the ground; if the reading goes up, you need the ground.

4.4.1.3 Mounting in a Vessel

When mounting a three-terminal sensing element in a nozzle, be sure the Cote-Shield extends through the nozzle, through wall buildup, and at least 2 inches (50 mm) into the vessel. See Fig. 4-4.

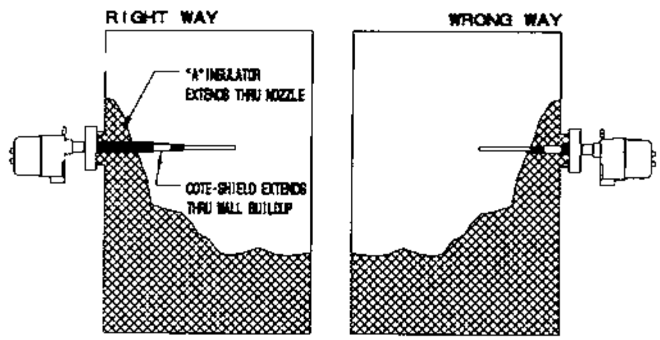


Figure 4-4
Three-Terminal Horizontal Probe Installation

4.4.1.4 Flexible Sensing Elements

Flexible sensing elements have a number of differences to be considered. Some are anchored and some are merely weighted. The choice depends mostly on the application and the characteristics of the material being measured. If the material is conductive, there is little difference in reading if the probe swings near the vessel wall; a weighted probe works well. If, however, the material has a low dielectric constant, the consistency of the distance to the vessel wall from the probe is important. If the vessel is highly agitated, then the probe should be anchored. If it is a storage vessel with only mild agitation, then bottom weights are generally sufficient.

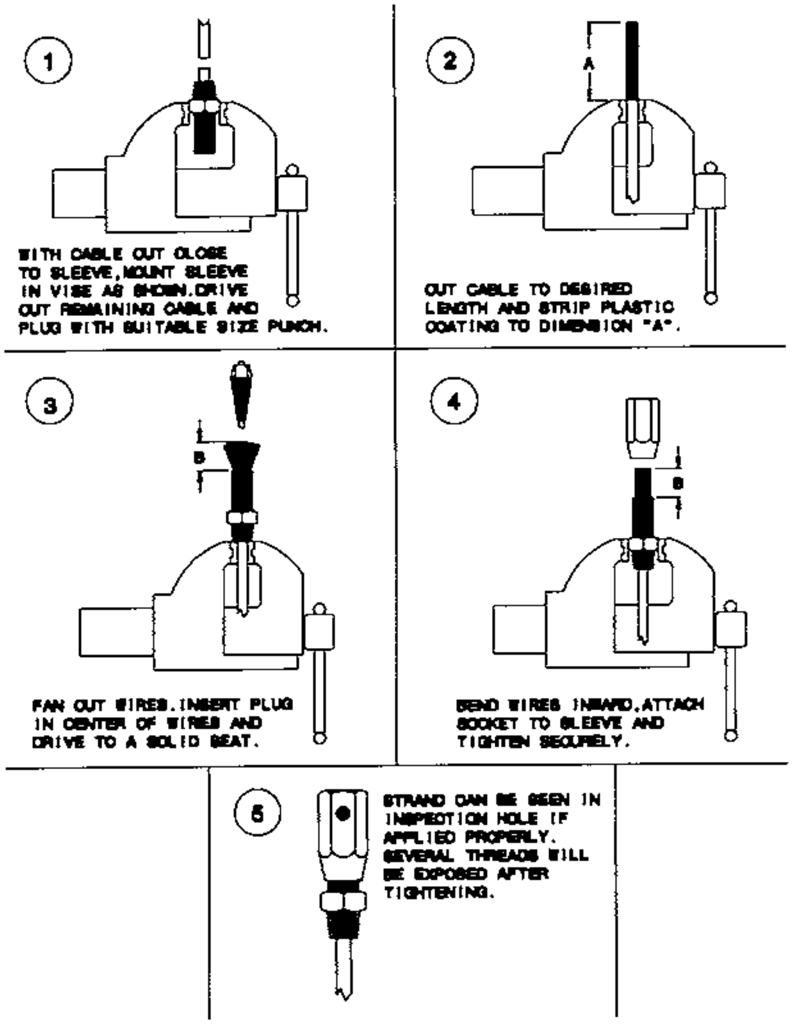


Figure 4-5
Field Shortening a
Flexible Cable Probe

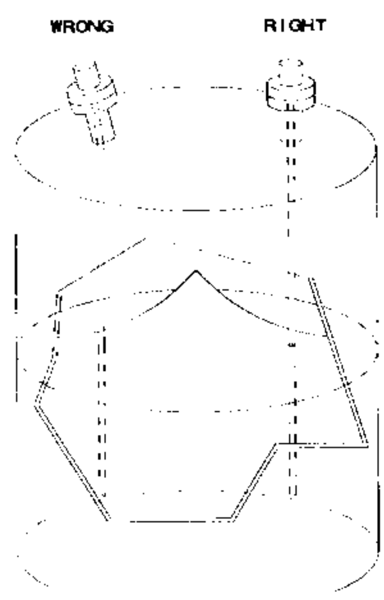


Figure 4-6
Flexible Cable
Probe Installation

There is a tendency for engineers, when specifying a flexible probe, to order it a few inches too long rather than have one too short. Sometimes this presents a problem. If there is too much slack, the cable can touch the side wall at some point. To shorten the cable in this case, remove the excess at the condulet and follow a procedure similar to that shown in Fig. 4-5.

If the sensing element is equipped with a slack adjusting feature, it should be adjusted only until the slack is removed. *Do not tighten* to the point of noticeable tension. If the cable probe enters through a nozzle, be sure the condition shown in Fig. 4-6 cannot occur.

Side supports are generally not recommended, as they often create more problems than they cure. If a side support is deemed necessary, it should be of rugged construction and similar to that shown in Fig. 4-7.

4.4.2 Open Channel Flow Probes

Sensing elements used to measure open channel flow must be mounted as shown in Fig. 4-8. The probe location in a flume is important for accuracy. Follow the recommendations of the flume manufacturer. The bottom edge of the sensing element must be at the elevation equivalent to zero flow. Zero flow is the highest water level that exists with no water leaving the flume. If an attempt is made to calibrate zero at some other point on the sensing element, notable inaccuracies will result.

Drexelbrook recommends installing a metal ground reference plate (in most applications) in the flow channel. The ground plate provides a stable reference for the sensing element to "see" and minimizes fluctuations in output signal due to variations in material conductivities. It should be a least 12 inches wide (except for smaller size Palmer Bowlus and Leopold Lagco flumes) and as long as the total insertion length of the sensing element. Consult factory if there is a question. The ground plate should be made of non-corroding metal, such as stainless steel, and be mounted per the installation drawing included with the flowmeter. In all cases, the plate should reach low enough into the flow channel to be in contact with the stream at all times, even during low flow conditions. Make sure that the plate does not cause turbulence or change the flow characteristics of the channel. Finally, connect the stainless steel ground wire from the ground plate to the ground screw on the sensing element. A Series 290 ground plate is available from Drexelbrook.

Leave enough slack in the coaxial cable so that the probe may be withdrawn from the flume and placed in a metal bucket to calibrate or verify calibration.

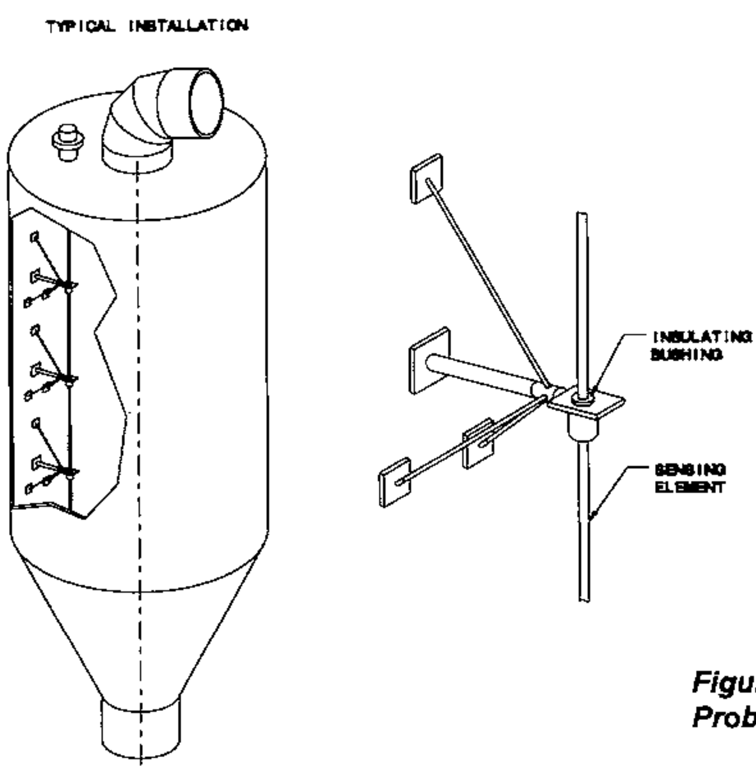


Figure 4-7
Probe Support Bracket

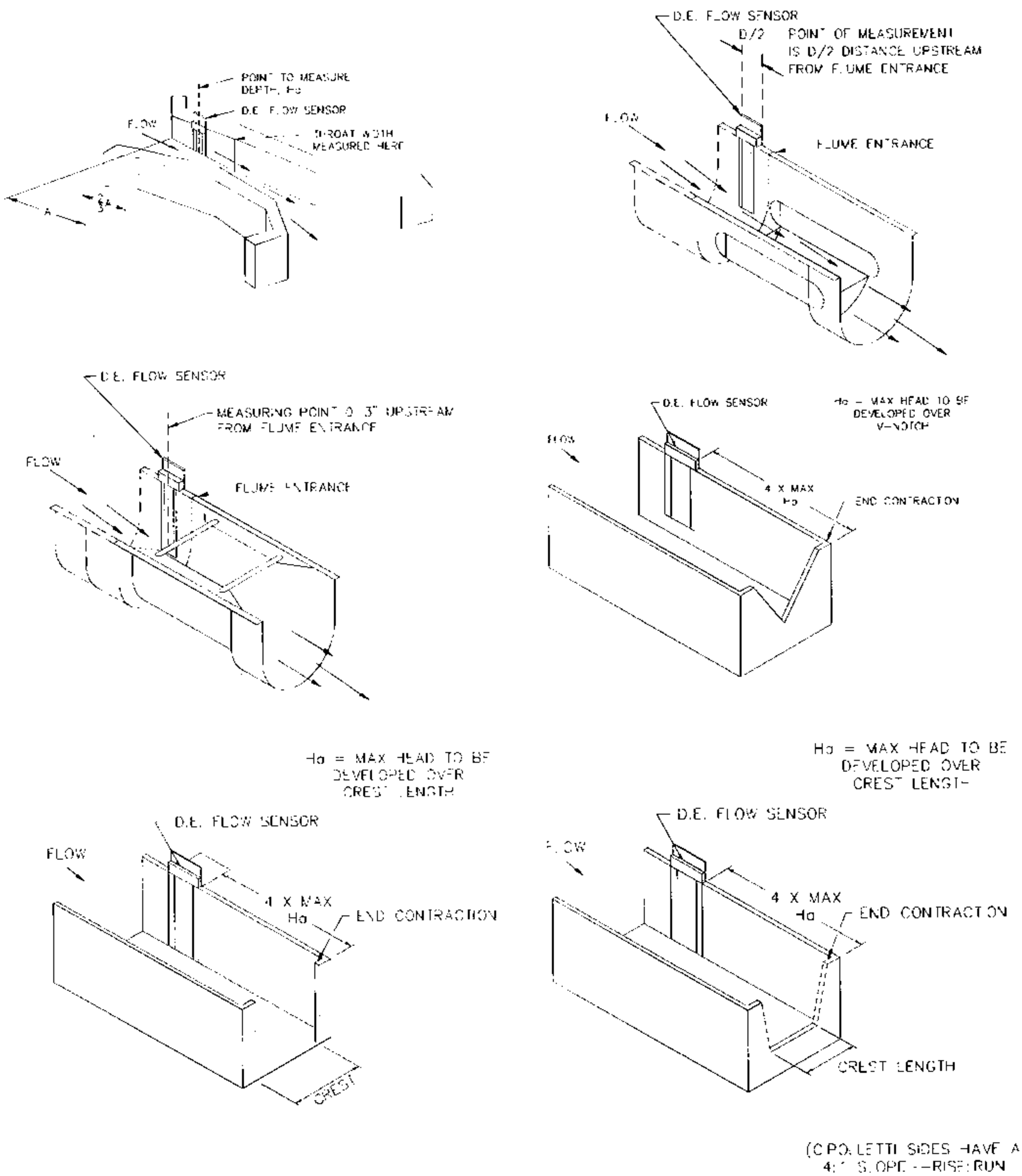


Fig. 4-8
Open Channel Flow Probes:
Mounting Requirements

5.0 CALIBRATION (ON/OFF)

5.1 Introduction (Manually Calibrated Instruments)

Probably the easiest, but most often incorrectly done, is the on/off calibration. Many old-time instrument people just turn the calibration adjustment until the relay switches, then believe they are finished. Chances are they will have to recalibrate after a short time, and accuse the instrument of drifting. Being familiar with what goes on during the process helps to calibrate the equipment correctly. For this reason, the theory of calibration will be described before the various methods of calibrating.

5.2 Theory of Calibration

In order to do a proper manual calibration of an on/off system, it helps to understand what is happening when making the adjustments. The electronic unit has a radio frequency bridge circuit that, when balanced (i.e. sensing element capacitance is equal to bridge capacitance), causes the relay to be on the edge of either the energized or de-energized condition. When the level of material at the sensing element increases, the capacitance increases and unbalances the bridge. The relay may or may not change state, depending on which state it was in to begin with. For example, a sensing element in an empty vessel might produce 8pF of capacitance. When the same sensing element is covered, it may produce 12pF (for a change of 4pF). The ideal place to set the calibration adjustment is where the mid-point (10pF) balances the bridge. This will provide a 2pF cushion to allow for changes in material, electronics drift, or other outside influences that may otherwise cause unreliable operation. The electronic unit typically only needs about .2pF to switch from energized to de-energized. In the above example, the sensing element is providing 20X the required changes, leaving ample margin for changes in material characteristic. See Fig. 5-1.

In systems normally supplied, no additional changes are required to calibrate the system. However, there are some instances where padding is required. This is required only when the operate point in air (empty vessel) exceeds the zeroing ability of the instrument, which is typically from 0-70pF*.

*Adjustment must not be turned past its stops, as this can easily cause damage.
This may occur when the material has a high dielectric, as in an interface, or in some longer sensing element applications. See Fig. 5-2.

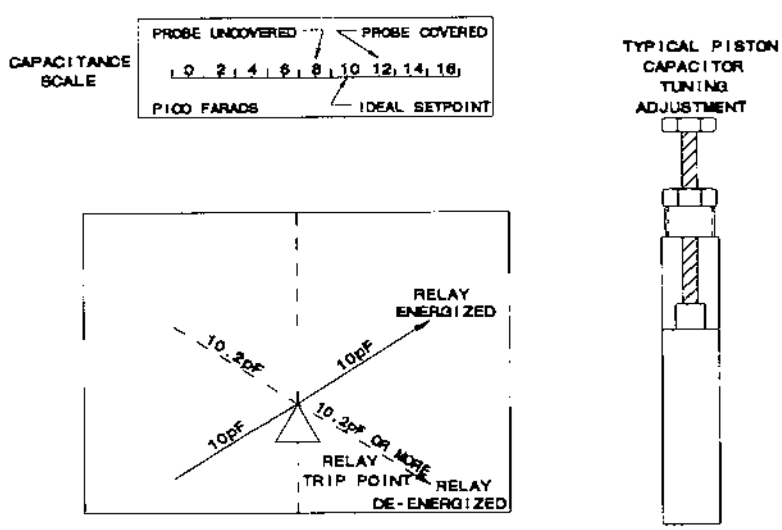


Figure 5-1

On/Off Calibration

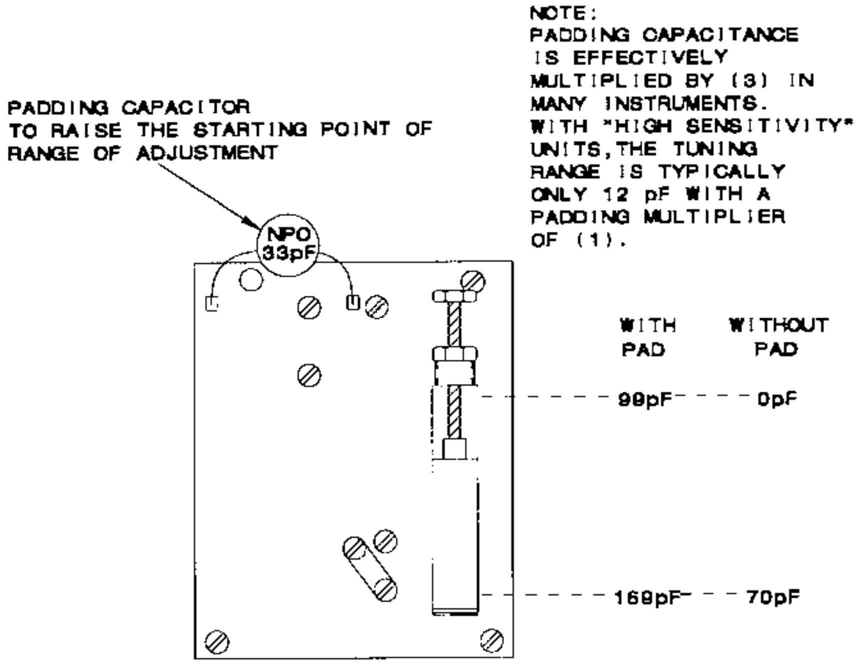


Figure 5-2

A padding capacitor, which is soldered onto two pad terminals, acts as an extension of the tuning adjustment on a 3:1 ratio), and is required when the sensing element standing capacitance exceeds the range of the unpadding unit. Generally, it is only needed on a probe with an unusually long active element. See Fig. 5-3.

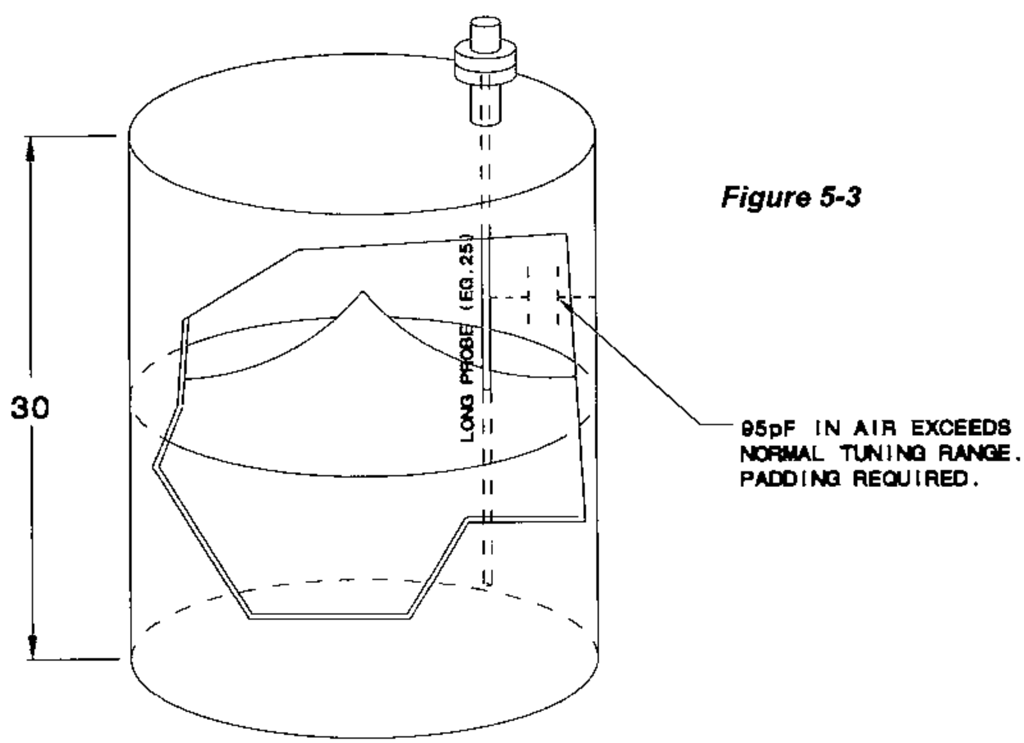


Figure 5-3

Figure 5-4

VERTICAL SENSING ELEMENT

HORIZONTAL SENSING ELEMENT

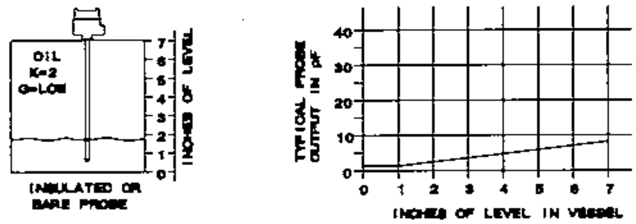


FIG.5-4A

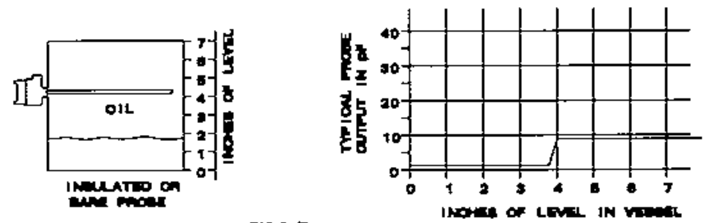


FIG.5-4D

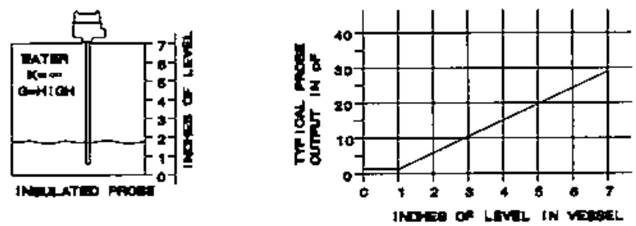


FIG.5-4B

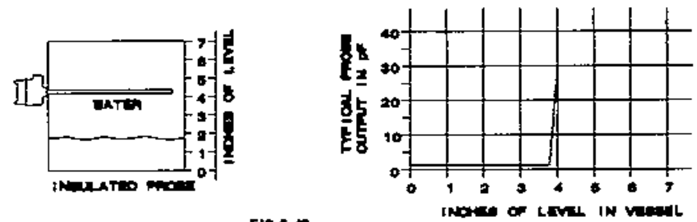


FIG.5-4D

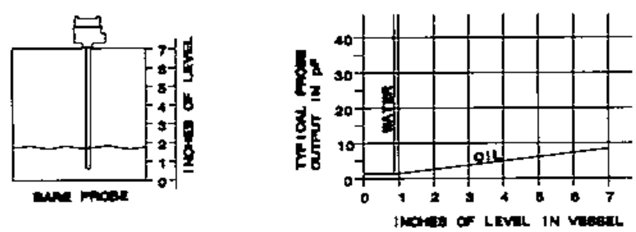


FIG.5-4C

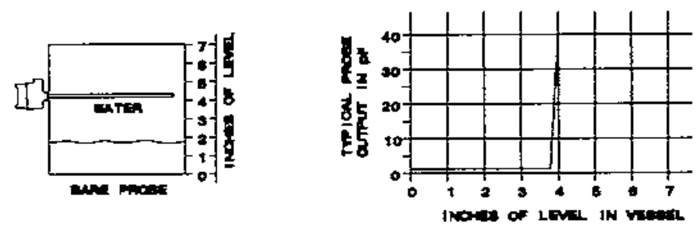


FIG.5-4D

ON/OFF INTERFACE

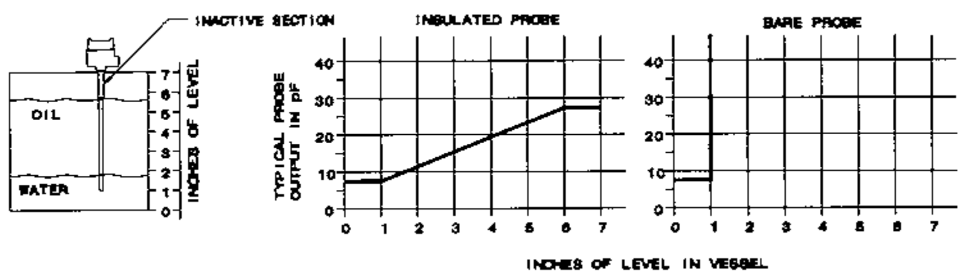


FIG.5-4G

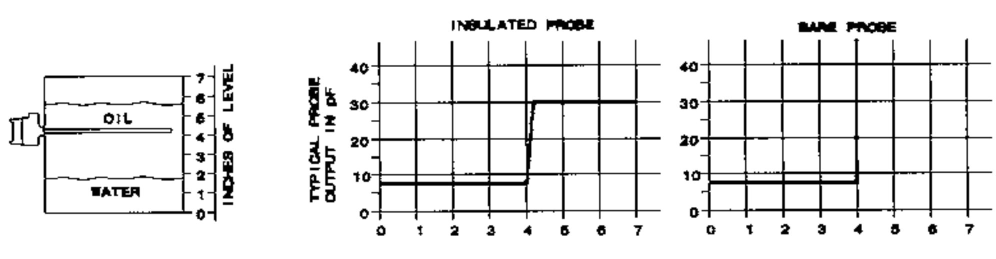


FIG.5-4H

On/Off Calibration

To further understand effects of mounting position, dielectric constant (K), and conductivity (G), study Fig. 5-4 (A through H). These figures show how sensing element output, in picofarads, is affected by several variables. The values given will vary in actual practice, but those shown are realistic.

The objective of the calibration procedures that follow is to put the operate point near the center of the change in probe output, between unimmersed and covered with material. Figures 5-4G and H show the effect of interface on output. In reality, all level measurements are really interface measurements between air and material. The word "interface" generally refers to detection of the separation line between two immiscible liquids.

Also, it must be determined whether the contacts are to open or close with high level or low level.

By studying Fig. 5-5, it can be seen how contact closure changes with level above the probe in high- and low-level fail-safe. Regardless of fail-safe, the relay is de-energized in failure conditions. When lit, the LED (Light Emitting Diode) on most instruments indicates a normal condition (relay energized) — ***not alarm condition!***

The second consideration in an on/off application is that the sensing element must produce enough change in signal to trigger the relay reliably and allow for material and environmental changes. There must be enough signal change to allow for variations in dielectric constant, ambient temperature, density, calibration error, etc. The change

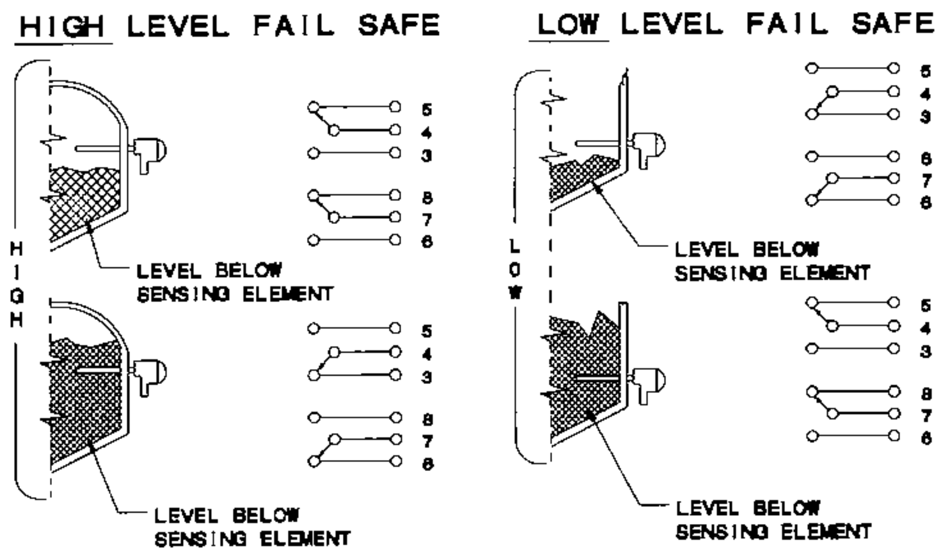


Fig. 5-5
Typical Relay Connections vs. level

5.3 Prior to Calibration

There are two considerations to keep in mind prior to calibrating an on/off instrument. *One is fail-safe*. Fail-safe means the relay condition that will occur in the instrument on loss of power, and on most internal failures of the instrument itself.

required is usually in the order of .2 pF for operation, and a similar amount for other factors. Ideally, a probe should produce a change of 3 pF or more. In most instruments, to change 1 pF requires 1/3 of a turn of the adjustment. This is usually the only adjustment for an on/off control.

Many people call this control a sensitivity adjustment, but it is not. It is an operate point adjustment only. Each full turn of the operating point adjustment typically changes the operating point by 3 pF. With high sensitivity units, .3 pF is considered adequate, and each adjustment turn contributes .6 pF of tuning.

5.4 Manual Calibration Procedures for Single Point Controls

5.4.1 #1 - Visual

With level at the desired operating point, adjust the electronics until the relay switch is in the correct condition. This method is only used with vertical probes when the level may be observed from outside the vessel, and a specific point on the probe is desired.

5.4.2 #2 - Blind

A blind setup can be used when the sensing element is horizontal. Find the operate point when the level is known to be well below the probe. Mentally record the position of the tuning adjustment pointer. Raise the level until it is known to be well above the probe. Find the new operate point, counting clockwise turns and fractions of turns of the tuning adjustment from the uncovered operate point. In some cases, it is possible to go all the way down to the stop and still not find a second operate point. Turn the tuning adjustment back until it is halfway between the operate points.

5.4.3 #3 - Without Raising Level

Lower the level in the vessel until it is known that the probe is uncovered, then start from the extreme counterclockwise position and go clockwise until the relay just operates, then go 1/2-turn further clockwise. This procedure should only be used when the material in the vessel is unknown, and/or there is no method of raising that material to the appropriate level at the time. The system should be tested as soon as possible, with the actual material to be used, to insure a reliable calibration.

5.4.4 Calibration for Interface

Interface calibration is the same as in #2, except that the nonconductive or least conductive phase is treated as air.

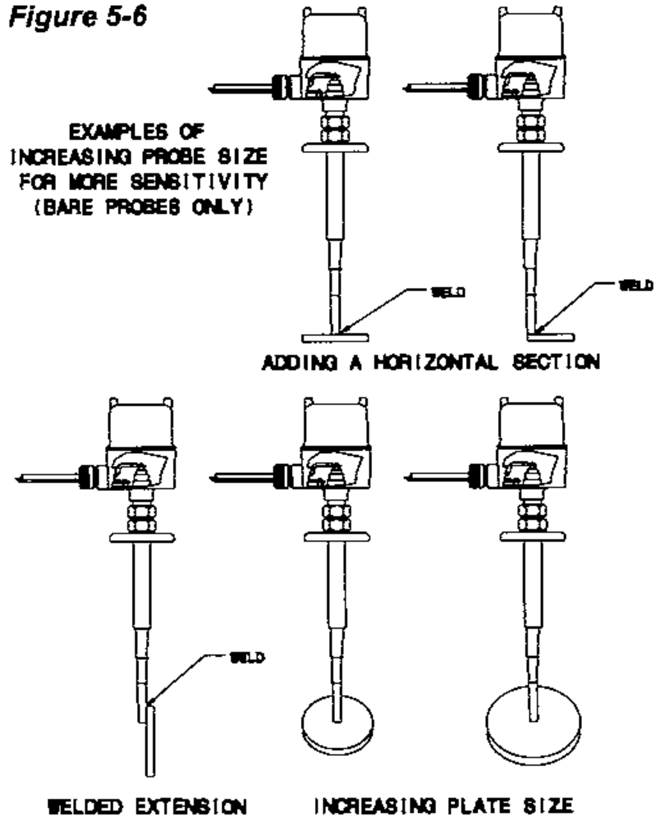
5.4.5 All Methods of Calibration

If less than 1/2-turn between operate points is found, it is suggested that the factory be contacted for further assistance. To increase C, and therefore the number of turns between operate points, it may be necessary to change probes, lengthen the active section of the probe, or add a ground. Operating with less than 1/2-turn between operate points will not be as reliable as it should be. See Fig. 5-6.

5.4.6 Highly Conductive Materials

Very conductive materials may require a change in probe geometry or a change in electronics. If you suspect your material is extremely conductive, call the factory for a recommendation.

Figure 5-6



5.4.7 Foam

An instrument may need to be modified when being used to ignore foam. This is done by adding various padding capacitors and/or a series of capacitors, at the center-wire connection on the instrument. Consult factory for specific requirements.

5.4.8 Calibration of Multipoint Controls

The Multipoint control has four setpoints and associated relays in one unit. Calibration procedures are the same as for a standard single-point on/off unit, except that each setpoint is calibrated individually.

5.5 Digital Calibration of Two-Wire Single Point Controls

With some models of two-wire point level controls, the calibration adjustments are made with an electronically switched capacitor network. Using a remote, push-button calibrator, the switched capacitor network in the transmitter can be controlled at the unit itself, in the control room, or anywhere the transmitter's signal wires are accessible. Because this type of transmitter accepts calibration instructions in the form of a special binary code, the transmitter's setpoint can only be changed by using the remote calibrator. Once the transmitter has been calibrated, the remote calibrator can also be used to verify the calibration. Refer to the appropriate instruction manual for specific calibration instructions.

5.6 On/Off Instrument Options

The following are some options generally available with on/off controls.

5.6.1 An Adjustable Differential

When it would be desirable to spread the pull-in and drop-out point of the relay over a predetermined distance on the probe, an adjustable differential can be added. This is still a single relay operation, but with a wide dead band. A typical application (Fig. 5-7) would be to start a pump when the level reads a high point, and turn it off when the level is low.

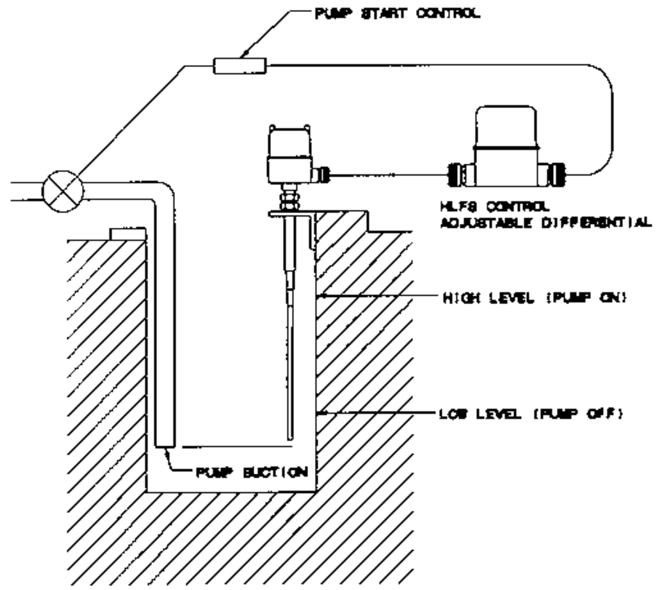


Figure 5-7
Typical Adjustable Differential Application (Control of a pump start and stop in a sump)

5.6.2 The Time Delay

This option can typically provide a time delay from 0-90 seconds. It is used to help alleviate variations

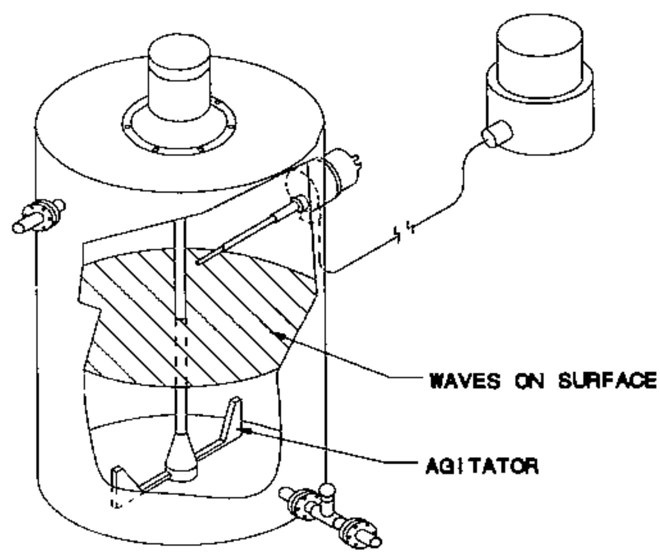


Figure 5-8
HLFS On/Off Time Delay Control

in the output due to agitation or frothing in the vessel. Please note that on most time-delay instruments, the delay applies only to recovery from the alarm condition. For a high-level fail-safe unit, the delay will be effective only on falling level. In Fig. 5-8, the output will indicate high level as long as the waves continue to touch the probe. It will recover the low level only after the time delay (since the last wave) has expired.

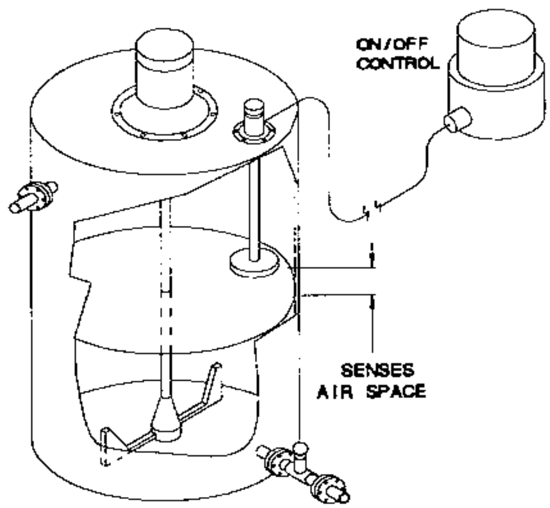


Figure 5-9
High Sensitivity On/Off Control
Using Proximity Sensing

5.6.3 High Sensitivity

High sensitivity is normally used only with very low dielectric granular materials, whose weight is less than 7 lb per cubic ft, in proximity applications (see Fig. 5-9), or where probe active length must be unusually short.

5.6.4 Multipoint

When two or more level trip points are desired on the same probe, a special Multipoint control is available. See Section 2.4 and 5.4.8.

6.0 TROUBLESHOOTING (ON / OFF)

6.1 Introduction

If there is a problem with your measurement system, divide the system into its component parts and test each part individually for proper operation. After each part has been tested and found to be functioning, there still may be a problem with the selection of equipment for the application. However, the problem is often an assumption made about what is going on inside the vessel. When possible, **test, don't assume,** and **don't rely on the opinion** of the operator as to the condition inside the vessel. Even sight gauges are sometimes misleading. The following troubleshooting procedures have been excerpted from typical on/off instrument instruction manuals. Although the procedures may vary slightly, depending on the model, they generally are similar to those presented here. Only a screwdriver, tuning wrench, and a multimeter are needed to do all the testing that follows. However, a calibration/test system is available and is more versatile for the plant that has a lot of instrumentation.

6.2 Testing the Electronics

Note: *This is a typical troubleshooting example. Consult instruction manual for exact procedure.*

1. Disconnect the coax cable from the **probe, Cote-Shield**, and **ground** terminals (shown in Fig. 6-1) at the instrument; leave power connected.

2. Starting with the adjustment in the extreme counterclockwise position, turn the insulated tuning wrench clockwise until the relay operates. (Adjust only with insulated tool sup plied.)

Note: *Do not turn the adjustment past its stops. This can cause damage.*

3. Slowly rotate the adjustment back and forth about this point, observing the travel of the pointer between relay pull-in and relay drop-out.

   The pointer should travel less than 1/8-turn to operate the relay. If so, the instrument is working properly.

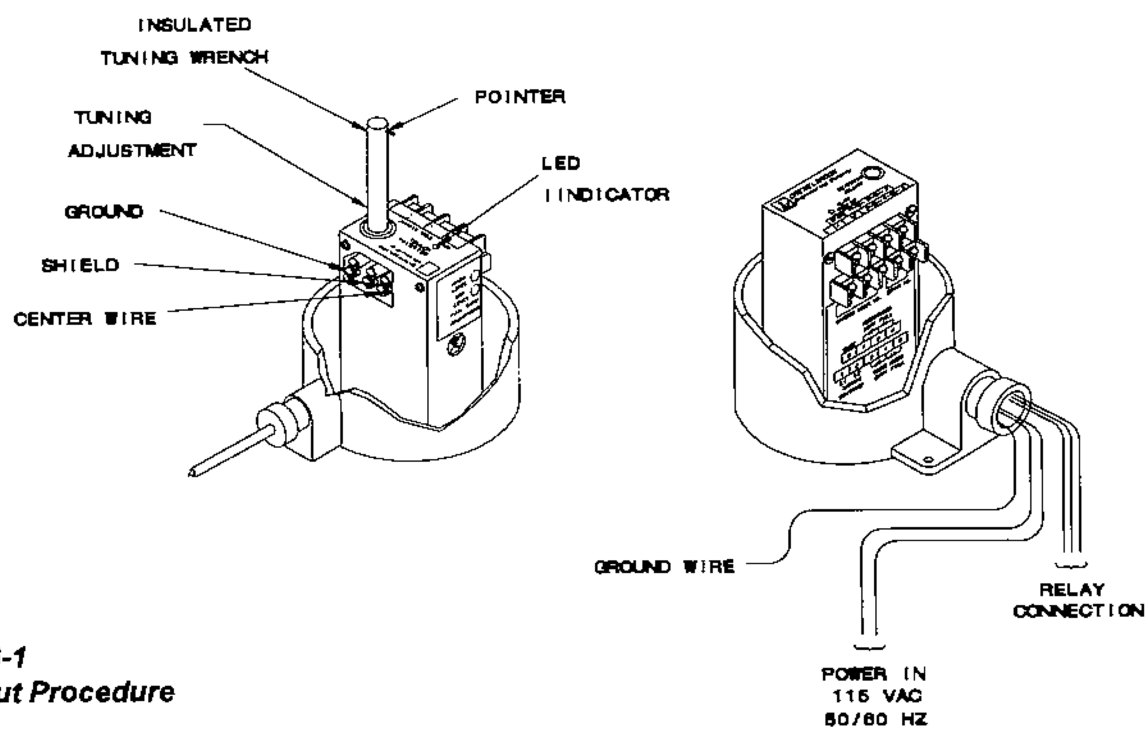


Figure 6-1
Checkout Procedure

6.2.1 Two-Wire, Three-Terminal On/Off Systems

Before testing a two-wire on/off system, mentally divide the system into two sections (see Fig. 6-2).

1. Transmitter electronics
2. Receiver electronics

6.2.2 Two-Wire Transmitter

1. Remove the sensing element cable and the two signal wires.

2. Connect the power supply and meter or calibration system as shown in Fig. 6-3.

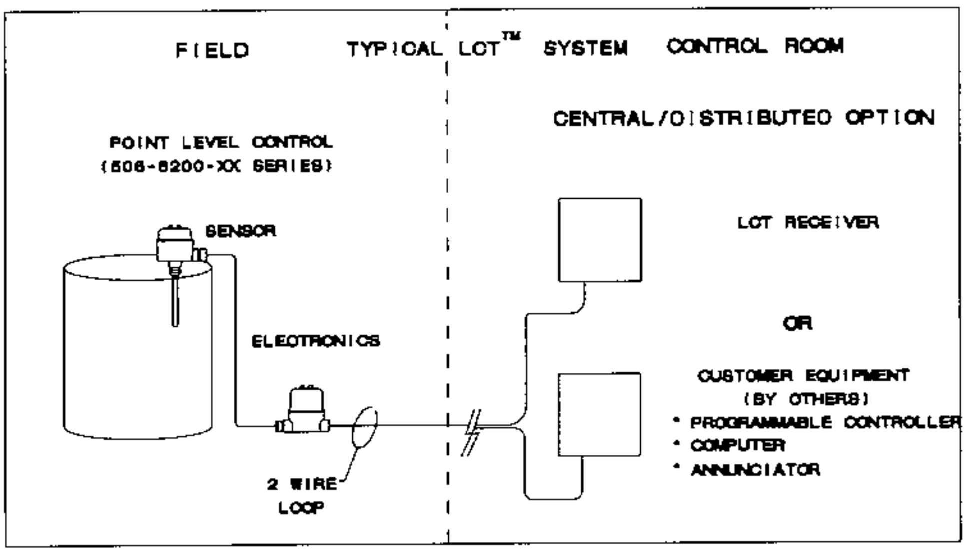


Figure 6-2
Two-Wire, Three-Terminal On/Off System

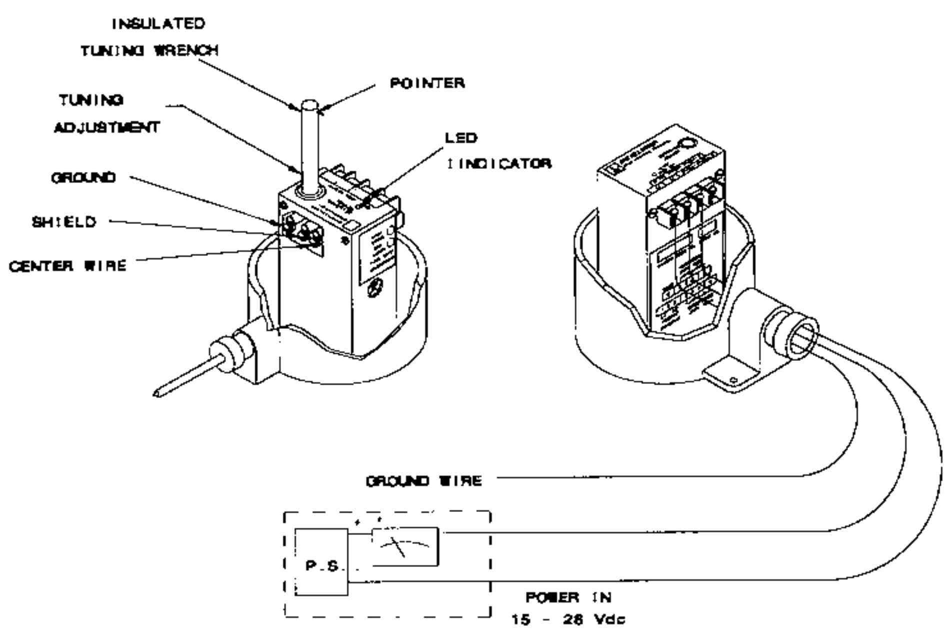


Figure 6-3
Two-Wire Checkout Procedure

3. Starting from the full counterclockwise position of the operating point adjustment, start turning clockwise until the LED indicator just changes state.

4. The meter should be between 4mA and 10mA (typical) with the LED unlit, and between 15mA and 20mA (typical) with the LED lit.

5. The rotation of the adjustment should be approximately 1/8-turn between LED ON and LED OFF.

If the above procedure checks out, proceed to the receiver check.

6.2.3 Two-Wire Receiver System

1. With all loops connected normally, look at all the LED indicator lights on the receiver package. See Fig. 6.4

A. Status monitor LED, if present, should be in 'normal'.

B. All receiver LEDs should indicate either 'hi' or 'lo' with all 'status' LEDs extinguished.

If A and B are true, go to Step 2; if not, go to Step 4.

2. Remove a '+' input wire from any input on the customer connection block.

A. The 'status' LED for that unit should light, also the status monitor LED should read 'fault'.

B. If the 'status' LED and the 'fault' LED do not light, momentarily add a jumper from the yellow wire to the green wire on the status monitor unit. The 'fault' LED should light. If not, replace the status monitor. If the 'fault' LED lights, check for broken or disconnected yellow wires. If the yellow wires are okay, replace the receiver.

C. Repeat Step 2 for all loops.

3. Connect a current source, or calibration system as shown in Fig. 6-4, in place of any transmitter.

A. Adjust the current source from 0-20mA while observing the meter, and check the LED indicator operation against the diagram in Fig. 6-5.

B. If okay, check each remaining level alarm. If not okay, replace that level-alarm module.

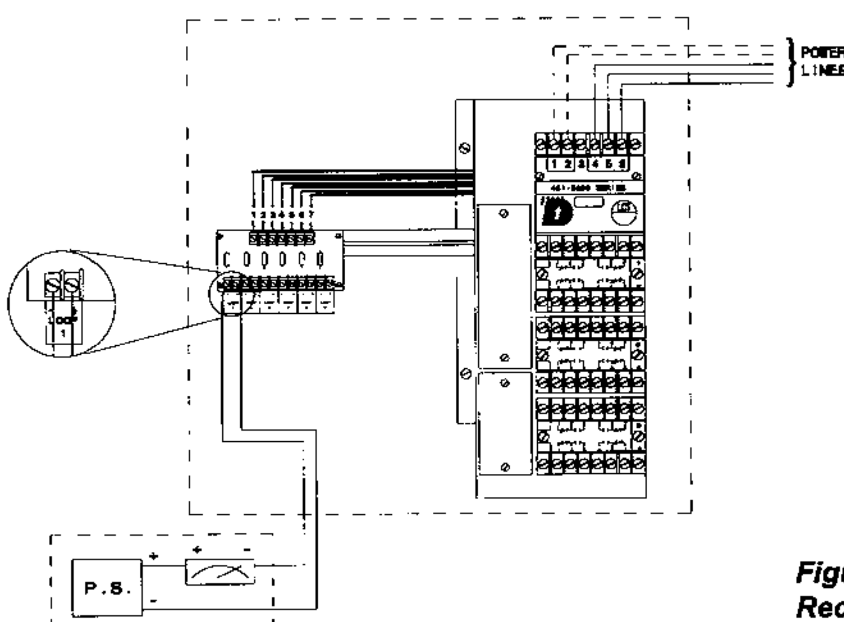


Figure 6-4
Receiver Checkout

On/Off Troubleshooting

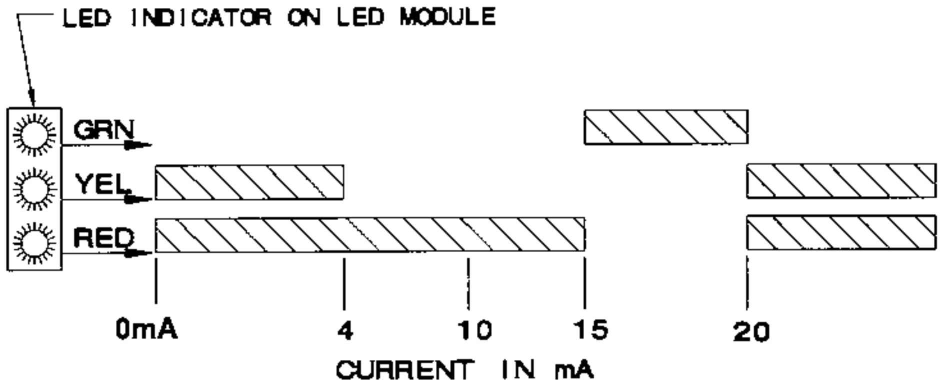


Figure 6-5
LED Indications vs Current

4. Power supply check

A. Measure the voltage across the red to blue wires; it should be between 18 and 30 Vdc.

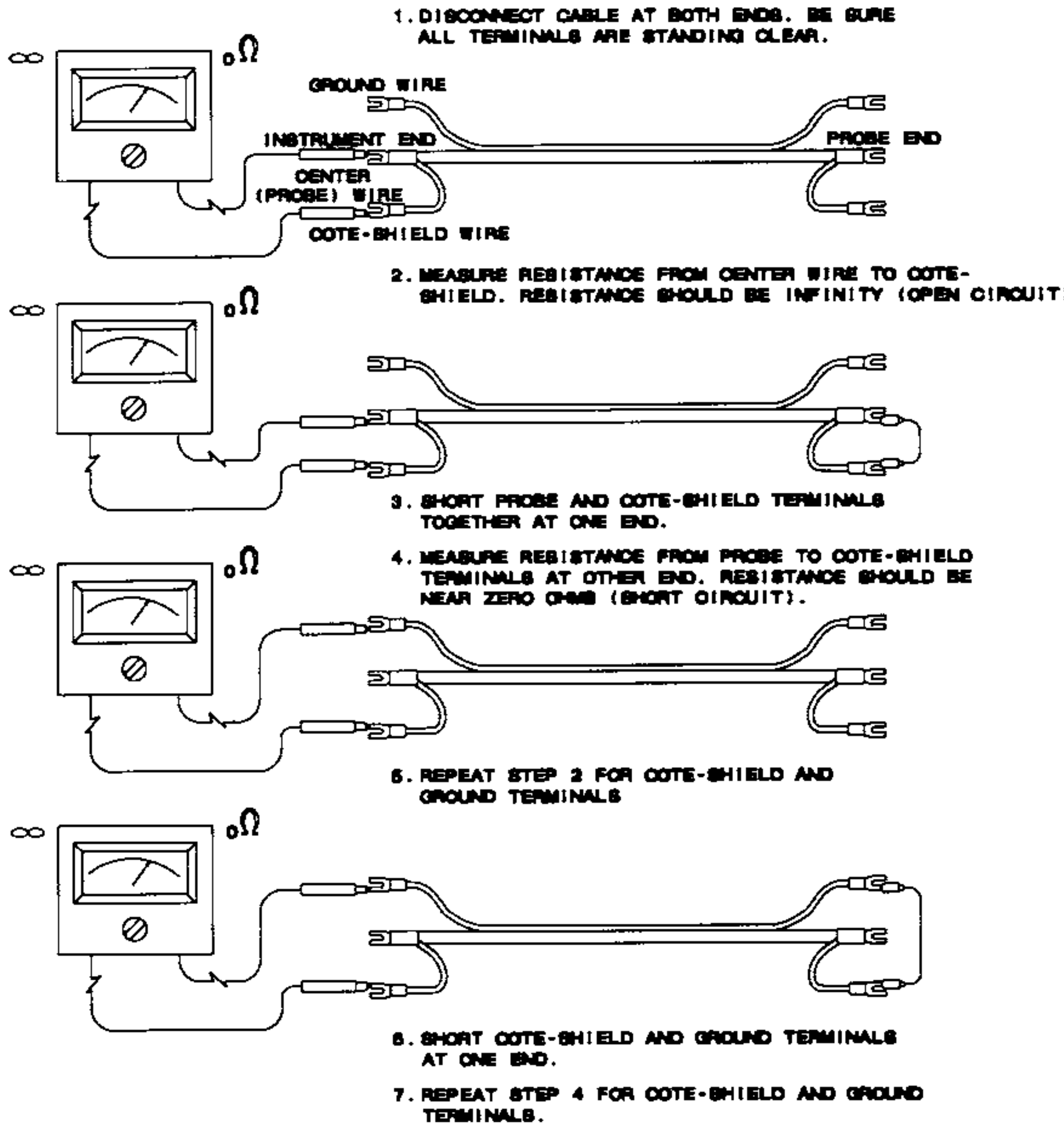
B. Measure the voltage across the red to green wires; it should be between 22 and 26 Vdc.

C. With the voltmeter across the red and green wires, there should be no change in voltage when any receiver input "+" terminal is shorted to ground (green wire).

THIS COMPLETES TESTING OF THE RECEIVER SYSTEM.

6.3 Testing the Sensing Element Cable

Figure 6-6



Note: This is a typical troubleshooting example. Consult instruction manual for exact procedure.

On/Off Troubleshooting

6.4 Testing the Sensing Element

Caution: Be sure to use an analog ohmmeter, not digital, for this test.

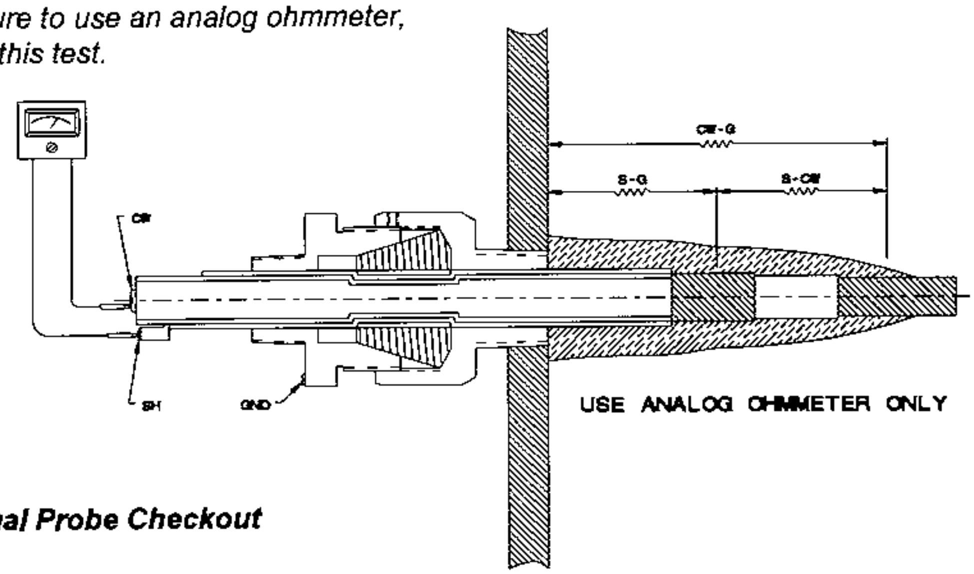


Figure 6-7
Three-Terminal Probe Checkout Procedure

MINIMUM RESISTANCE:

PROBE TO GROUND	1K Ω
PROBE TO SHIELD	600Ω
SHIELD TO GROUND	300Ω

NOTE: This is a typical troubleshooting example. Consult instruction manual for exact procedure.

6.5 Testing the Relay Circuit

The relay circuit consists of one set or more of single-pole, double-throw contacts brought out to a terminal strip.

When the instrument is properly adjusted, one pair of contacts will be open with high or low level, and one pair closed with high or low level. Relay operation may generally be heard as an audible click when the background noise is too high. Relay operation may also be determined with one of the circuits shown.

Tune the instrument as described in the instrument checkout procedure. Use one of the methods shown below to determine if relay contacts are switching.

Difficulty in calibration can often be traced to improper wiring of the relay terminals to an annunciator or other panel device. Check the wiring against the wiring diagram in the instruction manual.

Be sure to use diagram for the fail-safe in which the instrument is connected. (Fig. 5-5 is typical)

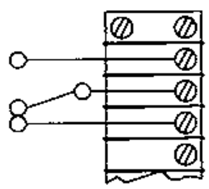


Figure 6-8

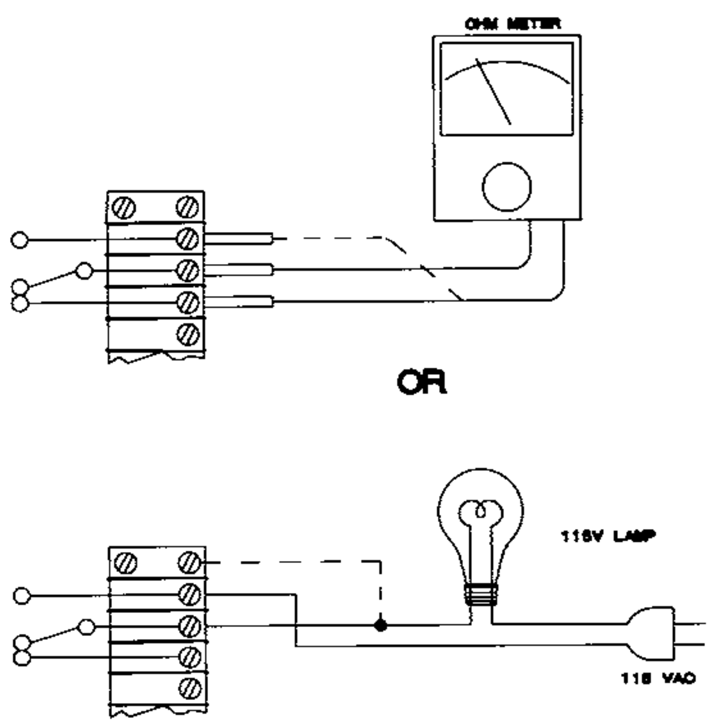


Figure 6-9

7.0 THEORY OF OPERATION: CONTINUOUS (ANALOG) LEVEL INSTRUMENTS

7.1 Two-Terminal Continuous Capacitance Instrument

For ease of understanding a discussion of the operating theory of RF-Admittance continuous or analog level measurement, we will begin with the two-terminal, capacitance-type system. However, these systems are now considered to be inferior and obsolete compared to the systems described later. Please refer to Fig. 7-1 which shows a block diagram of a typical two-terminal, continuous-capacitance level transmitter, with the connection cables, meter, and sensing element that make it a level measuring system.

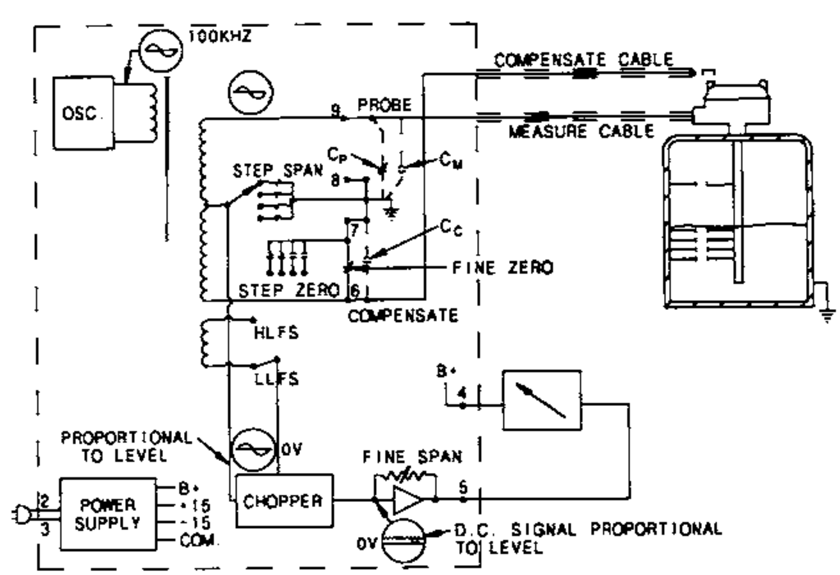
Typically, the capacitance level transmitter was powered by a 115V 60Hz power source. Internally, there is a power supply that provides +60Vdc, + 15 and -18Vdc to power the various parts of the circuit. The oscillator circuit generates a sinusoidal radio frequency waveform of about 100 Khz and is connected to the bridge circuit. The bridge circuit contains three of the four calibration controls, and is the connection point for the measuring (sensing element) cable and the compensate cable.

The 100Khz signal is transmitted to the sensing element through the coaxial cable, identified in Fig. 7-1 as the measuring cable. Electrically, the sensing element and the vessel (with its contents) can be represented by a single capacitor C_F. The capacitance of the measure cable is shown as C_M, and the capacitance of the compensate cable as C_C. The length of the measure and compensate cables should be approximately the same. Since they are connected to opposite sides of the bridge, any temperature effect from the measure cable would be subtracted from the effect of the compensate cable on the other side of the bridge.

When the vessel is empty, its capacitance C_P is at its minimum value. At this time, the STEP and FINE ZERO controls are adjusted to balance the bridge and produce a zero level signal at the chopper and, therefore, on the meter.

As the level rises, material begins to cover the sensing element and its capacitance increases. The bridge is no longer balanced; the signal is demodulated (rectified), amplified, and the meter reading goes up. When the level reaches the full point, the imbalance will be so great that the meter will indicate off scale. The STEP and FINE SPAN controls are then adjusted until the meter reads the correct level.

Figure 7-1
Two-Terminal Continuous-Capacitance Level Measuring System



Continuous Theory

The simple capacitance system described works quite well for materials that are not conducting or, if conducting, won't leave film or coating on the sensing element. This generally limits its use to water-like material. Even acids and caustics that don't appear to have a coating are so conductive that the thin film they leave on the sensing element can cause serious errors. Because of these limitations, the *Two-Terminal Continuous Cote-Shield Transmitter* was developed.

7.2 Two-Terminal Continuous Cote-Shield Transmitter

The theory of operation for the Cote-Shield transmitter is very similar to that of the capacitance transmitter, *but with two very important circuit additions.* These additions followed an important discovery about the electrical nature of a conductive coating. This will be discussed more thoroughly in the paragraphs that follow. Fig. 7-2 shows the block diagram of the two-terminal Cote-Shield transmitter with the two additional circuits shown in heavy outline. These are the *OSCILLATOR BUFFER* and the *CHOPPER DRIVE* circuits.

In order to better understand the need for these circuits, take a close look at the electrical nature of the signal produced by a sensing element with a conductive coating above the level.

Fig. 7-3A depicts a vessel filled with a highly conductive material. Since the material is conductive, the ground may be considered to be at the outside surface of the probe insulation, presenting only a pure capacitance to the transmitter. In this case, either a capacitance or a Cote-Shield (more technically, an admittance) transmitter can adequately measure the level.

Figure 7-2
Simple Two-Terminal Continuous Cote-Shield Level Measuring System

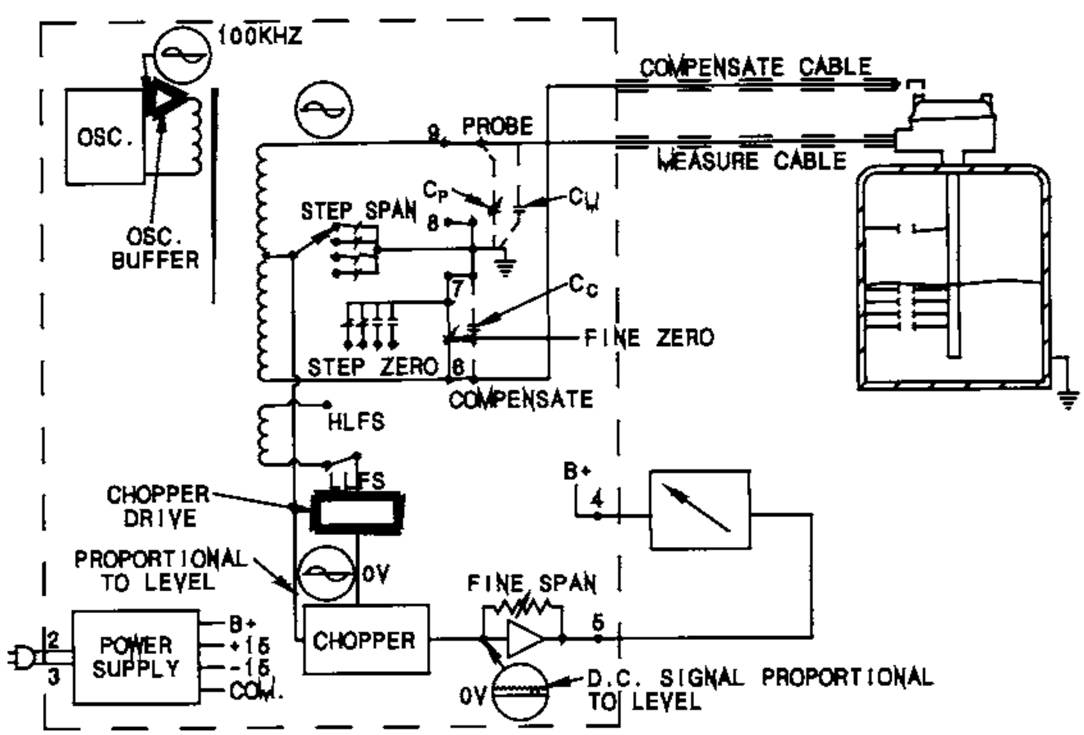


FIG. 7-3
Exaggerated Views of a Sensing Element in a Vessel

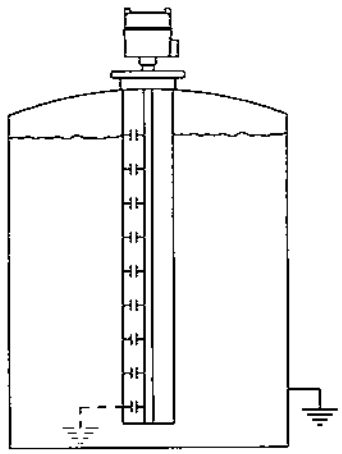


Figure 7-3A

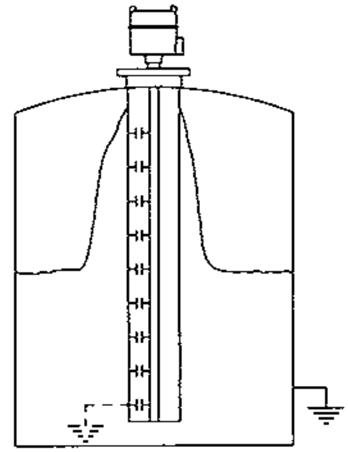


Figure 7-3B

As the vessel is drained, the picture changes (Fig. 7-3B). What was before a pure capacitance, now becomes a complex impedance made up of capacitance and resistance, causing two problems.

The first problem results from the fact that the probe circuit is a capacitance; it consumes no energy from the transmitter. Pure capacitors do not dissipate energy. When resistance enters the probe circuit, energy is consumed in the resistance of the coating, tending to draw down the oscillator voltage. Any drop in oscillator voltage results in a reading error.

To prevent this problem, a buffer amplifier is placed between the oscillator and the bridge circuits so that the dissipated power does not lower the oscillator voltage applied to the probe.

The second problem is that a capacitance instrument indicates that the level is still at the top of the coating because there is still the same amount of sensing element connected to ground.

In reality, no material is perfectly conductive. Fig. 7-4A electrically represents the coating as a resistance. The coated portion of the sensing

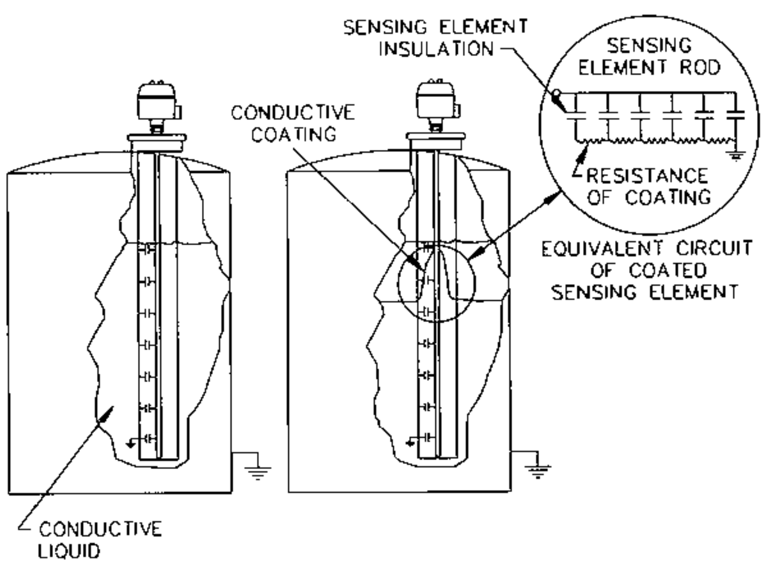


Figure 7-4A

Figure 7-4B

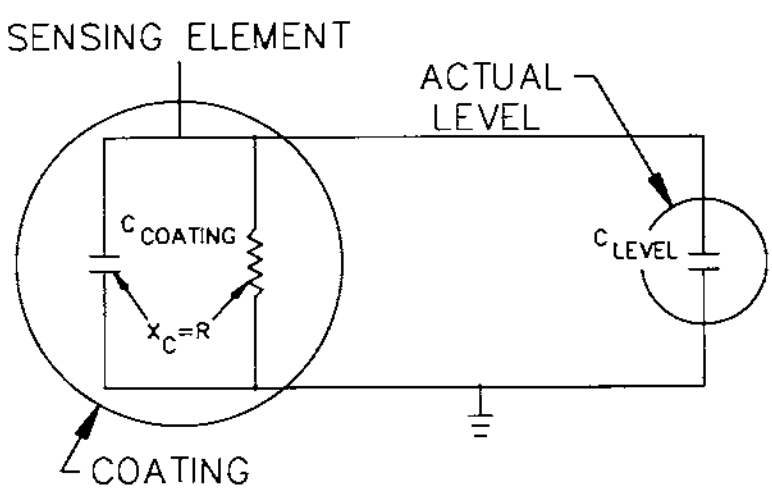
element looks like an electrical transmission line composed of an infinite number of infinitely small capacitive and resistive elements. This can be drawn schematically as shown in 7-4B.

Mathematically, it can be shown that if the coating is long enough, the resistive and capacitive components of the coating have equal impedances. See Fig. 7-5.

To benefit from information contained in the coating resistance, we add a second circuit, the *chopper drive*, shown in Fig. 7-2. This is the circuit that makes the major difference between a *capacitance* transmitter and an *admittance* transmitter.

This circuit, in conjunction with the chopper or synchronous detector, permits separate measurement of resistance and capacitance Since the resistance and capacitance of the coating are of equal magnitude, the total capacitance is measured by adding $C_{level} + C_{coating}$ and subtracting an amount equal to the resistance. As a result, only the capacitance due to the actual level is measured, and the instrument has "ignored" the coating.

Figure 7-5



The coating must be electrically "long" for this measurement to work *perfectly*. Long enough will depend on the thickness of the coating, the saturation capacitance of the sensing element, sensing element diameter, and the frequency at which the measurement is made. In practical terms, generally a coating that measures from several inches to one foot is long enough not to produce an error. Shorter coatings have some error, but only a fraction of the length of the coating. For any one set of coating parameters, the coating error is in inches, not percent! A set of conditions that produces a coating error of one inch will always produce an error of one inch, regardless of the length of the sensing element or calibrated span.

7.3 Three-Terminal, Two-Wire Continuous Cote-Shield (Admittance) Instruments

The next logical development was an instrument that has all the features of the two-terminal admittance unit, plus the practical benefit of making the measurement at the end of two signal wires instead of having to run 115Vac power out to the field. See Fig. 7-6.

By the time this instrument was developed, the three-terminal sensing element bridge circuit had already been in use for several years in the on/off (Cote-Shield) control. Its principles of operation and advantages are described in Section 2.2.

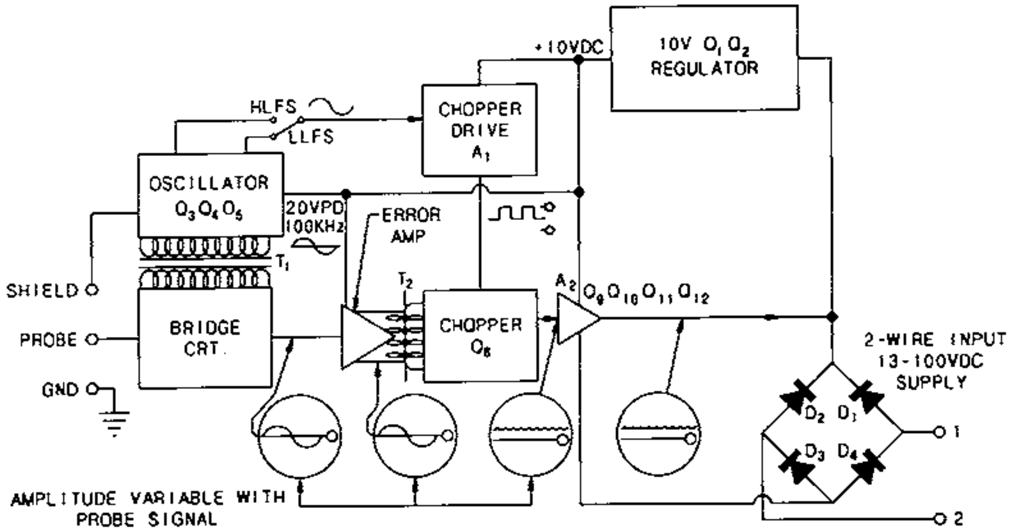


Figure 7-6
Three-Terminal, Two-Wire Cote-Shield (Admittance) Transmitter

By replacing the balanced bridge used earlier with the three-terminal approach, the two-wire instrument eliminates the need for a compensate cable and generally permits the use of longer distances between the sensing element and the transmitter. A further improvement in the bridge circuit allows spans as high as 60,000pF, instead of the 4000pF allowed in the two-terminal models. This span increase permits measurement in larger vessels and makes it possible to use sensing elements with higher saturation capacitance in order to improve the instrument's ability to ignore coating. A great advantage with this unit is that it can be made intrinsically safe. This removes conduit and explosion proof requirements, and eliminates safety hazards to the instrument mechanic.

7.4 Three-Terminal, Two-Wire Ramp (Capacitance) Instruments

For many "easy" applications like insulating materials or conductive materials (e.g. water) that don't leave a coating on the sensing element, there is a less expensive RF Continuous transmitter without all the capabilities of the Admittance systems. The "Ramp" capacitance unit uses less expensive digital integrated circuits to generate and measure the RF signal. With its departure from a bridge circuit and phased chopper, the "ramp" does not perform as well as the RF-Admittance unit in materials that leave a conductive coating on the sensing element. However, it does a good job measuring insulating materials with a stable dielectric, and conductive materials that don't leave a coating. A description of the operating theory follows. Refer to the Block Diagram, Figure 7-7.

The variable frequency oscillator in the ramp-capacitance unit is connected to the sensing element or probe installed in the vessel containing the material level which is to be measured. The probe in the vessel, with its contents, forms a capacitance shown on the diagram as C1.

The capacitance of C1 is charged and discharged through the resistance of Resistor R. The value

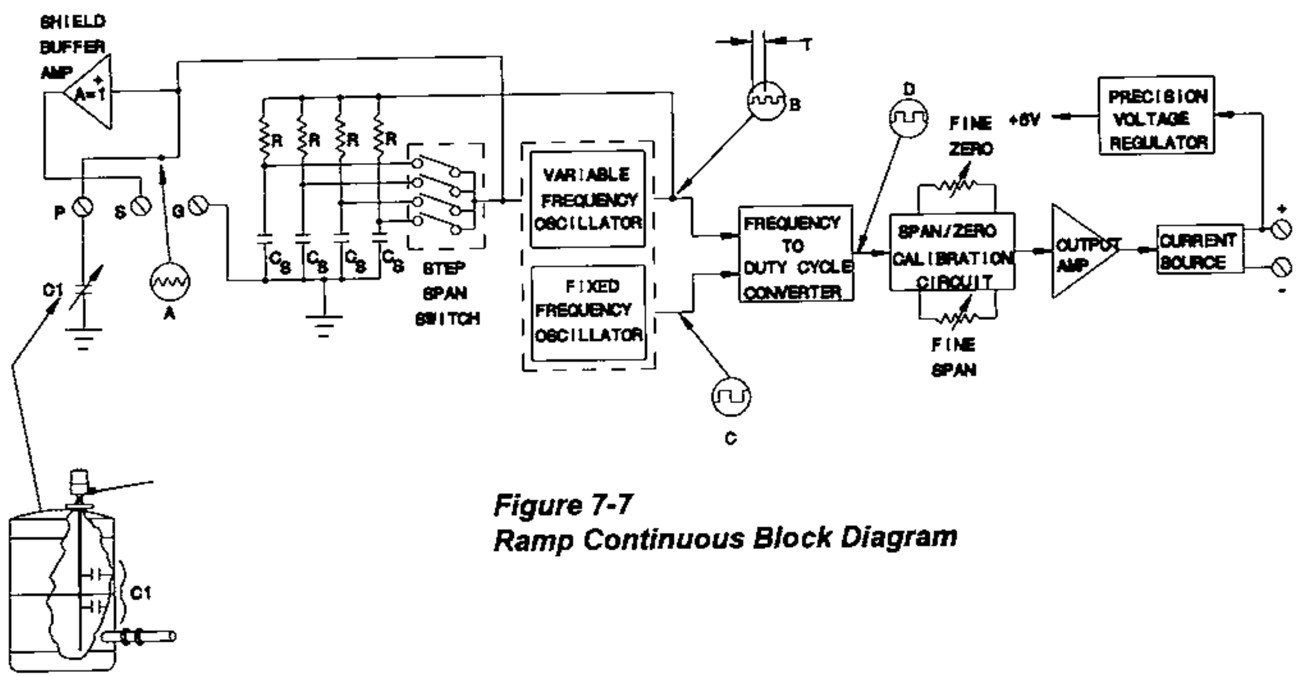


Figure 7-7
Ramp Continuous Block Diagram

of Resistor R depends on which step span switch position is selected. A symmetrical RAMPing voltage is present across the probe capacitance C1 (See callout A on Figure 7-7).

The time period required to charge C1 to the reference voltage is restricted to a narrow range over a comparatively wide range of values of C1. This is done through the proper selection of the step span switch position. The value of capacitor C1 actually determines the variable oscillator's time period.This variable time period ("T" in callout B) is converted to a variable duty cycle signal (callout D) by its comparison to a separate fixed frequency oscillator (callout C).

The average dc voltage of the duty cycle signal is proportional to the probe capacitance C1, i.e., the material level. This proportional voltage is amplified by the Fine Zero and Fine Span calibration circuits. The signal is then converted to a standard 4-20 mA output proportional to level by the output amp.

A Shield Buffer Amplifier is also connected to the probe signal. The gain of this amplifier is exactly "1" in both amplitude and phase. Its output is connected to the "S" (shield) terminal on the transmitter. This shield voltage makes it possible to connect a coaxial cable up to 25 feet between the transmitter and probe without the usual temperature-capacitance errors associated with two-terminal capacitance units.

Ramp technology works well when the sensing element sees only pure capacitance. In conductive material applications that leave coatings on the sensing element, the conductivity portion of the coating forms a complex impedance that causes measurement errors. The solution to this problem, if it exists, is to use an admittance technology RF instrument.

7.5 True Level™

In a continuous application, where material being measured changes in dielectric constant and/or conductivity, a special approach may be required.

If conductivity is always above 20 micromho/cm, a conventional continuous transmitter will operate

satisfactorily. But, if the conductivity falls below the 20 micromho/cm level, and/or material changes in dielectric constant, a True Level™ transmitter will provide a consistent calibration — regardless of gross changes in electrical characteristics.
A True Level transmitter in its most basic form is two continuous transmitters connected to an arithmetic divider circuit (Fig. 7-8).

This figure shows that the sensing element connected to Transmitter #1 "sees" both changes in electrical properties of the material (dielectric and/or conductivity) and changes in level.

same electrical properties. Therefore, True Level is generally unsuitable to measure granular products — and never suitable to measure interfaces.

Because the composition (bottom) sensing element must be covered with material, it is not possible to measure level down to the very bottom of the vessel.We wish to emphasize that the majority of applications do not require a True Level transmitter. Conductive materials over 20 micromho/cm (water, acids, caustics, etc.) or dielectric materials with unchanging electrical

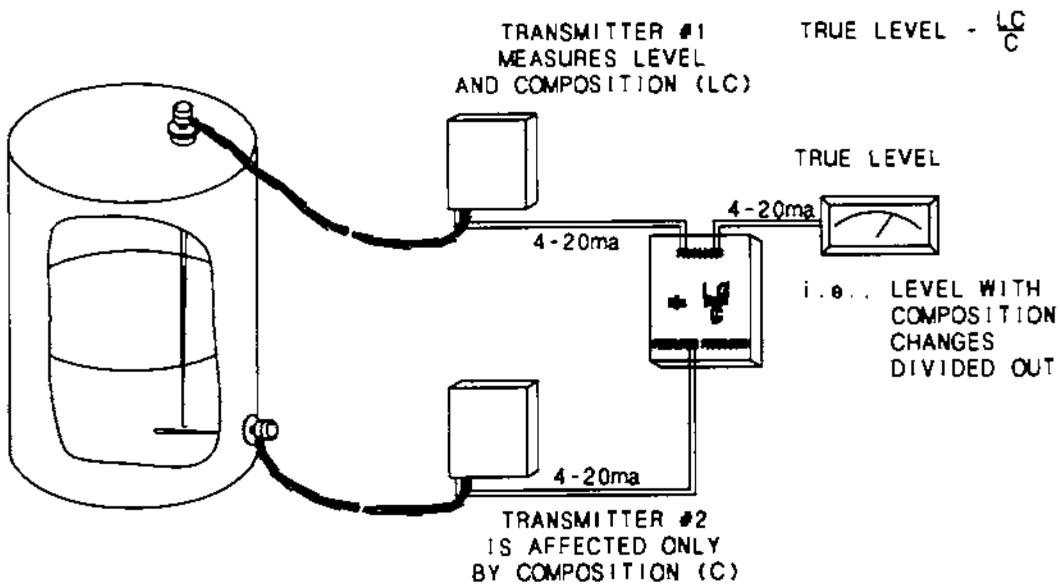


Figure 7-8

The sensing element connected to Transmitter #2 "sees" only changes in electrical properties, because the length of probe covered by material remains constant.

The divider circuit divides out the composition value, leaving a 4-20 mA signal that is proportional solely to the liquid level, despite electrical changes.

Success of True Level requires that the material being measured be homogeneous in composition from bottom to top, so that both probes "see" the

properties, such as fuel oil or liquid sulfur (at constant temperature), can be handled very satisfactorily by a conventional continuous transmitter.

To progress from the most basic transmitter described above, (Fig. 7-8) it can now be simplified by combining the two sensing elements — to require only a single, top penetration of the vessel (see Fig. 7-9).

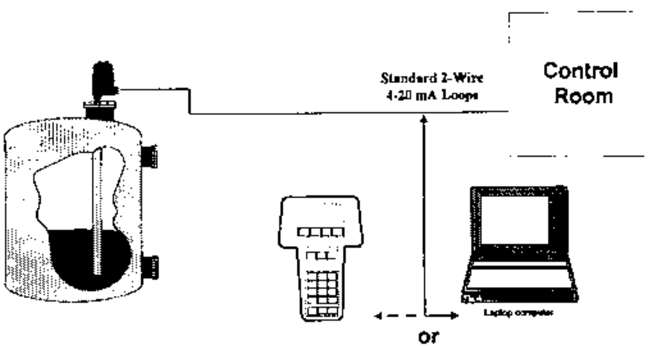


Figure 7-9

Here, although the sensing element appears to be a single unit, it actually contains two independent sensing elements, with the composition sensing portion physically located in the bottom three inches of the probe. These True Level sensing elements feature their own uniform ground reference.

In remote mounting installations, the dual sensing element is connected by dual cables to a single two-wire electronic unit which contains both of the transmitters, as well as the divider circuit.The newest trend in True Level instrumentation is toward smart transmitters, located on the vessel. Also there are systems that send out two independent signals. As before, one of these signals represents level and composition while the other represents composition only. The two output signals are then divided in a microprocessor receiver which can also be used to measure other level signals. This system combination usually results in the most application versatility and lowest installed cost, particularly when multiple setpoints are needed.

7.5.1 True Level Sensing Elements

Selection of True Level sensing elements requires the same considerations as in selection of a continuous sensing element, with an important reminder.

The measure and composition probes must be of the same type (construction) and have the same relationship to the ground reference. This is usually accomplished by providing True Level sensing elements with a concentric shield or caged ground reference (see Fig. 7-10). The zero point will be above the composition sensing section, typically five inches above the tip.

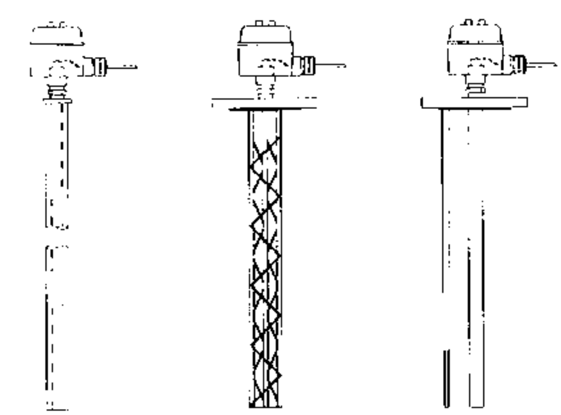


Figure 7-10
True Level™ Sensing Elements

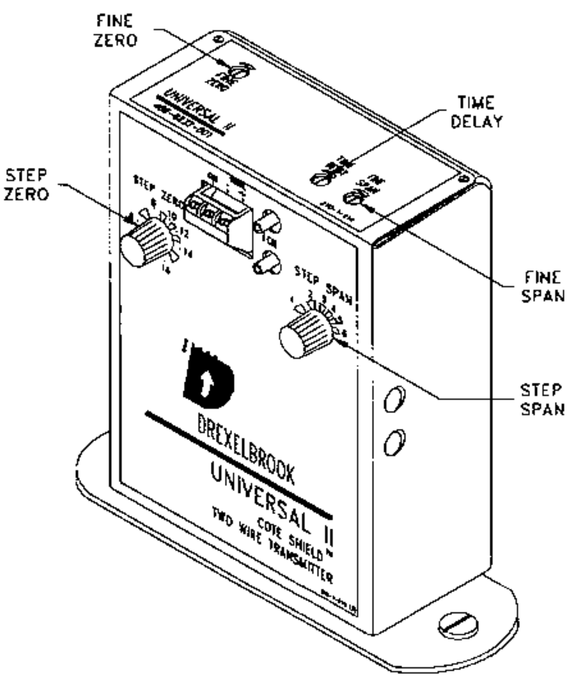
8.0 CALIBRATION OF CONTINUOUS LEVEL TRANSMITTERS

8.1 Introduction

The purpose of this section is to provide a general understanding of what should be done during the calibration process. It is in no way intended to be all-inclusive or to replace the instruction manual provided with the equipment. The procedures are very similar regardless of the particular model being calibrated.

8.2 Calibration Controls

8.2.1 Analog Transmitters



Typical Continuous Analog Level Transmitter Showing The Four Calibration Controls Figure 8-1a

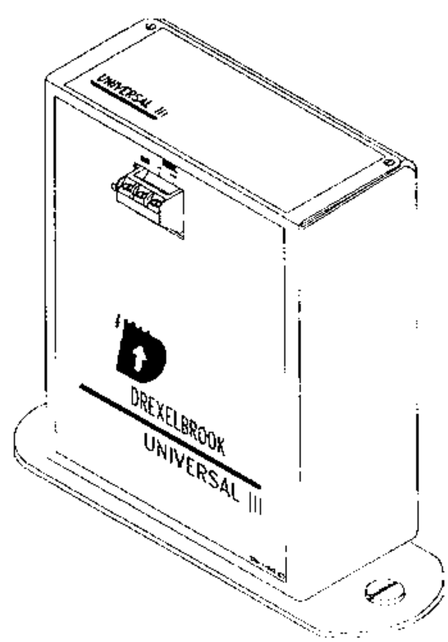
(For a review of how the output from the sensing element changes with level, see Section 3.4). There are four controls to be adjusted during the process of calibration (see Fig. 8-1a).

The first two are the STEP and FINE ZERO controls associated with the bridge circuit. These are used to 'balance' the bridge when the level is at its lowest or 'zero' point. The STEP ZERO control is a switch containing several fixed capacitors that provide a coarse adjustment to balance out the capacitance generated by the sensing element with a minimum level. The FINE ZERO is in parallel with the STEP ZERO and makes it possible to get exactly a 4mA or 0% reading with minimum level.

The second two controls are the STEP and FINE SPAN controls. These are connected to the bridge and amplifier circuits respectively. Their function is to provide coarse and fine adjustment of the output current (sensitivity) to make the instrument read correctly with level. There are no adjustments for Cote-Shield action; this is handled automatically by the circuit.

8.2.2 Smart Transmitters

For smart level transmitters, there are no zero or fine span controls. There is a range jumper or switch that allows a single transmitter to cover all ranges. All other adjustments are handled through a handheld calibrator or laptop computer with calibration software. See Fig. 8-1b.



Typical Smart Continuous Level Transmitter with No Calibration Controls Figure 8-1b

8.3 Prior to Calibration

There are several factors to keep in mind prior to calibrating a continuous instrument.

8.3.1 Fail-Safe

Fail-safe is the signal condition with loss of power. It is also called direct or indirect acting. The normal condition is called direct acting, increased output with increased level, or LLFS.

> (LLFS) 100% = Full tank - Direct Acting
> (HLFS) 100% = Empty tank - Reverse Acting

LLFS is used in more than 95% of all applications.

8.3.2 Adequate Signal From Probe

In a continuous application, the sensing element must produce enough change in signal to enable the transmitter to generate a 0-100% output. Some transmitters require a 5pF to 10pF change in capacitance to produce full output. If the sensing element is expected to produce less than this amount, a high-sensitivity instrument should be specified.

8.3.3 Zero Padding

In the systems normally supplied, no additional changes usually are required to calibrate the system. However, some applications require padding. Padding is required when the 0% point exceeds the zero adjust range of the instrument which, in many units, is from 0-350pF. This can be a problem, as in some interfaces, when the material has a high dielectric, or when using some long cable probes and long inactive sections. Consult the instruction manual or the factory service department on padding instructions if it is not possible to set the zero controls so that the output measures 0%.

8.4 Methods of Calibration

The following summary lists most of the calibration methods commonly used to calibrate continuous level systems. Following this summary is a more detailed explanation of each of those methods. As pointed out earlier, these are for concept and not intended to be substituted for the procedure listed in the instruction manual supplied with the equipment.

Precalibrated at Factory: When the application parameters are specified with the new equipment order, precalibration may be ordered as an option. When the equipment is installed, it will be calibrated for the material being used. However, it may sometimes require a minor adjustment of zero or span to compensate for vessel geometry or material dielectric constant.

Calculated Calibration: Theoretical values of zero and span capacitance for a particular application and equipment combination are connected to the electronic instrument by use of a substitution box, or, in the case of a smart transmitter, are entered directly from a handheld calibrator or laptop computer.

Empty & Fill: This is the most commonly used method of calibration for analog transmitters. The instrument is set to 4mA output with the vessel empty and spanned with a filled or partially-filled vessel.

Long Cable Probes: This is similar to the *Empty & Fill* method except the zero is adjusted outside the vessel due to the difficulty of emptying and filling large vessels.

Interface Applications resemble the *Empty & Fill* methods except that an empty vessel would be equal to all of just one part of the interface (usually the organic part).

Open Channel Flow Applications are similar to the *Empty & Fill* applications but are commonly done in the flume or weir.

Insulating Granular Applications can be calibrated by the *Empty & Fill* method. However, the radio frequency transmitter will tend to produce a reading that is in weight rather than level.

8.4.1 Precalibrated at the Factory

Many continuous level systems may be precalibrated at the factory if certain conditions exist (see Fig. 8-2). If the material being measured is nonconductive, the sensing element should be of a ground reference type, and the material's dielectric constant and conductivity should be known, or a sample submitted for testing. When precalibrating conducting liquids without using a concentric shield, the approximate vessel geometry and location of sensing element should be submitted.

For interface, specify material parameters or samples for testing, plus the approximate vessel geometry.

While the accuracy that can be consistently achieved with factory precalibration is not as precise as using the actual material to calibrate, results in the range of about 2% are usually possible. Perhaps the greatest advantage of precalibration occurs when starting-up a large number of systems nearly simultaneously. Here, having the systems precalibrated saves a lot of aggravation. There are also a number of applications with no secondary means of determining the level, ruling out an empty-and-fill-type calibration.

8.4.2 Any Two-Point Calibration (Smart Transmitters)

With a smart transmitter, it is not necessary to empty and fill the vessel. Any two points of level, with at least a 10% span differential, may be used to calibrate the system. Neither point needs to be at the empty or zero point, and either point can be done first. The smart transmitter will extrapolate the 4mA and 20mA points. See the specific instruction manual for the exact procedure.

8.4.3 Calculated Calibration

If the sensing element is concentric — or if the vessel geometry, probe location, and material characteristics are known, it is possible, in many cases, to calculate the values, for zero and full scale. These values may then be 'dialed in' on a calibration box that substitutes for the actual sensing element. In the case of a smart transmitter, the capacitance values may be entered directly in pF (picofarads) from the handleld calibrator or computer (PC). The accuracy of this method ranges from very good to fair, depending on how precisely the parameters are known. In general, accuracy is very good on conductive or high dielectric materials, or concentric probes. It can be fair on low dielectric materials, and poor if the spans are less than two feet. While it is beyond the intent of this section to teach how to calculate the zero and span values for any given application, the factory can calculate these values when given the appropriate information. See Fig. 8-2.

To summarize, the CALCULATED method is less accurate than PRECALIBRATION where the actual sensing element parameters are used, or EMPTY & FILL METHODS where the actual material and equipment are used. It does, however, usually produce satisfactory results.

8.4.4 Empty & Fill (Analog Transmitters)

The most common method of continuous level calibration used with analog transmitters is by the Empty & Fill method. It is also the most accurate and reliable. On the other hand, it has the drawback of sometimes requiring large amounts of product to be moved. While there are a number of variations of this method, they are all similar.

The normal or Empty & Fill Method of Calibration starts with an empty vessel, or at least one in which the probe is not immersed in the material, and the STEP SPAN in its most sensitive position. First, zero out the standing capacitance of the probe. This consists of a gland and sensing element capacitance. The gland capacitance is a fixed value which varies with sensing element type. For a given style of sensing element, gland capacitance will be consistent from one to another. The capacitance generated by the sensing element in air will vary due to vessel geometry, sensing element location in the vessel, type of sensing element, and, most important, sensing element length. By using a bridge network in the electronic instrument, this capacitance can be balanced or zeroed out.

PRECALIBRATION INFORMATION SHEET

PRECALIBRATION IS AVAILABLE IN THE FOLLOWING APPLICATIONS:

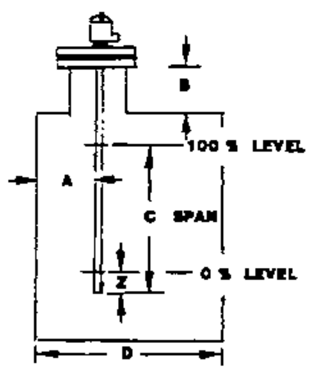
1. **CONDUCTING LIQUIDS**
2. **INSULATING LIQUIDS USING CONCENTRIC SHIELD SENSING ELEMENTS**
3. **INTERFACE**

COMPANY __________ CITY __________ STATE __________
CUSTOMER P.O.# __________ ITEM __________ DE# __________ TAG # __________
FILLED OUT BY __________ DATE __________ TELEPHONE(   ) __________

FILL IN THE MISSING DIMENSIONS:

"A" __________ NOT REQUIRED IF GREATER THAN 12"
"B" __________ NOT REQUIRED IF LESS THAN 6"
"C" __________
"D" __________
"Z" __________ NOT REQUIRED IF AT TIP

NOZZLE DIA.: __________ NOT REQUIRED IF GREATER THAN 2" OR IF SENSING ELEMENT IS THREADED INTO VESSEL.



☐ CHECK HERE IF HORIZONTAL CYLINDER

☐ YES ☐ NO IS A PERMANENT CALIBRATION REFERENCE BOX (401-6-6) DESIRED?

MATERIAL SPECIFICATIONS

	MATERIAL	ELECTRICAL CHARACTERISTICS IF KNOWN	
		CONDUCTIVITY*	DIELECTRIC CONSTANT*
UPPER PHASE			
LOWER PHASE			

*If conductivity greater than 200μmhos/cm or water content is greater than 20%; fill in "N/A"

Figure 8-2

By turning the FINE ZERO adjustment, the meter can be set to read 4mA (0%). If the unit will not zero, turn the STEP ZERO switch to the next position and repeat the FINE ZERO adjustment. When 4mA (0%) is reached, the instrument is zeroed and the span can be adjusted.

If possible,it is best to fill the vessel to the 100% mark or whatever is considered to be full. At this point, the instrument is in its most sensitive position. As soon as the material begins to cover the probe, the meter will probably jump to over 100%. Continue filling the vessel, making no adjustment to the instrument.

When the vessel is full, turn the step span switch until the meter drops below 100% then turn the switch back one step. Example: If the reading drops to approximately 16mA after reaching STEP SPAN #5, turn the switch CCW to STEP SPAN #4. Next, go to the FINE SPAN knob and rotate CCW until the meter reads 100%. The unit is now calibrated and, since the zero is independent of the span, it is not necessary to readjust the zero controls. Calibration is now complete.

If it is not possible to fill the vessel, the instrument can still be spanned. After setting the zero controls, raise the material level to a known point.

Again, using the STEP SPAN switch, turn it until a reading shows on the scale. Now adjust the FINE SPAN until it reads the % of material that is on the probe. Example: If the probe is 50% covered, adjust the FINE SPAN to read this.

A word of caution: In most installations, the probe does not reach the bottom of the tank. It is important to differentiate between feet of material in the tank and feet of material on the probe. For example, if a 10-ft. tank is equipped with a 9-ft. probe, we must determine whether zero output will indicate an empty tank or material beneath the tip of the probe. If we want to read total feet of material in this vessel, we must do the following.

1. Using the ZERO adjustment, set output to 0% with empty tank.
2. Add material to tank.
3. Set SPAN so that output corresponds to feet of probe that are covered (i.e., with 7 ft. in tank, adjust for 60% output).
4. Readjust ZERO so that output corresponds to actual feet of material in tank (i.e., with 7 ft. in tank,adjust for 70% output).

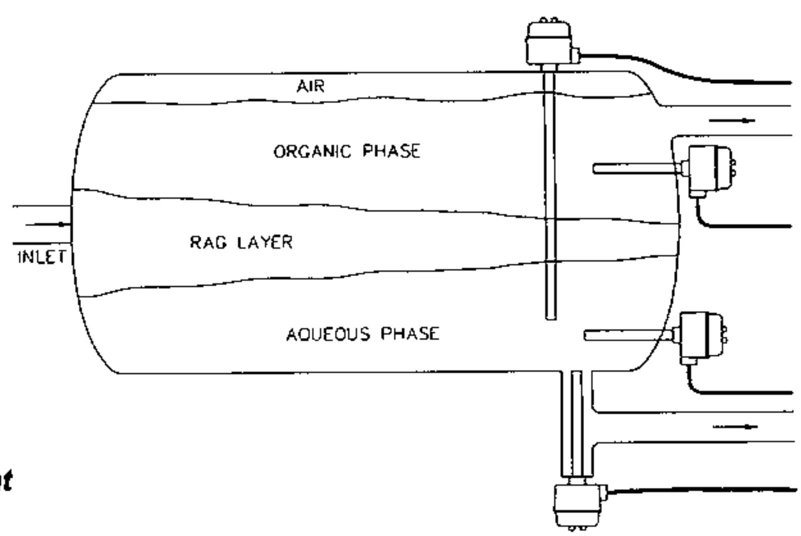
Remember, the probe cannot indicate a level of material which is below its tip! In our example, output will read 10% no matter what level is beneath the tip of the probe.This is only a brief explanation of a normal calibration. Refer to the instruction manual for more specific details on calibration. Some instruments may require a slight deviation from this method.

8.4.4a *Long Probes:* In many applications, the vessels are so large that an Empty & Fill calibration would be impractical because of the large volume of material to be moved. In addition, these vessels may already be filled before the level system is in stalled and calibrated.

In such cases, a reasonably good calibration of the zero can usually be obtained by holding the probe outside the vessel at the same distance from the vessel wall as it will be when installed.

In deep-well applications, where even this method cannot be used, a calculated zero value is substituted for low level, and the probe may be spanned in a grounded metal bucket. The zero value should be calculated by the factory, based on the well casing size. Deep well probes over 75 ft. long generally need padding to zero properly.

8.4.4b *Interface Calibration:* The following two methods are variations of the normal or Empty & Fill calibration method. It is important to note that all standard calibrations are measuring interfaces, e.g., air/water, air/oil or air/acid. In all these examples, air is interfacing with some other material. With interface measurements, specific reference is



Interface Measurement
Figure. 8-3

usually being made to the measurement between two immiscible liquids, e.g., oil/water, toluene/ water, etc.

There are two types of interface measurements. The first, and most common, is called normal. A normal interface has the insulating material on top and the conductive material on the bottom. The other type is called inverted interface, with the conductive, or higher dielectric constant material on top, and the insulating, or lower dielectric constant material on the bottom. In some cases, a second interface develops with an air layer on top of the other two. If the overall level is constant, this air layer can be ignored. If the level varies, a sensing element with an inactive section extending through the air and below the lowest overall level may be called for under certain conditions, but is unnecessary in most normal interfaces. A reasonable calibration is usually obtained using air and water. The zero is readjusted with a known interface at a later date.

Here's a helpful trick to find where the interface actually exists in a nonpressure vessel. With a stick, lower a pair of wires (stripped of the last inch of insulation) into the liquid. Connect the other ends of the wires to an ohmmeter. When the bare ends go through the interface, the ohmmeter often detects it.

In Normal Interface Calibration, first immerse the sensing element totally in the upper phase (least conductive or lower dielectric). Next, adjust the STEP and FINE ZERO controls for 4mA (0%). It may be necessary to place a padding capacitor across the pad terminals on the instrument if the instrument cannot be zeroed after using all STEP and FINE ZERO positions. In this case, contact the factory service for the correct padding capacitor. Information required will be the type of equipment being used, materials being measured, sensing element type and length, calibration length, and, if possible, the D.E. order number. If 4mA (0%) is obtained, zero adjustment is complete.

Now the instrument can be spanned. First, raise the lower phase of the material to the upper control point (100%), leaving the upper interface material on top. Next, set the STEP and FINE SPAN controls, as explained previously, to read 100%. The unit can be calibrated using some known intermediate level, but all previous precautions must still be applied. Calibration is now complete. *Refer to the instrument instruction manual for specific instructions on interface.*

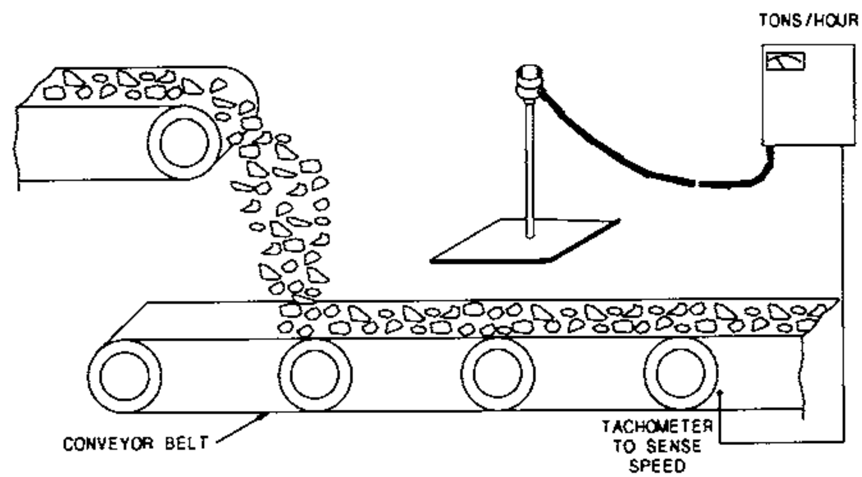
8.4.4c *Proximity Applications* actually measure the air space between the metal plate attached to the sensing element and the surface of the material being measured. Calibration is similar to the *Empty & Fill* method in that the zero percent or 4mA point is set when the material is at the lowest point. The span controls are set to obtain full scale when the material is at the highest level.

Because of the nature of the proximity measurement, it is not linear like an immersion sensing element application, and it is usually limited to inches of span (see Fig. 8-5). The maximum obtainable span in inches is controlled mostly by the area of the proximity plate in square inches, and the distance from the plate to the low level point.

8.4.4d *Open Channel Flow Calibration:* In measuring open channel flow, a standard admittance transmitter is used, but the sensing elements used are unique to this type measurement. A characterized flush probe is normally used. With characterized sensing elements, the signal will be linear with flow, using a standard transmitter.

There are two methods of calibrating an open channel flow system. The first calibrates the sensing element in the flume or weir, and the second uses a metal bucket. It is always best to calibrate in the flume or weir if possible.

When calibrating in a bucket, always use a grounded bare metal bucket since the sensing element must sense ground to give an accurate reading. Because most flumes are plastic or fiberglass, it is recommended that a ground plate be installed in the flume. (See Section 4.4.2 for details.) During calibration, hold the sensing element by the head or condulet. Never touch the active element



Typical Proximity Sensing Application
Figure 8-4

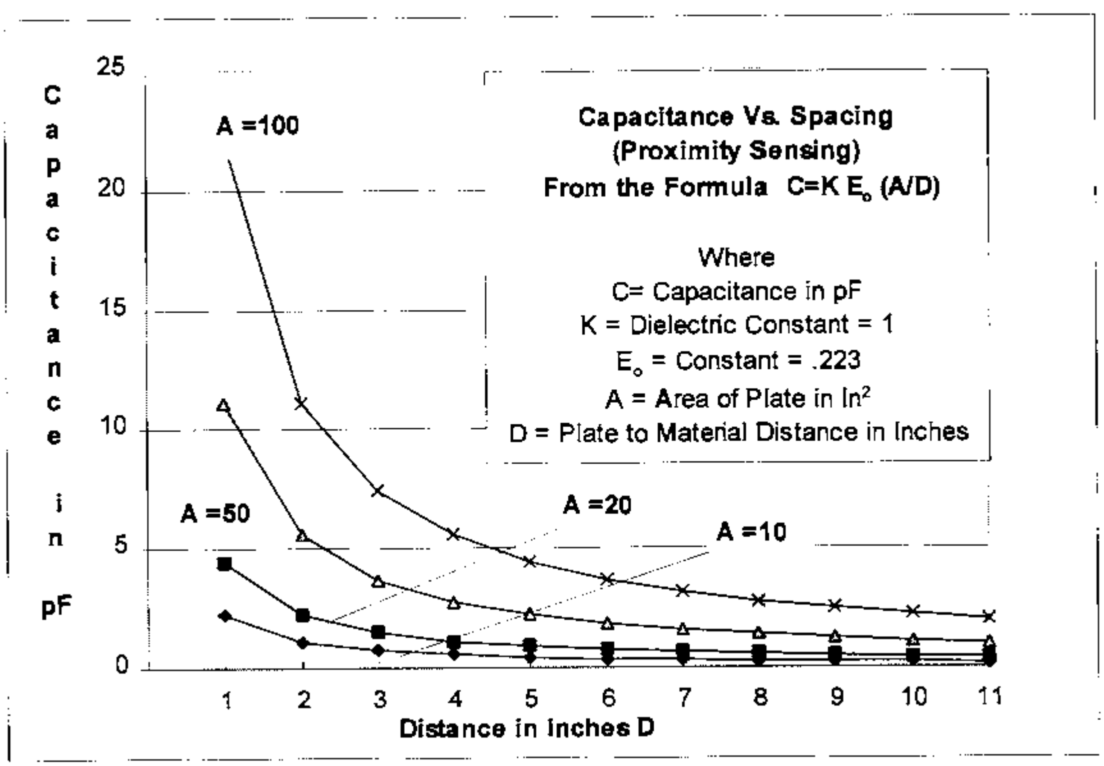


Figure 8-5

as this may produce erroneous readings. Finally, be sure the sensing element is mounted correctly in the flume or weir. *In weirs,* the sensing element (and any readings taken) must be at least three times the maximum head height back from the weir. This is due to a condition called drawdown. For a detailed explanation of the installation, please refer to the instruction manual supplied with the system.

When calibrating in a bucket, hold the sensing element tip at the surface of the water and adjust the STEP and FINE ZERO controls to read 4mA. Next, determine the maximum flow rate in gpm and, by referring to the chart for this flume or weir, find the head height in inches. Immerse the sensing element to this maximum flow point using the STEP and FINE SPAN controls on the instrument as previously explained. Adjust for a 20mA (100%) output. Calibration is now complete. Install the sensing element in the flume or weir to the correct height and attach the ground wire. Since the flush probe head is potted, it will not be damaged if the probe becomes submerged. When the condition clears, it will return to normal flow readings. It is also recommended that time delay be considered to reduce the effects of turbulence common to this kind of flow.

8.4.4e *True Level Calibration Theory and Controls:* True Level™ transmitters are used primarily in applications with insulating liquids where the electrical characteristics of the material being measured can change during the process. The basic True Level system consists of two transmitters, one True Level computing unit, and either two sensing elements or a single dual-sensing element. Calibration is the same for both. For smart True Level transmitters, follow the instruction manual because the procedure is different and much simpler.

Each system has a composition sensing element (the longer or lower probe) which compensates for the electrical variations in the material, and a level measurement sensing element which changes with both electrical and material level variations. A key point to remember in all True Level applications is that the *composition sensing element must always be completely covered by the material,* until the level falls below the tip of the measuring probe.

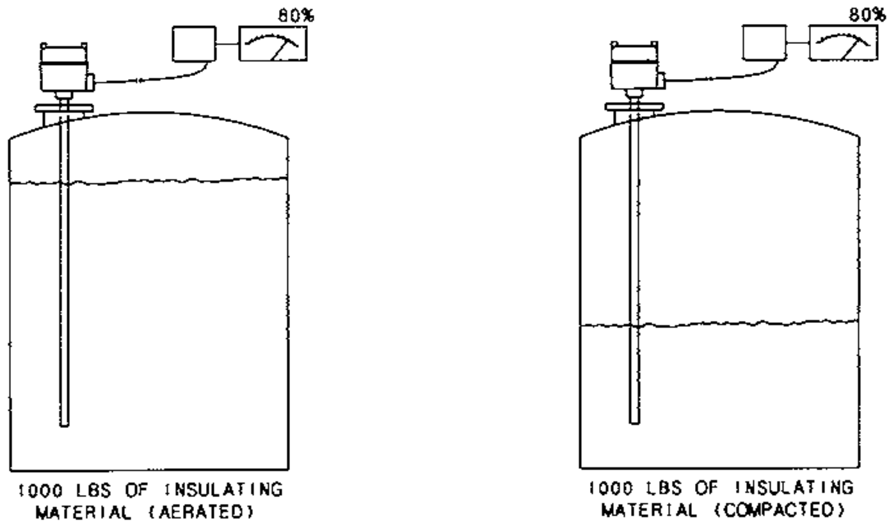
The calibration of a True Level system is some what different from our other measuring instruments. Starting with an empty vessel, place a milliammeter in series with the composition transmitter. Adjust the STEP and FINE ZERO controls on the composition transmitter to read 4mA (0%). Next, place a milliammeter in the True Level output loop (output from computing unit), and adjust the zero controls on the level transmitter. Adjust the STEP and FINE ZERO controls on this transmitter to read 4mA (0%) in the True Level output channel. The zero adjustments are now complete.

Fill the vessel to some known level. Again, place the milliammeter in the output loop of the composition channel. The transmitter should produce a reading of greater than 20mA (100%). At this point, if the material in the vessel is known to be the highest dielectric, or if it is conductive, adjust the STEP and FINE SPAN controls to read 19.5mA (95%). If the material being calibrated is not known to be the highest dielectric constant, then adjust the composition transmitter current to read approximately 60%. Never adjust the span on a True Level composition channel to read 100% (20mA). If the material becomes more conductive, or the dielectric increases, an erroneous output will result. Next, place the milliammeter in series with the True Level (computing unit) output loop and adjust the STEP and FINE SPAN controls on the level transmitter for the output corresponding to the existing level. The only time a meter should be used in the level channel is for troubleshooting the system. The primary requirement for accuracy in True Level installations is homogeneity. If both probes don't see the same electrical characteristics, the instrument is defeated.

8.4.4f *Insulating Granular:* Continuous measurement of insulating granular material is a measurement of weight, not necessarily of level. If a granular material to be measured compacts greatly or expands greatly to fill a vessel, we would be measuring its weight, not its level.

Electrically, there is no difference between the two drawings in Fig. 8-6. Variations in moisture content can affect the accuracy of a continuous granular measurement. Special equipment, called Comad™, will compensate for these variations.

Figure 8-6



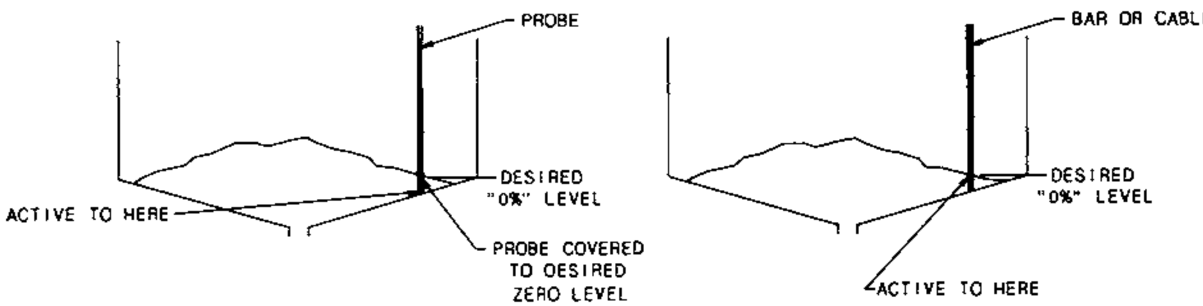


Figure 8-6A ZERO MAY BE SET AT ANY LEVEL BELOW ACTIVE SECTION OF PROBE

When measuring insulating granular, how the vessel is filled and emptied must be considered to determine the proper location of the sensing element, in order to prevent an angle-of-repose error. There is usually a location in the vessel that is only slightly affected by angle of repose. For example, in center fill/center dump cylindrical vessels, that location is usually about 1/6 of the vessel diameter from the outer wall. Contact an applications engineer for specific recommendations.

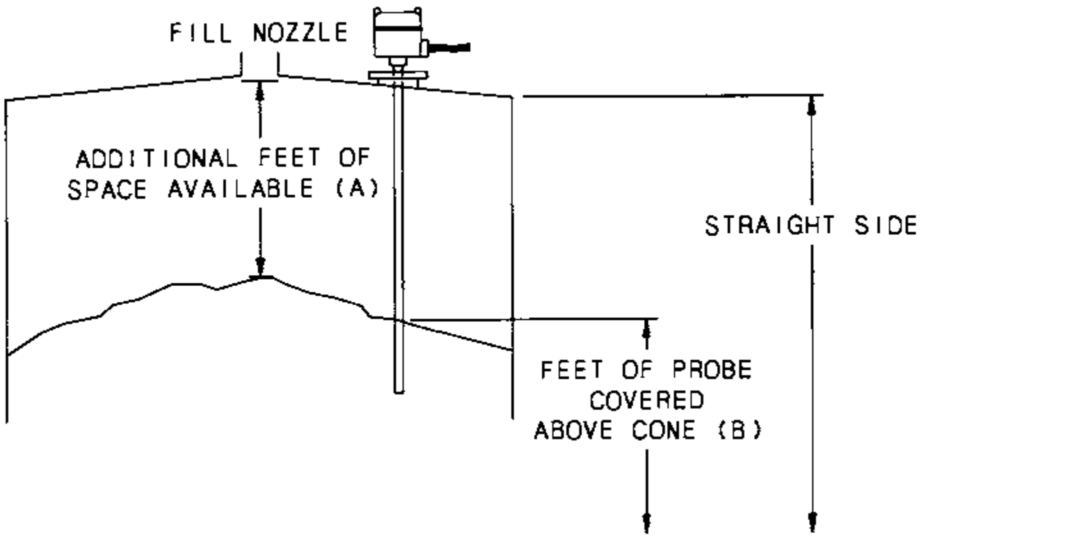
Conductive granulars behave much like conductive liquids when particle size is small, giving a real *level* rather than weight.

Calibration of transmitters with granular materials is identical to the method used for liquids. The big problem is finding how much is in the vessel when adjusting ZERO and SPAN.

Most users prefer to measure only the straight side of a bin or silo, so the conical bottom should be below zero. If this is the case, the active probe should terminate at the intersection of cone and straight side. Then zero may be set with bin empty.

Continuous Calibration

Fig. 8-6B



If the active probe enters the cone area, it will be necessary to fill the cone with material before adjusting ZERO (see Fig. 8-6A).

$$\text{PERCENT FULL} = \frac{B}{A+B} \times 100$$

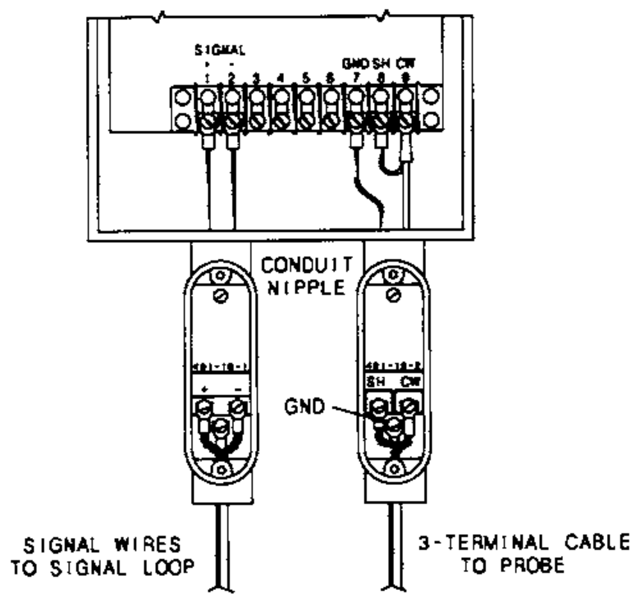
To set SPAN, fill vessel to a point just above 50%. Measure how much of probe is actually covered (above zero point), then set SPAN so output corresponds in feet. If output is in percent, you must calculate exactly how many feet of probe will be covered at the 100% level. DO NOT USE length of straight side as 100% value (see Fig. 8-6B).

8.5 Options Available

There are several options available with most continuous transmitters. The following is a brief summary of the most common standard options. Contact the factory if more information is required.

8.5.1 RFI Protection

With the increased industrial use of walkie-talkies, there have been a number of problems due to their interference. Typically, these walkie-talkies, when used near an electronic instrument, can cause the instrument output to read in error. Very often this error can trigger an alarm in the control room.

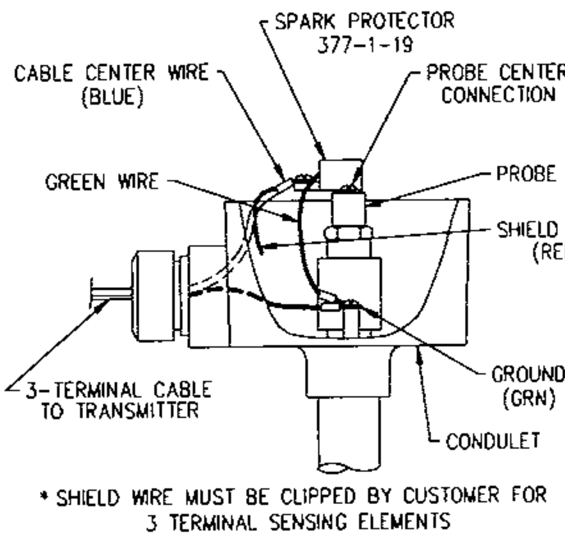


RFI Protection
Figure 8-7

To protect an RF level transmitter, all electrical lines to the housing must be filtered to prevent interference. One is placed in line with the sensing element cable, another in line with the signal cable. See Fig. 8-7 for a typical installation. A filter must be present on each line entering or leaving the housing, and must be close-coupled to the housing. The housing must also be earth-grounded.

8.5.2 Spark Protection

Installations with the sensing element mounted in a vessel containing insulating material, particularly dry granulars, need spark protection due to static electricity buildup in the material. The spark arcs to the probe, instead of the tank wall. This condition generally occurs when the material being measured is transferred to, or moved within, the vessel at high rates. An example would be pneumatic conveyance of plastic chips into the vessel. Conductive materials do not require spark protection.



Typical Spark Protection
Figure 8-8

If ever in doubt, specify spark protection. Its presence seldom causes a problem, but lack of spark protection when needed will give trouble. A typical symptom of spark damage is a drop in reading (lower sensitivity) or complete lack of output due to the deterioration of the chopper transistor. The spark protector should be mounted in the sensing element condulet whenever possible. A good earth ground at the condulet is also suggested. See Fig. 8-8.

8.5.3 Time Delay

Time delay or, more accurately, 'damping', is available for most level transmitters. It is an R-C time constant circuit that is variable over a period of a few seconds to about 30 seconds. For most applications requiring damping, five or ten seconds is usually sufficient. Calibration of the transmitter is with the time delay turned off. After calibration is complete, then the time delay can be added without affecting calibration. Occasionally, when the time delay is first turned on, there is a temporary upset in the transmitter output until the circuit 'times-out'. The time delay period specified is the time required for the output current to reach 90% of its final value. For example, if the level in the vessel changed from empty to full instantaneously, the output would reach 90% in the time delay period specified. Regardless of the amount of change, the time delay period is 90% of that change.
Fig. 8-9 shows a typical application using time delay to ignore the waves caused by an agitator.

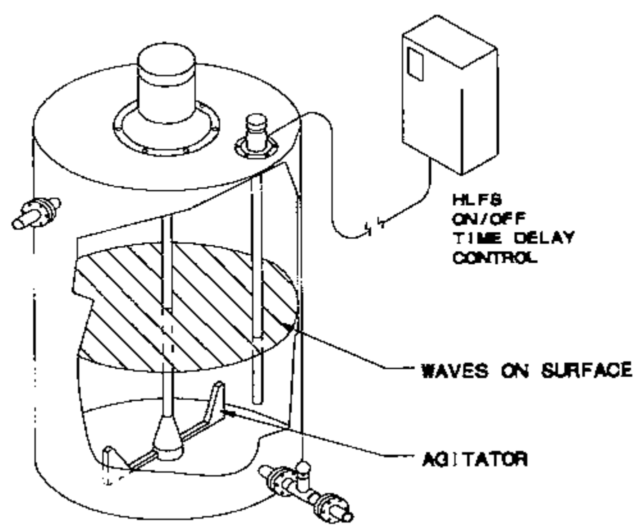


Figure 8-9
Typical Time Delay Action

8.5.4 High Sensitivity

Some applications, such as proximity or short spans of a low dielectric constant material, require a unit with greater sensitivity than the standard transmitter. To achieve this special high gain, three-terminal transmitters have been developed. Increasing cable length reduces the sensitivity of these instruments. Mount the transmitter as close as possible to the sensing element, preferably an integral transmitter.

Three-terminal sensing elements are often used with high-sensitivity transmitters. Two-terminal sensing elements and long sensing elements will require special padding in order to do the zero calibration. Fig. 8-9A shows a typical high-sensitivity application.

8.6 Recalibration

8.6.1 Recalibration of Analog Transmitters

In some applications, it is difficult or even impossible to completely fill or empty a vessel. In this case, it is desirable to have a secondary calibration standard which can be used to simulate the capacitance of an empty vessel without actually emptying it.

In order to establish the zero or empty vessel calibration, set up the instrument as described under calibration. After initial calibration, do the following:

a. Disconnect the coax cable from the transmitter.

b. Connect the calibration standard to the instrument in place of the original cable.

c. Adjust the standard until the instrument indicates the appropriate zero current (i.e., 1mA, 4mA or 10mA depending upon output current range).

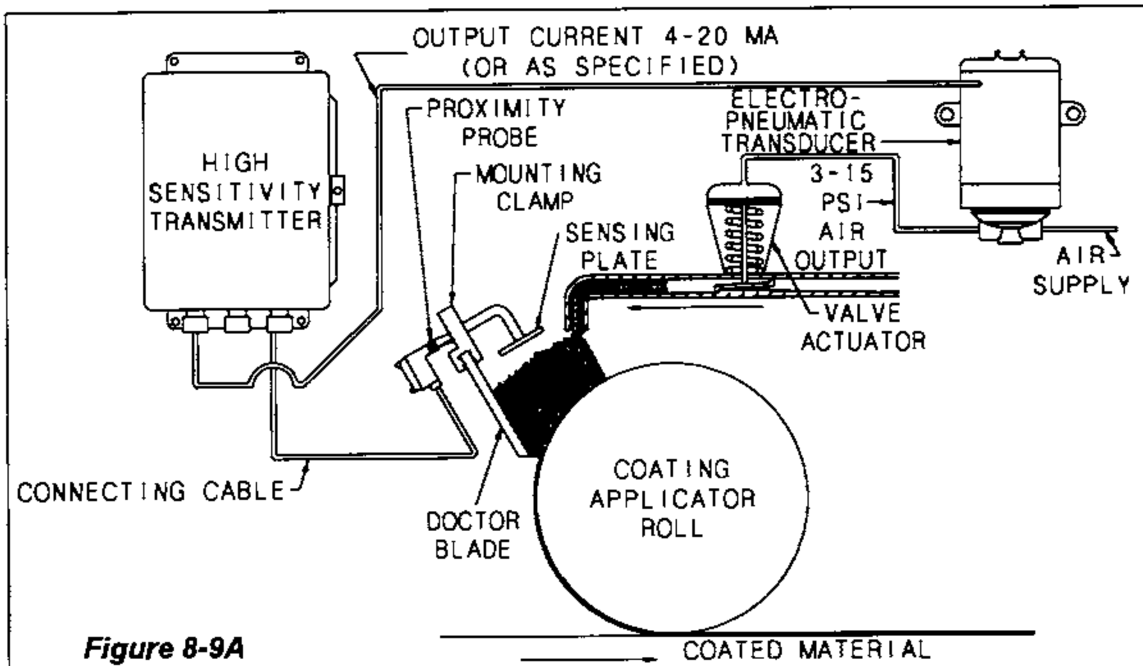


Figure 8-9A

TYPICAL HIGH SENSITIVITY APPLICATION

d. Record the value read on the calibration standard, and its serial number for later use. Recording the value on the inside of the instrument door is also suggested.

e. Adjust the standard until the instrument indicates full scale current (i.e., 20mA, or 50mA).

f. Record capacity value as in Step d.

g. Disconnect the calibration standard from the instrument terminals.

h. Reconnect the original cable.

Whenever it is desired to check or reset the calibration, or replace the instrument, the calibration standard set to the value recorded above may be substituted for the sensing element. This is done as follows:

a. Disconnect the coax cable from the transmitter.

b. Connect the calibration standard in place of the original cable.

c. Set the calibration capacitor to the above recorded values.

d. Adjust the ZERO controls for the minimum current calibration, and the SPAN controls for the maximum current calibration.

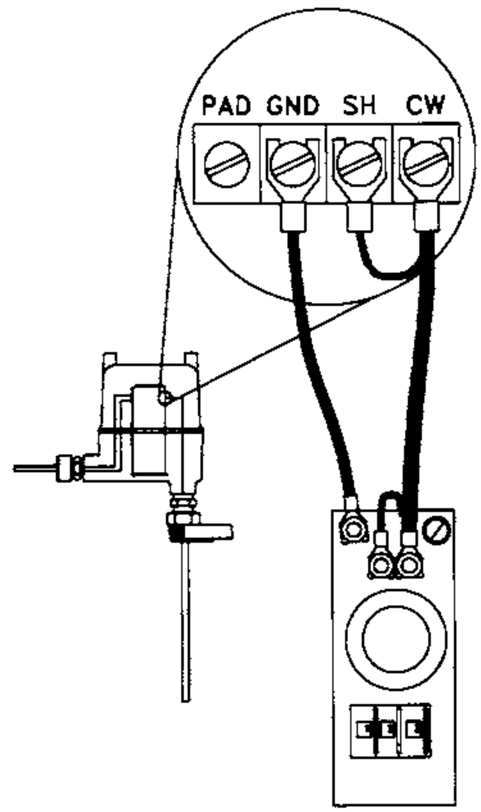
e. Disconnect the calibration capacitor.

f. Reconnect the coax cable.

UNIT IS AGAIN READY FOR SERVICE

8.6.2 Recalibration of Smart Transmitters

Smart transmitters can be recalibrated by entering the values of zero and span capacitance directly, from the handheld calibrator or PC. A Calibration Standard is usually not required in this case. When PC calibration software is used, it is usually possible to merely "download" the previously saved configuration file for that transmitter.

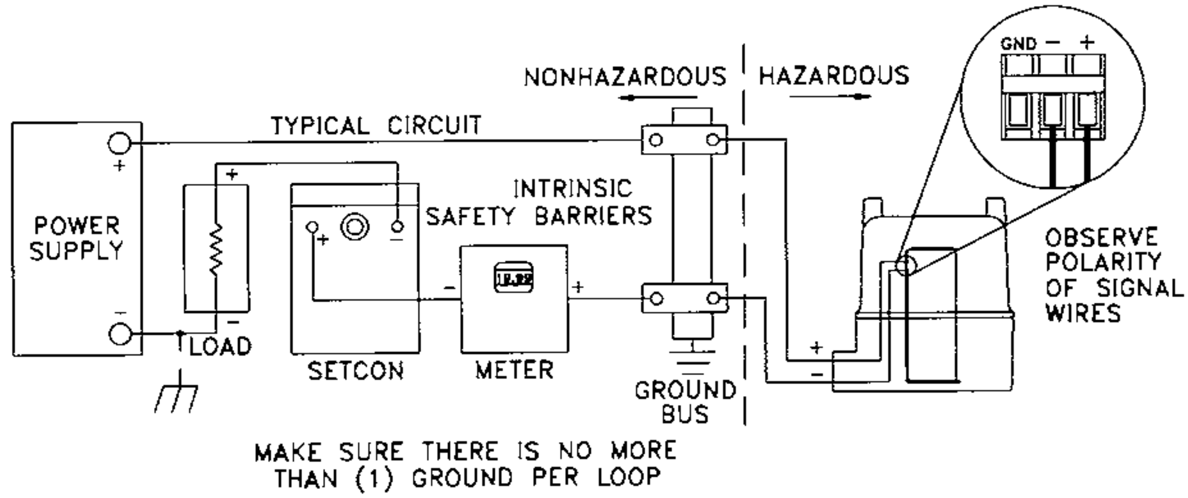


Typical Calibration Standard
Figure 8-9B

9.0 AROUND THE LOOP

9.1 Introduction

This section deals with various elements in the current loop or transmitter output.



Typical Two-Wire Transmitter Current Loop
Figure 9-1B

9.2 Limits of Resistance and Voltage

The two-wire current loop has a total resistance limit determined by the power supply voltage output and the minimum voltage required to operate the transmitter. For example, to calculate the maximum loop resistance for a 24-volt power supply, feeding a transmitter that requires 13 volts minimum, to produce a 20mA output, use the formula:

$$R_{max} = \frac{\text{V power supply} - \text{V transmitter (minimum)}}{\textit{max loop current in amperes}}$$

$$R_{max} = \frac{24 - 13}{.020}$$

$$R_{max} = 550 \text{ ohms}$$

In this case, the maximum loop resistance that can be inserted between the power supply and the transmitter is 550 ohms, including the resistance of the wires. The maximum voltage of the power supply is limited by the manufacturer's specification. It may be as high as 50Vdc, but 24Vdc is the most common power supply voltage used.

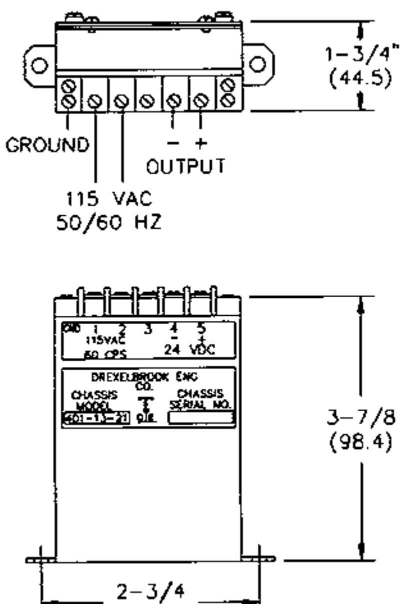
9.3 Power Supplies

The power supply chosen to drive the current loop need not be highly regulated. The transmitter can produce the correct output current as long as the supply voltage is between the minimum and maximum values (transmitter specification).

Several transmitters can be driven from one power supply as long as the power supply current capacity, at rated voltage, is greater than the maximum loop current per transmitter, times the number of transmitters. For example, to drive 30 transmitters with 4-20mA loops from one 24-volt supply, the power supply must be rated for 30 X .02A = 600mA output at 24 volts. The obvious disadvantage to the single power supply is that its failure causes all transmitters to go down.

The power supply may be grounded on either side, or ungrounded, and still function. However, if there is a choice, grounding on the negative side is preferred to keep down any possible 'noise' problems or instabilities due to transients. If another component in the loop must be grounded, the power supply output should be isolated from ground.

9.4 Setcon™



Setcon Current-Activated Alarm
Figure 9-2

Setcon is a Drexelbrook tradename for a current-operated alarm. It has a single- or double-pole, double-throw relay contact closure. The trip point of the relay is calibrated for 0-100% over 4-20mA, typically.

The standard differential or the dead-band is approximately .5% of that range. There is an adjustable-differential model available with a dead-band range of 0-100%, as well as a set point range of 0-100% of full scale. As in other types of controls, both high-level and low-level fail-safe are available. The input resistance on the 4-20 mA range is 100 ohms.

9.5 Proportional Setcon (Proportional Controller)

The proportional Setcon is a compact proportional controller that can take a 4-20mA signal and retransmit it with an adjustable 2% to 50% proportional band. It is an output amplifier with a gain of 50% down to 2%, with the starting point adjustable. For example, with a 2% proportioning band, a secondary signal of 4mA can be produced with 30% output of the original signal. When the original signal reaches 32%, the secondary signal will be 20mA. On the other hand, with a 50% proportioning band, 4mA can be produced at 30% of the original signal, and 20mA corresponding to 80% of the original signal. As with other devices, the fail-safe is selectable between direct-acting (LLFS) and indirect-acting (HLFS). This Setcon output has a built-in power supply that can drive up to 750 ohms on a 4-20mA range. Ranges of 1-5mA and 10-50mA are also available.

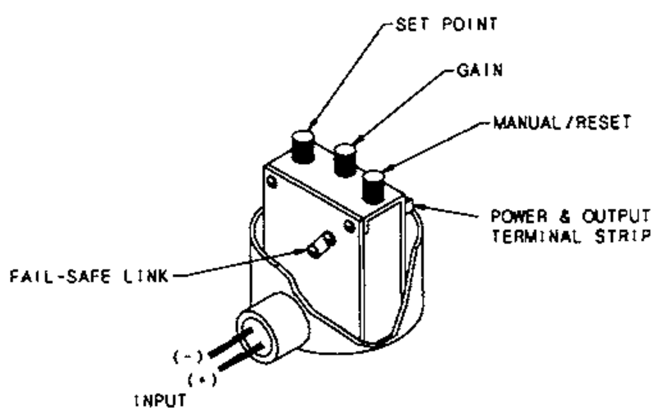


Figure 9-3
Proportional Setcon

9.6 Meters and Indicators

Most meters used today are liquid crystal displays (LCD); however, the older style analog meters are still available. Like the analog meter, the modern LCD meter is loop powered. That is, it does not require an external power source, but derives its operating power from the 4-20 mA loop, typically dropping about two volts. The LCD is normally calibrated 4-20 mA = 0 to 100%. However, they may be reset for other values, for example, 0-12 ft., 80 to 1000 tons. There are two adjustments for zero and span settings, along with the ability to move the decimal point. The digital panel meter is available in a number of mounting configurations including Nema 4X, explosionproof and panel-mount. See Figure 9-4.

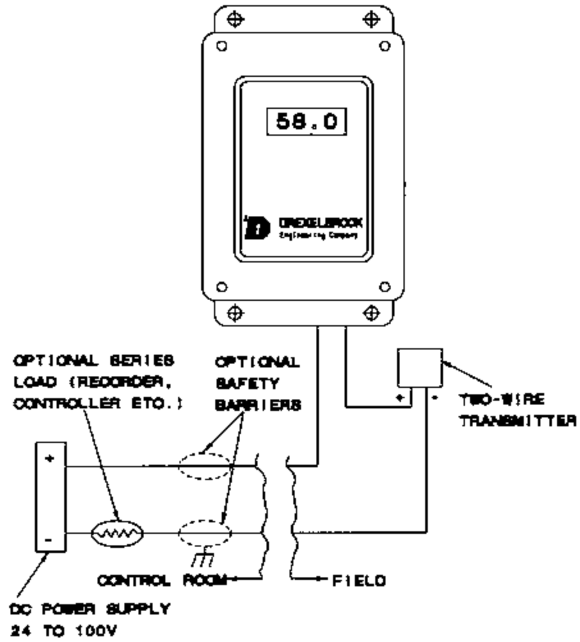
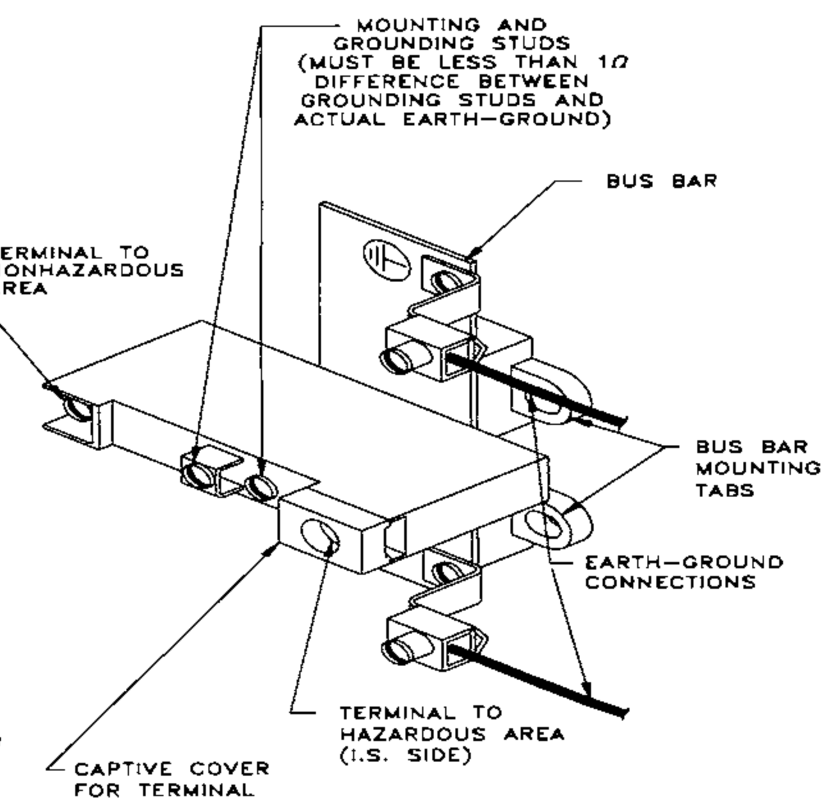


Figure 9-4
Digital Panel Meter

9.7 Intrinsic Safety Barriers

Intrinsic safety barriers come in several designs and configurations. Be sure to follow the instructions for the barrier used, as well as applicable hazardous area codes.



Typical Barrier Mounting
Figure 9-5

There are a few general things to check for, like the insertion resistance of each barrier. Since most barriers are limited to a 24-volt power supply, the barriers can consume most of the usable loop resistance, leaving little for other devices in the loop.

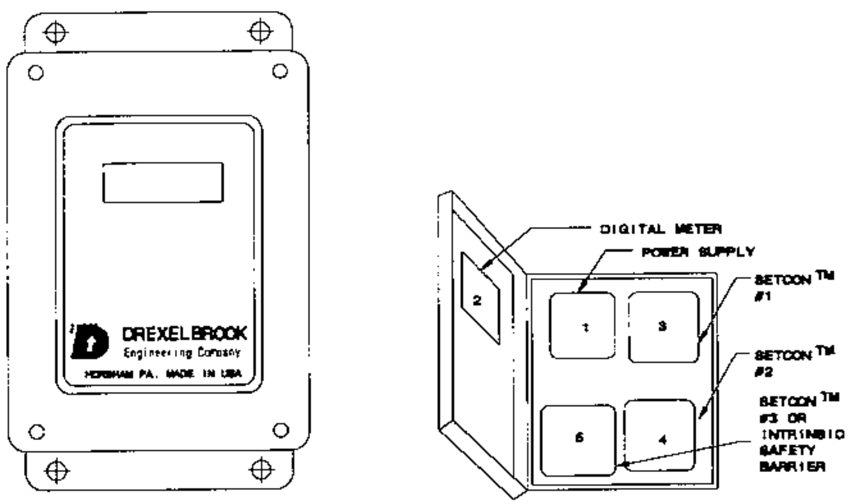
Some barriers, after fault condition, trip and stay tripped until the power is totally removed and the fault is cleared. Some barriers have a non-replaceable fuse built into the barrier. It is good practice to put a lower-value replaceable fuse in series with each loop on the nonhazardous side of the barrier. If this is done, a blown fuse will not be so expensive. See Appendix B-7 for further information on barriers, as well as the manufacturer's instructions. See Figure 9-5.

to any two-wire, 4-20 mA transmitter providing power, indication, and/or control.

9.9 Microprocessor Receivers

The development of the microprocessor chip has brought to the process industry a whole new range of benefits at an affordable price. Some of these benefits include providing setpoints for relay operation, tank strapping tables, automatic computations, loop fault alarms, the ability to remotely calibrate, and many many others. These microprocessor receivers may be single channel input or multiple channel input, typically in multiples of two or eight.

Figure 9-6



NEMA 4X HOUSING

9.8 Single Channel Receivers

Figure 9-6 shows a typical single channel receiver, which is a combination of the previously described power supplies, setcons and meters. In the single channel receiver, the power supply, digital meter, and one or more Setcon current trips, as well as intrinsic safety barriers, may all be prewired in the same weatherproof or Nema 4X housing. These units are packaged in the most popular combinations of power supply and control functions, and quickly mount as a single unit. The single channel receivers are convenient and useful companions

The input signal to these devices is typically in the 4-20 mA range. However, one of the chief advantages of this type of device is the ability to use a current greater than 4, but less than 20 mA and scale the calibration for 0-100 percent or the engineering units of users' choice. These non 4-20 mA signals can be referred to as X to Y signals or Magi-Cal™. By not requiring that the transmitter be calibrated for exactly 4-20 mA, the microprocessor will accept any two values within that range to represent 0 and 100 percent. With this capability, the field-mounted transmitter does not need the full range of zero and span controls that it would have required otherwise. This reduces the cost of the field mounted transmitter. A side benefit is the ability to calibrate the field-mounted instrument at the microprocessor, which is frequently mounted in a central location near a control room. The cost savings associated with using lower cost transmitters frequently pays for the cost of the microprocessor receiver in multiple loop systems.

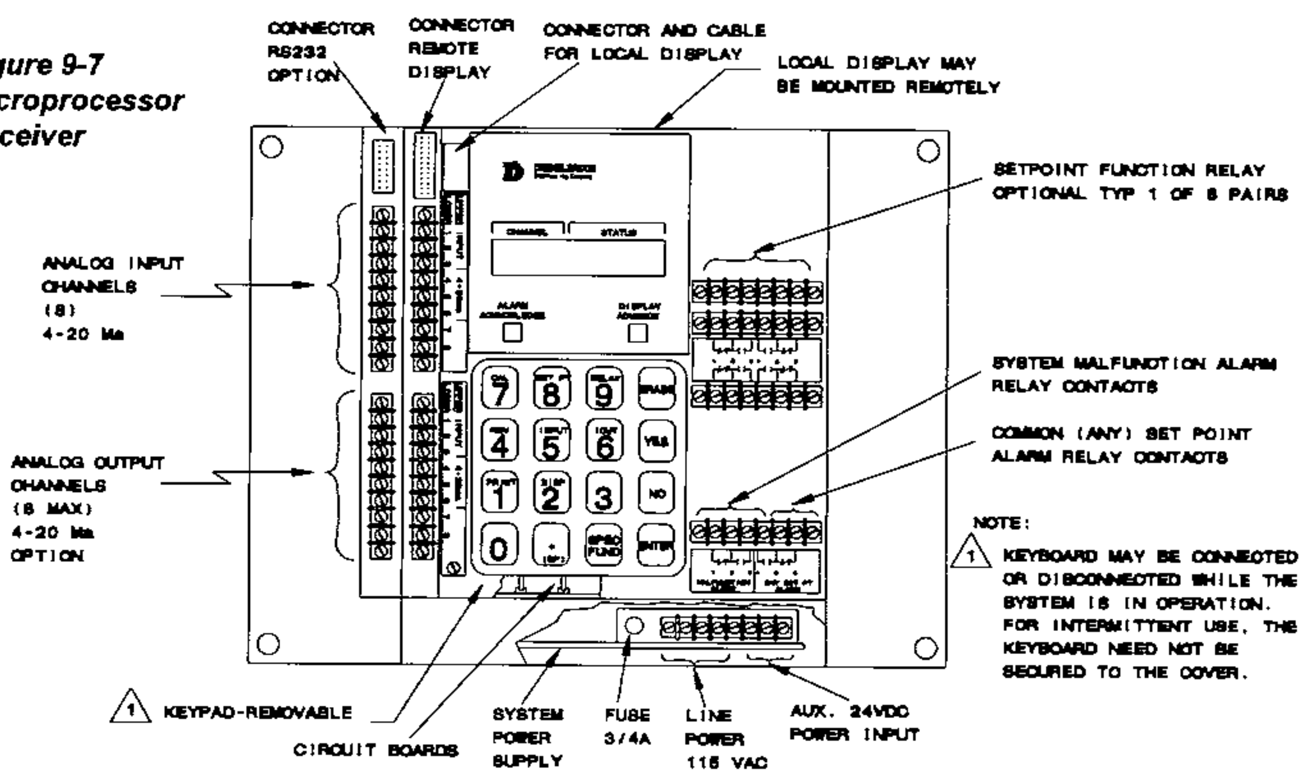
The microprocessor receiver provides a number of important and needed functions such as: providing power to each of the transmitter loops, reading the output in percent or engineering units from each of the transmitters, providing relay actuation at the users' setpoints (usually high and low levels), and providing an alarm if any loop goes out of range due to wiring or transmitter problems.

Typical output functions of a microprocessor receiver include: a re-transmitted 4-20 mA that is proportional to 0-100 percent, event and status reporting to a printer, relay control points, and communications to higher level devices such as personal computers, programmable controllers, and distributed control systems. Figure 9-7 shows a typical eight-channel microprocessor receiver.

Most of the microprocessor receiver's capabilities come from the software instruction set contained in its internal memory. Some common software capabilities include: relay logic, non-linear characterization, pump start sequencing (also called pump alternation), assignment of engineering units such as gallons, pounds and feet, detection of small leaks in vessels, subtraction or division of one signal with another, temperature compensation, and automatic calibration. Through special software, one microprocessor is able to "talk" to another such as between programmable controllers or between a controller and management information main frame. Some special purpose software packages are available for applications like submerged flow and traveling screen.

In brief, the microprocessor receiver includes all of the capabilities of the Setcons, power supplies, and meters mentioned earlier, as well as many additional functions.

Figure 9-7 Microprocessor Receiver



10.0 TROUBLESHOOTING (CONTINUOUS)

10.1 Introduction

If difficulty occurs when operating a measurement system, it will be necessary to divide the system into small sections, e.g. power supply, loop wiring, indicators, etc., and test each individually for proper operation. After each part has been tested and found to be functioning, there still may be a problem. In this case, the trouble may be in the selection of equipment for the application. However, many times the problem is due to an assumption being made about what is going on inside the vessel. When possible, **test, don't assume,** and **don't rely** on the opinion of the operator as to the condition inside the vessel. Even sight-gauges are sometimes misleading. The following troubleshooting procedures have been taken from typical continuous-instrument instruction manuals. Although the procedures may vary slightly depending on the model, they generally are similar to those presented here. A screwdriver and a multimeter are enough to do all of the tests. However, a calibration/test system is available and is indispensable to the plant that has a lot of instrumentation.

10.2 Checking the Transmitter

Note: These are examples of typical procedures. Consult the instruction manual for the exact procedure. It is best to check the transmitter last so as not to disturb any settings.

Operation Check (Analog Transmitters)

A. Remove the sensing element and signal wires from the transmitter.

B. Be sure Fail-Safe link is in low-level fail-safe position.

C. With pencil, mark the positions of all controls on the faceplate in order to return to them.

D. Put the Step Span in Position #1 and the Fine Span in the full clockwise position. Put the Step Zero in Position #1 (most sensitive position).

E. Observing polarities, connect a DC milliammeter and DC power supply (11.5 to 50 volts) in series, and complete the loop by connecting Terminals (-) and (+). See Figure 6-3.

F. Adjust the Fine Zero until the meter reads 0% (4 mA).

G. Turn the Fine Zero one clockwise turn further. The output should read approximately between 33% and 100% (9-20 mA). If so, the instrument is probably working correctly.

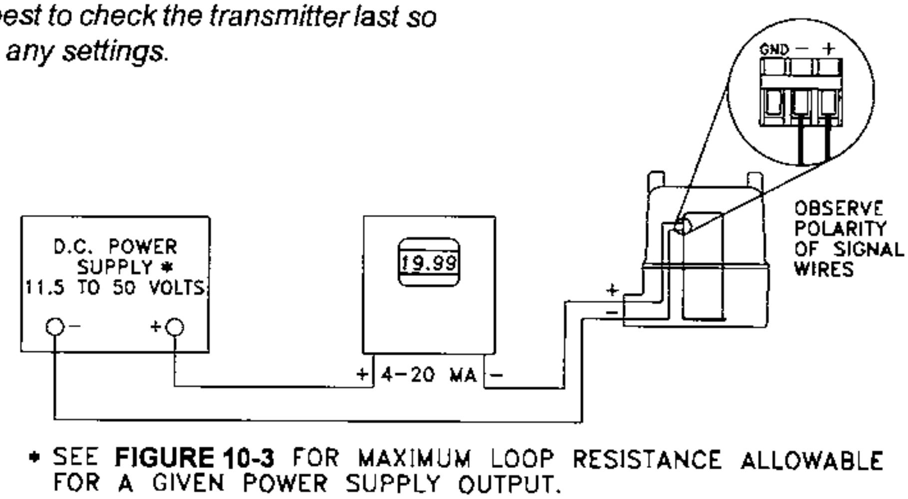


Figure 10-1

Each turn of the Fine Span changes the input a known amount. This checks the operation and gain of the transmitter.

H. If the difficulty has not been located at this point, proceed to the output checkout procedure in paragraph 6.3.

Drift Check

If the output of a transmitter seems to be drifting, it is important to determine whether the drift is in the transmitter or in the probe. (A properly connected cable never drifts.)

1. Remove the sensing element cable from the transmitter.

2. Without disturbing the dial settings, connect a capacitance standard or an NPO capacitor across the probe to ground input. Adjust the capacitance standard or select a capacitor value that will bring the unit on scale.

3. Observe the reading over a 24-hour period to see if it is stable.

4. If the reading is stable, the sensing element or the application must be the source of the drift. If the reading drifted, return the instrument for repair. Be sure to mark on the tag that the problem is drift.

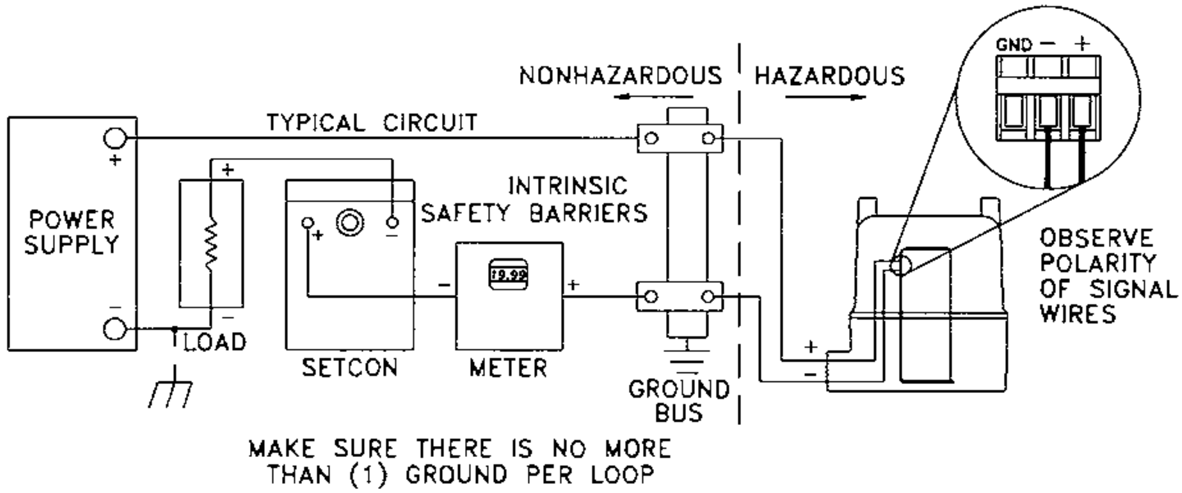
10.3 Checking the Loop

Note: These are examples of typical procedures. Consult instruction manual for exact procedure.

1. With a capacitance standard, or by following the instrument checkout procedure, adjust the transmitter output until 20mA flows. If it is not possible to get 20mA, then measure the voltage across the transmitter output . If there is less than the minimum usually required (approx. 13 volts), the loop has too much resistance, or not enough power supply voltage.

2. If in Step #1 above, the voltage is not between 13 and 50 Vdc, disconnect the power supply leads at the power supply and at the unit. Next, short the wires that went to the power supply (+) and (-) terminals.

3. Measure the resistance between the two wires that were just connected to the loop terminals of the transmitter. Fig. 10-3 illustrates when the resistance is too great.



Loop Check
Figure 10-2

Minimum Allowable Resistance

V(SUPPLY) (VOLTS)	MAXIMUM LOOP RESISTANCE (OHMS)
50	1925
40	1425
30	925
24	625
20	425
18	325
12	25
11.5	0

Figure 10-3

10.4 Checking the Sensing Element Cable

All steps are described in Fig. 10-4, below.

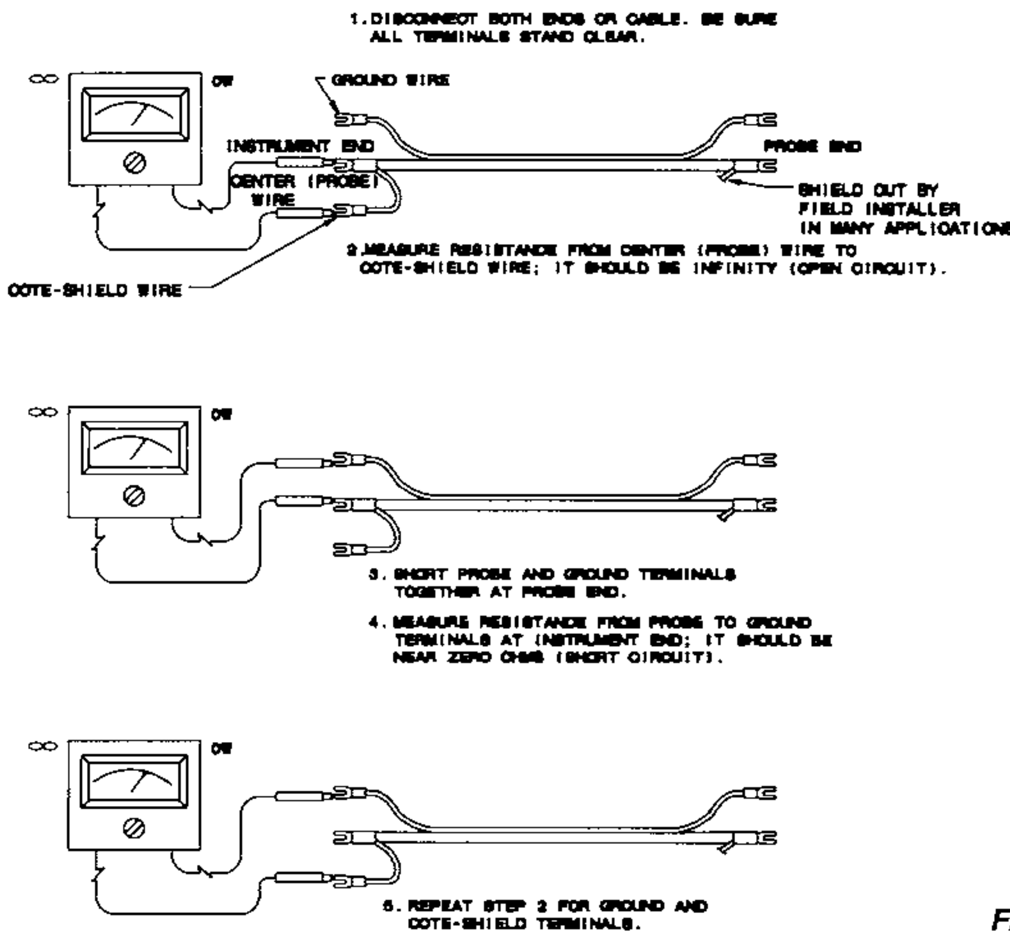


Figure 10-4

10.5 Checking the Sensing Element

Note: These are examples of typical procedures. Consult instruction manual for exact procedure.

CAUTION: Be sure to use an ***analog*** *ohmmeter, not digital, for this test.*

Step 1

Check the resistance of the probe to ground with level below the probe (Fig. 10-5A).

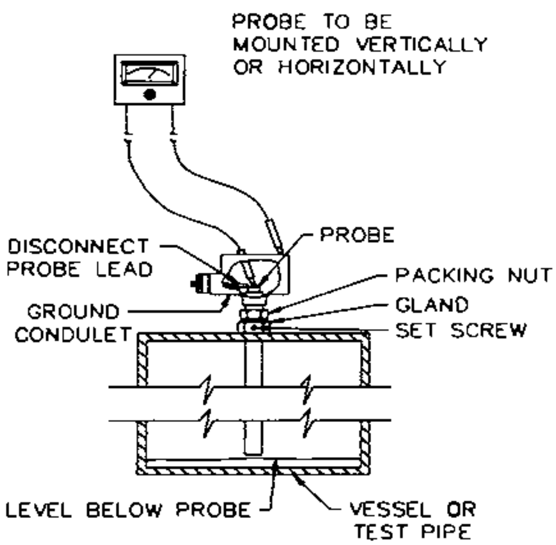


Figure 10-5A

Resistance should be infinite. Resistance less than 1 megohm indicates excessive leakage, probably due to product or condensation in the gland/packing nut area. (Consult factory.)

Step 2

Check the resistance of the probe to ground with level above the probe (Fig. 10-5B). Resistance readings less than 1 megohm indicate either defects in the probe insulation or, if a bare probe, that the material is conductive and an insulated sensor is needed.

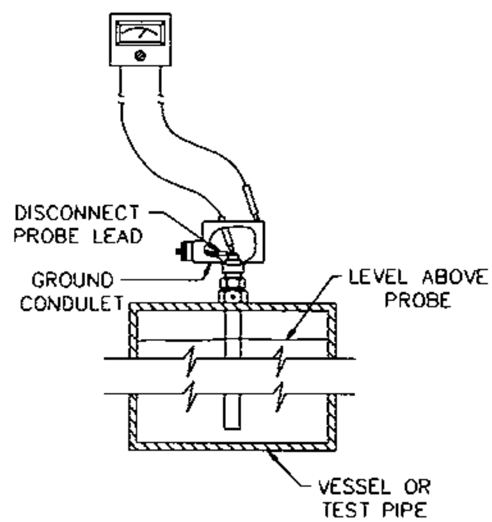


Figure 10-5B

11.0 PROPERTIES OF MATERIALS

11.1 Material Types

There are four types of materials found in industry today. The four types of materials are: **liquids, granulars, slurries**, and **interface**.

By liquids we are describing free-flowing liquids such as water, acids, caustics, fuels, solvents, even molten sulfur.

Granulars are defined as any solid material that may vary in particle size from talcum powder to coal, to rocks three feet in diameter.

Slurries are mixtures of liquids and granulars that are typically viscous and heavily agitated to keep the particles in suspension.

An interface is the line between any two immiscible liquids. The most common example is, of course, oil and water.

11.2 Physical and Chemical Properties

A level measuring device must make a measurement independent of changes in material density, chemical composition, build-up, viscosity, or electrical properties. Some technologies depend on some of these specific properties to make their measurements and are, therefore, sensitive to changes in them. For example, differential pressure infers level from a measurement of pressure, which is directly affected by material density. Any changes in density will cause an error in level reading.

11.3 Electrical Properties

RF ADMITTANCE is a universal technology. When measuring level, RF Admittance measures properties common to everything in the universe. All things, even a vacuum, have an electrical property called DIELECTRIC CONSTANT (k). The other electrical property is conductivity (g). **RF Admittance** takes both properties into account when computing the level.

By contrast, **CAPACITANCE** level technology looks at only one parameter, dielectric constant. A capacitive level measurement can only be successful in those applications where the conductivity is very small compared to the capacitive reactance.

Without becoming too technical, this section will discuss the two electrical properties of dielectric constant and conductivity and how they influence the RF level measurement.

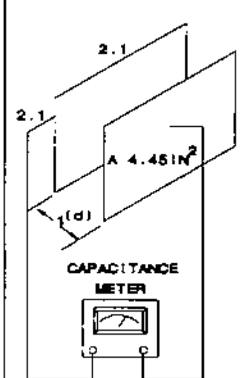
11.3.1 Dielectric Constant

Dielectric constant is the electrical parameter that causes capacitance. It is present everywhere and in everything, including a vacuum. Capacitance is determined by the formula:

$$C = \frac{k\,e\,A}{d}$$

Where C = Capacitance
k = Dielectric constant
A = Area of each conductor
d = Distance between conductors
e = Absolute permitivity of a given dielectric in free space (can be ignored for this discussion).

Figure 11-1
Dielectric Constant (k)



TYPICAL VALUES

MATERIAL BETWEEN PLATES	K	CAPACITANCE IN PICOFARADS
VACUUM	1	1.000
AIR	1.0006	1.0006
POLY CHIPS	1.3	1.3
SOAP POWDER	1.55	1.55
KEROSENE	1.8	1.8
SAND	4.8	4.8
ALCOHOL	33	33
D.I. WATER	78	78

$$C = \frac{k\,A}{d}$$

Dielectric constant can be measured experimentally in the laboratory by a test setup as shown in Figure 11-1 above. With the plate sizes and distances depicted, the meter should read directly in pico-Farads and dielectric constant.

A very important observation here is that the dielectric constant of air or, for that matter, any gas or vapor, is insignificant compared to the dielectric constant of any liquid or granular.

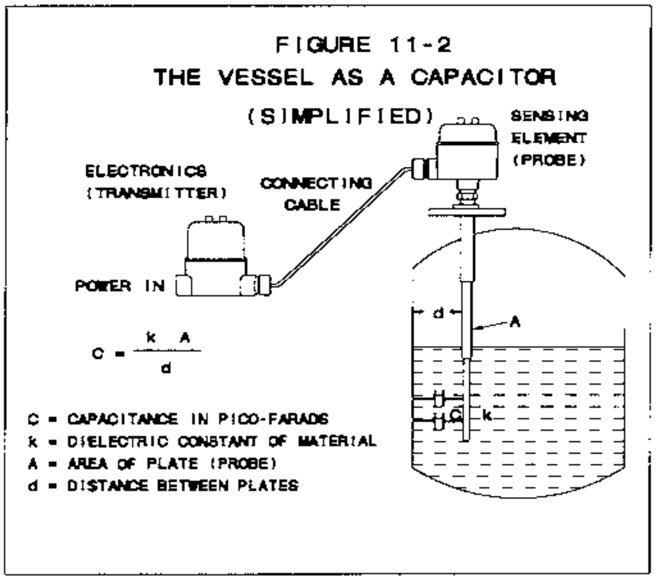


Figure 11-2

This is important because regardless of what vapor exists above the material being measured, it will have no practical effect on the accuracy of the measurement. Contrast this with an ultra-sonic measurement where the vapor density and the vapor temperature must be known to achieve acceptable accuracies.

Figure 11-2 shows a more practical example of how the plates shown in Figure 11-1 would look in an actual vessel where RF ADMITTANCE is being used to measure level.

11.3.2 Conductivity

Conductivity is the other electrical parameter which frequently exists in the materials we store in our vessels.

Conductivity is the mathematical reciprocal of the more familiar term resistance, i.e.,

$$g = \frac{1}{R}$$

where
g = conductivity in micro-mhos
R = resistance in Ohms

Similar to Figure 11-1, Figure 11-3 shows how conductivity could be measured in the lab. It also shows typical conductivities for several well known materials across the conductivity spectrum. In the interest of clarity, the conductivity spectrum has been broken into three ranges:

1. Insulating
2. Semi-Conducting
3. Conducting

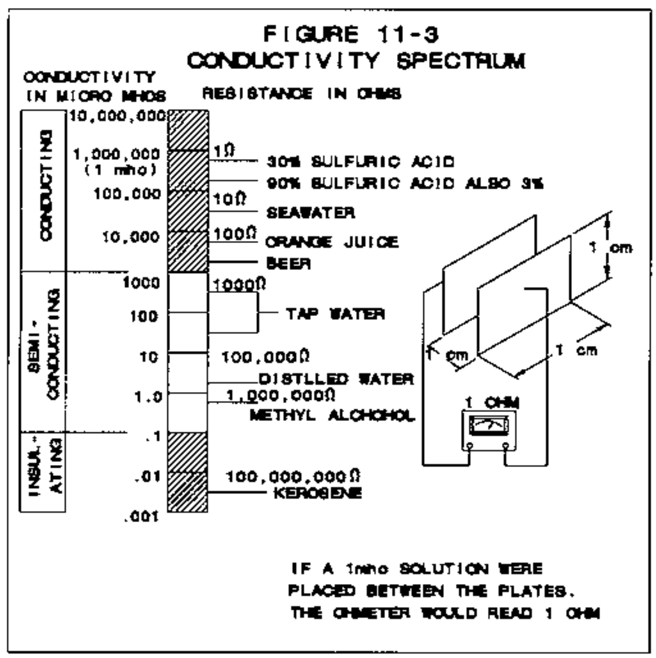


Figure 11-3

The width of the semi-conducting range in Figure 11-3 is somewhat variable due to the frequency of the measurement and the sensing element parameters.

As mentioned earlier, conductivity has been the nemesis of *capacitive* level measurement. *RF ADMITTANCE* level measurement, on the other hand, uses this parameter in computing the real level.

11.4 The Effect of Materials on Point Level RF Controls

To guarantee a reliable point level measurement that is independent of the electrical properties of the material in the vessel, always choose a *three terminal*, radio frequency, point level control. Three-terminal controls are those which have circuitry providing a very low impedance drive terminal to power a driven shield on the sensing element. This driven shield is necessary to prevent conductive coatings from causing false high-level signals. Figure 11-4 illustrates this type measurement. Just having a third terminal isn't sufficient. To be an all purpose control, it must be capable of driving a shield to vessel impedance of less than 30 ohms *without* need for recalibration.

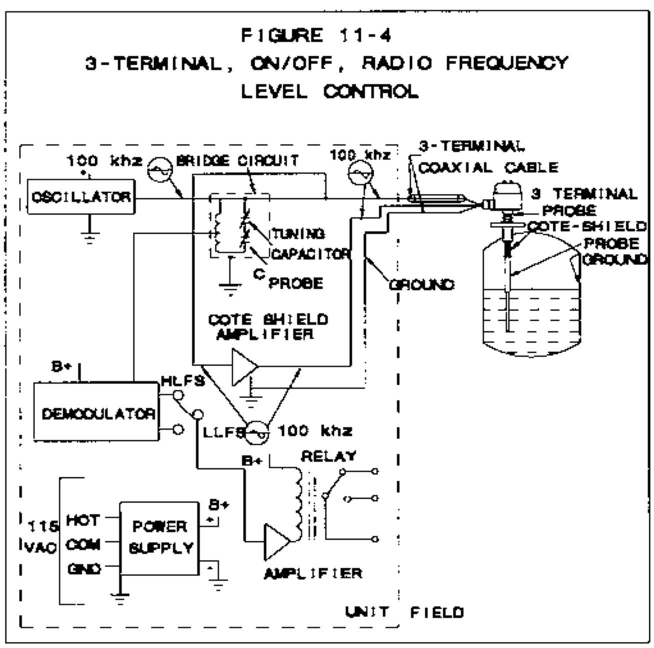


Figure 11-4

Having selected a control with the above capabilities, it is necessary to decide whether the device should be line-powered with self-contained relay, or two-wire dc powered with the power and control being done elsewhere.

The same three-terminal point level transmitter can be used in all applications measuring all four material types, regardless of physical or chemical properties. All that remains is to select a sensing element to meet the process conditions.

11.5 The Effect of Materials on Continuous Level RF Admittance Controls

No material has a dielectric constant that it too high or too low to measure continuously with RF ADMITTANCE. The only practical issues are:

1. If the material is insulating, is it a stable dielectric constant?

2. If the material is semi-conducting, can it be made to "look conducting" by go ing to a lower frequency of measurement?

These issues are important in determining which of two types of RF ADMITTANCE transmitters to choose.

1. Level measurement only (single channel)

2. Level and composition measure ment (dual channel)

The second type level transmitter actually makes separate, simultaneous measurements of level and the electrical properties of the material composition).

Actually, the dual measurement could be used in all continuous level measurements but it is only required in about 10% of the applications. Because of the complexity of the circuitry, it is more costly to produce this equipment. For these reasons, most continuous level measurements are done with the single level measurement, RF ADMITTANCE type.

Figure 11-5 shows the basis for choosing between the single or dual measurement systems to get the best value for your money. Nothing is to be gained by a dual measurement when a single measurement will do the job.

Experience and prior testing have already determined which category most materials fall into; it is only necessary to identify the material, and the correct transmitter will be supplied. When the material is new or unknown, a quick test of its electrical properties will make the final determination. If still in doubt, choose the dual measurement system.

Conducting materials only require the single measurement type, regardless of the stability of the conductivity. RF ADMITTANCE will automatically handle any errors due to coatings that would cause a capacitance transmitter to read incorrectly. Most materials that contain more than 10% water generally fall into this conducting category.

MATERIAL CHARACTERISTCS CATEGORY	RF ADMITTANCE TRANSMITTER TYPE
INSULATING (STABLE DIELECTRIC)	SINGLE MEASUREMENT
INSULATING (VARIABLE DIELECTRIC)	DUAL MEASUREMENT
SEMI-CONDUCTING (STABLE)	SINGLE (LOW FREQUENCY) MEASUREMENT
SEMI-CONDUCTING (VARIABLE)	DUAL MEASUREMENT
CONDUCTING (STABLE OR VARIABLE)	SINGLE MEASUREMENT
DON'T KNOW (eg.NON-DEDICATED VESSELS)	DUAL MEASUREMENT

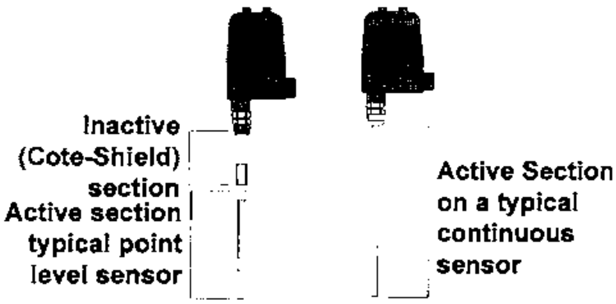
Figure 11-5

ABBREVIATIONS USED IN DREXELBROOK LITERATURE

ac	Alternating Current
AL	Active Length
CS	Cote-Shield (TM)
C.S.	Carbon Steel
CSA	Canadian Standard Association
CSL	Cote-Shield (TM) Length
dc	Direct Current
D.E.	Drexelbrook Engineering
DP	Differential Pressure
DPDT	Double-Pole, Double-Throw
E/P	Electro-Pneumatic
F.M.	Factory Mutual
FLNG	Flange
HLFS	High-Level Fail-Safe
HSG	Housing
Hz	Frequency of One Cycle Per Second
I.D.	Inside Diameter
I.L.	Insertion Length
IPS	International Pipe Schedule
K	Dielectric Constant
KC	Kilocycle (1000 Cycles/Sec.)
KHz	Kilohertz (1000-Hertz)
LLFS	Low-Level Fail-Safe
mAdc	Milliamperes Direct Current
MHO	Units of Conductivity
MPB	Minimum Proportional Band
NEMA	National Electronics Manufacturers Assoc.
NPT	National Pipe Thread
NSD	Not Standard Delivery
O.D.	Outside Diameter
P.B.	Proportional Band
pF	Picofarad
PRF	Proof
RF	Radio Frequency
R.F. Flange	Raised-Face Flange
RFI	Radio Frequency Interference
SD	Standard Delivery
SPDT	Single-Pole, Double-Throw
SS	Stainless Steel
3PDT	Triple-Pole, Double-Throw
TFE	Tetrafluorethylene
TM	Trademark
"X"	High-Capacitance Insulation Used on Sensing Elements
"Y"	Modification to Standard Equipment

GLOSSARY OF TERMS COMMON TO LEVEL INSTRUMENTS

Active Section:
That part of a sensing element which responds to changes in the process material. In on/off applications, this is usually the section near the tip of the sensing element.

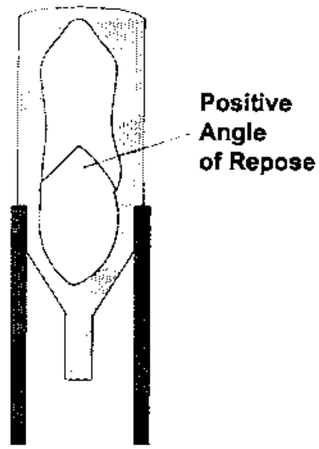


Adjustable Differential:
Normally applied only to on/off instruments. Differential is the dead-band or minimum change in level required to switch a relay. Adjustable Differential enables a relay to be actuated IN at one point with rising level, and OUT at another point with decreasing level. The difference between these points is the differential which can be adjusted.

Admittance:
The complex sum of conductance and susceptance.

Admittance Measurements:
The technique by which both the resistive and capacitive components of admittance are used in making measurements, such as level, composition or flow.

Angle of Repose:
The angle a granular material assumes in a vessel as the vessel is either emptied or filled. During filling, a positive angle of repose results; during emptying, a negative angle of repose results.



Capacitance:
A measure of the ability of a material to store an electrical charge. The unit of capacitance is the farad; but for practical purposes, we must speak of picofarads, or farad times ten to the minus twelve. Another term used is micromicrofarad, which is equivalent to picofarad.

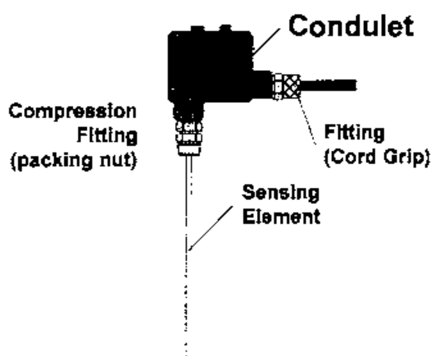
Comad (TM):
An abbreviation for Computed Admittance. This technique used both the conductive and susceptance components of the signal to make level measurements, allowing the system to disregard outside influences, such as varying moisture content in a granular measurement or sensing element buildup on liquid measurement.

Compensate Cable:
A coaxial cable equal in length to the measuring cable. However, it is terminated only at the instrument end and is connected to a special circuit. Its sole purpose is to compensate for the effect of ambient temperature on the measuring cable.

Conductance:
The ability of a circuit to pass an electric current. Conductance is expressed in mhos. A mho equals ÷ 1 ohm and it represents the ability of a substance to pass one ampere of current at one-volt potential.

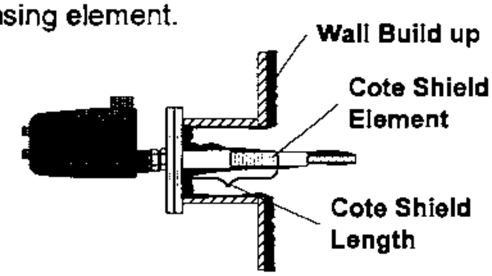
Conductivity:
A measure of how well electricity is conducted. The unit used for measurement of conductivity is micromho per centimeter (mho/cm).

Condulet:
A metal housing covering the head of a sensing element, to protect electrical connections.



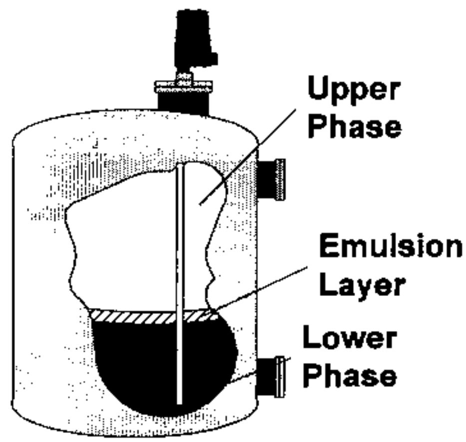
Cote-Shield (TM):
A trademark of Drexelbrook Engineering Company, referring to the ability to ignore coating on a sensing element. This is achieved through the electronics used in Drexelbrook equipment. Cote-Shield action is implemented differently in continuous and on/off systems, but the effect of ignoring the coating on the sensing element is the same.

Cote-Shield Electrode:
In on/off systems, an exposed conducting electrode between the sensitive electrode and ground. The Cote-Shield electrode allows the system to ignore conductive coatings on the sensing element.



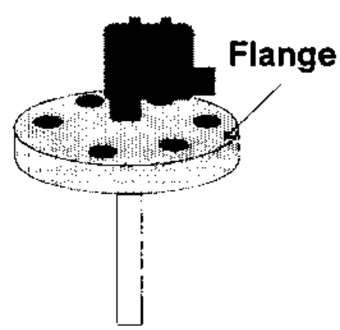
Dielectric Constant (K):
A number relating the ability of material to carry alternating current to the ability of vacuum to carry alternative current. The capacitance created by the presence of the material is directly related to the Dielectric Constant of the material.

Emulsion Layer:
In many interface applications, a layer or band of material that is a mixture of both the upper phase and the lower phase. Other terms of Emulsion Layer are "Sludge Layer", "Rag Layer", and "Scum Layer".

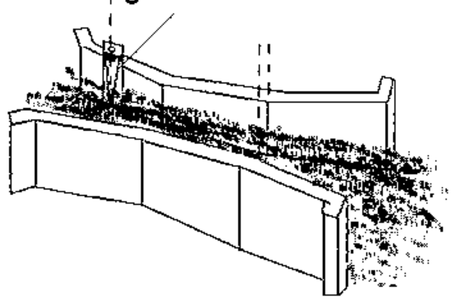


Fail-Safe:
The output reading of an instrument in the event of a power failure or instrument failure. In level measurement it is called either high-level fail-safe (HLFS) or low-level fail-safe (LLFS).

Flange:
A round, usually metal disc, used to connect pipes and sensing elements to vessels. A flange-mounted sensing element is mounted in a flange and then the entire unit is bolted to the vessel.



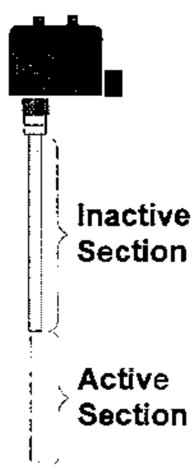
Flume:
A narrow channel inserted in a stream, through which the stream must pass. The height of liquid in the channel is a measure of the flow through it. See Weir.



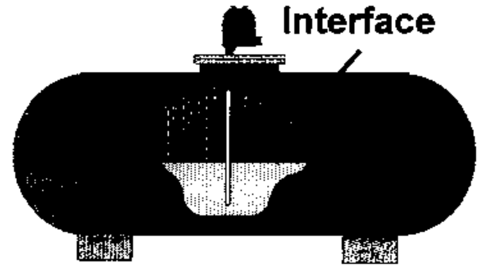
Hazardous Area:
In instrumentation, Hazardous Area refers to any area which may contain gases or dusts that are capable of ignition.

Impedance:
The opposition to the flow of alternating current. Also see Admittance.

Inactive Section:
The part of a sensing element which does not respond to changes in the process material. It is usually made inactive by a grounded metal tube surrounding the sensing element and shielding it from the process material.



Interface:
The boundary layer or line between two immiscible fluids.



Example: Oil and Water. Interface measurements either indicate the position of this line, or signal when it has passed a predetermined point on a probe. Also see Emulsion Layer.

Intrinsic Safety:
Equipment and wiring are considered to be intrinsically safe when, under normal or abnormal conditions, they are incapable of relating sufficient electrical or thermal energy to cause ignition of a specific hazardous atmospheric mixture in its most easily ignited concentrations.

Load Resistance:
The total resistance in ohms that may be connected in series to the output terminals of a continuous instrument.

Micromicrofarad (mmF):
Equivalent to picofarad. See Picofarad.

Multipoint:
Point level control with 3 or more independent setpoints on one sensing element.

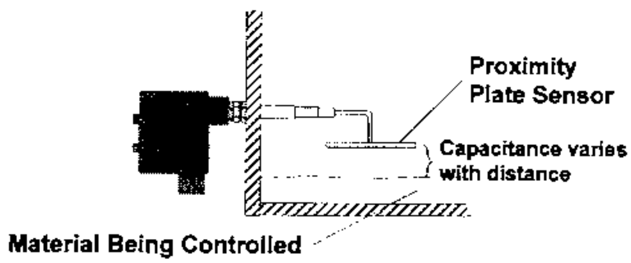
Nonconductive:
With Drexelbrook equipment, a material is considered to be nonconductive if it has a conductivity of less than 20 micromhos per centimeter.

Picofarad (pF):
The unit of measure for capacitance. It is ten to the minus 12 farads. See Capacitance.

Probe:
Term commonly used in reference to sensing element.

Proportional Band:
The change in input required to provide a full range in output.

Proximity:
Proximity sensing can determine the level of or presence of a material without any device actually touching the product being measured. The sensing element is generally a flat plate or disc attached to a rod.



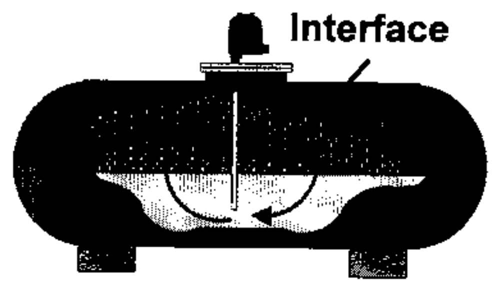
Proximity - Non-Contact Level Measurement

Puff:
Slang term for Picofarad (pF).

Resistance:
Resistance is a measure of how poorly a circuit conducts current. Its unit of measure is the ohm.

Resistivity:
A measure of how poorly a material conducts current. The unit of measurement is ohm/cm.

Rollover:
The action of two immiscible liquids when they change phases in an interface. That is, the bottom layer or phase rolls over to the top and vice versa. This often occurs due to a temperature change. also see Interface.



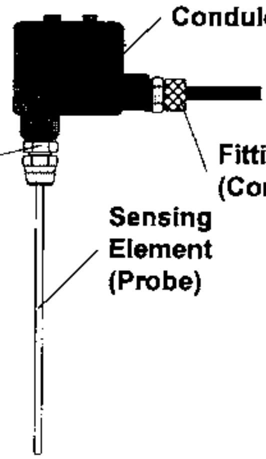
Rollover

Saturation Capacity:
Maximum capacitance that can be obtained from an insulated sensing element that is fully immersed in a conductive liquid. It is generally specified in terms of picofarads per foot. Sensing elements are often classified by their saturation capacity. The higher the saturation capacity the better the Cote-Shield action.

Safety Barrier:
A device placed in a signal transmission line to limit the power passing through the line to a value considered to be safe.

Seal Tyte (TM):
Sensing element with flanged connection that can be hermetically sealed.

Sensing Element:
The element directly responsive to the value of the measured variable. Other terms frequently used are sensing probe, primary element or primary measurement element. Drexelbrook Engineering jargon for the sensing element is probe.



Setcon (TM):
An adjustable device which regulates the pull-in, pull-out points of a relay. It is used with continuous instruments.

Slurry:
A mixture of a liquid (usually water) and undissolved solids, often resulting in a viscous liquid that tends to leave a coating on sensing elements. Slurried generally require Cote-Shield circuitry and heavier sensing elements because they are usually agitated.

Span:
Used to describe the number of inches or feet, or capacitance in picofarads between the zero-percent point and the hundred-percent point of a measurement, typically 4 to 20 mAdc.

Speed of Response:
The amount of time an instrument requires to signal a change in level.

Susceptance:
The mathematical reciprocal of capacitive reactance. Its units are mhos. See Capacitance.

Temperature Effect:
The effect ambient temperature has on the accuracy of an electronic unit.

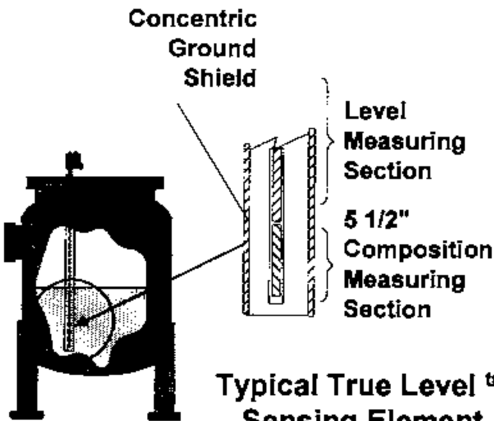
Three-Terminal Measurement:
The number of connections to the sensing element on a level control. There are sensing electrode, ground electrode and a third, called by Drexelbrook, the Cote-Shield electrode. See Cote-Shield Electrode. Also see Two-Terminal Measurement.

Time Delay:
The circuit in an instrument that is used to delay or slow the response of the instrument. This is particularly useful in a situation where the surface of the material being measured contains waves that would, unwantedly, change the output each time a wave hits the sensing element.

Transducer:
A device which receives information in the form of one quantity and converts it to information in the form of the same or another quantity. An I/P transducer converts a 4-20 mA signal into a 3-15 psi pneumatic pressure indication.

Transmitter:
A transmitter responds to a measured variable by means of a sensing element (sensing probe) and converts the low level signal to a standard signal which can be sent to another location. This signal is a function of the measured variable. Frequently called Electronic Unit.

True Level (TM):
A Trademark of Drexelbrook Engineering Co., for systems which provide reliable and accurate level measurement of any homogeneous liquid — independently of changes in the characteristics (dielectric constant, conductivity, density, temperature, or pressure) of the liquid being measured.

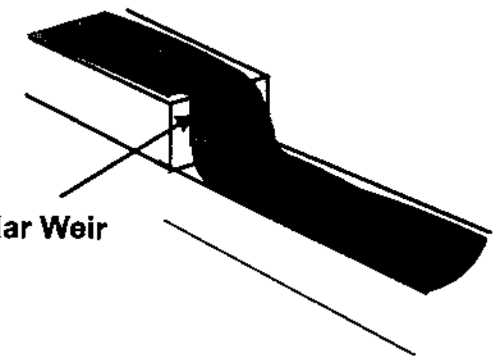


Typical True Level tm Sensing Element Construction

Two-Terminal Measurement:
A Two-Terminal Measurement refers to the sensing element connections on a level control. Two-Terminal Measurements are those which involve only sensing electrode and ground connections. See also Three-Terminal Measurement.

Two-Wire Instruments:
One that uses a single pair of wires to obtain its power to operate and to transmit its output signal.

Weir:
A dam-like obstruction in a stream. The purpose of a Weir is to facilitate the measurement of liquid flow in a stream. The height of liquid cresting in the Weir is related to the flow over the Weir. Also see Flume.



Typical Rectangular Weir

Wetted Surface:
That part of an instrument (sensing element, flange, gland) that comes in direct contact with the materials of the process.

Zero:
The adjustment on a transmitter allowing calibration of the instrument to achieve a zero (0) percent output for an empty vessel.

UNIT CONVERSION FACTORS

ENGLISH CONVERSION TABLE

MULTIPLY	BY	AND OBTAIN
— Length —		
Inches	.0833	Feet
Inches	02778	Yards
Inches	00001578	Miles
Feet	.3333	Yards
Feet	.0001894	Miles
Yards	36.00	Inches
Yards	3.00	Feet
Yards	.0005681	Miles
Miles	63360.00	Inches
Miles	5280.00	Feet
Miles	1760.00	Yards
Cir. of circle	.3188	Diameter
Dia. of circle	3.1416	Circumference
— AREA —		
Sq. inches	.00694	Sq. feet
Sq. inches	.0007716	Sq. yards
Sq. feet	144.00	Sq. inches
Sq. feet	.11111	Sq. yards
Sq. yards	1296.00	Sq. inches
Sq. yards	9.00	Sq. feet
Dia. of circle sq.	.7854	Area
Dia. of sphere sq.	3.1416	Surface
— VOLUME —		
Cu. inches	.0005787	Cu. feet
Cu. inches	.00002143	Cu. yards
Cu. inches	.004329	US gals.
Cu. feet	1728.00	Cu. inches
Cu. feet	.03704	Cu. yards
Cu. feet	7.4805	US gals.
Cu. yards	46656.00	Cu. inches
Cu. yards	27.00	Cu. feet
Dia. sphere cubed	.5236	Volume
— WEIGHT —		
Grains (Av.)	.002286	Ounces
Ounces (Av.)	.0625	Pounds
Ounces (Av.)	.00003125	Tons
Pounds (Av.)	16.00	Ounces
Pounds (Av.)	01	Hundredweight
Pounds (Av.)	.0005	Tons
Tons (Av.)	62000.00	Ounces
Tons (Av.)	2000.00	Pounds
— ENERGY —		
Horsepower	33000.	Ft.-lbs./min.
B. t. u.	778.26	Ft.-lbs.
Ton of refrig.	200.	B.t.u./min.
— PRESSURE —		
MULTIPLY	**BY**	**AND OBTAIN**
Lbs./sq. in.	2.31	Ft. water 60°F
Ft. water 60°F	.433	Lbs./sq. in.
Ins. water 60°F	.0361	Lbs./sq. in.
Lbs./sq. in.	27.70	Ins. water 60°F
Lbs./sq. in.	2.041	Ins. Hg. 60F
Ins. of Hg. 60°F	.490	Lbs./sq. in.
— POWER —		
Horsepower	746.	Watts
Watts	.001341	Horsepower
Horsepower	42.4	B.t.u./min.
— WATER FACTORS — (at point of greatest density — 39.2°F)		
Cu. inches H2O	.57798	Ounces
Cu. inches H2O	036124	Pounds
Cu. inches H2O	.004329	US gals.

ENGLISH CONVERSION TABLE (Continued)

MULTIPLY	BY	AND OBTAIN
Cu. inches H2O	.003607	Imperial gals.
Cu. feet H2O	62.425	Pounds
Cu. feet H2O	03121	Tons
Cu. feet H2O	7.4805	US gals.
Cu. feet H2O	6.232	Imperial gals.
Ounces H2O	1.73	Cu. inches
Pounds H2O	26.68	Cu. inches
Pounds H2O	.01602	Cu. feet
Pounds H2O	.1198	US gals.
Pounds H2O	.0998	Imperial gals.
Tons H2O	32.04	Cu. feet
Tons H2O	'239.6	US gals.
Tons H2O	199.6	Imperial gals.
US gals.	231.00	Cu. inches
US gals.	.13368	Cu. feet
US gals. H2O	8.345	Pounds
US gals.	.8327	Imperial gals.
US gals.	3.785	Liters
Imperial gals.	277.41	Cu. inches
Imperial gals.	.1605	Cu. feet
Imperial gals. H2O	10.02	Pounds
Imperial gals.	1.201	US gals.
Imperial gals.	4.546	Liters

METRIC CONVERSION TABLE

MULTIPLY	BY	AND OBTAIN
— LENGTH —		
Millimeters	.03937	Inches
Centimeters	.3937	Inches
Meters	39.37	Inches
Meters	3.281	Feet
Meters	1.0936	Yards
Kilometers	.6214	Miles
Kilometers	3280.8	Feet
Inches	25.4	Millimeters
Inches	2.54	Centimeters
Inches	.0254	Meters
Feet	.30481	Meters
— AREA —		
Sq. millimeters	.00155	Sq. in.
Sq. centimeters	.155	Sq. in.
Sq. meters	10.764	Sq. ft.
Sq. kilometers	247.1	Acres
Hectares	2.471	Acres
Sq. in.	645.16	Sq. mm.
Sq. in.	6.4516	Sq. cm.
Sq. meters	10.764	Sq. ft.
— VOLUME —		
Cu. centimeters	.06102	Cu. in.
Cu. centimeters	.03381	Fl. oz.
Cu. meters	35.314	Cu. ft.
Cu. meters	1.308	Cu. yards
Cu. meters	264.2	US gals.
Liters	61.023	Cu. in.
Liters	33.82	Fl. oz.
Liters	.2642	US gals.
Liters	.0353	Cu. ft.
Hectoliters	3.531	Cu. ft.
Hectoliters	.1308	Cu. yards
Hectoliters	26.42	US gals.
Cu. in.	16.39	Cu. centimeters
Fluid oz.	29.57	Cu. centimeters
Cu. ft.	.0283	Cu. meters
Gallons (US)	.0038	Cu. meters
Cu. in.	.01639	Liters

METRIC CONVERSION TABLE (Continued)

MULTIPLY	BY	AND OBTAIN
Fluid oz.	02957	Liters
Gallons (US)	3.785	Liters
Cu. ft.	28.32	Liters
— WEIGHT —		
Grams	15.432	Grains
Grams	0010194	Dynes
Grams (water)	03381	Fl. oz.
Grams	03525	Oz. avoir
Kilograms	2.2046	Lbs.
Kilograms	35.27	Oz. avoir
Kilograms	.0011023	Ton (2000 lbs.)
Fluid oz.	29.57	Grams (water)
Oz. avoir.	28.35	Grams
Pounds	.4536	Kilograms
Oz. avoir	.02835	Kilograms
Tons (2000 lbs.)	907.185	Kilograms
— UNIT WEIGHT —		
Grams/cu. cm.	03613	Lbs./cu. in.
Kilo./meter	.672	Lbs./ft.
Kilo./cu. meter	.06243	Lbs./cu. ft.
Kilo./cheval	2.235	Lbs./h.p.
Grams/liter	.06243	Lbs./cu. ft.
Lbs./cu. in.	27.68	Grams/cu. cm.
Lbs./foot	1.488	Kg./meter
Lbs./cu. ft.	16.02	Kg./cu. m.
Lbs./cu. ft.	16.02	Grams/liter
— PRESSURE —		
Kilograms/sq. cm.	14.223	Lbs./sq. in.
Kilograms/sq. cm.	32.843	Ft. of water 60°F
Lbs./sq. in.	0.07031	Kg./sq. cm.
Ft. water 60°F	0.03048	Kg./sq. cm.

MISCELLANEOUS

MULTIPLY	BY	AND OBTAIN
Atmospheres	14.696	Lbs. sq. in.
Atmospheres	33.947	Ft. H2O 62°F
Atmospheres	29.929	Inches Hg. 32°F
Atmospheres	2116.35	Lbs./sq. ft.
Atmospheres	760.18	Mm. Hg. 32°F
Feet, H2O 62°F	.0295	Atmospheres
Feet, H2O 62°F	.8826	Inches Hg.
Feet, H2O 62°F	.434	Lbs./Sq. in.
Inches Hg.	.03342	Atmospheres
Inches Hg.	1.133	Feet of water
Inches Hg.	70.73	Lbs./sq. ft.
Inches Hg.	.4912	Lbs./sq. in.
Inches Hg.	7.855	Ounces/sq. in.
Inches H2O 62°F	.00246	Atmospheres
Inches H2O 62°F	07355	Inches, Hg.
Inches H2O 62°F	5.202	Lbs./sq. ft.
Inches H2O 62°F	.577	Ounces/sq. in.
Inches H2O 62°F	.03613	Lbs./sq. in.
Barrel, Oil	42.0	Gallons
Barrel, Oil	5.6146	Cu. ft.
Barrel, Oil	9702.03	Cu. inches
Barrels/hr. Oil	.0936	Cu. ft./min.
Barrels/hr. Oil	7	Gals/min.
Barrels/day	02917	Gals/min.
Cubic feet	.1781	Bbl. oil (42 gal.)
Cu. ft./min.	7.481	Gals./min.
Cu. ft./sec.	448.831	Gals./min.
Cu. ft./sec.	646272.0	Gals./day
Gals/min.	00223	Cu. ft./sec.
Temp. (Fahr. - 32)	5555	Temp. ° Cent.
	(T°C. x 1.8) + 32 =	Temp. ° Fahr.

Figure B-1

Circles, Cylinders
Circumference, Area ,Volume

Dia. in Feet	Circum.	Area of Circle	Volume per Foot of Height U.S. Gal	Cu. Ft	Dia. in Feet	Circum.	Area of Circle	Volume per Foot of Height U.S. Gal	Cu. Ft
1	3.14159	0.785	5.875	0.785	51	160.22109	2042.819	15281.307	2042.819
2	6.28318	3.142	23.501	3.142	52	163.36268	2123.715	15886.449	2123.715
3	9.42477	7.069	52.876	7.069	53	166.50427	2206.182	16503.341	2206.182
4	12.56636	12.566	94.003	12.566	54	169.64586	2290.219	17131.984	2290.219
5	15.70795	19.635	146.879	19.635	55	172.78745	2375.827	17772.377	2375.827
6	18.84954	28.274	211.506	28.274	56	175.92904	2463.007	18424.521	2463.007
7	21.99113	38.484	287.883	38.484	57	179.07063	2551.756	19088.414	2551.756
8	25.13272	50.265	376.011	50.265	58	182.21222	2642.077	19764.058	2642.077
9	28.27431	63.617	475.888	63.617	59	185.35381	2733.969	20451.453	2733.969
10	31.4159	78.540	587.517	78.540	60	188.4954	2827.431	21150.598	2827.431
11	34.55749	95.033	710.895	95.033	61	191.63699	2922.464	21861.493	2922.464
12	37.69908	113.097	846.024	113.097	62	194.77858	3019.068	22584.138	3019.068
13	40.84067	132.732	992.903	132.732	63	197.92017	3117.243	23318.534	3117.243
14	43.98226	153.938	1151.533	153.938	64	201.06176	3216.988	24064.680	3216.988
15	47.12385	176.714	1321.912	176.714	65	204.20335	3318.304	24822.576	3318.304
16	50.26544	201.062	1504.042	201.062	66	207.34494	3421.192	25592.223	3421.192
17	53.40703	226.980	1697.923	226.980	67	210.48653	3525.649	26373.620	3525.649
18	56.54862	254.469	1903.554	254.469	68	213.62812	3631.678	27166.768	3631.678
19	59.69021	283.528	2120.935	283.528	69	216.76971	3739.277	27971.665	3739.277
20	62.8318	314.159	2350.066	314.159	70	219.9113	3848.448	28788.313	3848.448
21	65.97339	346.360	2590.948	346.360	71	223.05289	3959.189	29616.712	3959.189
22	69.11498	380.132	2843.580	380.132	72	226.19448	4071.501	30456.861	4071.501
23	72.25657	415.475	3107.963	415.475	73	229.33607	4185.383	31308.760	4185.383
24	75.39816	452.389	3384.096	452.389	74	232.47766	4300.837	32172.409	4300.837
25	78.53975	490.873	3671.979	490.873	75	235.61925	4417.861	33047.809	4417.861
26	81.68134	530.929	3971.612	530.929	76	238.76084	4536.456	33934.959	4536.456
27	84.82293	572.555	4282.996	572.555	77	241.90243	4656.622	34833.859	4656.622
28	87.96452	615.752	4606.130	615.752	78	245.04402	4778.358	35744.510	4778.358
29	91.10611	660.519	4941.015	660.519	79	248.18561	4901.666	36666.911	4901.666
30	94.2477	706.858	5287.649	706.858	80	251.3272	5026.544	37601.062	5026.544
31	97.38929	754.767	5646.035	754.767	81	254.46879	5152.993	38546.964	5152.993
32	100.53088	804.247	6016.170	804.247	82	257.61038	5281.013	39504.616	5281.013
33	103.67247	855.298	6398.056	855.298	83	260.75197	5410.603	40474.019	5410.603
34	106.81406	907.920	6791.692	907.920	84	263.89356	5541.765	41455.171	5541.765
35	109.95565	962.112	7197.078	962.112	85	267.03515	5674.497	42448.074	5674.497
36	113.09724	1017.875	7614.215	1017.875	86	270.17674	5808.800	43452.728	5808.800
37	116.23883	1075.209	8043.102	1075.209	87	273.31833	5944.674	44469.131	5944.674
38	119.38042	1134.114	8483.740	1134.114	88	276.45992	6082.118	45497.285	6082.118
39	122.52201	1194.590	8936.127	1194.590	89	279.60151	6221.134	46537.190	6221.134
40	125.6636	1256.636	9400.266	1256.636	90	282.7431	6361.720	47588.845	6361.720
41	128.80519	1320.253	9876.154	1320.253	91	285.88469	6503.877	48652.250	6503.877
42	131.94678	1385.441	10363.793	1385.441	92	289.02628	6647.604	49727.405	6647.604
43	135.08837	1452.200	10863.182	1452.200	93	292.16787	6792.903	50814.311	6792.903
44	138.22996	1520.530	11374.321	1520.530	94	295.30946	6939.772	51912.967	6939.772
45	141.37155	1590.430	11897.211	1590.430	95	298.45105	7088.212	53023.373	7088.212
46	144.51314	1661.901	12431.851	1661.901	96	301.59264	7238.223	54145.530	7238.223
47	147.65473	1734.943	12978.242	1734.943	97	304.73423	7389.805	55279.437	7389.805
48	150.79632	1809.556	13536.382	1809.556	98	307.87582	7542.958	56425.094	7542.958
49	153.93791	1885.739	14106.274	1885.739	99	311.01741	7697.681	57582.502	7697.681
50	157.0795	1963.494	14687.915	1963.494	100	314.159	7853.975	58751.660	7853.975

Figure B-2

A.N.S.I. STEEL FLANGE DIMENSIONS

Nominal Pipe Size Inches 150 lb.	Nominal Pipe Size Inches 300 lb.	Dia. of Flange	Flange Thick-ness*	Dia. Raised Face	Dia. Bolt Circle	No. Bolts	Dia. Bolts
3/4		3 7/8	1/2	1 11/16	2 3/4	4	1/2
	3/4	4 5/8	5/8	1 11/16	3 1/4	4	5/8
1		4 1/4	7/16	2	3 1/8	4	1/2
	1	4 7/8	11/16	2	3 1/2	4	5/8
1 1/4		4 5/8	1/2	2 1/2	3 1/2	4	1/2
	1 1/4	5 1/4	3/4	2 1/2	3 7/8	4	5/8
1 1/2		5	9/16	2 7/8	3 7/8	4	1/2
	1 1/2	6 1/8	11/16	2 7/8	4 1/2	4	3/4
2		6	5/8	3 5/8	4 3/4	4	5/8
	2	6 1/2	7/8	3 5/8	5	8	5/8
2 1/2		7	11/16	4 1/8	5 1/2	4	5/8
	2 1/2	7 1/2	1	4 1/8	5 7/8	8	3/4
3		7 1/2	3/4	5	6	4	5/8
	3	8 1/4	1 1/8	5	6 5/8	8	3/4
3 1/2		8 1/2	11/16	5 1/2	7	8	5/8
	3 1/2	9	1 3/16	5 1/2	7 1/4	8	3/4
4		9	15/16	6 3/16	7 1/2	8	5/8
	4	10	1 1/4	6 1/16	7 7/8	8	3/4
5		10	15/16	7 5/16	8 1/2	8	3/4
	5	11	1 3/8	7 5/16	9 1/4	8	3/4
6		11	1	8 1/2	9 1/2	8	3/4
	6	12 1/2	1 7/16	8 1/2	10 5/8	12	3/4
8		13 1/2	1 1/8	10 5/8	11 3/4	8	3/4
	8	15	1 5/8	10 5/8	13	12	7/8
10		16	1 3/16	12 3/4	14 1/4	12	7/8
	10	17 1/2	1 7/8	12 3/4	15 1/4	16	1
12		19	1 1/4	15	17	12	7/8
	12	20 1/2	2	15	17 3/4	16	1 1/8
14		21	1 3/8	16 1/4	18 3/4	12	1
	14	23	2 1/8	16 1/4	20 1/4	20	1 1/8
16		23 1/2	1 7/16	18 1/2	21 1/4	16	1
	16	25 1/2	2 1/4	18 1/2	22 1/2	20	1 1/4
18		25	1 5/16	21	22 3/4	16	1 1/8
	18	28	2 3/8	21	24 3/4	24	1 1/4
20		27 1/2	1 11/16	23	25	20	1 1/8
	20	30 1/2	2 1/2	23	27	24	1 1/4
24		32	1 7/8	27 1/4	29 1/2	20	1 1/4
	24	36	2 3/4	27 1/4	32	24	1/12

includes 1/16" raised face.

Nominal Pipe Size Inches 400 lb.	Nominal Pipe Size Inches 600 lb.	Dia. of Flange	Min. Flange Thick-ness*	Dia. Raised Face	Dia. Bolt Circle	No. Bolts	Dia. Bolts
3/4		4 5/8	5/8	1 11/16	3 1/4	4	5/8
	3/4	4 5/8	5/8	1 11/16	3 1/4	4	5/8
1		4 7/8	11/16	2	3 1/2	4	5/8
	1	4 7/8	11/16	2	3 1/2	4	5/8
1 1/4		5 1/4	13/16	2 1/2	3 7/8	4	5/8
	1 1/4	5 1/4	13/16	2 1/2	3 7/8	4	5/8
1 1/2		6 1/8	7/8	2 7/8	4 1/2	4	3/4
	1 1/2	6 1/8	7/8	2 7/8	4 1/2	4	3/4
2		6 1/2	1	3 5/8	5	8	5/8
	2	6 1/2	1	3 5/8	5	8	5/8
2 1/2		7 1/2	1 1/8	4 1/8	5 7/8	8	3/4
	2 1/2	7 1/2	1 1/8	4 1/8	5 7/8	8	3/4
3		8 1/4	1 1/4	5	6 5/8	8	3/4
	3	8 1/4	1 1/4	5	6 5/8	8	3/4
3 1/2		9	1 3/8	5 1/2	7 1/4	8	7/8
	3 1/2	9	1 3/8	5 1/2	7 1/4	8	7/8
4		10	1 3/8	6 3/16	7 7/8	8	7/8
	4	10 3/4	1 1/2	6 3/16	8 1/2	8	7/8
5		11	1 1/2	7 5/16	9 1/4	8	7/8
	5	13	1 3/4	7 5/16	10 1/2	8	1
6		12 1/2	1 5/8	8 1/2	10 5/8	12	7/8
	6	14	1 7/8	8 1/2	11 1/2	12	1
8		15	1 7/8	10 5/8	13	12	1
	8	16 1/2	2 5/16	10 5/8	13 3/4	12	1 1/8
900 lb.							
3/4		5 1/8	1	1 11/16	3 1/2	4	3/4
1		5 7/8	1 1/8	2	4	4	7/8
1 1/4		6 1/4	1 1/8	2 1/2	4 3/8	4	7/8
1 1/2		7	1 1/4	2 7/8	4 7/8	4	1
2		8 1/2	1 1/2	3 5/8	6 1/2	8	7/8
2 1/2		9 5/8	1 5/8	4 1/8	7 1/2	8	1
3		9 1/2	1 1/2	5	7 1/2	8	7/8
4		11 1/2	1 3/4	6 1/16	9 1/4	8	1 1/8

**1/4" raised face is standard on the 400 lb., 600 lbs., and 900 lbs. ranges and is added to the minimum flange thickness.*

Figure B-3

STEEL PIPE DATA

Nominal Pipe Size In.	Schedule No.	Outside Dia. In.	Inside Dia. In.	Wall Thickness	Area of Metal Sq. In.	Wt. Lbs. Per Ft Pipe (lbs.)	Wt. of Water Per Ft. Pipe (lbs.)	Transverse Internal Area Square Inches	Transverse Internal Area Square Feet	Functions of Inside Dia d^5	Functions of Inside Dia F	Normal Thread Engagement In
1/8	40s	.405	.269	.068	.0720	.244	.025	.0568	.00040	.00141	14.391	1/4
	80x	.405	.215	.095	.0925	.314	.016	.0364	.00025	.000459	17.751	
1/4	40s	.540	.364	.088	.1250	.424	.045	.1041	.00072	.00639	10.901	3/8
	80x	.540	.302	.119	.1574	.535	.031	.0716	.00050	.002513	12.929	
3/8	40s	.675	.k493	.091	.1670	.567	.083	.1910	.00133	.02912	8.317	3/8
	80x	.675	.423	.126	.2173	.738	.061	.1405	.00098	.01354	9.523	
1/2	40s	.840	.622	.109	.2503	.850	.132	.3040	.00211	.09310	6.807	1/2
	80x	.840	.546	.147	.3200	1.087	.102	.2340	.00163	.04852	7.610	
	160	.840	.466	.187	.3836	1.300	.074	.1706	.00118	.002197	8.739	
	..xx	.840	.252	.294	.5043	1.714	.022	.050	.00035	.00102	15.294	
3/4	40s	1.050	.824	.113	.3326	1.130	.231	5330	.00371	.3799	5.394	9/16
	80x	1.050	.742	.154	.4335	1.473	.188	.4330	.0030	.2249	5.874	
	160	1.050	.614	.218	.5698	1.940	.128	.2961	.00206	.08726	6.882	
	..xx	1.050	.434	.308	.7180	2.440	.064	1.148	.00103	.01540	9.308	
1	40s	1.315	1.049	.133	.4939	1.678	.375	.8640	.00600	1.270	4.464	11/16
	80x	1.315	.957	.179	.6388	2.171	.312	.7190	.00499	.8027	4.791	
	160	1.315	.815	.250	.8365	2.840	.230	.5217	.00362	.3596	5.442	
	..xx	1.315	.599	.358	1.0760	3.659	.122	.262	.00196	.07711	7.028	
1 1/4	40s	1.660	1.380	.140	.6685	2.272	.649	1.495	.01040	5.005	3.651	11/16
	80x	1.660	1.278	.191	.8815	2.996	.555	1.283	.00891	3.409	3.856	
	160	1.660	1.160	.250	1.1070	3.764	.458	1.057	.00734	2.100	4.138	
	..xx	1.660	.896	.382	1.534	5.214	.273	.630	.00438	.5775	5.045	
1 1/2	40s	1.900	1.610	.145	.7995	2.717	.882	2.036	.01414	10.82	3.285	11/16
	80x	1.900	1.500	.200	1.068	3.631	.765	1.767	.01225	7.594	3.445	
	160	1.900	1.338	.281	1.429	4.862	.608	1.406	.00976	4.268	3.731	
	..xx	1.900	1.100	.400	1.885	6.408	.420	.950	.0060	1.611	4.306	
2	40s	2.375	2.067	.154	1.075	3.652	1.45	3.355	.02330	37.72	2.804	3/4
	80x	2.375	1.939	.218	1.477	5.022	1.28	2.953	.02050	27.41	2.915	
	160	2.375	1.689	.343	2.190	7.440	.97	2.241	.01556	13.74	3.182	
	..xx	2.375	1.503	.436	2.656	9.029	.77	1.774	.01232	7.670	3.440	
2 1/2	40s	2.875	2.469	.203	1.704	5.79	2.07	4.788	.02233	91.75	2.532	15/16
	80x	2.875	2.323	.276	2.254	7.66	1.87	4.238	.02942	67.64	2.620	
	160	2.875	2.125	.375	2.945	10.01	1.54	3.546	.02463	43.33	2.758	
	..xx	2.875	1.771	.552	4.028	13.70	1.07	2.464	.01710	17.42	3.086	
3	40s	3.500	3.068	.216	2.228	7.58	3.20	7.393	.05130	271.8	2.265	1
	80x	3.500	2.900	.300	3.016	10.25	2.86	6.605	.04587	205.1	2.328	
	160	3.500	2.626	.437	4.205	14.32	2.35	5.416	.03761	124.9	2.450	
	..xx	3.500	2.300	.600	5.466	18.58	1.80	4.155	.02885	64.36	2.634	
3 1/2	40s	4.000	3.548	.226	2.680	9.11	4.29	9.886	.06870	562.2	2.122	1 1/16
	80x	4.000	3.364	.318	3.678	12.51	3.84	8.888	.06170	430.8	2.171	
4	40s	4.500	4.026	.237	3.174	10.79	5.50	12.73	.08840	1058.	2.015	1 1/8
	80x	4.500	3.826	.337	4.407	14.98	4.98	18.19	.1283	2583.	1.893	
	120	4.500	3.626	.437	5.578	19.00	4.47	16.35	.1136	1978.	1.926	
	160	4.500	3.438	.531	6.621	22.51	4.02	14.61	.1015	1492.	1.965	
	..xx	4.500	3.152	.674	8.101	27.54	3.38	12.97	.0001	1107.	2.008	
5	40s	5.563	5.047	.258	4.300	14.62	8.67	20.01	.1390	3275.	1.865	1 1/4
	80x	5.563	4.813	.375	6.112	20.78	7.88	11.50	.07986	819.8	2.056	
	120	5.563	4.363	.500	7.953	27.10	7.09	10.33	.0717	626.8	2.102	
	160	5.563	4.313	.625	9.696	32.96	6.33	9.28	.0645	480.3	2.151	
	..xx	5.563	4.063	.750	11.340	38.55	5.61	7.80	.0542	311.1	2.237	
6	40s	6.625	6.065	.280	5.581	18.97	12.51	28.89	.2006	8206.	1.776	1 5/16
	80x	6.625	5.761	.432	8.405	28.57	11.29	26.07	.1810	6346.	1.798	
	120	6.625	5.501	.562	10.70	36.40	10.30	23.77	.1650	5037.	1.819	
	180	6.625	5.189	.718	13.32	45.30	9.18	21.15	.1469	3762.	1.850	
	..xx	6.625	4.897	.864	15.64	53.16	8.16	18.84	.1308	2816.	1.882	

Note: *Letters "S", "X" and "XX" in the Schedule No. column indicate pipe commonly referred to as standard weight, extra heavy and double extra heavy, respectively.*

$$F = 1 + \frac{3.6}{d} + .03d$$

Figure B-4

Fahrenheit / Celsius Conversion Chart

°F	°C	°F	°C	°F	°C	°F	°C	°F	°C	°F	°C
-300	-184	-80	-62	145	63	370	188	595	313	820	438
-295	-182	-75	-59	150	66	375	191	600	316	825	441
-290	-179	-70	-57	155	68	380	193	605	318	830	443
-285	-176	-65	-54	160	71	385	196	610	321	835	446
-280	-173	-60	-51	165	74	390	199	615	324	840	449
-275	-171	-55	-48	170	77	395	202	620	327	845	452
-270	-168	-50	-46	175	79	400	204	625	329	850	454
-265	-165	-45	-43	180	82	405	207	630	332	855	457
-260	-162	-40	-40	185	85	410	210	635	335	860	460
-255	-159	-35	-37	190	88	415	213	640	338	865	463
-250	-157	-30	-34	195	91	420	216	645	341	870	466
-245	-154	-25	-32	200	93	425	218	650	343	875	468
-240	-151	-20	-29	205	96	430	221	655	346	880	471
-235	-148	-15	-26	210	99	435	224	660	349	885	474
-230	-146	-10	-23	215	102	440	227	665	352	890	477
-225	-143	-5	-21	220	104	445	229	670	354	895	479
-220	-140	0	-18	225	107	450	232	675	357	900	482
-215	-137	5	-15	230	110	455	235	680	360	905	485
-210	-134	10	-12	235	113	460	238	685	363	910	488
-205	-132	15	-9	240	116	465	241	690	366	915	491
-200	-129	20	-7	245	118	470	243	695	368	920	493
-195	-126	25	-4	250	121	475	246	700	371	925	496
-190	-123	30	-1	255	124	480	249	705	374	930	499
-185	-121	35	2	260	127	485	252	710	377	935	502
-180	-118	40	4	265	129	490	254	715	379	940	504
-175	-115	45	7	270	132	495	257	720	382	945	507
-170	-112	50	10	275	135	500	260	725	385	950	510
-165	-109	55	13	280	138	505	263	730	388	955	513
-160	-107	60	16	285	141	510	266	735	391	960	516
-155	-104	65	18	290	143	515	268	740	393	965	518
-150	-101	70	21	295	146	520	271	745	396	970	521
-145	-98	75	24	300	149	525	274	750	399	975	524
-140	-96	80	27	305	152	530	277	755	402	980	527
-135	-93	85	29	310	154	535	279	760	404	985	529
-130	-90	90	32	315	157	540	282	765	407	990	532
-125	-87	95	35	320	160	545	285	770	410	995	535
-120	-84	100	38	325	163	550	288	775	413	1000	538
-115	-82	105	41	330	166	555	291	780	416	1005	541
-110	-79	110	43	335	168	560	293	785	418	1010	543
-105	-76	115	46	340	171	565	296	790	421	1015	546
-100	-73	120	49	345	174	570	299	795	424	1020	549
-95	-71	125	52	350	177	575	302	800	427	1025	552
-90	-68	130	54	355	179	580	304	805	429	1030	554
-85	-65	135	57	360	182	585	307	810	432	1035	557
-80	-62	140	60	365	185	590	310	815	435	1040	560

Figure B-5

	IEC AND CENELEC COUNTRIES (Countries accepting International Electrotechnical Commission standards, e.g. Australia, Europe, S. Africa)	USA & CANADA (May adopt IEC terminology in due course)
Intrinsic safety	Technique that achieves safety by limiting the ignition energy and surface temperature that can arise in normal operation, or under certain foreseeable fault conditions, to levels that are insufficient to ignite an explosive atmosphere.	
Intrinsic safety standards	EEx ia: safety maintained with up to two component faults: hazardous area equipment may be used in Zones 0, 1 & 2 EEx ib: safety maintained with up to one component fault: hazardous area equipment may be used in Zones 1 & 2	One standard only: safety maintained with up to two component faults: hazardous area equipment may be used in Divisions 1 & 2 1996 NEC will probably include optional Zone 0, 1, 2 classification.
Note	Type N equipment (safe in normal operation) may be used in Zone 2	Non-incendive equipment (safe in normal operation) may be used in Division 2
Type of industry	I: underground mining II: surface	No classification, but mining and surface industries dealt with by different authorities
Type of hazard	Explosive mixtures of air with flammable gases or vapors (dusts under consideration)	Explosive mixture of air with: Class I: gases or vapors Class II: dusts Class III: fibers or flyings
Degree of hazard	Zone 0: explosive gas-air mixture continuously present, or present for long periods Zone 1: explosive gas-air mixture is likely to occur in normal operation Zone 2: explosive gas-air mixture not likely to occur and, if it occurs, it will exist only for a short time	Class I, Division 1: hazardous concentrations of flammable gases or vapors continuously, intermittently or periodically present under normal operating conditions Class I, Division 2: volatile flammable liquids or flammable gases present, but normally confined within closed containers or systems, from which they can escape only under abnormal operating or fault conditions
Ignition by spark	Apparatus is grouped according to the ignition energy produced under fault conditions, in terms of the gas-air mixture that it will not ignite Representative gases are: Group IIC: hydrogen, acetylene Group IIB: ethylene Group IIA: propane Group I: methane	Explosive atmospheres are grouped according to their ignition energy. Representative atmospheres are: Group A: acetylene Group B: hydrogen Group C: ethylene Group D: propane Group E: metal dust Group F: carbon dust Group G: flour, starch, grain
Ignition by hot surface	Hazardous area apparatus is classified according to the maximum surface temperature produced under fault conditions at an ambient temperature of 40°C (or as otherwise specified) T1: 450°C T2: 300°C T3: 200°C T4: 135°C T5: 100°C T6: 85°C	
Gas characteristics	Details of gas grouping by ignition energy and of gas ignition temperatures are contained in: British Standard Code of Practice for Electrical Apparatus and Associated Equipment for use in Explosive Atmospheres (other than Mining Applications), BS5345: Part 1—Basic requirements for all parts of the code	NFPA, Vol. 5 Electrical, Article 500, Table 500-2(c) (ignition energy) NFPA 325M, Fire Hazard Properties of Flammable Liquids, Gases, Volatile Solids, 1969 (ignition temperature)
Approval	National certifying authorities issue Apparatus and/or System Certificates for approved equipment, or Listings of approved equipment, defining all or most of the following: IS standard; Apparatus (gas) group; Temperature class; Installation conditions; Cable parameter limits; Zone (division) classification In Europe, common CENELEC standards will be adopted by all national authorities in due course.	In USA, OSHA requires either FM or UL approval for Division 1.

NOTE: Applying safety barriers requires some knowledge of intrinsic safety principles and terminology. Summary covers the two main systems in international use.

HAZARDOUS AREA TERMINOLOGY

Figure B-6

BASEEFA	USA & CANADA
1. Installation	
a. The barrier must be protected as follows: Safe area: No protection required for MTL barriers Zone 2: Type N enclosure Zone 1: Flameproof or pressurized enclosure. The temperature at the barrier must not exceed the specified maximum operational value. b. The case of the barrier must be so connected to earth that the total earth loop impedance does not exceed 1 Ω as measured in accordance with Appendix 6, paragraph 2 of the Institution of Electrical Engineers' Requisitions for the Elelectrical Equipment of Buildings, 14th Edition. For marine applications, the impedance should be measured to a secure bond to the hull of the ship. c. A key to the system certificate numbers of the protected circuits must be provided inside the enclosure.	a. USA: the barrier must be located in a non-hazardous (safe) area, and be mounted in an appropriate enclosure or other protected space. Canada: the barrier may be located in Division 2 if suitably enclosed. USA & Canada: the temperature at the barrier must not exceed the specified maximum value. b. The barrier device must be grounded via a single connection to a ground electrode in the non-hazardous area. Grounding practice should conform to NEC Article 250 or the relevant CSA code. The resistance from the barrier to the ground electrode must not exceed 1 Ω. It is good practice to isolate the busbar electrically from the panel frame. c. It is recommended that a key to the loops protected by the barriers is provided inside the enclosure.
2. Safe area requirements	
a. Apparatus connected to the safe area terminals must not be supplied from, nor contain, a source of potential with respect to earth under normal or fault conditions exceeding 250V rms or 250V dc. b. Mains powered apparatus connected to the safe area terminals must be isolated from the mains supply by a double wound transformer. The primary winding of the transformer must be protected by an appropriately rated fuse of adequate breaking capacity.	a. Equipment connected to the non-hazardous area terminals must not be supplied from, nor contain, a source of potential with respect to ground under normal or fault conditions exceeding 250V rms. b. Mains powered equipment connected to the non-hazardous area terminals must be isolated from the mains supply by a double wound transformer, unless the applicable electrical code permits multiple grounding of the neutral lead.
3. Hazardous area circuits	
a. Circuits connected to the hazardous area terminals must not be interconnected to any other circuit, including barrier-protected circuits, nor share earth return cables with them. b. Cables must not share any electrical connector with cables connected to non-intrinsically safe circuits. c. Each circuit must be insulated from earth and capable of withstanding a test voltage of 500V rms to earth. All conductors must be insulated for 500V test and have a strand diameter of at least 0.19 mm. d. The total capacitance of the cables in each circuit and either (i) the total inductance of the cables or (ii) the L/R ratio of any of the cables must not exceed the values stated in the schedules of the appropriate certificate. e. Multicore cables may be used in Zone 1 or Zone 2 provided they contain only intrinsically safe circuits, and the wires of each circuit are adjacent (preferably twisted) and tested to 800V rms.	a. Wiring connected to the hazardous area terminals must be separated from non-intrinsically safe wiring. b. All wiring has distributed inductance and capacitance. The maximum permitted cable parameters for the particular barrier must not be exceeded. c. Different intrinsically safe systems shall not be run in the same multiconductor cable. Different intrinsically safe circuits of the same intrinsically safe system shall not be run in the same cable, unless at least 0.25 mm thickness insulation is used on each conductor, or unless no hazard results from interconnection.
4. Hazardous area apparatus	
a. "Energy storing" apparatus, such as transmitters and transducers, must be separately certified for use with the barrier. b. "Simple" apparatus of the following types may be used without certification, provided that it does not form part of units containing other electrical circuits, and is normally protected to IP20. (i) Resistive devices having an inductance not exceeding 5% of the permissible cable inductance or having an L/R ratio not exceeding 50% of the permissible L/R ratio of the cable for the most onerous gas groupe in the parameter table for the particular barrier configuretion. (ii) Switches: (Note, switches to which the gas has access are subject to a doubling of the safety factor in Zone 0). (iii) Thermocouples generating less than 1V. (iv) Photocells generating less than 1V. (v) Light emitting diodes. c. The surface temperature of apparatus in the hazardous area under normal or fault conditions must not exceed the ignition temperature of the gas. Temperatures higher than that of the marked temperature class can be permitted for small components, such as transistors or resistors. "Simple" apparatus protected by Group IIC certified shunt-diode safety barriers (all MTL barriers) in configurations where the combined output of the barriers cannot produce an optimum (matched or maximum) power in excess of 1.3 W is deemed to have a temperatura classification of T4. In all other cases, the temperature classification for simple apparatus will be given in the Schedules to the appropriate System Certificate. d. For acetylene applications, parts made of copper, brass or silver must be suitably protected against the formation of acetylides.	a. "Energy storing" equipment, such as 4/20 mA transmitters, must be explicitly approved as intrinsically safe when used with the barrier. b. Non voltage-producing devices, such as switches, thermocouples, resistances and LEDs, may be used without further certification, provided that they do not form part of units containing other electrical circuits. c. Hazardous area equipment shall not have exposed any surface that operates at a temperature in excess of the ignition temperature of the specific gas, vapor or dust. ***Figure B-7*** **SUMMARY OF INTRINSIC BARRIER CODES** *NOTE: Be sure to obtain a copy of the latest code before doing any new installations.*
5. Recommended Cable	
Multicore miniature electric cable to DEF 61-12, part 5, screened or unscreened. Cores are of 16/0.20 mm tinned copper wire, PVC insulated and PVC sheathed overall. Cable to this specification can be obtained from ITT Electronic Services, Harlow, Essex.	18 to 22 AWG wire in the form of a twisted pair. Alternatively, general purpose wiring may be used.

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