

Process Control

Radar Level Transmitters

Instructor Guide

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By the staff of Festo Didactic

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e-mail: did@de.festo.com

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


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Safety and Common Symbols

The following safety and common symbols may be used in this manual and on the equipment:

Symbol	Description
	DANGER indicates a hazard with a high level of risk which, if not avoided, will result in death or serious injury.
	WARNING indicates a hazard with a medium level of risk which, if not avoided, could result in death or serious injury.
	CAUTION indicates a hazard with a low level of risk which, if not avoided, could result in minor or moderate injury.
	CAUTION used without the <i>Caution, risk of danger</i> sign  , indicates a hazard with a potentially hazardous situation which, if not avoided, may result in property damage.
	Caution, risk of electric shock
	Caution, hot surface
	Caution, risk of danger
	Caution, lifting hazard
	Caution, hand entanglement hazard
	Notice, non-ionizing radiation
	Direct current
	Alternating current
	Both direct and alternating current
	Three-phase alternating current
	Earth (ground) terminal

Safety and Common Symbols









Symbol	Description
	Protective conductor terminal
	Frame or chassis terminal
	Equipotentiality
	On (supply)
	Off (supply)
	Equipment protected throughout by double insulation or reinforced insulation
	In position of a bi-stable push control
	Out position of a bi-stable push control

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Preface

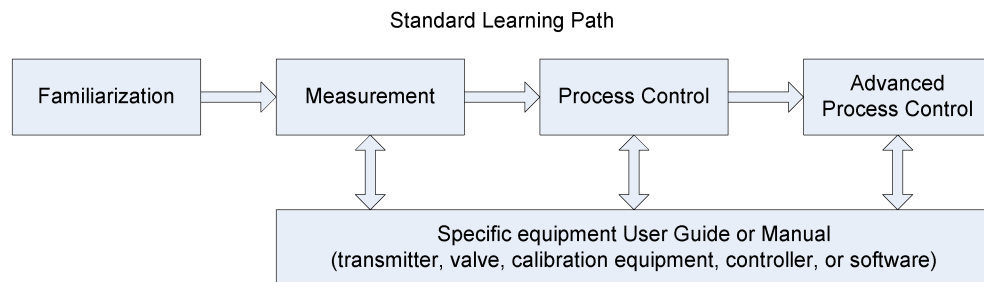
Automated process control offers so many advantages over manual control that the majority of today's industrial processes use it to some extent. Breweries, wastewater treatment plants, mining facilities, and the automotive industry are just a few industries that benefit from automated process control systems.

Maintaining process variables such as pressure, flow, level, temperature, and pH within a desired operating range is of the utmost importance when manufacturing products with a predictable composition and quality.

The Instrumentation and Process Control Training System, series 353X, is a state-of-the-art system that faithfully reproduces an industrial environment. Throughout this course, students develop skills in the installation and operation of equipment used in the process control field. The use of modern, industrial-grade equipment is instrumental in teaching theoretical and hands-on knowledge required to work in the process control industry.

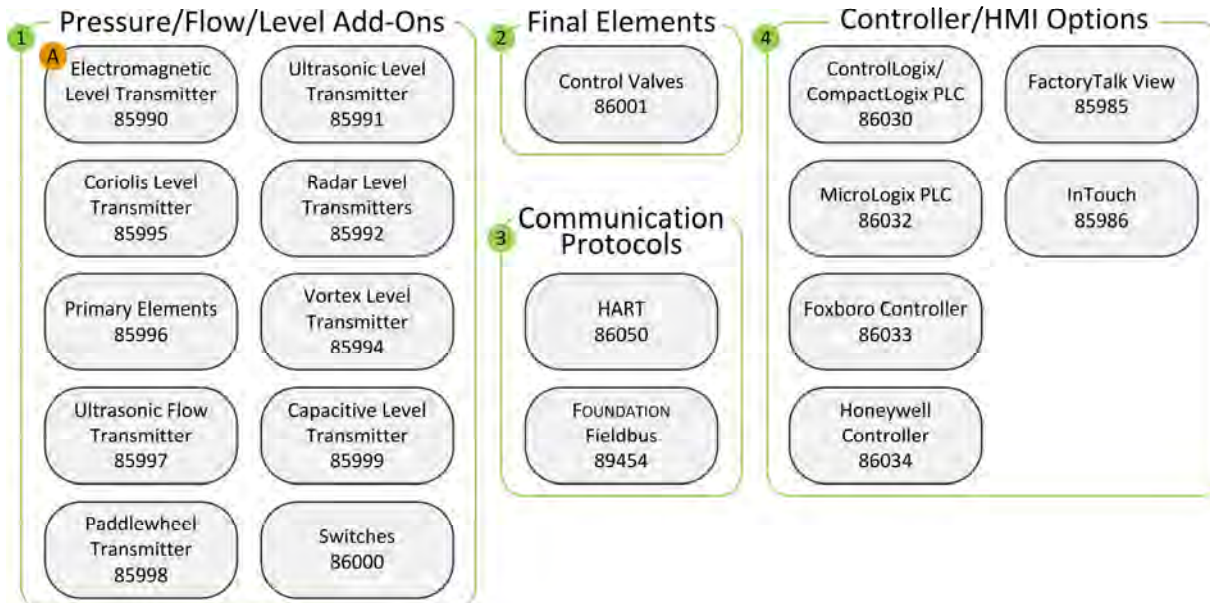
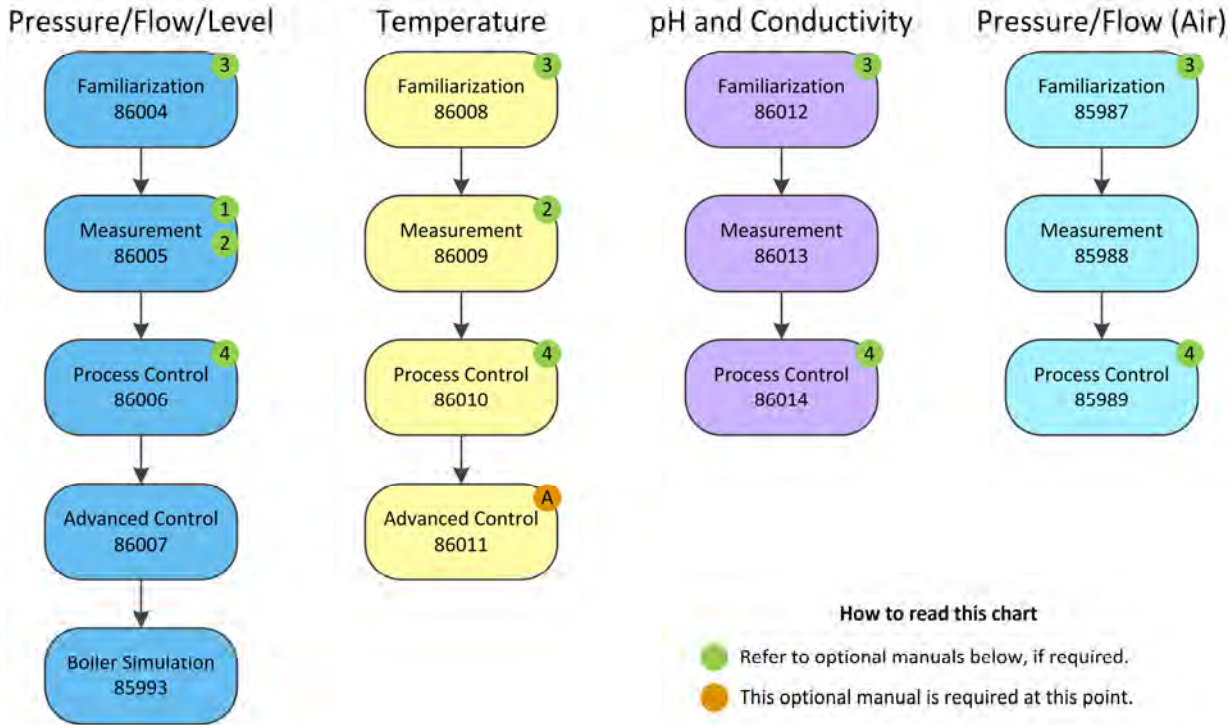
The modularity of the system allows the instructor to select the equipment required to meet the objectives of a specific course. Two mobile workstations, on which all of the equipment is installed, form the basis of the system. Several optional components used in pressure, flow, level, temperature, and pH control loops are available, as well as various valves, calibration equipment, and software. These add-ons can replace basic components having the same functionality, depending on the context. During control exercises, a variety of controllers can be used interchangeably depending on the instructor's preference.

We hope that your learning experience with the Instrumentation and Process Control Training System will be the first step toward a successful career in the process control industry.



Preface

Manuals of the 353X Series



About This Manual

Safety considerations

Safety symbols that may be used in this manual and on the equipment are listed in the Safety Symbols table at the beginning of the manual.

Safety procedures related to the tasks that you will be asked to perform are indicated in each exercise.

Make sure that you are wearing appropriate protective equipment when performing the tasks. You should never perform a task if you have any reason to think that a manipulation could be dangerous for you or your teammates.

Systems of units

Units are expressed using the International System of Units (SI) followed by the units expressed in the U.S. customary system of units (between parentheses).

To the Instructor

You will find in this Instructor Guide all the elements included in the Student Manual together with the answers to all questions, results of measurements, graphs, explanations, suggestions, and, in some cases, instructions to help you guide the students through their learning process. All the information that applies to you is placed between markers and appears in red.

Accuracy of measurements

The numerical results of the hands-on exercises may differ from one student to another. For this reason, the results and answers given in this manual should be considered as a guide. Students who correctly performed the exercises should expect to demonstrate the principles involved and make observations and measurements similar to those given as answers.

Sample Exercise
Extracted from
the Student Manual
and the Instructor Guide

Fundamentals of Radar Level Transmitters

EXERCISE OBJECTIVE

Understand the fundamentals of radar level measurement and be able to install and configure a radar level sensor for accurate level measurement.

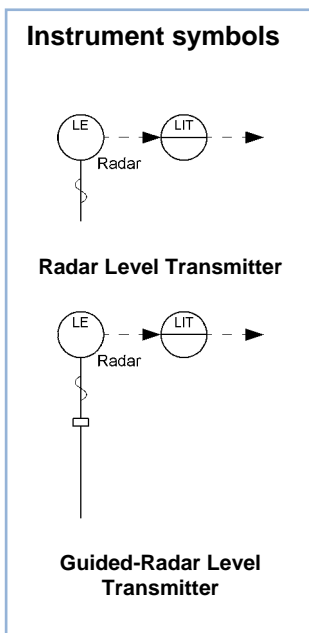
DISCUSSION OUTLINE

The Discussion of this exercise covers the following points:

- Introduction
- How do radar level sensors work?
Measuring a level. Blocking distance. Dielectric constant. Echo.
- What is the difference between a horn-antenna radar level sensor and a guided-radar level sensor?
- Advantages and limitations
- Characteristics of the supplied radar level transmitter
Remote display keys. Summary of technical specifications.
- Characteristics of the supplied guided-radar level transmitter
Remote display keys. Summary of technical specifications.
- Installing a radar level transmitter
- Commissioning a radar level transmitter
Advanced process conditions. Reset of the transmitter. Linearization. Echo envelope curve. Correction offset.

DISCUSSION

Introduction



Radar level sensors use high-frequency **electromagnetic waves** to detect the level of liquids or solids in different types of containers such as tanks, silos, or even a lake. Radar level measurement devices are either contact sensors or non-contact sensors. Since radar level sensors have no moving parts, they require very low maintenance. Figure 1 shows two level-measurement applications using radar level sensors. The first application (Figure 1a) is a liquid level-measurement application using a **non-contact** radar level sensor. The second application (Figure 1b) is a solid level-measurement application using a guided-radar level sensor. The differences between the two types of sensors are presented later in this discussion.

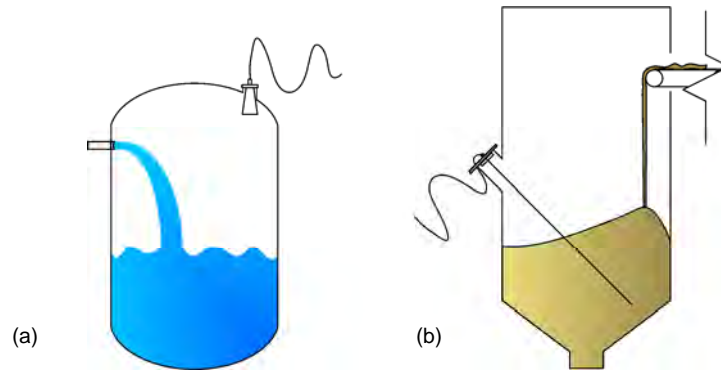


Figure 1. Typical applications of radar level sensors.

Unlike ultrasonic level sensors, radar level sensors are not very sensitive to temperature changes. However, they are sensitive to changes in the value of the dielectric constant of the medium being measured. Changes in the dielectric constant may have an influence on the quality of the level detection since radar level sensors are strongly dependent on the quality of the electromagnetic waves reflected by the process liquid or solid. The reflected waves are called the **echo**.

The intensity of the echo is inversely proportional to the square of the distance between the sensor and the surface of the substance. Thus, the farther the sensor is from the surface of the measured substance, the weaker the echo. The quality of the echo is also reduced by the absorption of the electromagnetic waves by vapor, mist, foam, or dust. The electromagnetic waves can also be reflected by other apparatuses, such as inlets or other sensors, in the detection path of the sensor. An echo suppression system usually reduces these extra reflections.

How do radar level sensors work?

You are already familiar with some types of electromagnetic radiations. Visible light, radio waves, and **microwaves** are all examples of electromagnetic radiations. Radar level sensors use electromagnetic waves with a frequency between 100 MHz and 30 GHz (i.e., microwaves) to measure levels. They use what is called the **time-of-flight method**. The sensor sends a microwave pulse toward the bottom of the vessel and, from the time it takes for the pulse to return, it calculates the distance between the sensor and the surface of the medium. The main difference between a radar level sensor and a guided-radar level sensor is that the later use a probe to guide the microwave pulse to the medium surface instead of an antenna. Figure 2 shows the relevant dimensions for a typical radar level sensor and for a guided-radar level sensor.

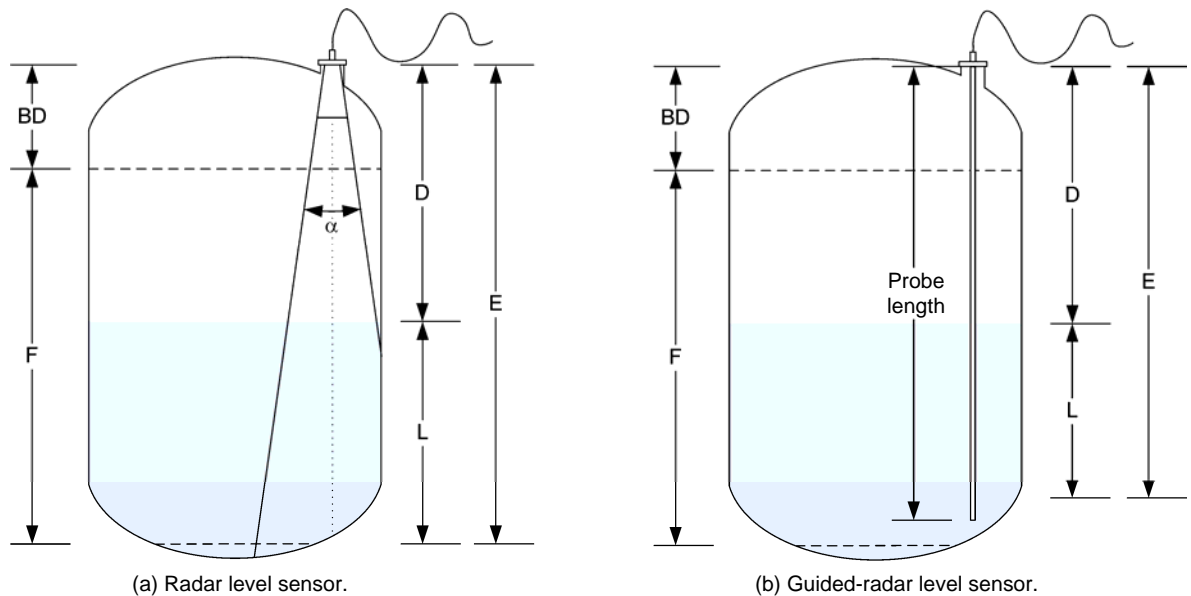


Figure 2. Relevant dimensions.

In this figure, F is the span or full distance in which measurements take place, E is the total distance between the sensor mounting flange and the lowest measurable level of the span, L is the portion of E currently filled with the product, D is the portion of E which is empty, and BD is the **blocking distance**. For a radar level sensor with a horn antenna, the **emitting angle** α can be used to calculate the detection radius for a given height.

Measuring a level

The radar level sensor can measure the time it takes for a high-frequency electromagnetic pulse to go back and forth from the sensor to the surface of the substance. Since electromagnetic waves travel at the speed of light, it is easy to calculate the distance from the sensor to the medium surface using Equation (1).

$$D = \frac{c \cdot t}{2} \quad (1)$$

where D is the distance between the sensor and the medium surface
 c is the speed of light, about 300 000 000 m/s (984 000 000 ft/s)
 t is the time it takes for the microwave pulse to go back and forth from the sensor to the surface of the substance

Since the empty distance (E) is programmed when setting up the sensor, the level in the vessel can easily be calculated using Equation (2).

$$L = E - D \quad (2)$$

where L is the level
 E is the empty distance
 D is the distance between the sensor and the medium surface

Blocking distance

Most radar sensors have a minimum distance that must be respected between the maximum level and the mounting flange of the sensor. This distance is called the blocking distance. Within the blocking distance the measurement is not reliable. Therefore, the level of the product must not be allowed to rise within the blocking distance.

Dielectric constant

When measuring the level of a liquid or solid using a radar sensor, the **dielectric constant** (or relative static permittivity) of the substance has an influence on how much of the microwave pulse is reflected back to the sensor. A medium with a high dielectric constant, such as water, strongly reflects the pulse. A substance with a low dielectric constant produces a weaker reflection.

With a guided-radar level detector, the sensitivity to variations in the dielectric constant can be used to measure the distance to the interface of two substances with different dielectric constants as illustrated in Figure 3. That is, the sensor can measure the thickness of the two layers of liquid, as well as the total level of liquid in the tank.

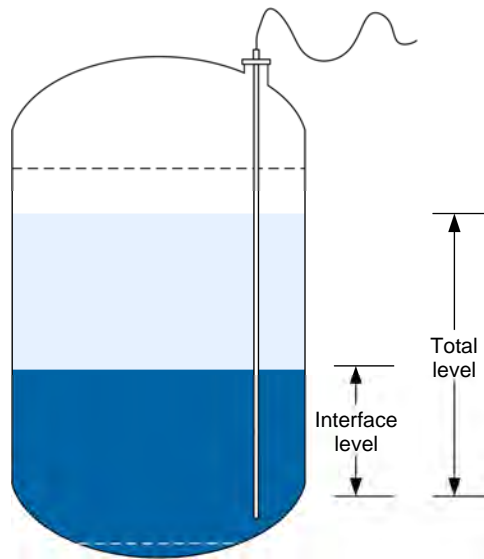


Figure 3. Measuring the distance to the interface of two liquids using a guided-radar level sensor.

Echo

As mentioned above, the echo is the portion of the electromagnetic pulses that travels back to the sensor when reflected at the **interface** between the air and the medium.

To measure a level, the sensor must be able to detect the echo. Therefore, the echo must have a sufficient intensity to be detected. Many factors influence the intensity of the echo. The most important ones are related to the propagation, absorption, and reflection of the electromagnetic waves. Electromagnetic waves naturally disperse as they propagate and their intensity is inversely proportional

to the square of the distance traveled. The more distance there is between the sensor and the surface of the product, the weaker the intensity of the echo will be. When an electromagnetic pulse hits the surface of the product, a portion of its energy is absorbed by the product instead of being reflected, thus diminishing the intensity of the returning wave. A sharp transition between the air and the medium is advisable to obtain reliable measurements. Foam, for example, can cause discrepancies when measuring the level of liquid with a radar level sensor.

What is the difference between a horn-antenna radar level sensor and a guided-radar level sensor?

Although they use the same measuring principle, non-contact radar level sensors, such as horn-antenna radar sensors, and guided-radar level sensors are different on many points. It is important to know these differences before selecting which of the two types of sensors you will use for a given application.

The most obvious difference between the two types of radar sensors is the probe or, for that matter, the absence of probe. Using a probe may improve the performance of the sensor in some circumstances such as in dusty environment. A probe also allows interface measurement of two liquids with different dielectric constants such as oil and water.

Guided-radar level sensors have the disadvantage of being bulky due to the probe. Also, the level measurement capabilities of such sensors are limited to a portion of the total length of the probe. As a matter of fact, there is a blocking distance near the transmitter at the top of the probe and close to the tip of the probe the precision of the measurement is not guaranteed. This last limitation prevents the measurement of level below the tip of the probe, hence preventing to know if a vessel is really empty or if there is a certain amount of substance left below the probe.

Non-contact radar level sensors, like all non-contact devices, can be used in harsh environmental condition where it is not desirable that the measured substance comes in contact with a probe. Since microwaves pass through plastic substances, a horn-antenna radar level sensor can even be installed outside a plastic tank to completely isolate it from the process.

Advantages and limitations

Radar level sensors, with or without probe, have several advantages and limitations. Some of the main advantages of radar level sensors are:

- No moving parts, thereby reducing maintenance costs
- Not sensitive to temperature or density changes, turbulences, and vibrations
- Available as non-contact sensors
- Guided-radar level sensors are suitable for interface measurement
- Reliable and accurate
- Ability to measure level in very deep tanks, up to 60 meters (200 feet)

However, some limitations are also to be considered:

- Dependency on the quality of the echo and object inside or outside the tank, which can cause measurement interference
- Dependency on the dielectric constant of the measured substance
- Accurate level measurement is impossible close to the mounting flange

Characteristics of the supplied radar level transmitter



This section gives the characteristics of the radar level transmitter, Model 46931. Go directly to the next section on page 10 for the characteristics of the guided-radar level transmitter, Model 46932.

The radar level transmitter, Model 46931, designed for the Instrumentation and Process Control System is shown in Figure 4. It consists of a radar level sensor/transmitter mounted on a flange cap, a remote display with a bracket for mounting the device on the process workstation, and a cable to connect the remote display to the transmitter.

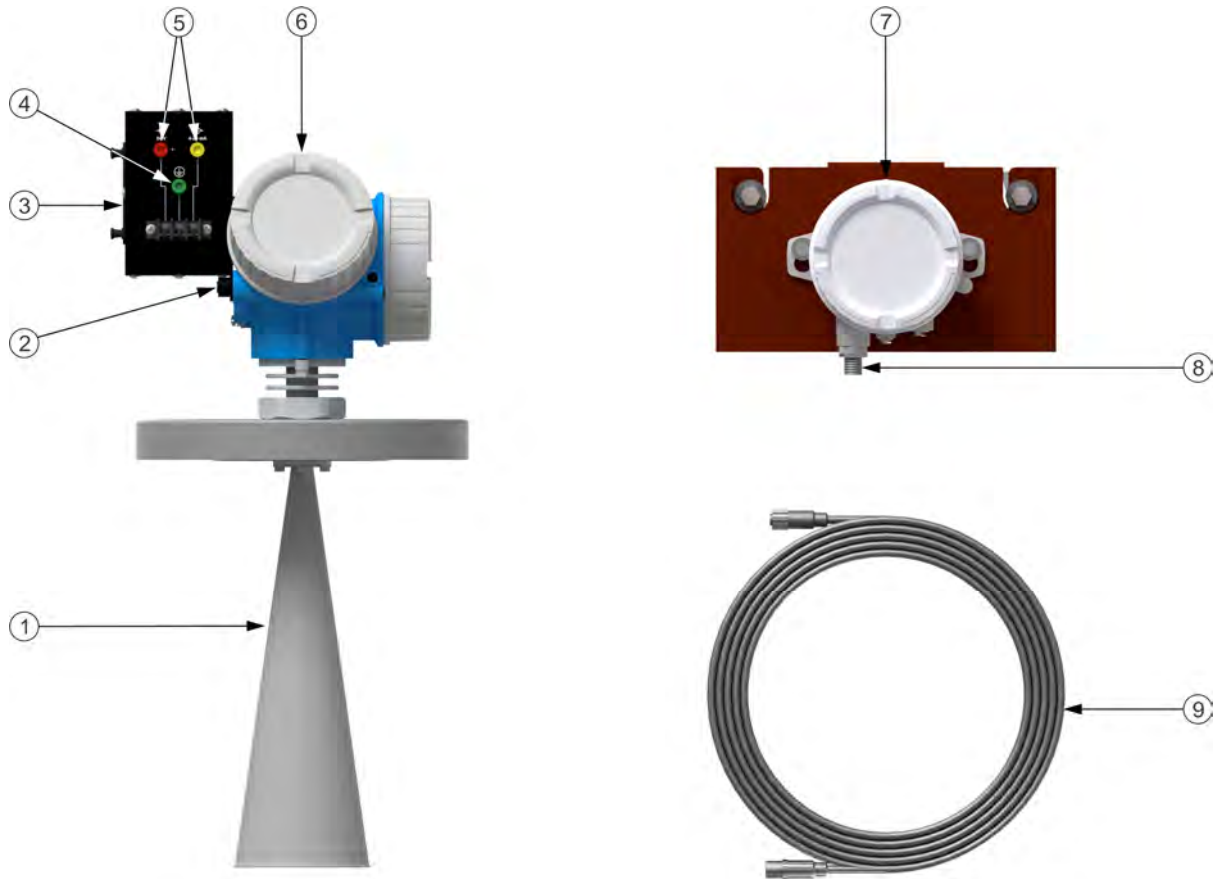


Figure 4. Radar level transmitter, Model 46931.

Table 1. Components of the radar level transmitter.

① Horn antenna	The radar sensor emits microwaves and detects the reflected echoes using this antenna.
② Transmitter	The digital transmitter is the computational center and the main component of this device. It determines the time of flight of the microwave pulses and calculates the level from this information.
③ Fault panel	Contains one switch used to simulate a fault with the radar apparatus.
④ Ground terminal	The ground terminal is used to connect the device to ground.
⑤ 24 V dc input	Used to energize the radar level transmitter with a 24 V dc signal.
⑥ Electronics housing	The transmitter's electronics housing is used to store the electronic components of the transmitter inside a protective shelter.
⑦ Remote display	The remote display shows the measured level and other information related to the operation of the transmitter. The control keys can be used to manually set the parameters of the transmitter.
⑧ Display connection jacks	Connection jacks used to connect the transmitter and the remote display to each other.
⑨ Remote display cable	A 20 meters (66 feet) long cable allows connecting the remote display to the transmitter.



The Display connection jack showed by ⑧ is connected to the transmitter at the location shown by ②. You can clearly see how the Transmitter and the Remote display are connected with the cable at Figure 10

Remote display keys

The remote display can be used to configure several parameters and to read the flow rate directly. The function of each button is described below:



Go backwards in a menu or modify a value



Go forward in a menu or modify a value



Select an item from a menu or store an entry



Press the + and – buttons simultaneously to return to the previous menu or display

Summary of technical specifications

Some of the technical specifications of the radar level transmitter are summarized in this section. For details, please refer to the manufacturer's documentation provided with the device.

Table 2. Technical specifications of the radar level transmitter.

Device name	Micropilot FMR51
Measured variable	Level (via time-of-flight)
Power supply	24 V dc
Communication protocols	HART
Operating frequency	~26 GHz
Accuracy	±2 mm
Operating temperature of the sensor	-40°C to 80°C (-40°F to 176°F)
Temperature of the process	-196°C to 450°C (-321°F to 842°F)
Operating pressure of the sensor	Vacuum to 16000 kPa (Vacuum to 2320 psi)
Blocking distance	200 mm (7.9 in)

Characteristics of the supplied guided-radar level transmitter



This section gives the characteristics of the guided-radar level transmitter, Model 46932. Go back to the previous section on page 7 for the characteristics of the radar level transmitter, Model 46931.

The guided-radar level transmitter, Model 46932, designed for the Instrumentation and Process Control System is shown in Figure 5. It consists of a radar level sensor/transmitter mounted on a flange cap, a remote display with a bracket for mounting the device on the process workstation, and a cable to connect the remote display to the transmitter.

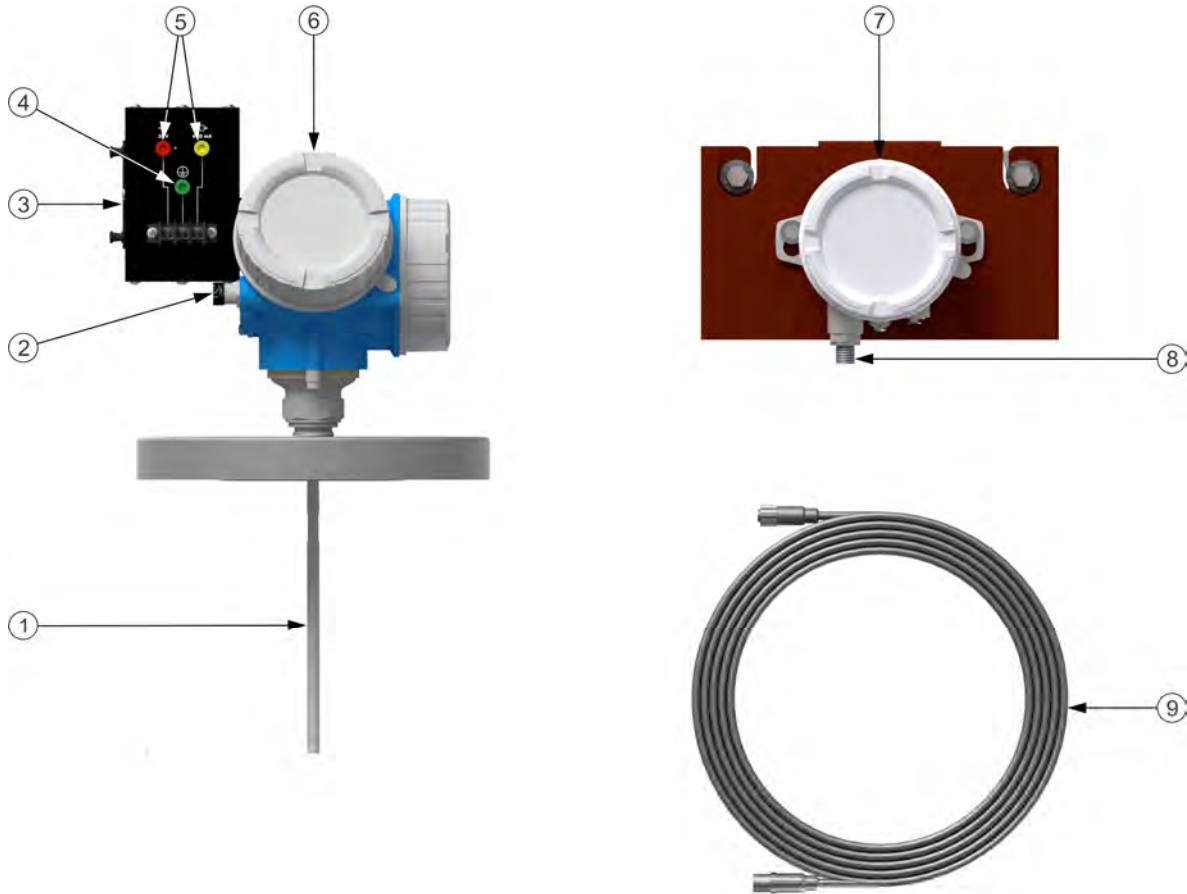


Figure 5. Guided-radar level transmitter, Model 46932.

Table 3. Components of the guided-radar level transmitter.

① Probe	The radar sensor emits microwaves that are guided along the probe.
② Transmitter	The digital transmitter is the computational center and the main component of this device. It determines the time of flight of the microwave pulses and calculates the level from this information.
③ Fault panel	Contains one switch used to simulate a fault with the radar apparatus.
④ Ground terminal	The ground terminal is used to connect the device to ground.
⑤ 24 V dc input	Used to energize the radar level transmitter with a 24 V dc signal.
⑥ Electronics housing	The transmitter's electronics housing is used to store the electronic components of the transmitter inside a protective shelter.
⑦ Remote display	The remote display shows the measured level and other information related to the operation of the transmitter. The control keys can be used to manually set the parameters of the transmitter.
⑧ Display connection jacks	Connection jacks used to connect the transmitter and the remote display to each other.
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Go forward in a menu or modify a value



Select an item from a menu or store an entry



Press the + and – buttons simultaneously to return to the previous menu or display

Summary of technical specifications

Some of the technical specifications of the guided-radar level transmitter are summarized in this section. For details, please refer to the manufacturer's documentation provided with the device.

Table 4. Technical specifications of the guided-radar level transmitter.

Device name	Levelflex FMP50
Measured variable	Level (via time-of-flight)
Power supply	24 V dc
Communication protocols	HART
Operating frequency	100 MHz to 1.5 GHz
Accuracy	±2 mm
Operating temperature of the sensor	-40°C to 80°C (-40°F to 176°F)
Temperature of the process	-40°C to 80°C (-40°F to 176°F)
Operating pressure of the sensor	Vacuum to 600 kPa (Vacuum to 87 psi)
Probe length	1.03 m (40.6 in)
Blocking distance	200 mm (7.9 in)

Installing a radar level transmitter



Installing a radar sensor at the top of the column may require climbing on a ladder. Always take precautionary measures when using a ladder and wear the appropriate protective equipment throughout the experiment (safety shoes, protective eyewear, etc.). In the other case, the installation of a radar transmitter may require lifting and rotating the water column. In this case, make sure that the column is empty and that you hold the column when taking off the bolts and nuts. This operation may require a team to be performed.

A radar level transmitter is pretty straightforward to install. The sensor/transmitter part of the device must be installed on the flange of the column (the sensor pointing towards the bottom of the column) and must be properly secured with bolts and nuts. The remote display is to be installed on the instrumentation workstation, at a convenient location.

Commissioning a radar level transmitter

The transmitter must be set up for the specific application at hand. The setup for a typical use on the Instrumentation and Process Control Training System is explained in the upcoming procedure section. A few important parameters are nonetheless covered here.

Advanced process conditions

The prevailing conditions in the process column can fluctuate significantly based on the relative magnitude of the flows, the dimensions of the column, and the way in which the column is filled (from the top of the column or from the bottom).

As a result, the surface of the liquid can vary from very turbulent to still and the level can change quickly or slowly, in a uniform way or not.

This wide spectrum of possibilities makes it difficult for the sensor to measure and display a precise level at an adequate rate. A balanced choice must be made between the stability and reliability of the measured value and the reaction time of the sensor. A slowly-varying level with a calm surface would be best measured if the sensor averaged its readings over a relatively long period of time. On the other hand, a quickly changing level may need to be monitored with a much shorter averaging time (e.g. to avoid an overflow), even if it must be done at the expense of some precision.

The transmitter offers a series of preset options for different applications, each with different parameters for the time-averaging filter and for the input-stabilizing filter. The most useful one is usually the *Small tanks (< 1m/3ft)* setting, since the process column (46901) is qualified as a small tank (relative to industrial tanks). Small tanks have levels that are likely to change quickly. Thus, they provide short reaction times. The options which are likely to be used are presented below. You are encouraged to test them and determine which ones give the best results in different situations.

Table 5. Summary of the main advanced process conditions options.

Advanced process conditions	Applications	Settings
<i>Foam (>5cm/0, 16ft)</i>	This option makes sure that no tank history is used which has been recorded while foam was present at the surface and thus is no reliable map of the tank property.	Evaluation mode = Long time history is deactivated.
<i>Changing DC values</i>	A tank history which has been recorded and is only valid for a fixed dielectric constant. The Changing DC values option avoids measuring values in the case of a changing dielectric constant.	Evaluation mode = Long time history is valid for a fixed dielectric constant.
<i>Small tanks (< 1m/3ft)</i>	This option provides a simple possibility to reduce the echo width of the sensor module. This enables an improved detection of superimposed echos - especially in the near field. Internally, all parameters related to the echo width are adjusted by this option.	Only available for liquid measurements with 26 GHz HF module.
None		

Reset of the transmitter

Radar level transmitters can be reset anytime you want to work with a clean configuration. Doing so restores the parameters to default values and deactivates linearization and interference echo settings. Keep in mind that a setup procedure like the one described below is always required after a reset.

Linearization

Radar transmitters offer the option of converting a measured level into another quantity (such as a volume, a mass, a percentage, etc.) according to one of many preset functions or according to a linearization table. As the process column has a regular cylindrical shape, only the *linear* type will be used (refer to the device documentation for information about the other types, if required).

The *linear* type needs three parameters:

- The portion of the tank you want to linearize (the filled part or the part above the level) and the type of unit (technical unit (CD) or distance unit (DU)).
- The unit you want to use (m^3 , ft^3 , L, kg, lbs)
- The maximal value (in the specified unit) for a 100% level. This linearization type assumes that the minimal value is 0 (in the specified unit) for a 0% level.

Echo envelope curve

Waves propagating in non-ideal conditions are likely to rebound on obstacles and eventually return to the sensor. The problem is that it takes such unwanted echoes a different time to go back to the sensor than it would normally take to hit the surface of the liquid and go back to the sensor in a straight line. This causes the detection of unwanted signals, unrelated to the actual level in the column, and skews the results. Thankfully, those unwanted echoes can be expected to be present with the same strength for a certain level of liquid every time an echo pulse is sent. Consequently, a background picture of parasitic echoes in an empty column can be recorded and looks as shown on Figure 6.

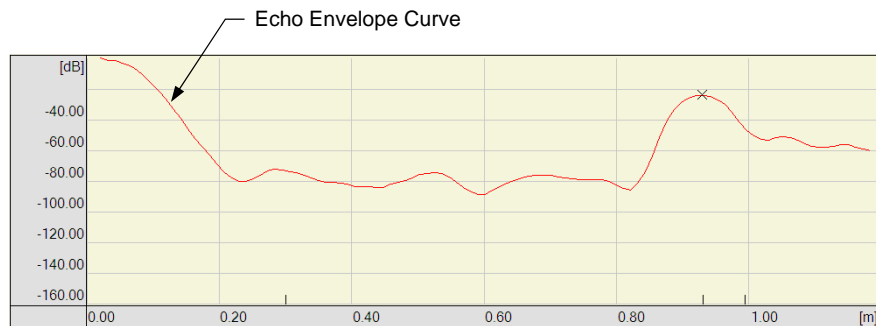


Figure 6. Envelope curve for an empty column.

The echo **envelope curve** is a recording of the relative intensity of returning electromagnetic waves as a function of the distance traveled by the waves before being reflected. An echo envelope curve gives a broad picture of all the signals measured by a sensor for a given level of liquid in the column.

Once the envelope curve of the empty vessel is known, it is straightforward to determine a filter **mapping** which will ignore any echo signals which are not stronger than the typical background echo noise. Doing so ensures that only relevant signals are considered, thus improving the reliability of the level measurement. A mapping computed automatically by the transmitter is shown in

Figure 7. Note that it is a curve slightly above but following closely the echo envelope curve in the range in which it is defined.

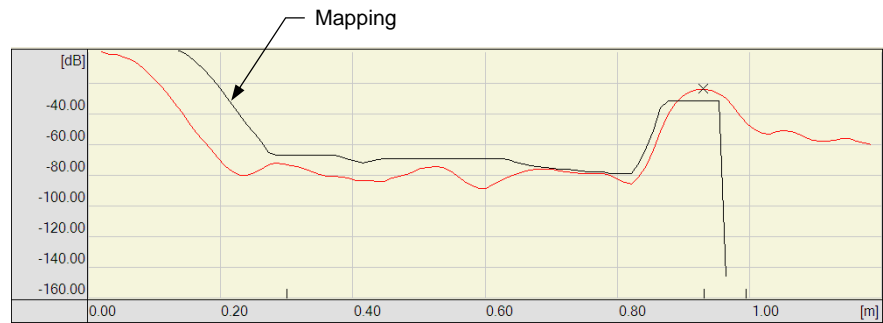


Figure 7. An appropriate mapping (in black) for the envelope curve.

If you change or modify the vessel in any way that affects the propagation of the microwaves (by adding an obstacle or a probe for instance), it is strongly recommended that a new envelope curve be recorded and a new corresponding filter mapping be produced. It is important to limit the range of the mapping so as to be a few centimeters (about an inch) short of the column baffle plate. This avoids filtering out the echo signaling that the level is at its minimum.

When a certain level of liquid is present in the column, the path of the microwaves pulses is altered. This results in a modified envelope curve with respect to the one of the empty column. To determine the level, the transmitter ignores the signals whose strength is below the mapping curve and identifies the first peak above the mapping curve as the correct signal (Figure 8).

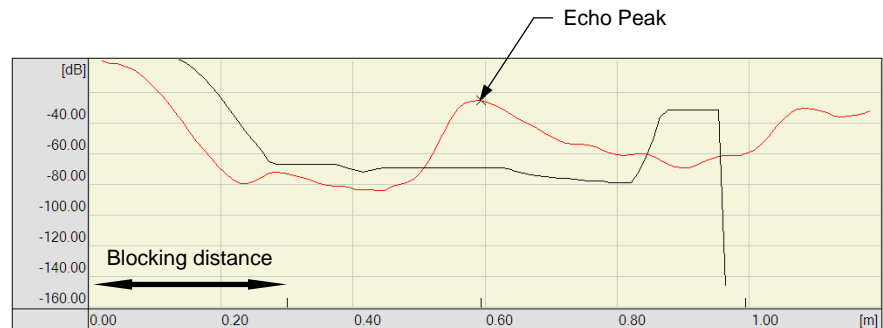


Figure 8. Determining the distance between the detector and the surface of the liquid.

Correction offset

It is possible to adjust the displayed value as measured by the radar level transmitter if you find out after a comparison with the value given by a ruler or another measuring device that it is off by a constant.

PROCEDURE OUTLINE

The Procedure is divided into the following sections:

- Set up and connections
- Commissioning the level transmitter
- Adding an offset
- Displaying level in percentage of span
- How to obtain a volume reading
Calculating the max. scale parameter.
- Making a new mapping
Making a new mapping with the radar level transmitter. Making a new mapping with the guided-radar level transmitter.

PROCEDURE

Set up and connections



Throughout this procedure the expression “radar level transmitter” or “transmitter” stand for either the transmitter Model 46931 or 46932, whichever you use.

1. Connect the equipment according to the piping and instrumentation diagram (P&ID) shown in Figure 9 and use Figure 10 to position the equipment correctly on the frame of the training system. To set up your system for this exercise, start with the basic setup presented in the *Familiarization with the Instrumentation and Process Control Training System* manual and add the equipment listed in Table 6.

2. Radar level sensors use electromagnetic waves to detect the level of water in a vessel. This has several advantages. However, in the case of a non-metallic tank, such as the column used in the current exercise, the electromagnetic waves emitted by the transmitter are not confined to the vessel. Like light, they can go through the column. Hence, the electromagnetic waves can also be reflected by objects around the column. To minimize the risk of level reading errors due to interferences from objects outside the column, try to remove from the process station any unused struts or devices close to the column.

Table 6. Material to add to the basic setup for this exercise.

Name	Model	Identification
Radar level transmitter or Guided-radar level transmitter	46931 or 46932	LIT 1
Electrical unit	46970	
Pneumatic unit	46971	
Accessories	46993	

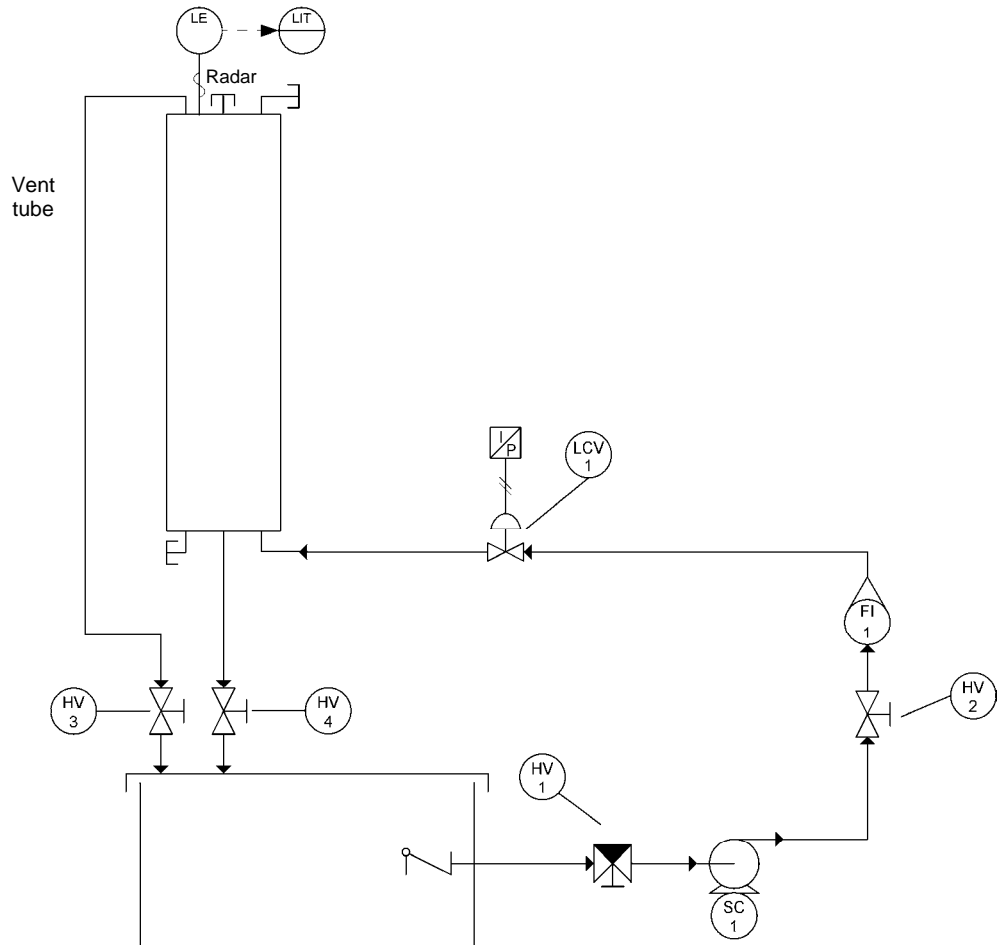


Figure 9. P&ID.

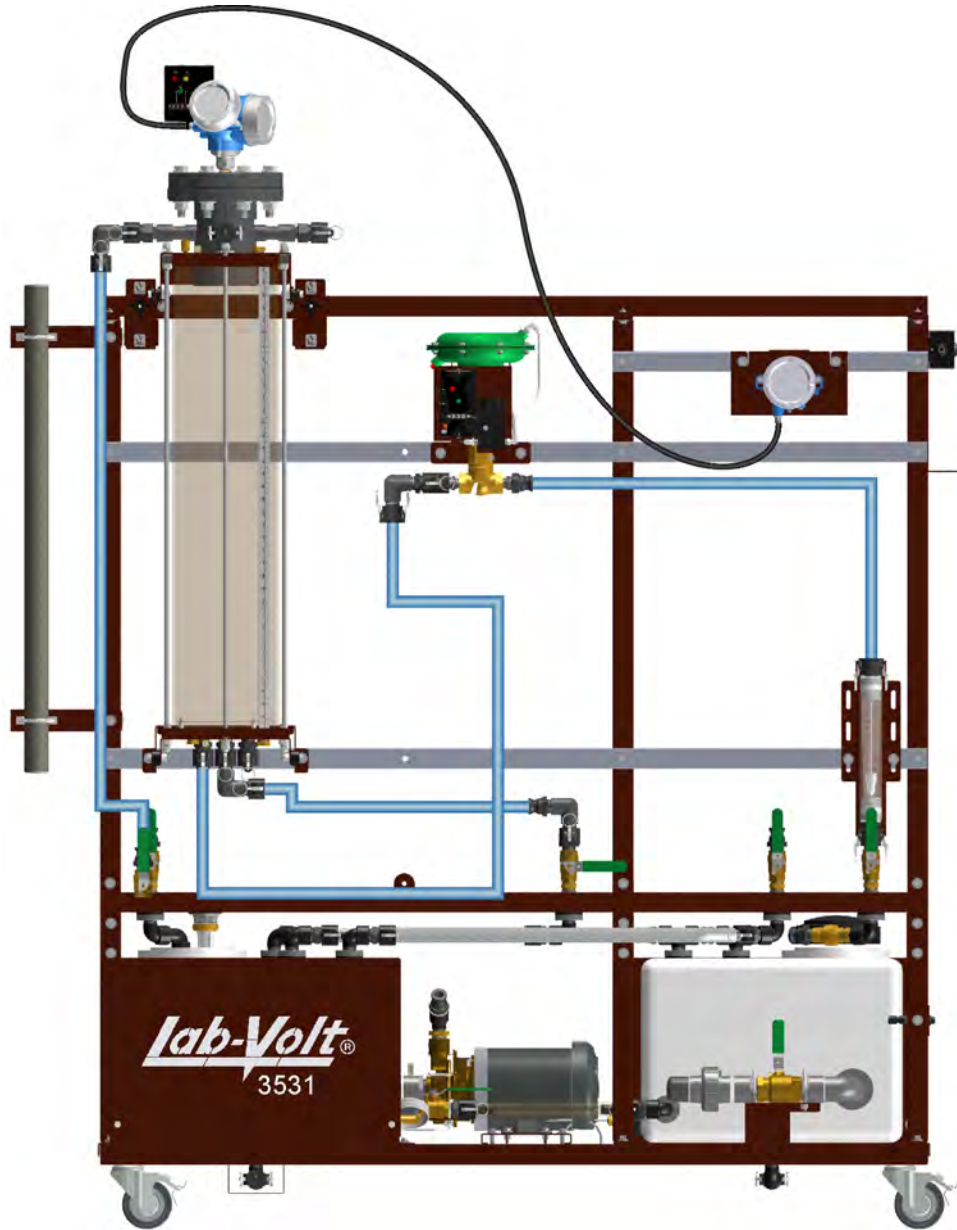


Figure 10. Setup.

3. Connect the control valve to the pneumatic unit. Details about the installation and operation of the control valve are available in the *Familiarization with the Instrumentation and Process Control Training System* manual.
4. Connect the pneumatic unit to a dry-air source with an output pressure of at least 700 kPa (100 psi).

5. Wire the emergency push-button so that you can cut power in case of emergency. The *Familiarization with the Instrumentation and Process Control Training System* manual covers the security issues related to the use of electricity with the system as well as the wiring of the emergency push-button.
6. Do not power up the instrumentation workstation yet. You should not turn the electrical panel on before your instructor has validated your setup—that is not before step 12.
7. If a flange top is already in place on the process column, unbolt and carefully remove this component from the column. Place the sensor/transmitter part of the radar level transmitter on top of the flange, the sensor pointing downwards into the column. Bolt the transmitter flange in place.

⚠ CAUTION



Installing a radar sensor at the top of the column may require climbing on a ladder. Always take precautionary measures when using a ladder and wear the appropriate protective equipment throughout the experiment (safety shoes, protective eyewear, etc.). In the other case, the installation of a radar transmitter may require lifting and rotating the water column. In this case, make sure that the column is empty and that you hold the column when taking off the bolts and nuts. This operation may require a team to be performed.

8. Install the remote display at a convenient location on the process workstation. Connect the remote display cable to the connection jacks on the transmitter and on the display.
9. Connect the transmitter to a 24 V dc power outlet on the electrical unit. Use one of the direct outputs to keep the transmitter from shutting off in case the emergency push-button or the *OFF* button (*S1*) is used.
10. Before proceeding further, complete the following checklist to make sure you have set up the system properly. The points on this checklist are crucial elements to the proper completion of this exercise. This checklist is not exhaustive, so be sure to follow the instructions in the *Familiarization with the Instrumentation and Process Control Training System* manual as well.



- All unused male adapters on the column are capped and the flange is properly tightened.
- The ball valves are in the positions shown in the P&ID.
- The valve at the suction of the pump (HV1) is set the open position, so that the flow is directed toward the pump inlet.
- The control valve is fully open.
- The pneumatic connections are correct.

11. Ask your instructor to check and approve your setup.
12. Make sure it is safe to energize the system for you and for the team working on the other side of the system, if any. When ready, turn on the main power by pushing the handle of the safety switch in the ON position. Do not press the **S2** button yet.

The transmitter initializes and the remote display turns on after 30 seconds or even more. This happens because the device is explosion proof.

Commissioning the level transmitter



The following procedure assumes you are using the remote display to program the transmitter. If you want to configure your transmitter from a computer, you can do so by accessing the same menus and inputting the same values in the appropriate fields of the FieldCare software, or the DeviceCare software. Please refer to the HART Software Configuration student manual (P/N 86050) for more information on how to connect your transmitter to a computer. Appendix A, Appendix B, Appendix C, and Appendix D give an overview of how to configure the radar level transmitter and the guided-radar level transmitter using FieldCare and DeviceCare.

13. It is recommended that you reset the device in order to start with the factory settings. To do this, press the **E** button from the main display to access the *Micropilot 5x* menu. Use the **+** and **-** buttons to select the *Setup* group and then press the **E** button to access the *Setup* function group. Next, press the **+** and **-** buttons to access the *Advanced setup* group. Once again, use the **+** and **-** buttons to reach the *Administration* group and press the **E** button. On the *Device reset* field, select *To factory defaults* using the **+** and **-** buttons. Press **E** to complete the reset.
14. Press **⏏** (i.e., the **+** and **-** buttons simultaneously) a few times to return to the *Micropilot 5x* menu.
15. The first thing you may want to configure on the transmitter is the type of unit used to indicate the level (% , m , ft , mm , or inch). From the *Micropilot 5x* menu, select the *Setup* menu group and press the **E** button. Using the **+** and **-** buttons, go to the *Advanced setup* menu and press the **E** button. Then proceed the same way to reach the *Level* sub-menu. Once there, press the **E** button and reach the *Level unit* field using the **+** and **-** buttons. Once there, select between *%*, *inch*, *m*, *ft*, and *mm*. Press **E** to confirm your choice and use **⏏** to return to the *Micropilot 5x* menu.
16. The transmitter can either display the level of liquid using the unit selected in the *Level unit* function or using the technical unit of your choice: %, unit of length, volume, or mass. How to display the volume or mass of liquid in the column is detailed later in this exercise. For the moment, we will use the unit selected at step 15.

17. To do so, select the *Linearization* function group on the *Advanced setup* sub-menu and, in the *Linearization type* function, select *Linear* and use $\left[\text{Esc} \right]$ to return to the *Setup* function, where the level value is displayed. The measured value should be in the unit set in the *Level unit* function. However, it is probably erroneous since the parameters ensuring the correct operation of the transmitter have not been set yet.
18. Go to the *Expert* menu using the **+** and **-** buttons and type *0000* in the *Access code* field. Press **E** to confirm. Then select the *Sensor* function menu and reach the *Level* sub-menu. In the *Output mode* field, make sure that *Level linearized* is chosen.
19. Depending on the unit you have selected, you may have to change the number of decimals displayed by the transmitter in order to obtain the desired precision. To do so, go to *Setup ▶ Advanced setup ▶ Display*. As you can see, the transmitter can display different types of values (Level linearized, Distance, Current output 1, Measured current, Terminal voltage, Electronic temperature, Analog output adv. diagnostics). These can be selected in the *Value display* fields. For each type of value, you can set the desired number of decimals in the *decimal places* field. Each *Value display* field has its related *decimal places* field, and they are identified by the same corresponding number. For now, we only use the *Value 1 display* field (set to *Level linearized*) and the *decimal places 1* field.
20. You must give information on the process to the transmitter so that it reads the level correctly. This information includes, among other things, the type of tank, the dielectric constant of the liquid or solid in the tank, the process conditions, the probe characteristics, the empty calibration value, the full calibration value, and the mapping information. You can provide all this information to the transmitter via the *Setup* function group.

The other options available in the linearization function are described and tested from step 38 to step 45 of this exercise.

Set the parameters in the *Setup* function group as shown in Table 7 for the radar level transmitter, Model 46931, or as in Table 8 for the guided-radar level transmitter, Model 46932.

Table 7. Setting for the level radar transmitter, Model 46931.

Function	Setting	Path	Description
Tank shape	Bypass/pipe	Setup -> Tank type	This is the type of tank proposed by the manufacturer.
Medium group	Water based (DC>=4)	Setup -> Medium group	Specifies the dielectric constant of the medium and presets the medium property parameter.
Empty calibr.	1.070 m (42 in)	Setup -> Empty calibr.	Distance between the mounting flange and the minimum level (0%).
Full calibr.	0.750 m (29 in)	Setup -> Full calibr.	Distance between the minimum (0%) and the maximum level (100%).
Confirm distance	Manual map	Setup -> Confirm distance	The range of mapping is to be defined manually.
Mapping end point	0.76 m (30 in)	Setup -> Map. End point.	The range of mapping for the radar level transmitter must not be below the baffle plate at the bottom of the column.
Medium type	Liquid	Setup -> Advanced -> Level -> Medium type	Indicates if the measured substance is a solid or a liquid.
Medium property	DC 4 ... 7	Setup -> Advanced setup -> Level -> Medium property	Dielectric constant of the measured medium.
Process property	Standard < 1 m (40 in) /min	Setup -> Advanced setup -> Level -> Process property	This is the most convenient mode.
Advanced process conditions	Small tanks (1m/3ft)	Setup -> Advanced setup -> Level -> Advanced process condition	This is the most convenient mode for the process column (46901).
Blocking distance	0.2 m	Setup -> Advanced setup -> Level -> Blocking distance	Mentioned above, in the Discussion section.

Table 8. Setting for the guided-radar level transmitter, Model 46932.

Function	Setting	Path	Description
Tank type	Bypass/pipe	Setup -> Tank type	Even though the column is non metallic, this setting also works relatively well because of the metallic baffle plate installed at the bottom of the column.
Medium group	Water based (DC > = 4)	Setup -> Medium group	Dielectric constant of the measured medium.
Empty calibration	1.070 m (42 in)	Setup -> Empty calibration	This is the most convenient mode. Different modes can also be used.
Full calibr.	0.740 m (29 in)	Setup -> Full calibration	Distance between the minimum (0%) and the maximum level (100%).
Confirm distance	Manual map	Setup -> Confirm distance	This setup is used since the range of mapping will be entered manually.
Mapping end point	1.03 m (42 in)	Setup -> Mapping end point	Since the mapping is done with an empty column, it is recommended to use a range of mapping equal to the probe length.
Medium type	Liquid	Setup -> Advanced setup -> Level -> Medium type	Indicates if the measured substance is a solid or a liquid.
Medium property	DC 4 ... 7	Setup -> Advanced setup -> Level -> Medium property	Dielectric constant of the measured medium.
Process property	Standard < 1m (40 in) /min	Setup -> Advanced setup -> Level -> Process property	This is the most convenient mode.
Blocking distance	0.2 m	Setup -> Advanced setup -> Level -> Blocking distance	Mentioned above, in the Discussion section.
Probe grounded	No	Setup -> Advanced setup -> Probe settings -> Probe grounded	The probe is not grounded.
Probe length	1.03 m (42 in)	Setup -> Advanced setup -> Probe settings -> Probe length	The probe length is measured from the flange to the tip of the probe.
Confirm probe length	Probe length ok	Setup -> Advanced setup -> Probe settings -> Confirm probe length	The transmitter can determine the length of uncovered probes automatically. This is not necessary since the length of the probe has been provided to the transmitter (see probe length above).

21. Press the **S2** button to power all the devices not already active on the station (i.e., the drive, the pneumatic devices, etc.) and make sure the **S1** button is set to the ON position.
22. Test your system for leaks. Use the drive to make the pump run at low speed to produce a small flow rate. Gradually increase the flow rate, up to 50% of the maximum flow rate that the pumping unit can deliver (i.e., set the drive speed to 30 Hz). Repair any leaks.

23. Fill the column with water up to a level of about 0.80 m (31 in) on the ruler.

24. Stop the pump and close HV2 and HV4.

25. Use HV4 to adjust the level of water until you read 0.75 m (29 in) on the radar level transmitter display. Write below the level of water indicated on the ruler.

About 0.717 m (27.7 in) using the radar level transmitter, Model 46931. The results may differ depending on your setup or the type of transmitter you use.

26. Use HV4 to adjust the level of water until you read 0.001 m (0.1 in) on the transmitter display. Write below the level of water indicated on the ruler.

About 0.04 m (1.5 in).

27. Explain why the level on the ruler does not correspond to the level on the display of the transmitter.

The zero of the ruler does not correspond to the zero entered in the basic setup function of the radar level transmitter. An offset must be added to the setting of the transmitter so that the two zeros match.

28. If you experience problems while trying to measure the maximum and minimum levels configured on the transmitter, your setup may require fine tuning of some of the transmitter parameters such as the mapping. You may go to the Making a new mapping section immediately to perfect your mastering of the transmitter mapping function and come back later to complete the rest of the exercise once you have fine tuned your transmitter.

Tuning a radar level transmitter is not an easy task and it requires a little bit of practice and a sound understanding of the mapping process. Be aware that you may also need to change some of the parameters entered in the *Setup* function to fit the tuning of your transmitter to your needs or to adapt it to some particularities of your setup.

Adding an offset

29. Fill the column again and close HV4 and HV2.

The results may vary depending if you are using the transmitter Model 46931 or 46932. The characteristics of these two transmitters differ slightly, especially at the top and bottom of the range.

30. Use HV4 to decrease the level of water in the column by steps of 5 cm (2 in). Fill Table 9 with the results. Also, calculate the difference between the level on the ruler and the level on the transmitter (Δ Level).

Table 9. Measurement of the level (ruler vs. radar level transmitter).

Level on the ruler cm (in)	Level on the transmitter cm (in)	Δ Level cm (in)
80 (31)		

The results are presented below.

Measurement of the level in centimeters.

Level on the ruler (cm)	Level on the transmitter (cm)	Δ Level (cm)
80	75.4	4.6
75	71.6	3.4
70	66.9	3.1
65	61.8	3.2
60	57.1	2.9
55	52.0	3
50	47.3	2.7
45	42.2	2.8
40	36.6	3.4
35	31.6	3.4
30	26.4	3.6
25	21.1	3.9
20	15.8	4.2
15	16.3	-1.3
10	7.4	2.6
5	1.6	3.4
0	0.0	0.0

Measurement of the level in inches.

Level on the ruler (in)	Level on the transmitter (in)	Δ Level (in)
31	29.6	1.4
29	27.7	1.3
27	25.7	1.3
25	23.8	1.2
23	21.7	1.3
21	19.8	1.2
19	17.8	1.2
17	15.8	1.2
15	13.7	1.3
13	11.6	1.4
11	9.5	1.5
9	7.5	1.5
7	5.8	1.2
5	4.7	0.3
3	1.8	1.2
1	0.0	1.0
0	0.0	0.0

31. You may have noted that Δ Level is relatively constant except for extreme values (i.e., at the top of the span or at the bottom of the span). Therefore, we can approximate that the offset between the level on the ruler and the level measured by the transmitter is constant.

For some applications, it may be convenient to match the level the transmitter displays with the level read on the column ruler. To do this, we will use the mean value of Δ Level for levels in the middle of the span.

32. First, calculate the mean value of Δ Level for levels on the ruler between 0.70 m and 0.20 m (27 in and 7 in).

Approximately 3.3 cm (1.3 in).

33. Go to the *Expert* menu. Enter *0000* in the Access code field if required. Then go to the *Sensor* function group and select the *Level* sub-menu.

34. In the *Level correction* field, enter the value calculated at step 32.

35. Fill the column again and close HV4 and HV2.

- 36.** Use HV4 to decrease the level of water in the column by steps of 5 cm (2 in). Fill Table 10 with the results. Also, calculate the difference between the level on the ruler and the level on the transmitter (Δ Level).



To switch between SI units and U.S. customary units, go to [Advanced setup ▶](#) Level.

Table 10. Measurement of the level (ruler vs. radar level transmitter).

Level on the ruler cm (in)	Level on the trans- mitter cm (in)	Δ Level cm (in)
80 (31)		

The results are presented below.

Measurement of the level in centimeters.

Level on the ruler (cm)	Level on the transmitter (cm)	Δ Level (cm)
80	79.1	0.9
75	75.0	0
70	70.2	-0.2
65	65.1	-0.1
60	60.6	-0.6
55	55.2	-0.2
50	50.6	-0.6
45	45.4	-0.4
40	40.1	-0.1
35	34.9	0.1
30	29.7	0.3
25	24.6	0.4
20	19.9	0.1
15	19.1	-4.1
10	10.0	0.0
5	4.8	0.2
0	0.0	0.0

Measurement of the level in inches.

Level on the ruler (in)	Level on the transmitter (in)	Δ Level (in)
31	31.0	0
29	29.0	0
27	27.1	-0.1
25	25.1	-0.1
23	23.1	-0.1
21	21.1	-0.1
19	19.0	0
17	17.0	0
15	15.1	-0.1
13	13.0	0
11	11.1	-0.1
9	8.9	0.1
7	7.3	-0.3
5	5.9	-0.9
3	3.1	-0.1
1	1.4	-0.4
0	1.4	-1.4

37. If there is still an important offset, correct the problem by adjusting the value of the offset function.

Displaying level in percentage of span

38. The transmitter can also display the level in percentage of the span or in other measuring unit. Switch to a level measured in percentage. To do so, use Table 11 to configure the display of the level in percentage.

Table 11. Settings for reading the level in percentage of span.

Path	Parameter	Value
Setup -> Advanced setup -> Level	Level unit	%
Setup -> Advanced setup -> Linearization	Linearization type	Linear
Setup -> Advanced setup -> Linearization	Unit after linearization	%
Setup -> Advanced setup -> Linearization	Maximum value	100%

39. The transmitter should now display the measured level in percentage of the span.

40. Fill the column again and close HV4 and HV2.

41. Use HV4 to decrease the level of water in the column by steps of 5 cm (2 in). Fill Table 12 with the results.

Table 12. Measurement of the level (ruler vs. radar level transmitter).

Level on the ruler cm (in)	Level on the trans- mitter %
80 (31)	

The results are presented below.

Measurement of the level in centimeters on the ruler.

Level on the ruler (cm)	Level on the transmitter (%)
80	105.0
75	99.8
70	93.6
65	86.7
60	80.6
55	73.6
50	67.5
45	60.3
40	53.5
35	46.4
30	39.5
25	32.3
20	25.3
15	22.4
10	15.1
5	6.3
0	4.4

Measurement of the level in inches on the ruler.

Level on the ruler (in)	Level on the transmitter (%)
31	107.5
29	100.2
27	93.5
25	87.1
23	79.8
21	73.3
19	66.5
17	59.1
15	52.0
13	44.7
11	37.6
9	30.5
7	25.6
5	20.4
3	10.5
1	5.2
0	5.2

42. Is the agreement satisfactory?

Yes No

Yes

How to obtain a volume reading

The radar level transmitter cannot directly measure the volume of liquid in a tank. However, given some information, it can infer the volume occupied by the liquid.

To correctly infer the volume of water in the column, the transmitter needs the volume of liquid in the column when the level is at 100%. This volume is the *max. scale* volume. Below is an example of how to calculate the maximum scale volume so that the transmitter displays a volume of 0 L (0 gal) when the transmitter measure a level of 0% and a volume corresponding to the maximum scale volume when the transmitter measure a level of 100%. Figure 11 shows the portion of the total volume of liquid in a vessel that is measured by the radar level transmitter using this method.

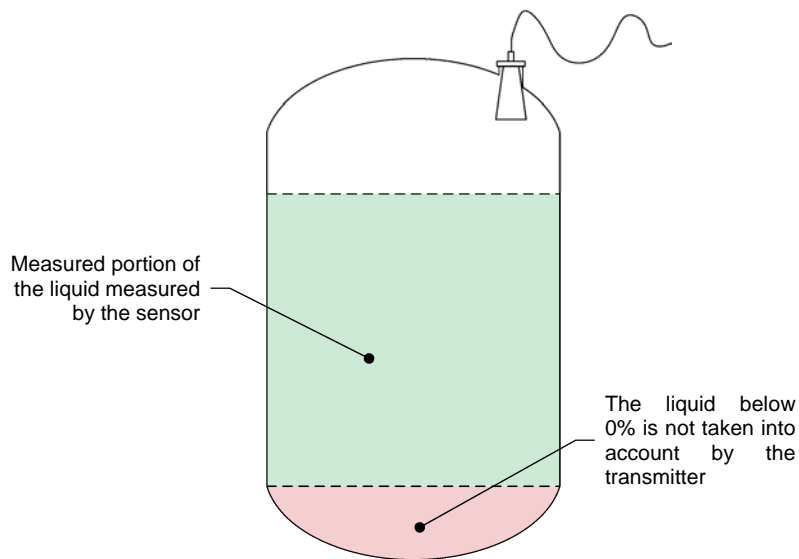


Figure 11. Portion of the total volume of liquid in a vessel measured by the radar transmitter.

Calculating the max. scale parameter

The volume of a cylinder can be calculated using Equation (3).

$$V_{cylinder} = \pi r^2 h \quad (3)$$

where r is the radius of the cylinder
 h is the height of the cylinder

The process column has an inner diameter of 0.203 m (8 in) and you have set before the value of the *full calibr.* parameter to 0.740 m (29 in).

Using these values and Equation (3), you can calculate the *full calibr.* parameter. Below is the calculation of the *full calibr.* parameter to display the volume in liters or in gallons:

$$\text{max. scale (L)} = \pi \cdot \left(\frac{0.203}{2}\right)^2 \cdot 0.740 \cdot 1000 = 24 \text{ L}$$

$$\text{max. scale (gal)} = \pi \cdot \left(\frac{8}{2}\right)^2 \cdot 29 \cdot 0.004329 = 6.31 \text{ gal}$$

43. Use Table 13 to set the transmitter to display the volume of water in the column.

Table 13. Setting the transmitter to display the volume of water.

Path	Parameter	Value
Setup -> Advanced setup -> Linearization	Linearization type	Linear
Setup -> Advanced setup -> Linearization	Unit after linearization	L or gal
Setup -> Advanced setup -> Linearization	Maximum value	24 l or 6.31 gal

44. The transmitter displays the volume of water in the column in the desired unit. With this setting, the volume of water in the column is 0 L (0 gal) at 0% of the span and 24 L (6.31 gal) at 100% of the span.
45. Fill the column with water and verify that at 100% of the span, the transmitter displays a volume of 24 L (6.31 gal) and that at 0% of the span, it displays a volume of 0 L (0 gal).

Making a new mapping

As detailed in the discussion section, adding a mapping to the setup of the transmitter may help to get rid of unwanted echo signals. Sometimes, mapping the column all the way to the bottom is not the best way to proceed. Moreover, for vessels without objects interfering with the transmitter signal, using a mapping may be more a nuisance than an advantage. This section explains how to delete an existing mapping and make a new one. To perfect your knowledge of mapping, it is recommended that you try different mapping distances, observe the resulting mapping curves, and try to understand how mapping works.

Before recording a new mapping it is essential to erase the existing mapping when the option is available. The procedure to make a new mapping differs slightly depending if you are using a radar level transmitter or a guided-radar level transmitter. Both procedures are resumed below.

Making a new mapping with the radar level transmitter

46. To proceed to the mapping, select *manual map* from the *Confirm distance* field in the *Setup* menu.

47. Using Table 14, set the mapping with the suggested parameters.

Table 14. Mapping setting for model 46931.

Function	Setting
Confirm distance	Manual map
Mapping end point	0.76 m (30 in)
Start mapping	On

Making a new mapping with the guided-radar level transmitter

48. To erase the existing mapping, select *delete map* from the *Confirm distance* field in the *Setup* menu.



This option is not available for the radar level transmitter.

49. To proceed to the mapping, select *manual map* from the *Confirm distance* field in the *Setup* menu.

50. Using Table 15, set the mapping with the suggested parameters.

Table 15. Mapping setting for model 46932.

Function	Setting
Confirm distance	Manual map
Mapping end point	1.03 m (43 in)
Record map	Yes

CONCLUSION

In this exercise you have learned how to commission a radar level transmitter for use on Instrumentation and Process Control system. You learned the principles of echo detection and the use of a filter mapping.

REVIEW QUESTIONS

1. Describe briefly the principle of operation of a radar level sensor.

A radar level sensor emits wave packets of microwaves and infers the level from the time it takes for the wave packets to bounce on the surface of the fluid (or solid) and return to the sensor. This method is called the time-of-flight method.

2. Which of the horn-antenna radar level transmitter or the guided-radar level transmitter is more suitable when the measured substance is corrosive?

Horn-antenna radar level transmitter

3. Give one advantage and one disadvantage of radar level transmitters:

Many answers are possible. Here are a few suggestions:

Advantages

- They have no moving parts, which reduces the maintenance costs
- They are not sensitive to temperature or density changes, turbulences, and vibrations
- They are available as non-contact sensors
- Guided-radar level sensors are suitable for interface measurement
- They are reliable and accurate
- They can measure level in very deep tanks, up to 60 meters (200 feet)

Disadvantages

- Radar level sensors depend on the quality of the echo and object inside or outside the tank may interfere with the measurement
- They depend on the dielectric constant of the measured substance
- Close to the mounting flange, the sensor cannot measure the level accurately or at all

4. What is an echo envelope curve?

The echo envelope curve is a recording of the relative intensity of the microwaves returning to the emitter as a function of the distance traveled by the microwaves before being reflected.

5. What is the mapping and what effects does it have on the measurement of the level inside a vessel?

The mapping is a curve approximating the echo envelope curve (usually for an empty vessel) but slightly above it. It acts as a filter which ignores any signal weaker than the mapping when determining the echo peak, thus avoiding known obstacles and improving the reliability of the measurements.