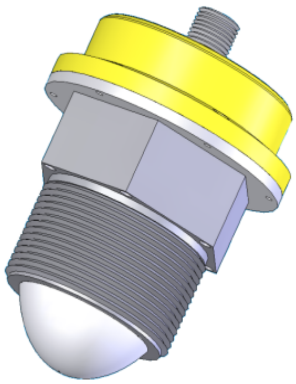
ARIAN
CONTROL & INSTRUMENTATION



FIR60

60Ghz Non-Contact Radar Level Sensor for liquids and solids.

Operating instructions.

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Sensor Description

The FIR60 sensor is a compact device for non-contact level measurement in liquids and bulk solids. Uses a 60 GHz radio signal emitted in short bursts in order to find distances by wave time of travel.

Parts in contact with the fluid are made in stainless steel SS316L and PTFE (Polytetrafluoroethylene) while PP (Polypropylene) is used for the external housing, making it suitable for use in aggressive environments and hygienic conditions.

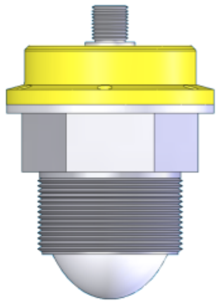
In many cases is possible to measure through a transparent interface such as a glass or plastic window. This way a complete isolation from the fluid is obtained.

Measured level may be converted to volume or fluid flow rate using internal programmable tables and formulas included in the sensor.

Avaliable in versions for 4-20ma output and for RS485 modbus RTU communications.

The sensor is configured by means of provided software (RPS2) running Windows or Linux OS using a Android smart phone as interconnecting device.

A graphical configuration tool helps sensor setting showing reflections intensity in real time.



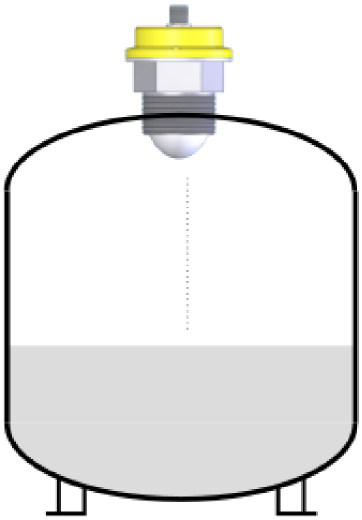
Advantages

- Non-contact level measure on corrosive liquids.
- Suitable for hygienic requirements.
- Maintenance free.
- Graphical configuration set-up tool.
- BLE Android Smart phone communication.
- Volume estimation from internal programmable tables.
- Flumes Flow rate formulas.

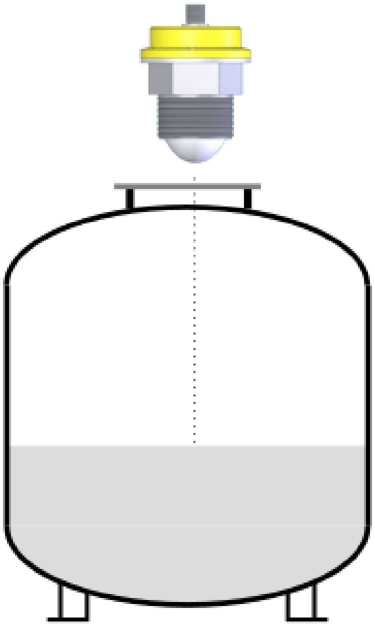
Technical Specifications

Applications	Liquid and bulk solids level measurement. Aggressive liquids. Liquids with hygienic requirements. Flow rate in open channel flumes. Parshall and Palmer-Bowlus.	
Measurement	Range	0... 6m
	Accuracy	+/- 5mm
Beam	Angular divergence	7 degree
	Frequency	60GHz
	Power	10dbm max (10mW)
Process	Fitting	1 ½ NPT
	Temperature	-30C ... 65C
	Pressure	-1… 2 bar
Enclosure	Wetted parts, antenna	PTFE, SS316L steel
	Housing	PET, Polypropylene (optional)
Power Supply	Voltage	12… 28 VDC
	Current consumption	60ma
	Electrical connector	Male M12 A-code 4 pin
Outputs	-420	4..20ma (range 0… 21.7ma) 800 ohms max at 24Vdc supply.
	-RS485	Isolated RS485 modbus RTU

Installation and mounting.



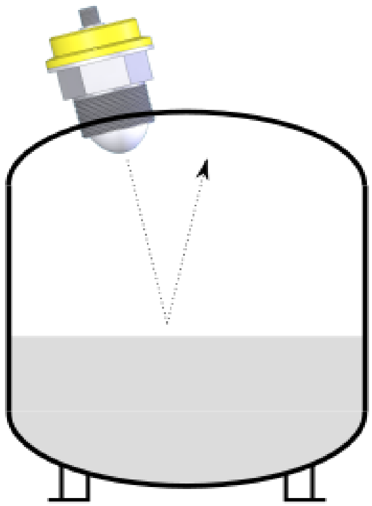
Best place for mounting should be the top center of the vessel, through a 1 ½ NPT thread connection.



The sensor can also placed in the vessel exterior.

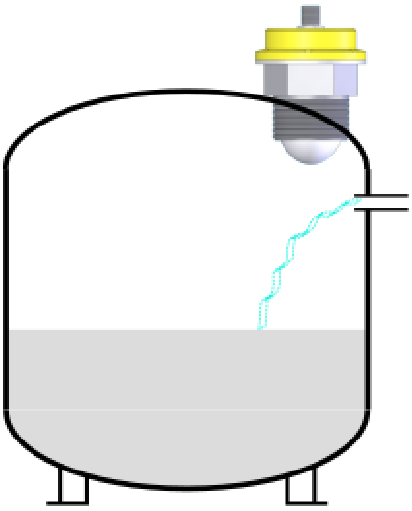
Microwaves can pass through glass, plastics and other non conductive dielectric materials.

Optimal for corrosive quemicals or hygienic vessels.



Incorrect mounting

The sensor must be pointing in straight angle (90 degrees) to the surface plane in order to receive a maximum reflected signal intensity.
In this case reflected signal is not returning back to the sensor.



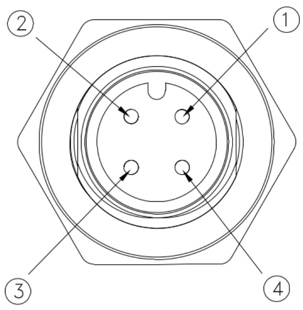
Incorrect mounting

The beam must be apart from the vessel inner walls to avoid internal reflections that could interfere measurement.

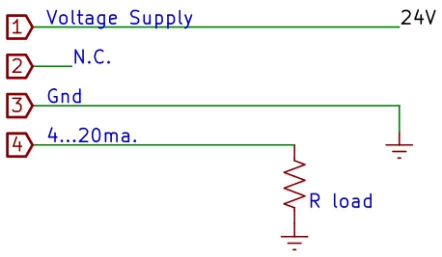
Also take care no fluid inlet (e.g filling inlet) is in the beam route.

Electrical Connections.

The top connector contains the electrical signals as described:



Top View
Male M12 A-code 4 pin



Version -420, with 4..20ma output

1	Vcc	Voltage Supply 12...28VDC
2	NC	No connection
3	Gnd	Gnd Common for Vcc, Iout
4	Iout	4..20ma Output

Version -RS485, with modbus RTU output

1	Vcc	Voltage Supply 12...28VDC
2	A	RS485 line A, Galvanic isolated from Vcc and Gnd.
3	Gnd	Gnd Common for Vcc, Iout
4	B	RS485 line B, Galvanic isolated from Vcc and Gnd.

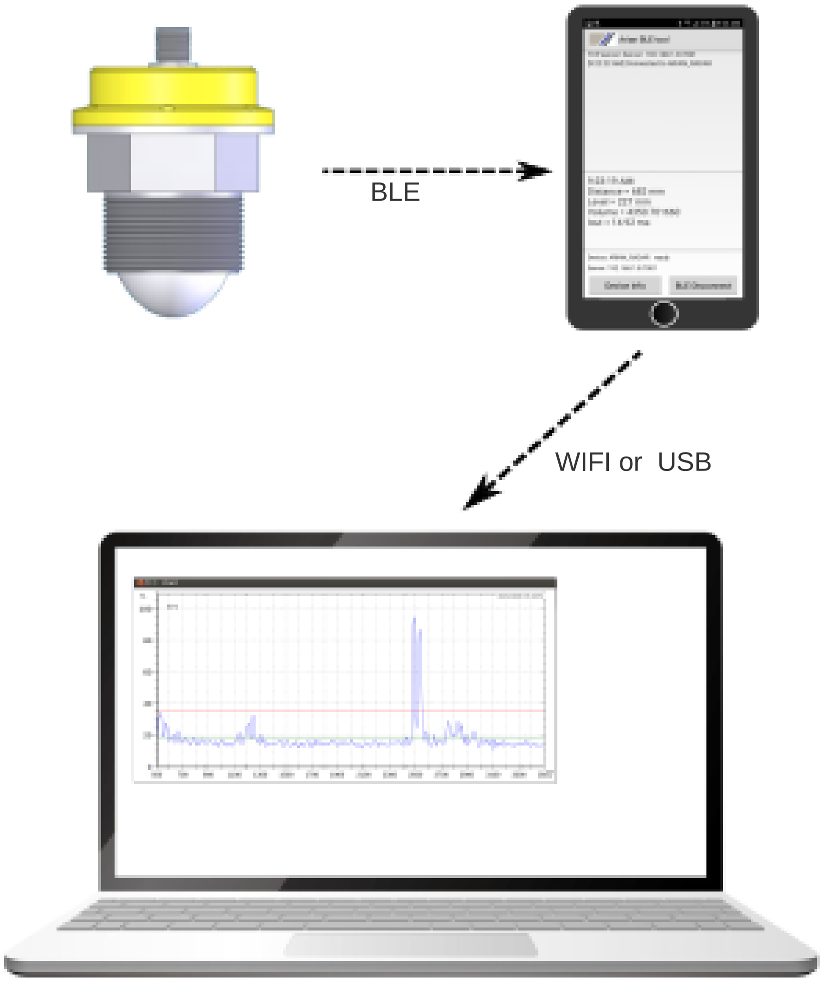
Connecting to Sensor

The sensor connects via BLE (Bluetooth Low Energy) to a Android smart phone running the “BLE_tool” Application.

The Android smart phone is connected to personal computer where RPS software is running. This connection can be done by WIFI or a USB cable.

The computer must be a Windows 10 computer running the RPS2 software configuration tool for parameters set up.

This way it is possible use the PC to set parameters, view real time sensor variables, save and load parameters configurations.

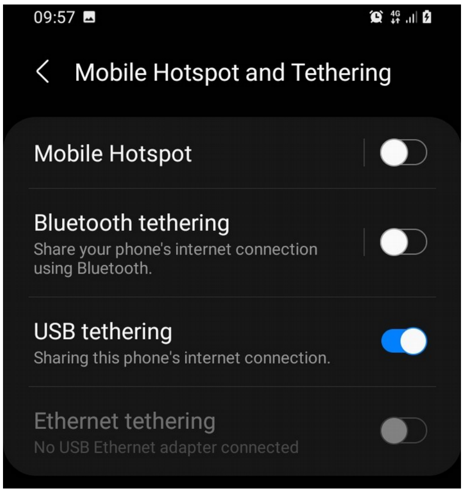


Smart phone to PC Communication

The PC communicates to the smart phone in one of this 3 alternatives ways:

USB

Prefered option.
Connect the smart phone to the pc with a USB cable.



Set up:

Settings → Connections → Mobile Hot spot and Tethering → USB-Tethering.

WIFI

Both smart phone and PC are connected to a WIFI router in the same local area network (LAN).

WIFI Hot Spot

Use your smart phone as WIFI hot spot to connect your PC as client.
Smart phone set up is found in:

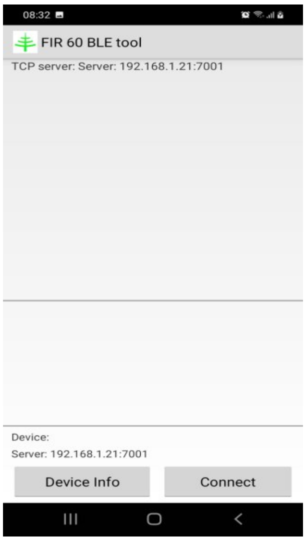
→ Settings → Connections → Mobile Hot spot and Tethering
→ Mobile Hot spot

Sensor to Smart phone Communication

Download the Android smart phone App from:
www.arian.cl/radar/FIR60_BLE_BRIDGE.apk

Install the downloaded App on the smart phone.
Launch it with sensor energized and placed at a close distance (eg. 5m or less).

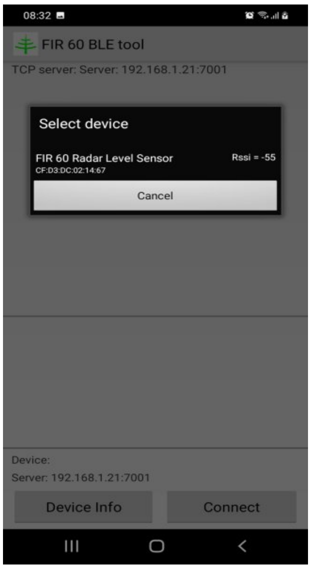
The App starts a data server with the actual smart phone IP address and port 7001.



The server address appears in the bottom line. In this example is:

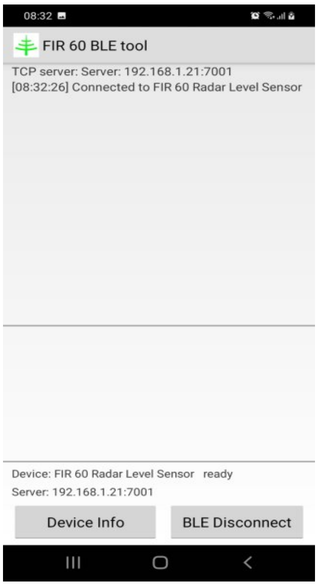
Server: 192.168.1.21:7001

IMPORTANT:
Make sure that the smart phone is communicating with the PC before you start the App, other way it will not show the server address.



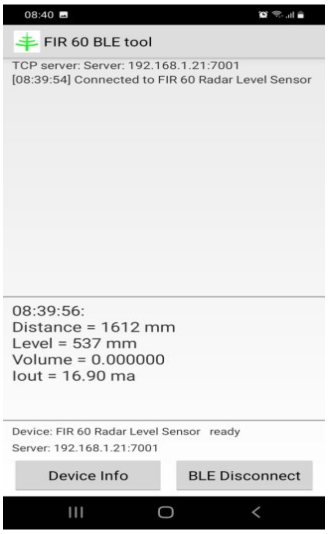
Press the “Connect” button on the app to see the available BLE devices around.

Select the “FIR 60 Radar” device to connect to it to the smart phone.



Now the smart phone should be BLE connected to the sensor and the bottom line reads:

"Device: FIR 60 Radar Level Sensor ready"



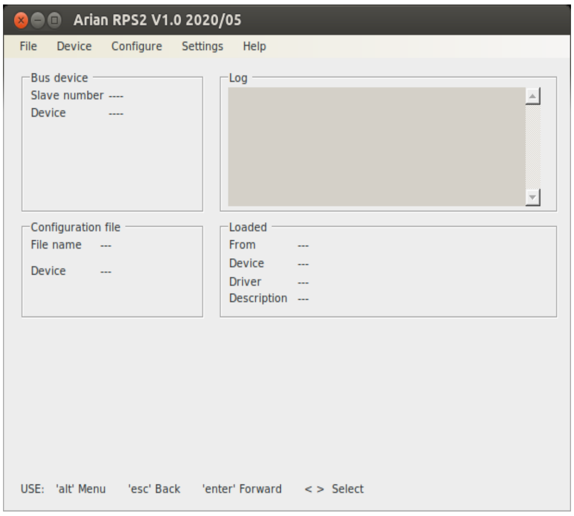
By pressing the "Device Info" button the app will report actual internal variables from the radar.

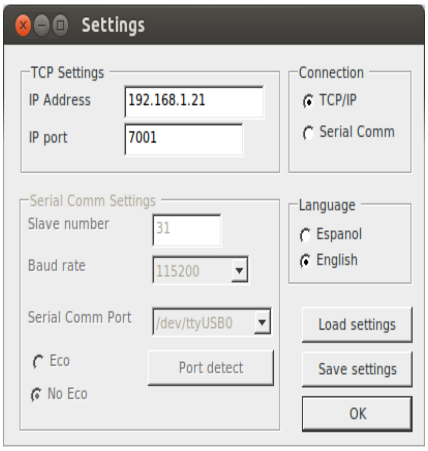
Configuring with the PC

Download the Windows RPS2 software from www.arian.cl/radar/rps2.zip

Uncompress the file in any folder of your PC .
The software doesn't need to be installed and will not modify the Windows Registry.
To remove it just delete the folder containing it.

Launch it by a double click the file rps2.exe.





Press “Settings” menu and select the following:

Connection:	TCP/IP
IP port:	7001

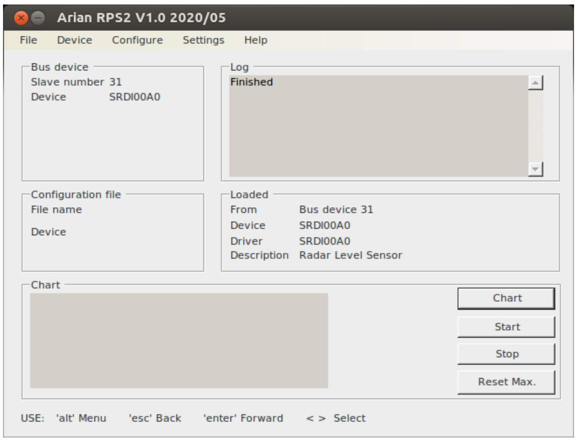
You must provide the IP server address given by the smart phone App.

IP Address:	192.168.1.8

Leave other parameters as shown.
Press “Save settings” and “OK” to close.

Parameters Configuration

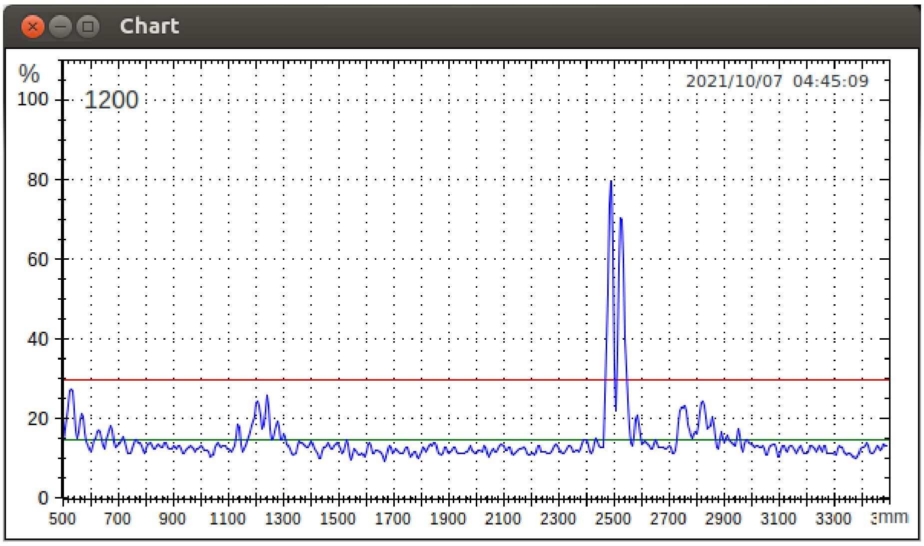
Press “Device” → “Read” to read the actual working configuration.
If all goes well, should detect and read a device type “SRDI0003” or similar.
Now the sensor parameters can be configured.



The “Chart” tool describes reflections intensity received by the radar, this helps understanding what is happening during the measurement.

Start the chart pressing the “Chart” button and then “Start” button, a chart plot will appear. The horizontal axis is distance (mm) from the radar and vertical axis is the received signal intensity.

For example you may see 2 close peaks near 2500mm that could be caused by reflections on some foam formed over the liquid surface and the main reflection on the surface. You may select which level you will want to measure, the first (foam) or the second (surface).



The vertical scale is expressed in % of the maximum intensity received since the chart started.

For the example the maximum intensity was 1200 and is shown close to text “100%”. The maximum can be reset using the “Reset Max.” button.

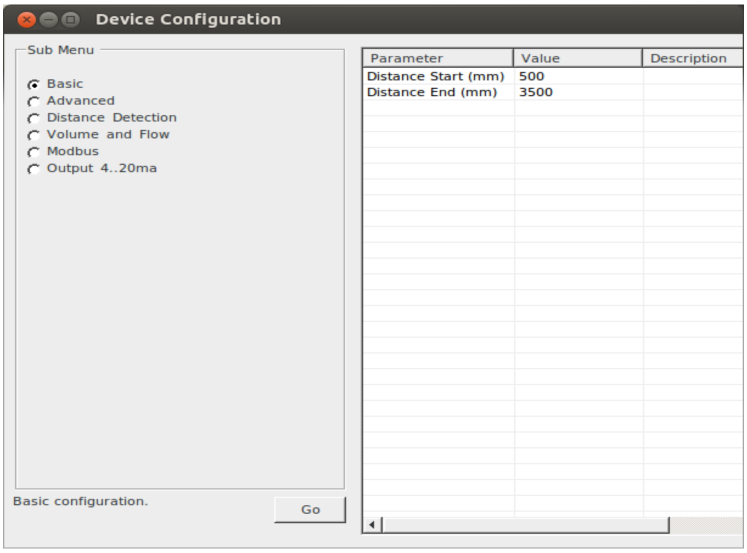
The charts horizontal green line is the received signal intensity media calculated over the receiving range (eg. 500 to 3500mm).

The red line is used to select the zones of the chart on which intensity peaks will be considered.
Any peak under the red line is not considered.
One maximum peak is registered for each contiguous zone above the red line.

Sensor Parameters

Parameters set up is done with the “Configure” menu where are modified and later downloaded to the FIR 60 device with “Device” → “Write” command.

The configuration menu is divided in several sections or sub menus



Select the sub-menu and press ”Go” button to enter.

Basic Menu

Distance Start (mm):

Starting distance in millimeters for measurement.
Set some distance to avoid reflections from targets close to the sensor.
In the example chart is set to 500mm.

Type:	Integer (mm)
Range:	250... 6000

Distance End (mm):

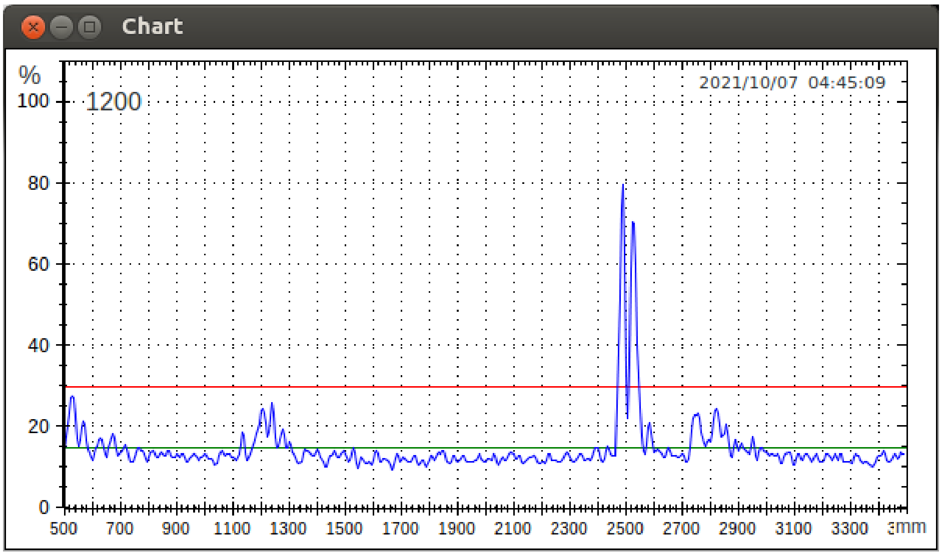
Ending distance in millimeters for measurement.
In the example chart is set to 3500m so the radar will detect targets between 500 and 3500 mm.

Type:	Integer (mm)
Range:	250... 6000

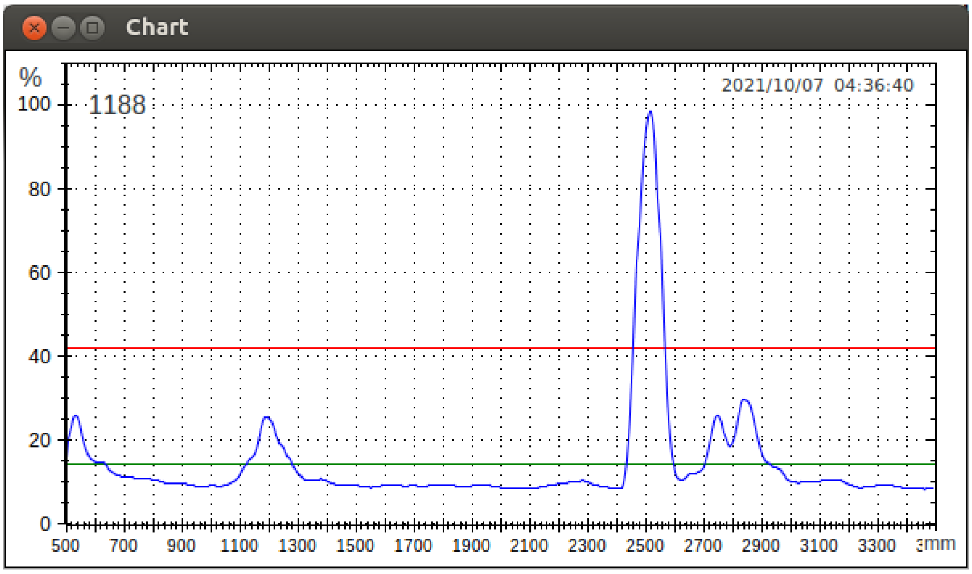
Advanced Menu

This sub menu contains advanced parameter that normally will be kept on the default values, you don't need to modify it unless special conditions.

Radar Beam Length
The 3 options [Short, Medium, Long] adjust the transmitted pulse time duration.
A short pulse can resolve 2 adjacent targets as 2 different peaks while a larger pulse time will show one single peak "fusing" the 2 targets.
A short time pulse resolve better but sends less energy so a large pulse is better on less reflective materials.
The following charts with the same conditions, "Short " was used in the first and "Medium" in the second where 2 adjacent peaks are seen as one. Recommended default value is "Medium"



Radar Beam Length, option "Short"



Radar Beam Length, option "Long"

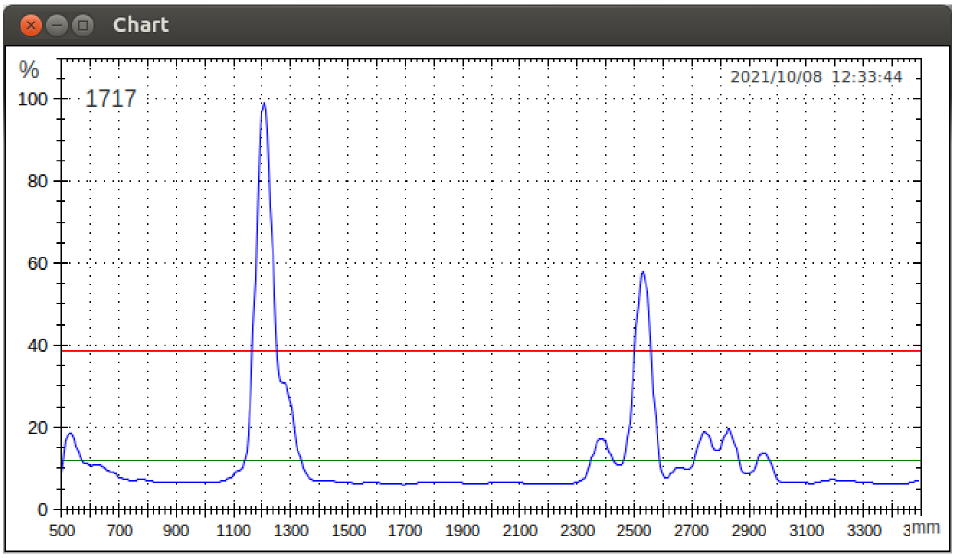
Radar Beam Length:		
	Time length of the emitted microwave beam.	
	Options:	Short Beam Medium Beam (default) Long Beam
Iterations Number:		
	This is the number of sub-measurements that the radar will do to give a single measurement from the results media . A measurement cycle is initiated each 4 seconds if previous measure has ended. Sub-measurements take about 0.2 seconds each, so a larger number implies a longer but more reliable measurement.	
	Type:	Integer
	Range:	1... 100
	Default:	16
Receiver Gain:		
	The radar receiver gain is a number from 0 to 100 where 100 is full gain. Full gain is not always useful since will amplify background noise as well as the radar reflection. What we need is to identify peaks from the base noise level.	
	Type:	integer
	Range:	0... 100
	Default:	50

Distance Detection

In this sub menu is set the way the measured distance will be determined.

Having the “distance” then “level” is calculated and with it we can obtain the vessel “volume” using internal tables or “flow rate” for a flume.

Distance measured is obtained from intensity peaks.
Peaks are defined as the distance for the maximum received intensity within a contiguous zone above the red line threshold.



In this chart are found 2 zones above the red line. First one the closest to the radar haves the peak at 1200mm and the other at 2520mm on the zone defined from 2500mm to 2550 where intensity is larger than the red line threshold.

If several zones are found, each with its local peak, you will have to choose the criteria for determining the “distance” process viariable chosing from the highest, nearest or second nearest peak.

Peak Detect:

Criteria for selecting the peak that represents the distance

Highest	The highest, no matter if it is the nearest or farthest
1st Nearest	The nearest, no matter if it is lower in intensity than the others. This could be useful for example if you want to measure foam level.
2nd Nearest	Not the nearest, but next one and no matter its intensity. For example use in case you have a peak from the foam but you need the surface level.

The threshold level shown as a horizontal red line and used do define zones is determined by the following formula where the parameter K will be set by user:

$$Red\ line\ level = <I> + K*\sigma(I)$$

$$<I> = Signal\,intensity\ media$$

$$\sigma(I) = Standard\,desviation = \sqrt{\langle (I - \langle I \rangle)^2 \rangle}$$

The standard deviation is the media of the square of (I - <I>).

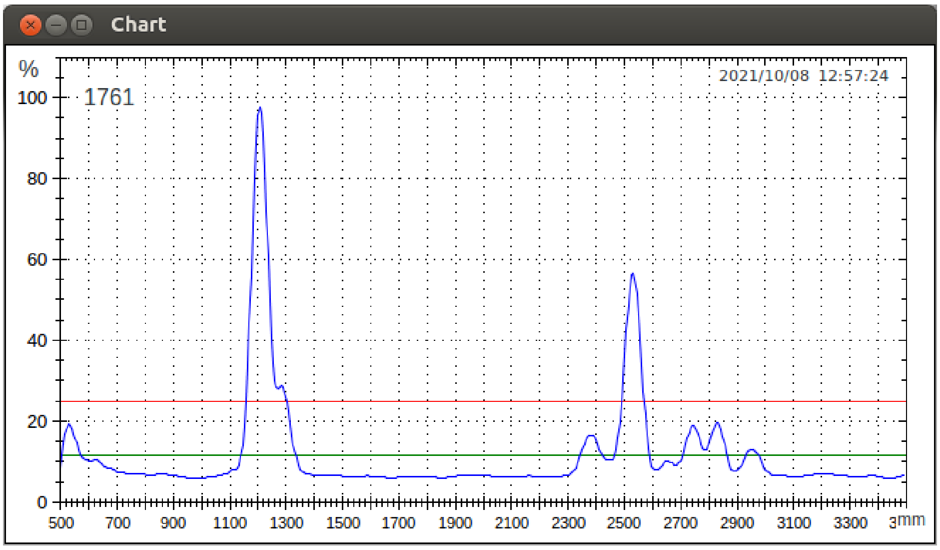
For example if Intensity is nearly flat, then $\sigma(I)$ tends to zero.

In the opposite case if the there are a lot of peaks and noise, then $\sigma(I)$ will be a large number.

The constant K is a positive parameter to be set in order to rise or lower the red line.

This way if the environment goes to be more noise, the red line raises dynamically to compensate.

For example in the previous chart was set K= 2, but in the following one K=1, the only difference is the red line threshold level change.



K Coefficient for Standard Deviation:

Constant to be used on defining the zone threshold level.
Larger number rises the threshold (red line on chart)

Type:	float
Range:	0.1 ... 10
Default:	3 , but must be estimated from chart information.

Distance A:

Once the "distance" from the radar is obtained, it must be scaled to the "level" .
In general distance is not the same as level, a large distance implies a low level (empty vessel)
Two different distance points A and B corresponds each to levels A and B (Refer to the image) .
The following parameters for levels and distances are all in mm.

Type:	Integer (mm)
Range:	0... 32000

Level A:

As explained previously

Type:	Integer (mm)
Range:	-32000... 32000

Distance B:

As explained previously

Type:	Integer (mm)
Range:	0... 32000

Level B:

As explained previously

Type:	Integer (mm)
Range:	-32000... 32000

Default Distance:

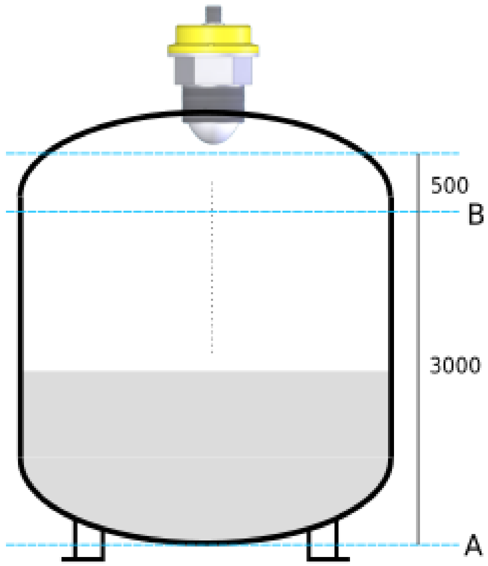
Default value for the distance if for any reason could not be determined. This helps to avoid that an error will be passed to the level, flow, volume calculations.

Type:	Integer (mm)
Range:	0... 32000
Default:	32000

Distance Change Maximum Speed:

This is the maximum change speed for the distance measurement. If for some faulty reason the beam is interrupted and a wrong distance is measured making a large distance change between consecutive measurements, then this last measure will be ignored. The parameter is the threshold in [mm/seconds] for accepting a new distance.
Under normal conditions vessels fill and empty slowly so set a large number to disable the option.

Type:	Integer (mm/sec)
Range:	0... 32000
Default:	32000



Distance is measured from the radar at the top to the target (liquid level)
For example:

Distance B = 500mm,
Level B = 3000mm

Distance A = 3500mm,
Level A = 0

Volume and Flow

Process Type:

Select the post processing type to be done with measured level.

Off	None.
Volume	Calculates actual vessel volume.
Flow Rate	Open Channel Flow Rate with Parshall, Palmer Bowlus and custom flumes.

Flow Rate

The radar can be used as flow meter for open channel devices such as Parshall and Palmer-Bowlus flumes typicaly deployed for measurement of irrigation flows, water rights apportionment and flow of sewage. Design of this flumes is described on standard documents allowing a economical construction with reliable results.
Instantaneous flow rate (eg. cubic Feet/second) is obtained from the water level height in the channel measured.

IMPORTANT:
Formulas for flumes need to have level in mm, please take care it is correctly scaled.
Flow rate will be zero for negative level values.

Flume Type:

Parshall	Flow rate is calculated using norm: ASTM D1941-91 (Re-approved 2013) "Standard Test Method for Open Channel Flow Measurement of Water with the Parshall Flume"
Palmer Bowles	Palmer Bowles and custom flumes.

Flume Size:

Select the standard Parshall flume size (inch) from list:

[1, 2, 3, 6, 9, 12, 18, 24 , 36, 48, 60, 72, 84, 96, 120, 144, 228, 240, 300, 360, 480, 600]

Flow Volume Units:

Select from the list the volume units for the flow rate.

[Custom, Cubic meter, Liter, Cubic Foot, US Gallon, Barrel]

Flow Volume Custom Constant:

If you select custom units, a conversion constant will be asked.
Must be a number that tells how much of your custom unit is equivalent to 1m3.
For example if your custom unit is liters then: constant = 1000

Type:	float
Range:	-1e8... 1e8

Flow Rate Time Units:

Select from the list the time units for the flow rate.
For example you selected (“volume units” = liters) and (“time units” = seconds) , then flow rate will be expressed in liter/second.

Options: [Seconds, Minutes, Hour, Day]

If Flume Type = “Palmer Bowles and custom flumes.” was selected, then you will need to provide the constants C and Exp for this formula:

$$Q = C * h^{\mathrm{Exp}}$$

Where
Q = Calculated flow rate in m3/Second
h = level in mm.

If h < 0 then Q returned will be 0.

For example a typical Palmer-Bowlus 8” flume will have:
C = 20.2407
Exp = 1.9

Custom Discharge Coefficient [C]

Type:	float
Range:	0... 1e6

Custom Exponent [Exp]

Type:	float
Range:	0… 5

C and Exp must be specified in order to have the calculated flow rate Q in m3/sec then later you can change volume and time units as in the Parshall flume options case.

Volume Estimation

Actual volume from measured level can be obtained from two types of tables containing:

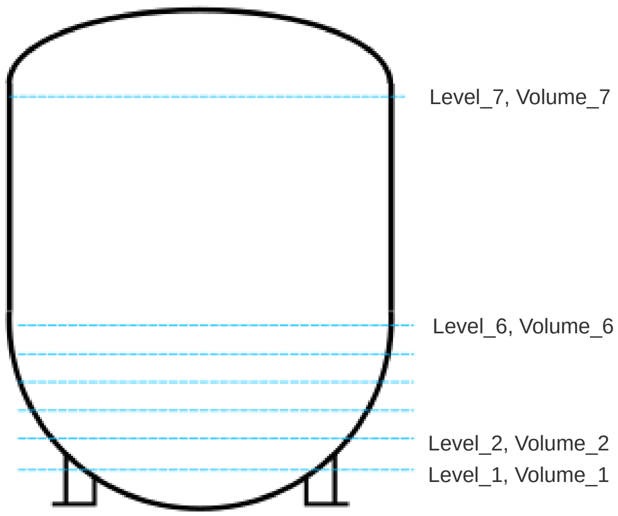
Volumes at different levels.

Transverse section area at different levels.

Of course this tables can also be used to linearize any other process value such as flow rate on non standard flumes.

Volumetric table case

A volumetric table will describe vessel capacity with [level n, volume n] pairs containing increasing levels and volume up to each level.



This example vessel is composed from a 60cm radius half spherical bottom part and a 120cm radius cylindrical upper part .

Is not necessary to have more points for the cylindrical section (or any constant traverse area section) only are needed 2 points one at the beginning and the other at the end of the cylindrical section, in this case points 6 , 7 .

On the opposite the lower part where traverse area changes rapidly with height is better to have more pairs for good accuracy.

The 7 points for the vessel where found are:

	Level (mm)	Volume (m3)
1	100	0.01780
2	200	0.06702
3	300	0.14137
4	400	0.23457
5	500	0.34033
6	600	0.45238
7	1600	1.58336

IMPORTANT
For each level point, the volume is the total under that point.
Points must be in increasing level order and with increasing volume always.
Levels must be integers in (mm)
Volumes float real numbers in (m3)

The points must be introduced in the sub-menu, first all the 1.. 7 levels an then the 1… 7 volumes., giving a sub-menu like this:

Parameter	Value	Description
Process Type	Tank Volume	Tank Volume Estimation
Table Type	Volumetric	
Number of Points	7	
Level_1	100	
Level_2	200	
Level_3	300	
Level_4	400	
Level_5	500	
Level_6	600	
Level_7	1600	
Volume_Area_1	0.0178	
Volume_Area_2	0.06702	
Volume_Area_3	0.14137	
Volume_Area_4	0.23457	
Volume_Area_5	0.34033	
Volume_Area_6	0.45238	
Volume_Area_7	1.58336	
Volume Units	Cubic meter	= 1 m3

The table volume units must be always given in m3 but you can change the units for the estimation on the last menu parameter “Volume Units” .

Table Type:

Select the table type for volume estimation.

Volumetric	A table with up to 16 pairs of (level, volume) points that describe the capacity of the vessel.
Transverse Area	The table contains levels and transverse section areas for each level. Uses shape information (conical, rectangular, etc)

Number of Points:

The number of points for the table

Type:	Integer
Range:	2... 16

Level_n:

The n'the level in mm

Type:	Integer (mm)
Range:	-30000... 30000

Volume_n

The n'th volume in m3

Type:	Float (m3)
Range:	0... 1e6

Volume Units

Select from the list the volume units for the resulting volume estimation.

Options:
[Custom, Cubic meter, Liter, Cubic Foot, US Gallon, Barrel]

Volume Custom Constant

If you select custom units, a conversion constant will be asked.
Must be a number that tells how much of your custom unit is equivalent to 1m3.
For example if your custom unit are liters then: constant = 1000

Type:	float
Range:	-1e8... 1e8

Transverse area tables

In this case the vessel is characterized using the transverse section area at each level and also information about the shape of the section between points.
Transverse area in some cases can be easily measured

Sections shape must be specified in one of this 3 categories:

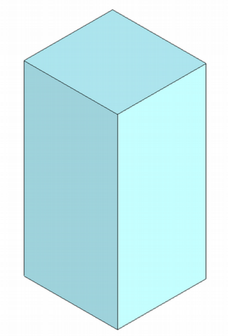
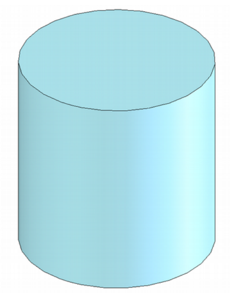
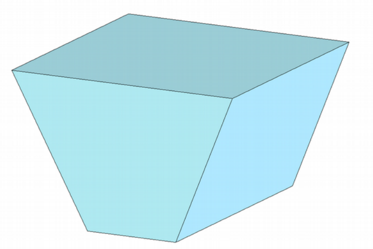
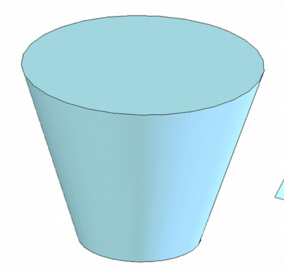
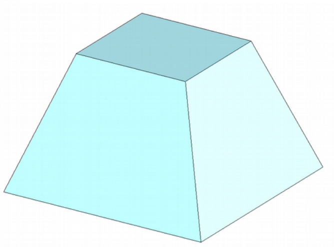
Cylindrical Cylinders with circular or rectangular sections. Anything shape where transverse area does not change with height. Volume = k * height	 
Trapezoidal They have 2 parallel sides The transverse area increases or decreases linearly with height and volume is proportional to (height)^2.	
Conical Cones or Pyramids The transverse area increases or decreases with the square of height and volume is proportional to (height)^3	 

Table points are defined by:

Level	The height or level in mm.
Area	The transverse area at this level in m2.
Type	Type of section starting above this level.

Points must be specified where there is a change in geometry e.g. changes in the section type.

Table Type:

Select the table type for volume estimation.

Volumetric	A table with up to 16 pairs of (level, volume) points that describe the capacity of the vessel.
Transverse Area	The table contains levels and transverse areas for each level. Uses shape information (conical, rectangular, etc)

Number of Points:

The number of points for the table

Type:	Integer
Range:	2... 16

The following 3 parameter are asked n times depending on the number of points

Section_Type_n:	The shape for the section defined above this level.	
	Options:	[Cylindrical, Trapezoidal, Conical]
Level_n:	The n'th level in mm	
	Type:	Integer (mm)
	Range:	-30000... 30000
Area_n	The n'th Area in m2	
	Type:	Float (m2)
	Range:	0... 1e6

Volume Units

Select from the list the volume units for the resulting volume estimation.
Options:
[Custom, Cubic meter, Liter, Cubic Foot, US Gallon, Barrel]

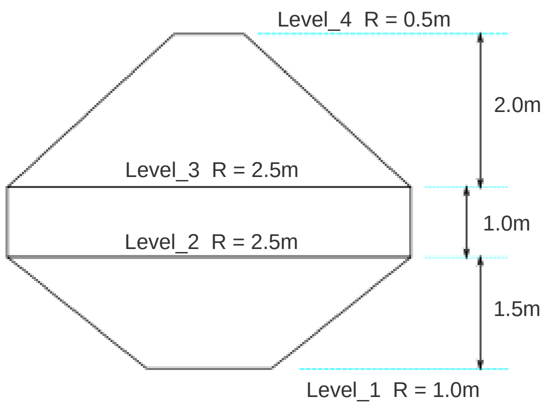
Volume Custom Constant:

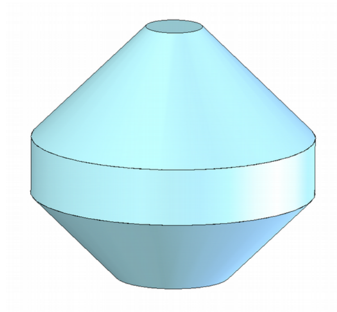
If you select custom units, a conversion constant will be asked.
Must be a number that tells how much of your custom unit is equivalent to 1m3.
For example if your custom unit is liters then: constant = 1000

Type:	float
Range:	-1e8... 1e8

Example_1

This vessel is composed with 3 elements, 2 cones and a cylinder in the middle





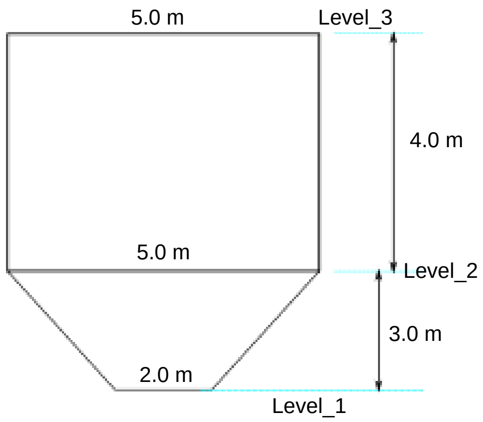
	Level (mm)	Area (m2) = pi*R^2	Section Type
1	0	3.141592	Conical
2	1500	19.63495	Cylindrical
3	2500	19.63495	Conical
4	4500	0.7853	-

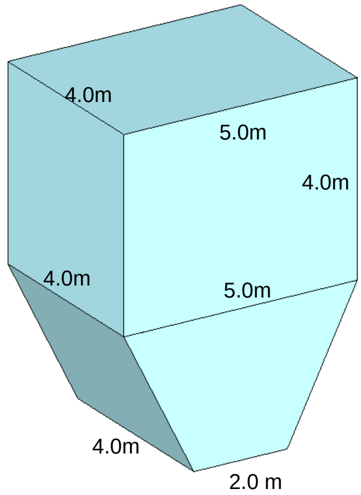
The last section type (Section_Type_4) is meaningless since describes the shape above level_4 and there is not vessel there.

Parameter	Value	Description
Process Type	Tank Volume	Tank Volume Estimation
Table Type	Transverse Area	
Number of Points	4	
Section_Type_1	Conical	Transverse Area proportional to height square
Section_Type_2	Cylindrical	Constant transverse area
Section_Type_3	Conical	Transverse Area proportional to height square
Section_Type_4	Cylindrical	Constant transverse area
Level_1	0	
Level_2	1500	
Level_3	2500	
Level_4	4500	
Volume_Area_1	3.141592	
Volume_Area_2	19.63495	
Volume_Area_3	19.63495	
Volume_Area_4	0.7853	
Volume Units	Cubic meter	= 1 m3

Example 2

The following vessel haves 2 parts as described in this images:





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	Level (mm)	Area (m2) = L x W	Section Type
1	0	4 x 2 = 8	Trapezoidal
2	3000	4 x 5 = 20	Cylindrical
3	7000	4 x 5 = 20	-

Parameter	Value	Description
Process Type	Tank Volume	Tank Volume Estimation
Table Type	Transverse Area	
Number of Points	3	
Section_Type_1	Trapezoidal	Transverse Area proportional to height
Section_Type_2	Cylindrical	Constant transverse area
Section_Type_3	Cylindrical	Constant transverse area
Level_1	0	
Level_2	3000	
Level_3	7000	
Volume_Area_1	8	
Volume_Area_2	20	
Volume_Area_3	20	
Volume Units	US gallon	= 3.785 411 784 e-3 m3

Output 4...20ma.

This is the 4.. 20ma current output settings sub menu.

4..20ma Output Variable:

The 4.. 20ma output can be set for any of the following options:

[Distance, Level, Volume, Flow]

Value for 4ma:

The the value of the selected process variable for which the current output will be 4ma. Values below the specified will go down to 2ma.

Type: float

Range: -1e8... 1e8

Value for 20ma:

The the value of the selected process variable for which the current output will be 20ma. Larger values will go up to 21.6ma.

Type: float

Range: -1e8... 1e8

For example the sensor calculates volume from a table for a vessel that will contain 0 to 1000 liters. The unit for volume where specified as liters. It is needed a 4ma out for 0 liters and 20ma for 1000, then:

4..20ma Output Variable:	Volume
Value for 4ma:	0
Value for 20ma:	1000

Modbus RTU Communications

This menu is only available on the FIR60 radar with modbus RTU communications option.

Baud Rate:

Baud rate for serial communications.

Type:	Integer
Range:	[2400, 4800, 9600, 19200, 38400, 57600, 115200]
Default:	115200

Slave number

The modbus RTU slave designated for this device

Type:	Integer
Range:	1... 255
Default:	31

Technical Notes

Material reflectivity

Successful level measurement by radio waves will depend on the reflectivity of the target, in this case the fluid being measured.

Radio waves and light are reflected by the same physical laws. Radio wave reflection occurs in electrical conductive materials (e.g. metal mirror) and also when there is a refractive index change of the media. This second mechanism is the important one for most of the liquid level measurements.

Electrical conductive fluids such as acids, alkalies or ionic solutions (e.g. salt water) are good reflectors and the level measurement is easy. This reflection comes mostly because they contain water and also because they are conductive.

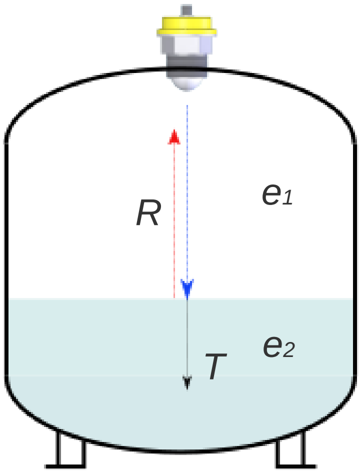
By the other side light is also reflected in a glass windows but in much lower degree.
Glass is not electrical conductive, but reflects because it haves a higher refractive index than air.

The proportion of reflected energy (R) when a wave goes from one media to another with Relative Permittivity e1 and e2 (also known as Dielectric Constant) is described by the formula:

$$R = \frac{\sqrt{e_2} - \sqrt{e_1}}{\sqrt{e_2} + \sqrt{e_1}} = \frac{n_2 - n_1}{n_2 + n_1}$$

$$n_1 = \sqrt{e_1}\ , \quad n_2 = \sqrt{e_2}$$

Where n1 and n2 are the refractive index of each media.
R value is 0 when there is no reflection and 1 in case of total reflection.
T value is the transmitted part of the incident beam that pass in to the e2 media. The transmitivity T = 1 – R is the transmitted not reflected part of the incident beam.



The e1 media is usually air or mostly air with some vapor so e1 = 1 and the formula reduces to :

$$R = \frac{\sqrt{e_2} - 1}{\sqrt{e_2} + 1} = \frac{n_2 - 1}{n_2 + 1}$$

The following table contains the Relative Permittivity "e" for some materials at 60GHz.

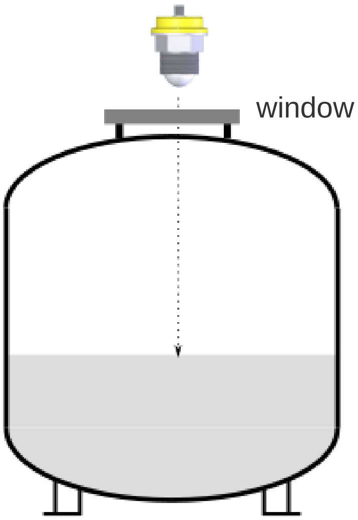
Material	Permittivity e2 at 60GHz	Reflectivity R with e1 = 1
Water	80	0.79
Diesel fuel	2.05	0.18
Ethanol	24.3	0.66
Methanol	32.7	0.7
Sulfuric acid	80… 100	0.79 … 0.81
Ethylene glycol	37	0.71

Is important to note that the "e" value depends on the frequency of the radio signal.
For water for example, e = 80 at 60Ghz, but for visible light e = 1.77 and R= 0.14 , that explains why light is not reflected much in water.

The low R materials are more difficult to measure but can be done with some fine settings on the sensor parameters.
For example the case of diesel fuel R = 0.18, only 18% of the signal is reflected, but that is enough return signal for making a good measurement.

Level measure through a window

In many cases where the fluid is extremely aggressive, explosive or may exist hygienic conditions is desirable to measure the level from the vessel exterior. To do it is needed a transparent (for 60GHz) window that lets pass through it the radio signal.



Following the considerations about reflectivity from last section, in this case we need the opposite, R reflectivity in the vessel window is the lowest possible.

The table suggest some possible materials with low reflectivity R and a high transmitivity (T = 1-R)

Material	Permittivity at 60GHz	Reflectivity with e1 = 1
PTFE	2.1	0.18
Pyrex Glass	3.7.. 10	0.32 … 0.52
Polyethylene	2.25	0.2
Polyimide	3.4	0.3
Polypropylene	2.2 … 2.4	0.19 … 0.22
Polystyrene	2.4 … 2.7	0.22 … 0.24

PTFE is a good choice for pharmaceutical use and polypropylene is used in food industry. Always the selected window material should be free from additives that may produce dielectric loss as the beam pass through. In general white or natural plastics are free from additives. Avoid use black plastics since they may contain conductive carbon black.

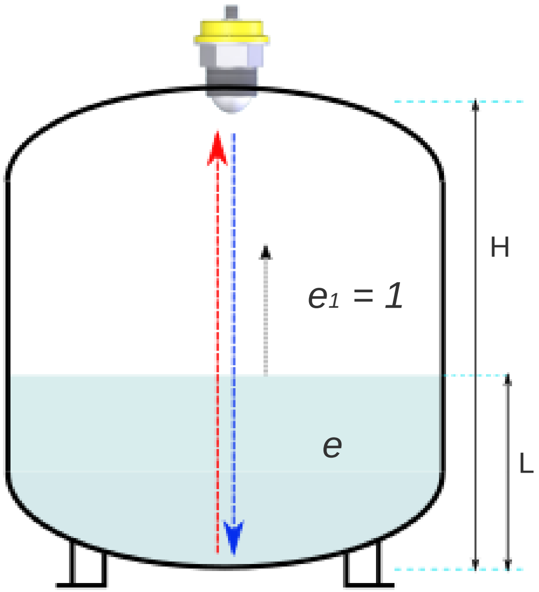
PTFE also have low dielectric loss so you can use a 2 or 3 cm window thickness.

Measuring Low Reflectivity Liquids

In some cases the fluid reflectivity is to much low and the intensity of the returning wave is not enough reliable. But there is a trick to do a reliable level measure in this cases.

If such liquid haves low dielectric losses the radar can detect the returning signal from the bottom of the vessel. The distance of the sensor to the bottom is fixed but the resultant measured distance will be higher.

The explanation of this phenomena is that when the radio signal propagates in a media with higher refractive index (n) , it speed is reduced , the time of transit gets larger and measured distance is larger than the one of the empty vessel.



In the drawing:

H	Real distance from the sensor to the vessel bottom.
L	Actual level being measured.
e	Relative Permittivity of the liquid.

The blue beam is the emitted one that is reflected in the vessel bottom and returns as the red one. The small black beam reflection is the one on the liquid surface.

The sensor will measure a distance D that is larger than H

$$D = (H-L) + n*L$$

Where $n = \sqrt{e}$ is the refractive index of the liquid.
The term $(H-L)$ represent the length that the beam travel on air and $n*L$ the travel on the liquid.

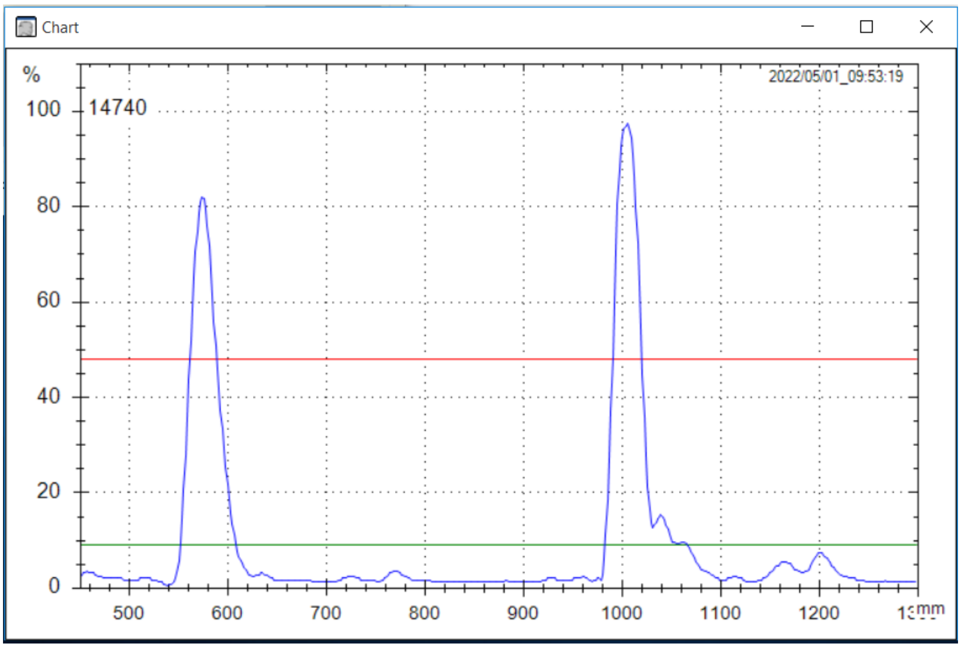
Then:

$$L = \frac{(D-H)}{(n-1)}$$

This formula gives the actual level L using the known distance H and actual measured distance to the bottom vessel.

When the vessel is empty the beam will be always in the e1=1 media so H = D and then L = 0

For example a vessel with diesel fuel is being measured.
In the following image you may see the reflections for this case



The first reflection at aprox 570mm is from the surface and the second at 1001 is from the bottom of the vessel

The refractive index for Diesel fuel is:

$$n = \sqrt{e} = \sqrt{2.05} = 1.432$$

The real measured height of the vessel from bottom to the sensor is H = 870mm.

When the sensor measures a 1001mm distance the actual level of diesel is:

$$L = \frac{(D-B)}{(n-1)} = \frac{(1001-870)}{(1.432-1)} = 303\,mm$$

This result is the expected because from the first reflection in the chart we already know that the level is at 570mm and 870 – 570 = 300 mm.

In order set sensor parameters for this application, first calculate the distance that would be measured when the vessel is full (or at any known level). Suppose the maximum level of diesel fuel is 500 mm.

$$D = (H-L) + n*L = (870-500) + 1.432*500 = 1086$$

Then parameters settings should be:

Peak Detect	Highest or 2nd Nearest, depending of the case
Distance A	870
Level A	0
Distance B	1086
Level B	500

The measured distance will vary 870… 1086 and the resultant level will vary 0… 500