

Introduction

This document introduces the reference design of ICLM human micro-motion detection mmWave sensor XenD101MM, including its basic functions, hardware specification, software configuration, installing condition, etc.

This document aims to guide users to get started with XenD101MM¹ human micro-motion detection solution quickly and easily, so that users can sort out suitable parameters for specified scenarios, and can design both precise and customized human micro-motion detection sensors.

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¹ Due to production batch variance, some products have the screen print of Xen101 D MMS01 or Xen101 D MM01, device map of these products are presented in [Chapter 3](#). This document refers the product as XenD101MM, which is the same with that on the [ICLM website](#).

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1. XenD101MM Overview

The XenD101MM is a human micro-motion detection reference design of ICLM EZ Sensor series. It contains a minimalist 24 GHz radar sensor hardware Xen101 and an intelligent algorithm firmware MM01.

The Xen101 hardware incorporates an AIoT mmWave sensor SoC S3KM1110, high-performance 24 GHz 1T1R antennas, and peripheral circuits. The human detection algorithm MM01 can precisely detect moving, motionless, and relaxed standing human target by adopting the mmWave radar range measurement technology and S3KM1110 specified signal processing technology.

The MM01 firmware is mainly applied to indoors scenarios for detecting moving and motionless human in the specified range, and reporting results in realtime. The XenD101MM can detect moving human target as far as 10 m. It allows users to flexibly adjust the detection range, trigger and hold threshold of each range gate, and absence report delay with the visualization tool. The XenD101MM supports both GPIO and UART interfaces and supports Plug and Play, so it can be applied flexibly in different scenarios and end products.

The main features of the XenD101MM are listed below:

- Integrate single chip smart mmWave sensor SoC and intelligent algorithm firmware
- Minimalist size: 20 mm × 20 mm
- Load default setting of life presence detection, support Plug and Play
- 24 GHz ISM bandwidth, in compliant with FCC, CE, and RC spectrum regulatory requirements
- 3.3 V power supply, support a wide voltage range of 3.0 V~3.6 V
- Average operating current 50 mA
- Detect moving and motionless human body
- Report detection results in realtime
- Provide a visualization tool, support configuring detection range, the sensibility of each range gate, and absence report delay
- Support detection range partition, totally block interference from outside area
- Detect as near as 0.2 m, with no blind area
- Maximum moving human detectable range up to 10 m
- Wide FOV of $\pm 60^\circ$
- Support multiple installation methods: top mounted, wall mounted
- Strong anti-disturbance ability, with trigger detection threshold and hold detection threshold independently configured

The XenD101MM human micro-motion detection sensor can detect moving, relaxed standing, and motionless human body and can be widely applied to various AIoT scenarios, including:

- **Smart Home**
Detect the human presence, report results in real-time, enable the MCU to control smart domestic appliances accordingly.
- **Smart Business**
Detect human approach or leaving in the specified range to turn on/off devices, keep devices on when human presence is detected.
- **Intelligent Security**
Entrance control, building intercom, visual doorbell and so on.
- **Intelligent Lighting**
Detect human body presence and location precisely, applicable to public lighting, various motion-sensor lights, LED bulbs, etc.

2. System Characteristics

The XenD101MM is a human micro-motion detection mmWave sensor reference design developed based on ICLM S3KM1110. It detects human body in the specified range and reports the results in real-time by adopting FMCW and incorporating radar signal processing with the built-in human detection algorithm. With this reference solution, users can develop precise human detection products conveniently.

The Xen101 hardware consists of a fully integrated ICLM smart mmWave sensor SoC S3KM1110, high-performance 24 GHz 1T1R antennas, MCU, and peripheral circuits. Incorporated with the firmware MM01 and a visualization tool, the XenD101MM allows users to flexibly adjust the detection range, trigger and hold threshold of each range gate, and absence report delay for human target detection.

The systematic characteristics of XenD101MM are shown in Table 2-1.

Table 2-1 XenD101MM characteristics

Parameter	Condition	Min.	Typ.	Max.	Unit
Xen101 Hardware					
Supporting frequency	In accordance with FCC, CE, and RC certification standards	24	-	24.25	GHz
Max. bandwidth		-	0.25	-	GHz
Max. EIRP		-	11	-	dBm
Power supply		3.0	3.3	3.6	V
Size		-	20 × 20	-	mm x mm
Environment temperature		-40	-	85	°C
XenD101MM System					
Detection range (wall-mounted)	Moving human target	-	10	-	m
	Motionless human target	-	6	-	m
Detection range (top-mounted)	Moving human target	-	5	-	m
	Motionless human target	-	4	-	m
Accuracy	Moving human target within 10 m in radial direction	-	0.15	-	m
Average operating current		-	50	-	mA
Report Cycle		-	100	-	ms

3. Hardware Overview

Device maps of hardware Xen101 are shown in Figure 3-1. Due to production batch variance, some products have the screen print of Xen101 D MMS01 or Xen101 D MM01, as shown in Figure 3-2.

The Xen101 hardware reserves 5 pins (default without contact pin) called J2 for power supply and communication; J1 pins as SWD interface for MCU programming and debugging.

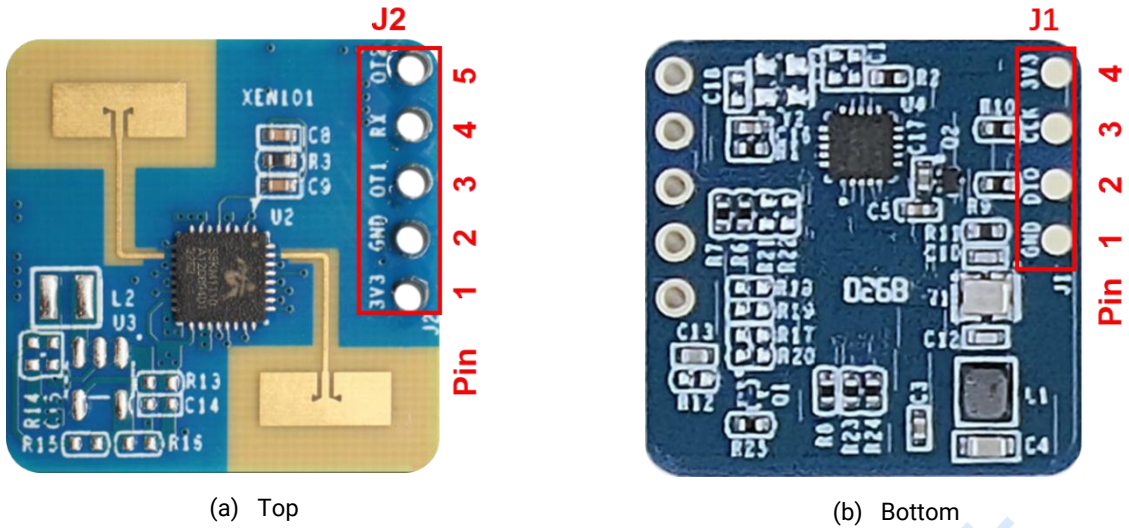


Figure 3-1 Top and bottom device map of hardware Xen101

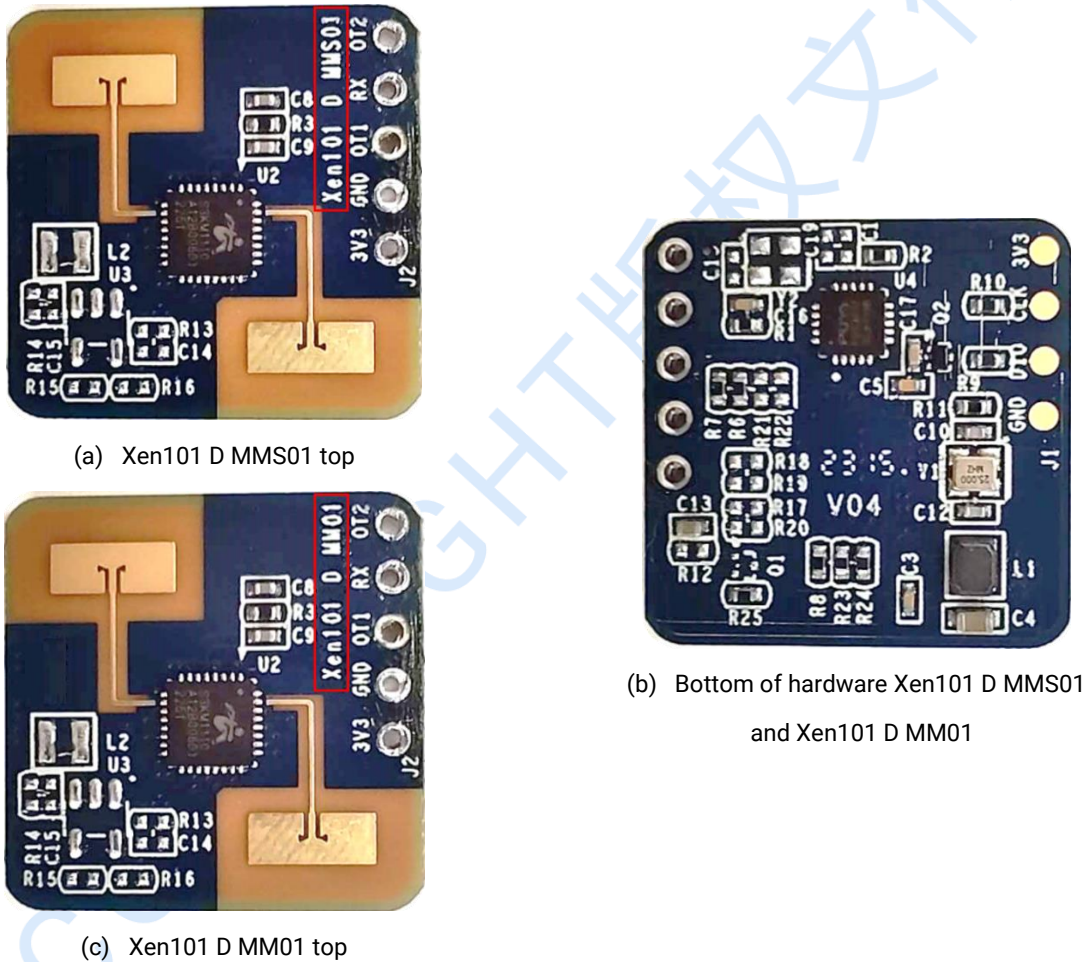


Figure 3-2 Top and bottom device map of hardware Xen101 D MMS01 and Xen101 D MM01

Details of J1 and J2 pins are listed in Table 3-1 and Table 3-2.

Table 3-1 J1 pin description

J#PIN#	Name	Function	Operating Range
J1 Pin1	GND	Ground	-
J1 Pin2	DIO	SWD data port	0~3.3 V
J1 Pin3	CLK	SWD clock signal	0~3.3 V
J1 Pin4	3V3	Power input	1.8 V~3.6 V, Typ. 3.3 V

Table 3-2 J2 pin description

J#PIN#	Name	Function	Operating Range
J2 Pin1	3V3	Power input	3.0 V~3.6 V, Typ. 3.3 V
J2 Pin2	GND	Ground	-
J2 Pin3	O_T1	UART_TX.	0~3.3 V
J2 Pin4	RX	UART_RX	0~3.3 V
J2 Pin5	O_T2	IO, report detection results: high level means a target is detected, low level means no target detected.	0~3.3 V

The XenD101MM supports Keil5 IDE programming. When programming the board, either a hex or a bin firmware file is acceptable. Users can download program using programmers such as J-Link (V9 or later version) and CMSIS-DAP. Ensure the Keil5 IDE has installed [Puya.PY32F0xx_DFP.1.1.0.pack](#).

4. Software Overview

This chapter introduces how to debug XenD101MM firmware, and how to use the visualization tool.

The XenD101MM is released with firmware MM01 programmed into the system, the firmware version is available on the external package of the module. ICLM provides a visualization software tool to configure XenD101MM from a host PC, users can optimize the detection results by adjusting parameters according to the applied scenarios.

4.1 Firmware Description

This section introduces how to debug XenD101MM firmware with a serial port tool.

Step 1: Connect the radar module with the host PC using a USB-TTL serial transfer board; the connection of pins is listed in Table 4-1 and shown in Figure 4-1.

Table 4-1 Mapping pattern of pins

Xen101	USB Serial Board
RX	TXD
O_T2	RXD
3V3	VCCIO
GND	GND

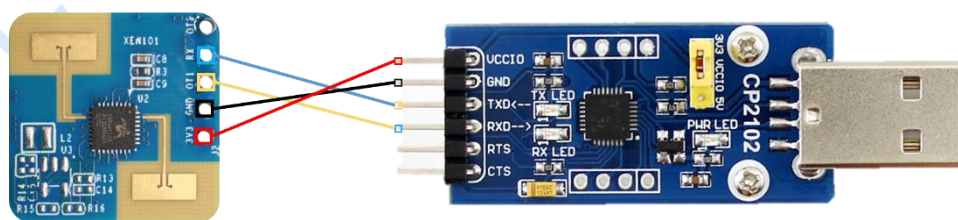


Figure 4-1 Connection between Xen101 hardware and USB serial board

Step 2: Open the **Device Manager** of the host PC, obtain the serial COM number of the radar module.

Step 3: Open the serial port tool, type in the radar serial COM number, set the baud rate as 256000, click the **Open Serial Port** button, then the radar detection results will show up on debugging tool console.

4.2 Visualization Tool Description

This section introduces how to use the visualization tool of XenD101MM, and helps users to understand the meaning of relevant parameters as well as how to determine their values.

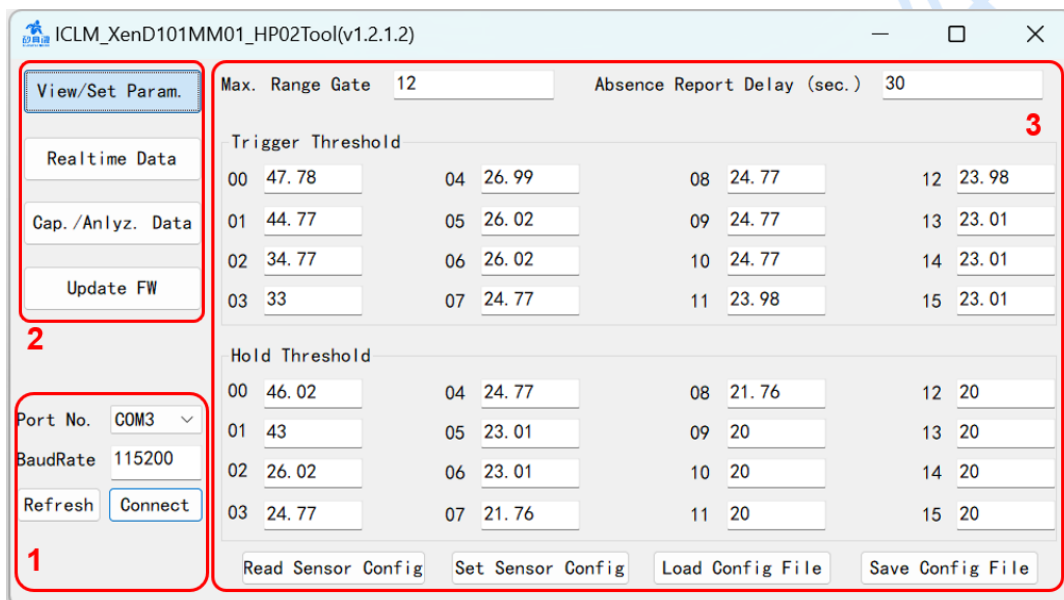
Note: Firmware debugging tool and visualization tool cannot be used at the same time!

Before using the visualization tool, users should first connect the radar module with the visualization tool, the steps are as follows:

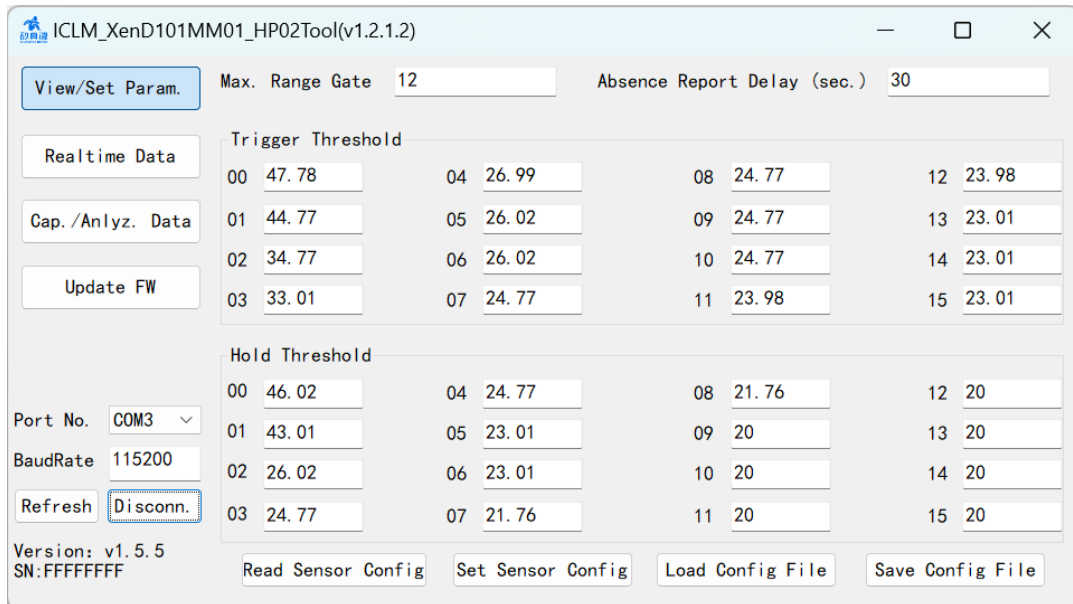
Step 1: Obtain the visualization tool [XenD101MM01_HP02Tool](#) from [ICLM website](#).

Step 2: Connect the XenD101MM module to the host PC according to Figure 4-1.

Step 3: Open the visualization tool, choose the radar module serial COM number, and type in baud rate 256000, click the **Connect Device** button to connect the radar module with the visualization tool.



(a) Before connecting with the radar



(b) After connecting with the radar

Figure 4-2 XenD101MM01_HP02Tool

As shown in Figure 4-2 (a), the GUI (graphic user interface) of XenD101MM01_HP02Tool can be partitioned into 3 zones: device operation (Zone 1), function buttons (Zone 2), and function page (Zone 3).

After connecting the visualization tool with the radar module, Zone 1 will display the radar module's firmware version (presented as "Version: ...") and serial number (presented as "SN: ..."; if the module has not programmed an SN, the visualization tool will display "SN: FFFFFFFF"), and the function page will display all the parameter settings of the radar module, as shown in Figure 4-2 (b).

4.2.1 View/Set Parameters

The View/Set Param. page of the visualization tool is shown in Figure 4-3, it displays the parameter values of the radar module and allows users to modify each parameter for actual scenarios.

The step for reading radar parameters is as follows:

- After connecting the XenD101MM module with the visualization tool, in the function buttons zone, click the **Read Sensor Config** button, a window writing "Succeed reading parameters" will appear, and the function page will display the parameters of the radar, click the **OK** button to close the note window.

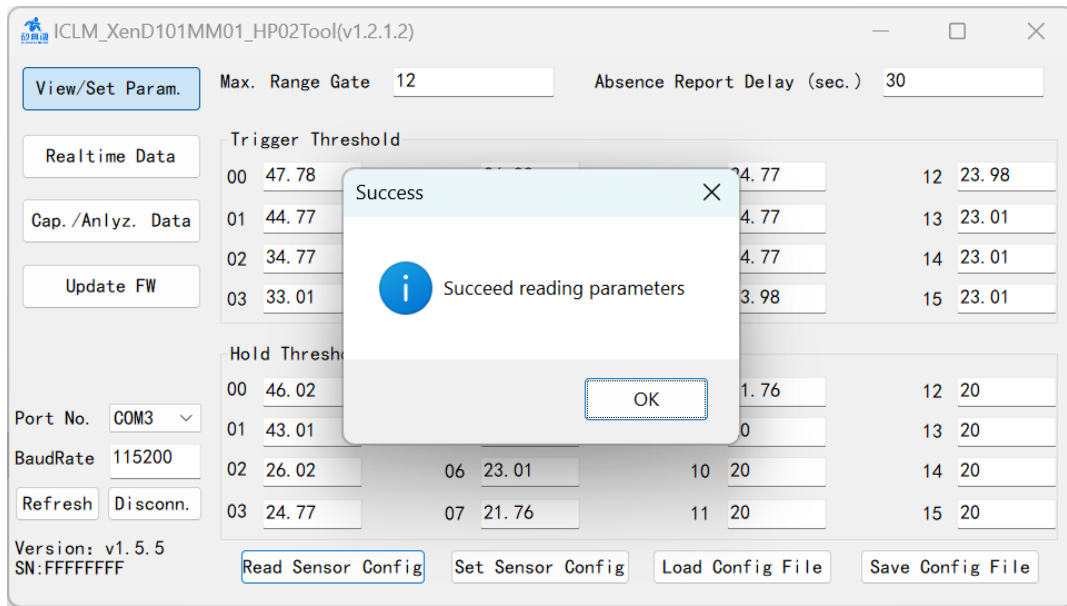


Figure 4-3 The View/Set Param page

The steps for setting radar parameters are listed below:

- Step 1: After connecting the XenD101MM module with the visualization tool, type in the new values for desired parameters;
- Step 2: Click the **Set Sensor Config** button, the visualization tool will send all the new values to the radar module, and a window writing "Succeed setting parameters" will appear, click the **OK** button to finish the process.

Descriptions of the parameters on the GUI are listed in Table 4-2.

Table 4-2 Descriptions of parameters on GUI

Parameter	Description	Range
Max. Range Gate	For setting the maximum valid detection range of the radar. The length of a range gate is 70 cm.	0~15
Target Absence Report Delay	For setting the delay time T before reporting target absence: during this time window, if radar detects a target again, it will report target information and reset the delay T; if no target is detected during time T, radar will report target absence.	0~65535
Trigger Threshold	For setting the motion energy threshold of the radar to decide whether there is a target in the detection range, it can be automatically calculated through "Calc. Thres." function.	0~65535
Hold Threshold	For setting the motion energy threshold of the radar to decide whether the detected target is motionless and stays presence in the detection range, it can be automatically calculated through "Calc. Thres." function.	0~65535

The visualization tool supports saving and loading configuration files of the radar:

- To save radar configuration, click the **Save Config File** button on the function page, choose a directory, the radar module will save the current configuration in a .xml file to the specified path; the default saving path is the visualization tool directory, and users can choose another saving path.
- To load a radar configuration file, click the **Load Config File** button on the function page, choose the desired radar configuration file, and the visualization will display the parameter values; click the **Set Sensor Config** button to apply the loaded parameters to the radar module.

4.2.2 Realtime Data

The Realtime Data page is shown in Figure 4-4. Descriptions of this page are as follows:

- The colored light icon represents whether the radar module has detected a target: when a human target

- is detected, the light is red; when no human target is detected, the light is green;
- The text box after the light icon displays the radial range of the detected target;
- The **Start/Pause** toggle button is to start or stop the radar detection;
- The **Calc. Thres.** button is to scan the environment noise and compute the trigger and hold threshold of each range gate;
- The **Apply Thres.** button is to send the new trigger and hold threshold of each range gate to the radar module;
- The **FP VS RG** line-chart is to display the motion energy (green line), trigger threshold (red line), and hold threshold (yellow line) of each range gate in realtime; the black background represents a valid detection range, and the grey background represents invalid detection range;
- The **Range VS Time** line-chart is to display the target range in the latest 60 s; the black background means there is no human target detected at that time, and the grey background means there is a target detected.



Figure 4-4 The Realtime Data page

The steps for checking the real-time data are as follows:

- Step 1: After connecting the XenD101MM module with the visualization tool, click the **Realtime Data** button to open this function page, then the radar will start detecting the human target and measuring the target range, and the visualization tool will display detection results in realtime, the Start/Pause toggle button displays "Stop";
- Step 2: Click the **Start/Pause** toggle button to stop the detection, and the colored light turns green, Target Range turns to 0.00 m, and the two line-charts stop updating.

The steps for computing and applying thresholds are as follows:

- Step 1: On the Realtime Data page, when the Start/Pause toggle button displays Pause, click the **Calc. Thres.** button to start scanning environmental noise, a window named Calculate Threshold will appear displaying the trigger energy and hold energy of each range gate in a table, and the scanning process bar below the table, as shown in Figure 4-5;
- Step 2: If users want to end the scan or abandon the scan results, click the **Cancel** button; otherwise, users click the **OK** button to save the values after the scan;
- Step 3 (Optional): If users choose to save the calculated thresholds in Step 2, the Apply Thres. button turns clickable, click the **Apply Thres.** button, the visualization tool will send the calculated values to the radar, and a window writing "Succeed setting threshold" will appear.

Users can check the latest radar parameter values on the View/Set Param. page after applying the calculated thresholds to the radar.

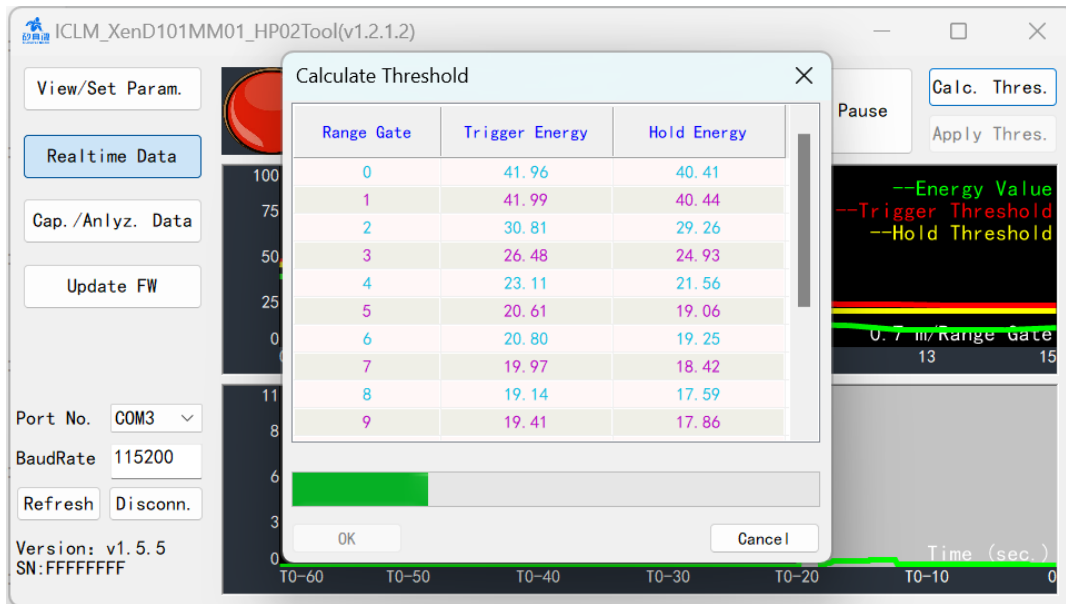


Figure 4-5 Calculate Threshold page

4.2.3 Capture and Analyze Data

The Cap./Anlyz. Data page is shown in Figure 4-6, the functions of this page are described as follows:

- **Scan Duration per RG(s):** set the scan duration for each range gate, default as 20 s, value ranges over 0~65535;
- **Save path:** choose the directory for saving captured radar data;
- **Choose Range Gate:** choose a range gate for analyzing the data, value ranges over 0~15;
- **Capture Data/Stop Capture** toggle button: start/stop capturing environment noise data; once stop the capturing process, users can find a .dat file whose name starts with RadarData and ends with time stamp;
- **Load Data:** open the previously saved radar scan data for analyzing;
- **Energy Information** line-chart: display the energy value, trigger threshold, and hold threshold of the selected range gate, the X axis represents time (s), and Y axis represents the fraction power of these parameters;
- **Range Information** line-chart: display the range of detected target, X axis represents time (s), and Y axis represents the distance (m).

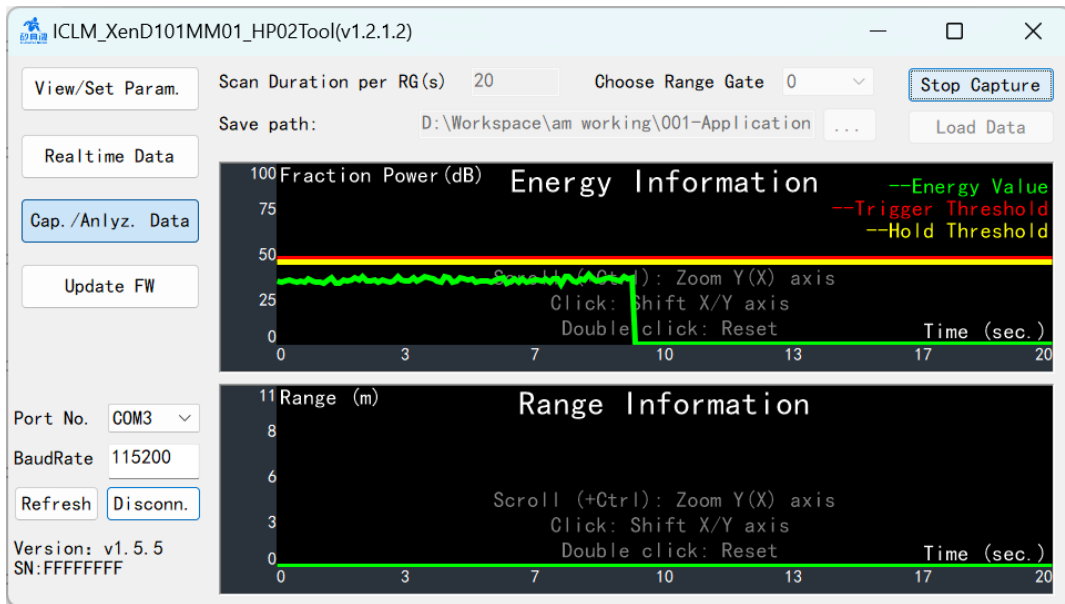


Figure 4-6 Capture and Analyze Data page

The steps for capturing energy data are as follows:

- Step 1: After connecting the XenD101MM module with the visualization tool, click the **Cap./Anlyz. Data** button to open this function page, click the directory selection button next to the Save path text box to set up the directory for saving radar data;
- Step 2: Type in the scan duration for each range gate in the text box, set the save path², ensure there is no moving target in the detection range during the scan process, click the **Capture Data/Stop Capture** toggle button to start capturing data;
- Step 3: Once the scan begins, users can terminate the process by clicking the **Capture Data/Stop Capture** toggle button, or wait till it stops automatically after a scan duration; either way, the captured data will be found under the path set in Step 2.

The steps for analyzing energy data are as follows:

- Step 1: After connecting the XenD101MM module with the visualization tool, click the **Cap./Anlyz. Data** button to open this function page;
- Step 2: Click the **Load Data** button, choose the data file that needs to be analyzed;
- Step 3: Choose a range gate, then the two line-charts will display the energy level, thresholds information, and target range information in that range gate;
- Step 4: If users want to check the exact value of a point in the curves, point the cursor at the point on the line, and a floating rectangle window will appear with the exact coordinate values of that point, as shown in Figure 4-7.

² It is recommended to choose the SaveData folder provided under the same directory as the ICLM_XenD101MM01_HP02Tool.exe file.

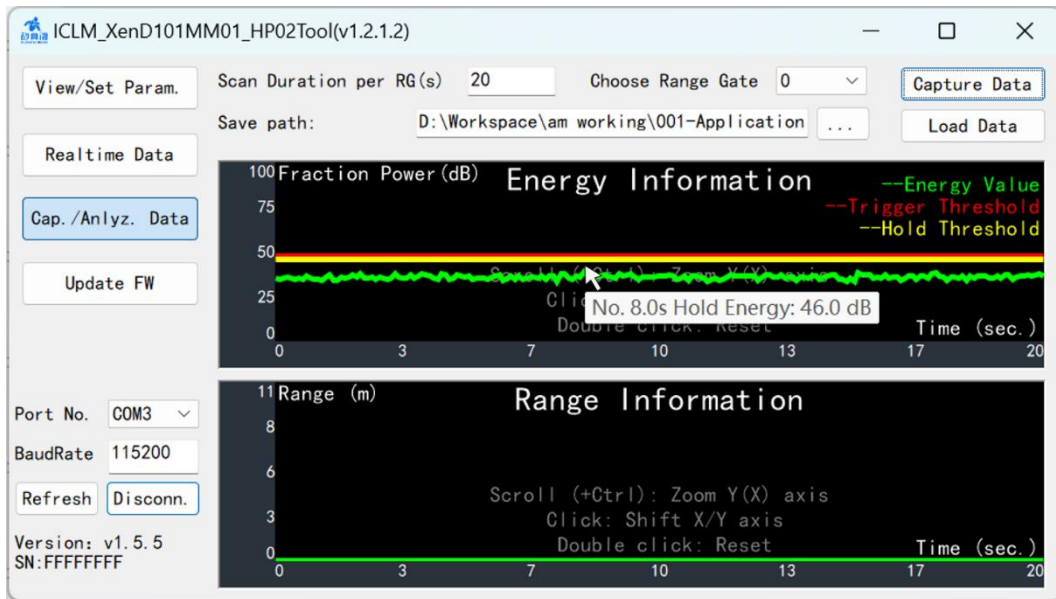


Figure 4-7 Analyze the loaded data

When checking the data on the Cap./Anlyz. Data page, users can zoom, drag, and reset the two line-charts:

- Zoom the X axis: put the mouse cursor on the chart, press the Ctrl button on the keyboard and scroll the mouse roller can zoom in (scroll upward) or zoom out (scroll downward) the X axis;
- Shift the curves: put the mouse cursor on the chart, press and hold the left button of the mouse, then the lines will shift with the move of the mouse;
- Reset the curves: put the mouse cursor on the chart, double click the mouse to reset the curves back to default presentation.

4.2.4 Update Firmware

The Update FW page is shown in Figure 4-8.

The steps for updating radar module firmware are as follows:

- Step 1: After connecting the XenD101MM module with the visualization tool, click the **Update FW** button to open this function page;
- Step 2³: Click the **Obtain Firmware Info.** button, and the text box on the rightmost will display device information;
- Step 3: Click the **Choose bin file path** button to choose the firmware file, click the **Download** button to start updating firmware, and the text box on the right will print the downloading states, the bin file information, and the downloading progress.

³ This step is necessary, users MUST NOT skip it when updating firmware through the visualization tool.

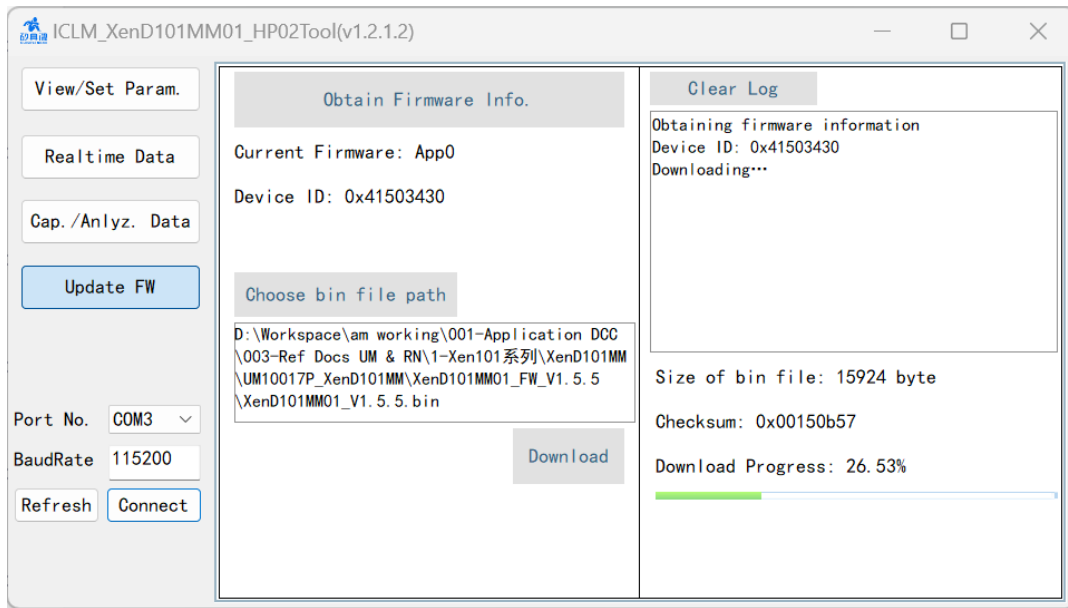


Figure 4-8 The Update Firmware page

After successfully updating the firmware, the text box on the right will print "Download successful!". Otherwise, the text box will print the error message.

5. Communication Protocol

This communication protocol is mainly for users who need to conduct further development without the visualization tool. XenD101MM communicates with the outside via the serial port (TTL). Both the radar data output and parameter configuration follow this protocol. The default serial port baud rate is 115200, with 1 stop bit and no parity bit.

This chapter consists of the following two parts:

- Configuration command format: includes the formats of the command and the acknowledgement (ACK);
- Report data format: includes the report data format applied in both the debugging mode and the normal working mode.

Steps for using commands to configure the radar are as follows:

1. Enter command mode;
2. Send the command for configuring/reading the parameter;
3. Exit command mode.

5.1 Protocol Format

5.1.1 Protocol Data Format

XenD101MM adopts MSB for data communication, and all the data in the tables of the following sections are hexadecimal.

5.1.2 Protocol Command Format

The formats of radar configuration command and ACK are shown in Table 5-1 and Table 5-3.

Table 5-1 Radar command frame format

Header	Length of Data Inside the Frame	Data Inside the Frame	Tailer
FD FC FB FA	2 bytes	Refer to Table 5-2	04 03 02 01

Table 5-2 Data format of the command frame

Command ID (2 bytes)	Command Parameter (N bytes)
----------------------	-----------------------------

Table 5-3 Radar ACK frame format

Header	Length of Data Inside the Frame	Data Inside the Frame	Tailer
FD FC FB FA	2 bytes	Refer to Table 5-4	04 03 02 01

Table 5-4 Data format of the ACK frame

ACK ID (2 bytes)	Command Status (2 bytes)	Return value (N bytes)
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5.2 Command and ACK

5.2.1 Read Firmware Version Command

This command reads the radar firmware version number.

Command word: 0x0000

Command value: NA

Return value: Length of the version number (2 bytes) + Version number

Sending data:

Byte 1 ~ 4	Byte 5, 6	Byte 7, 8	Byte 9 ~ 12
FD FC FB FA	02 00	00 00	04 03 02 01

ACK: (Succeed, Example)

Byte 1 ~ 4	Byte 5, 6	Byte 7, 8	Byte 9, 10	Byte 11, 12	Byte 13 ~ 18	Byte 19 ~ 22
FD FC FB FA	0C 00	00 01	00 00	06 00	76 31 2E 35 2E 35	04 03 02 01

5.2.2 Enable Configuration Command

This command enables the radar to enter configuration mode. All the other commands should be sent after this command, otherwise the command will be invalid.

Command word: 0x00FF

Command value: 0x0001

Return value: 2 bytes ACK status (0 for success, 1 for failure) + 2 bytes protocol version number (0x0002) + 2 bytes buffer size (0x0020)

Sending data:

Byte 1 ~ 4	Byte 5, 6	Byte 7, 8	Byte 9, 10	Byte 11 ~ 14
FD FC FB FA	04 00	FF 00	01 00	04 03 02 01

ACK(Succeed):

Byte 1 ~ 4	Byte 5, 6	Byte 7, 8	Byte 9, 10	Byte 11, 12	Byte 13, 14	Byte 15 ~ 18
FD FC FB FA	08 00	FF 01	00 00	02 00	20 00	04 03 02 01

5.2.3 End Configuration Command

This command enables the radar to exit configuration mode. After successfully conducting this command, the radar will return to normal working mode. If another radar command needs to be conducted, an Enable Configuration Command needs to be sent beforehand.

Command word: 0x00FE

Command value: NA

Return value: 2 bytes ACK status (0 for success, 1 for failure)

Sending data:

Byte 1 ~ 4	Byte 5, 6	Byte 7, 8	Byte 9 ~ 12
FD FC FB FA	02 00	FE 00	04 03 02 01

ACK(Succeed):

Byte 1 ~ 4	Byte 5, 6	Byte 7, 8	Byte 9, 10	Byte 11 ~ 14
FD FC FB FA	04 00	FE 01	00 00	04 03 02 01

5.2.4 Read Serial Number Command

This command reads the radar serial number.

Command word: 0x0011

Command value: NA

Return value: 2 bytes ACK status (0 for success, 1 for failure)

Sending data:

Byte 1 ~ 4	Byte 5, 6	Byte 7, 8	Byte 9 ~ 12
FD FC FB FA	02 00	11 00	04 03 02 01

ACK(Succeed):

Byte 1 ~ 4	Byte 5, 6	Byte 7, 8	Byte 9, 10	Byte 11, 12	Byte 13, 14	Byte 15 ~ 18
FD FC FB FA	08 00	11 01	00 00	02 00	CD AB	04 03 02 01

5.2.5 Write Serial Number Command

This command writes the serial number into the radar.

Command word: 0x0010

Command value: Length of SN (2 bytes) + SN

Return value: 2 bytes ACK status (0 for success, 1 for failure)

Sending data: (Example)

Byte 1 ~ 4	Byte 5, 6	Byte 7, 8	Byte 9 ~ 12	Byte 13 ~ 16
FD FC FB FA	06 00	10 00	02 00 CD AB	04 03 02 01

ACK(Succeed):

Byte 1 ~ 4	Byte 5, 6	Byte 7, 8	Byte 9, 10	Byte 11 ~ 14
FD FC FB FA	04 00	10 01	00 00	04 03 02 01

5.2.6 Read Radar Register Command

This command reads the register value of the radar.

Command word: 0x0002

Command value: 2 bytes SoC address + (2 bytes address) * N

Return value: (2 bytes data) * N

Sending data:

Byte 1 ~ 4	Byte 5, 6	Byte 7, 8	Byte 9 ~ 12	Byte 13 ~ 16
FD FC FB FA	06 00	02 00	40 00 40 00	04 03 02 01

ACK(Succeed):

Byte 1 ~ 4	Byte 5, 6	Byte 7, 8	Byte 9, 10	Byte 11, 12	Byte 13 ~ 16
FD FC FB FA	06 00	02 01	00 00	07 02	04 03 02 01

5.2.7 Configure Radar Register Command

This command writes the register value of the radar.

Command word: 0x0001

Command value: 2 bytes IIC address + (2 bytes address + 2 bytes data) * N

Return value: 2 bytes ACK status (0 for success, 1 for failure)

Sending data:

Byte 1 ~ 4	Byte 5, 6	Byte 7, 8	Byte 9, 10	Byte 11~ 14	Byte 15 ~ 18
FD FC FB FA	08 00	01 00	40 00	40 00 07 42	04 03 02 01

ACK(Succeed):

Byte 1 ~ 4	Byte 5, 6	Byte 7, 8	Byte 9, 10	Byte 11 ~ 14
FD FC FB FA	04 00	01 01	00 00	04 03 02 01

5.2.8 Read Radar Parameter Command

This command reads the radar parameters.

Command word: 0x0008

Command value: (2 bytes parameter ID) * N

Return value: (4 bytes parameter value) * N

Sending data: (Example)

Byte 1 ~ 4	Byte 5, 6	Byte 7, 8	Byte 9, 10	Byte 11 ~ 14
FD FC FB FA	04 00	08 00	01 00	04 03 02 01

ACK: (Succeed, the maximum range gate is 12)

Byte 1 ~ 4	Byte 5, 6	Byte 7, 8	Byte 9, 10	Byte 11~ 14	Byte 15 ~ 18
FD FC FB FA	08 00	08 01	00 00	0C 00 00 00	04 03 02 01

5.2.9 Configure Radar Parameter Command

This command sets the parameter values of the radar. The parameter word for each radar parameter is presented in Table 5-5.

Table 5-5 Radar parameters

Parameter	Parameter ID	Range of Parameter Value
Minimum Range Gate	0x0000	0~15
Maximum Range Gate	0x0001	0~15
Absence Report Delay	0x0004	0~65535, unit s (second)
Trigger Threshold	0x0010 ~ 0x001F	$0 \sim 2^{32} - 1$, the square of the amplitude
Hold Threshold	0x0020 ~ 0x002F	$0 \sim 2^{32} - 1$, the square of the amplitude

Command word: 0x0007

Command value: (2 bytes parameter ID + 4 bytes parameter value) * N

Return value: 2 bytes ACK status (0 for success, 1 for failure)

Sending data: (set the maximum range gate to 12)

Byte 1 ~ 4	Byte 5, 6	Byte 7, 8	Byte 9, 10	Byte 11, 12	Byte 13, 14	Byte 15 ~ 18
FD FC FB FA	08 00	07 00	01 00	12 00	00 00	04 03 02 01

ACK(Succeed):

Byte 1 ~ 4	Byte 5, 6	Byte 7, 8	Byte 9, 10	Byte 11 ~ 14
FD FC FB FA	04 00	07 01	00 00	04 03 02 01

5.2.10 Configure System Parameter Command

This command configures the system parameter of the radar.

Command word: 0x0012

Command value: (2 bytes parameter ID + 4 bytes parameter value) * N

Return value: 2 bytes ACK status (0 for success, 1 for failure)

Sending data: (Example)

Byte 1 ~ 4	Byte 5, 6	Byte 7, 8	Byte 9, 10	Byte 11~ 14	Byte 15 ~ 18
FD FC FB FA	08 00	12 00	00 00	04 00 00 00	04 03 02 01

ACK(Succeed):

Byte 1 ~ 4	Byte 5, 6	Byte 7, 8	Byte 9, 10	Byte 11 ~ 14
FD FC FB FA	04 00	12 01	00 00	04 03 02 01

5.3 Radar Report Data

In the normal working mode, the XenD101MM released firmware outputs the detection results via the serial port. The output data are ON/OFF strings as well as the range gate of the detected target. In other modes, the host PC is able to obtain the data during the processing. Therefore, in command mode, the firmware provides two data transfer modes other than normal working mode, they are debugging mode and reporting mode.

In command mode, users can control the radar report data type by adjusting the working mode parameter in the command frame. Figure 5-1 presents an example of the structure of a command frame.

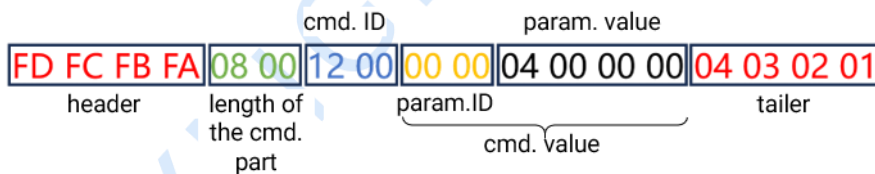


Figure 5-1 Example of a command (cmd.) frame

In the example, the parameter value of the command value determines the radar's working mode in a way that:

- 0x0000 means debugging mode;
- 0x0004 means reporting mode;
- 0x0064 means normal working mode.

The reporting data frame format in debugging mode is shown in Table 5-6.

Table 5-6 Report data format of debugging mode

Header	Data	Tailer
AA BF 10 14	RDMAP: 20(Doppler) * 16 (number of range gate) * 4 (square of the amplitude)	FD FC FB FA

In debugging mode, the RDMAP data of all the range gates of a certain chirp are sent out each time, i.e., the

data of all the 16 range gates of the first chirp will be sent out first, then goes the second chirp, and so on.

The reporting data frame format in reporting mode is shown in Table 5-7.

Table 5-7 Report data format of reporting mode

Header	Length of Data Inside the Frame	Detection Result	Distance of the Target	Energy of Each Range Gate	Tailer
F4 F3 F2 F1	2 bytes (The sum of data bytes of Detection Result, Target Distance, and Energy of Each Range Gate)	1 byte (0x00 for no target; 0x01 for target exist)	2 bytes	32 bytes (16 * 2 bytes)	F8 F7 F6 F5

Figure 5-2 presents an example of the structure of a data frame in reporting mode.

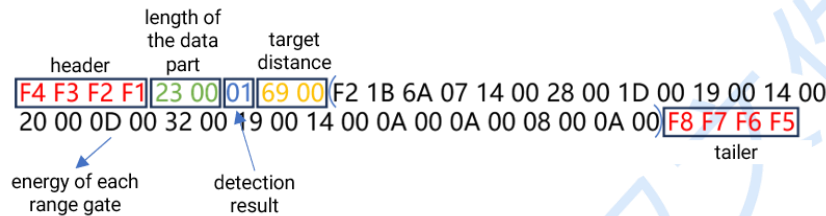


Figure 5-2 Example of a report data frame in reporting mode

The meaning of each part of data in the example is as follow:

Length of the data part: the sum of data length of Detection Result, Target Distance, and Energy of Each Range Gate;

Detection result: whether a target is detected;

Target distance: the radial distance between the detected target and the radar;

Energy of each range gate: the energy value of each range gate (0~15).

The data in Figure 5-2 can be parsed as:

Length: 0023, the sum of data bytes of Detection Result, Target Distance, and Energy of Each Range Gate = 35

Detection result: 01, a human target is detected in current scenario;

Target distance: 0069, the radial distance between the detected target and the radar = 105 cm;

Energy of each range gate:

Range gate 0 = 1BF2

Range gate 8 = 000D

Range gate 1 = 076A

Range gate 9 = 0032

Range gate 2 = 0014

Range gate 10 = 0019

Range gate 3 = 0028

Range gate 11 = 0014

Range gate 4 = 001D

Range gate 12 = 000A

Range gate 5 = 0019

Range gate 13 = 000A

Range gate 6 = 0014

Range gate 14 = 0008

Range gate 7 = 0020

Range gate 15 = 000A

6. Installation and Detection Range

The XenD101MM supports both top mounted and wall mounted installation. The recommended method is top mounted installation.

Directions relative to the radar module are shown in Figure 6-1. The direction of X axis is defined as 0°, Z axis is defined as 90°, and Y axis is perpendicular to X-Z plane (also known as normal direction).

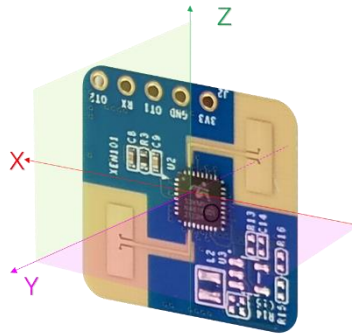


Figure 6-1 Illustration of radar module relative directions

6.1 Top Mounted

The recommended installation height for top mounting method is 2.7 m ~ 3.0 m. In this case, the detection range of XenD101MM under default setting is a conic area with 5 m base radius, as shown in Figure 6-2.

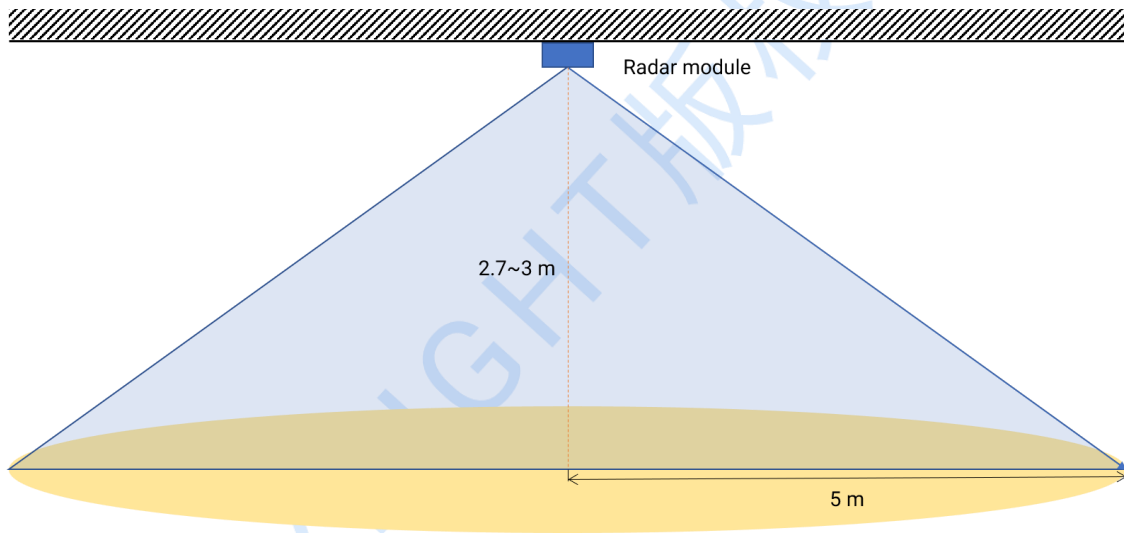


Figure 6-2 Illustration of top mounted XenD101MM detection range

The detailed detection ranges of both moving target and motionless target are shown in Figure 6-3 when applying top mounted with the height of 2.7 m.

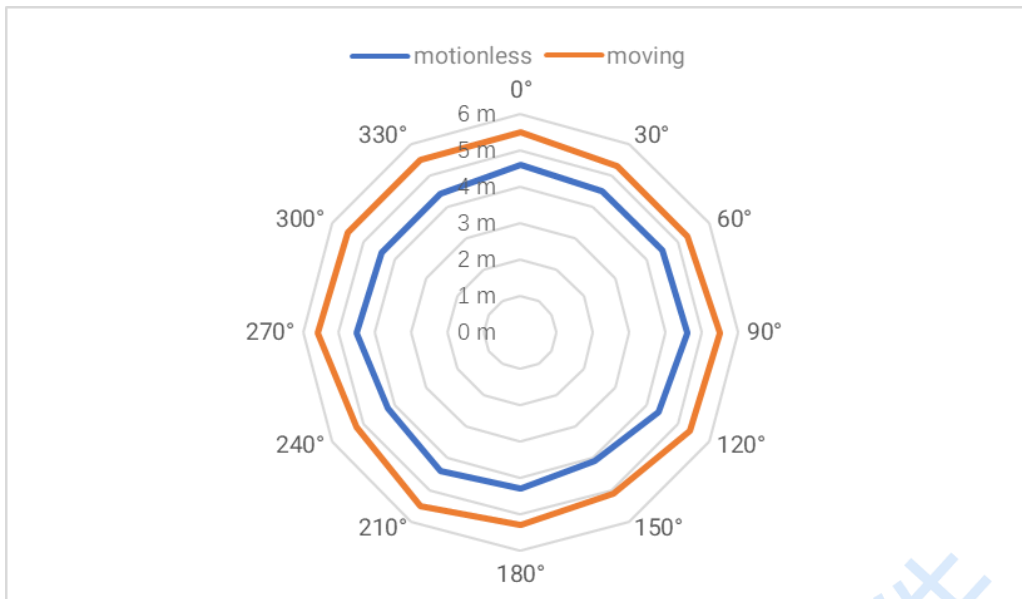


Figure 6-3 Detection range of top mounted XenD101MM

6.2 Wall Mounted

The recommended installation height for wall mounting method is 1.5 m ~ 2.0 m. When wall mounted, the X axis of radar module (refer to Figure 6-1) should be horizontal, Z axis should point upwards, Y axis should point to the detecting area. the motion detection range of XenD101MM under default setting is a cubic fan shaped area with a radius of 10 m, azimuth and pitch angle of $\pm 45^\circ$, as shown in Figure 6-4.

The detailed detection ranges of both moving target and motionless target are shown in Figure 6-5, when applying wall mounted with the height of 1.5 m.

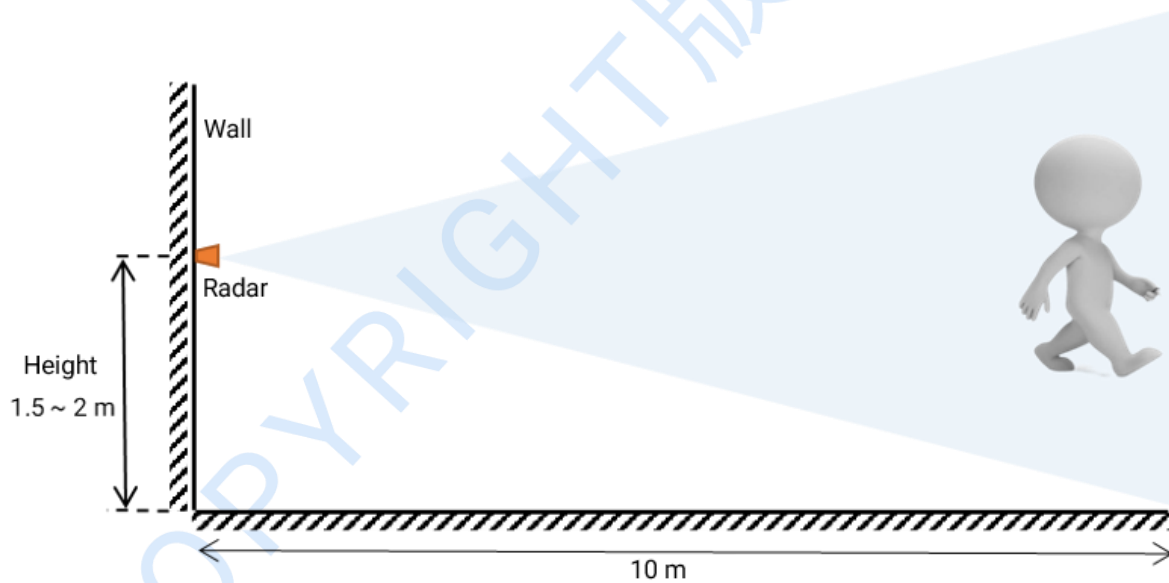


Figure 6-4 Illustration of wall mounted XenD101MM detection range

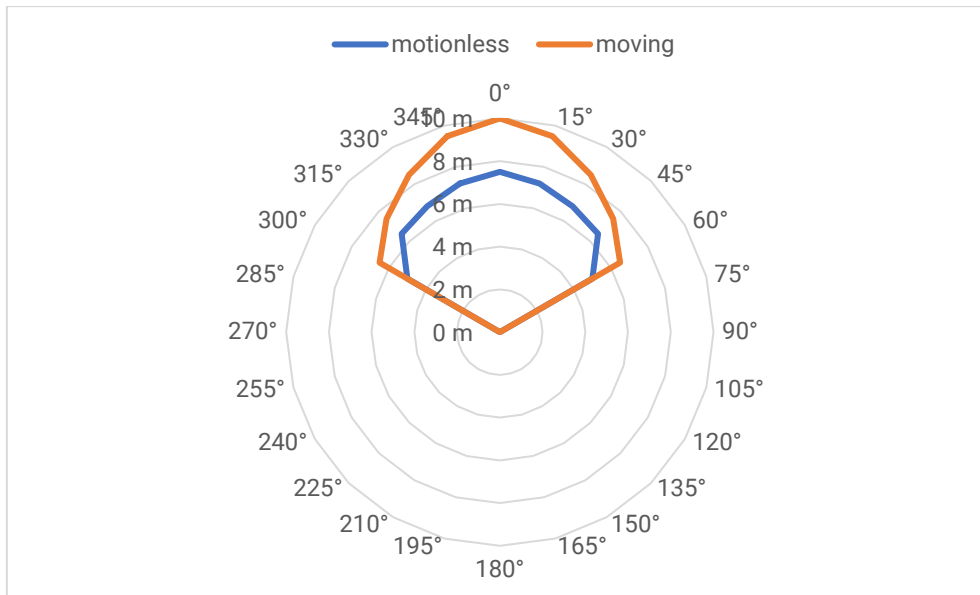


Figure 6-5 Detection range of wall mounted XenD101MM

6.3 Detection Range Test

This section introduces how to test the XenD101MM radar trigger and hold detection range.

- **Trigger detection range:**

The tester stands somewhere inside the radar FOV but further than the radar detection range and the radar reports *No Target*, then the tester gradually walks towards the radar and stops immediately when the radar reports target detected, the radical distance between the tester and the radar is called trigger border in this direction; the trigger boarder in various direction forms the trigger detection range of the radar.

- **Hold detection range:**

The tester stands somewhere inside the radar FOV and detection range, with the radar reports a target is detected, then the tester keeps making minor movements such as shrug and moving hands for 60 s, if the radar reports a target is detected during the whole process, then the location of the tester is within the hold detection range, otherwise, the location is outside the hold detection range.

7. Mechanical Size

Figure 7-1 presents the mechanical size of Xen101 hardware, all the unit is mm. The board thickness is 1.2 mm with a tolerance of $\pm 10\%$.

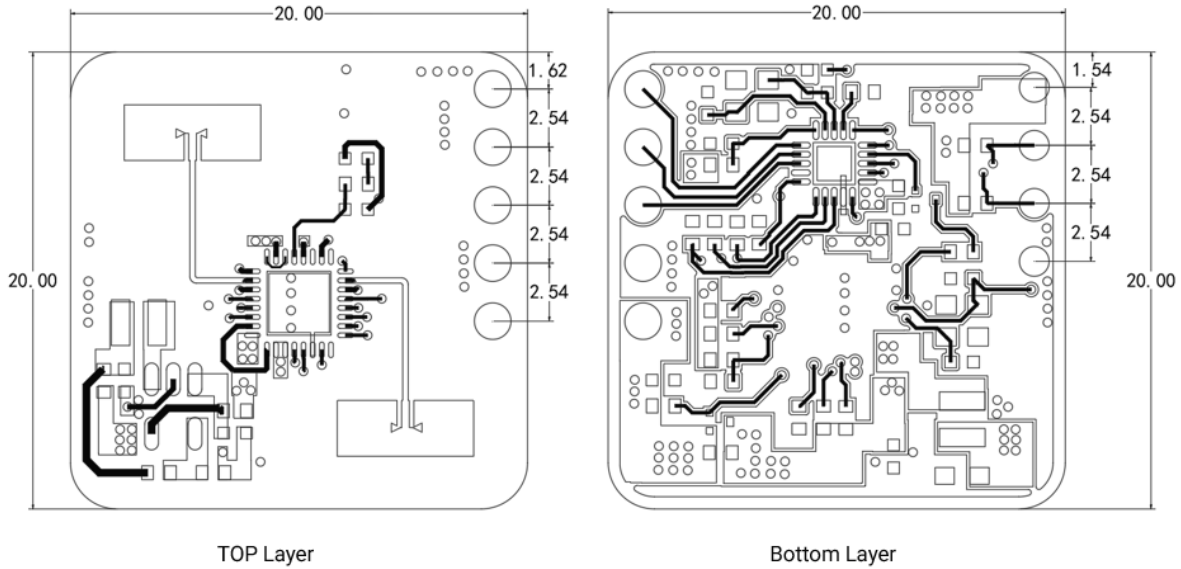


Figure 7-1 Xen101 mechanical size

8. Installation Requirement

Radome Requirements

If there is a need to install a radome, the material selected must have good transparency for 24 GHz wave, and do not contain any material that may block electromagnetic wave such as metal. More details please refer to [Guide of mmWave Sensor Antenna Radome Design](#)⁴.

Before installing the radar, it is required to try out the minimum mounting clearance between the antennas and the cover. It is recommended to maintain the gap within 4 ~ 6 mm, because the radar will reach saturation if the cover is too close to the antenna. The minimum mounting clearance varies with respect to the material, thickness and shape of the cover.

Installation Environment

When installing the product, certain requirements should be taken into consideration in case the detection performance is interfered. Features of unsuitable environment are listed below.

- Continuous moving non-human objects in detection area, such as moving animals, swinging curtains, big shaking plants in front of an active vent etc.
- Large strong reflectors will interfere with detection performance when put in front of the antennas.
- Interferences of on-ceiling home appliances such as air-conditioners, fans, etc. should be taken into consideration while top mounted.

Important Requirements

- Ensure the radar antennas are facing squarely to desired detection area with a clear field of view.
- Ensure the installation position of the sensor is solid and stable. Motion of the radar itself can hugely impact signal processing.
- Ensure there is no object moving or vibrating behind the radar. Motion behind antennas can also be detected due to the penetrability of radar RF wave, thus interferes detection accuracy. It is recommended to use a radome or a backplane to reduce the interference.

⁴ Currently, only Chinese version is available.

- When there are multiple 24 GHz radar installed in close areas, ensure their beamforms do not face to each other, try to separate them as far as possible to avoid interference.

Power Supply

The XenD101MM supports power supply from 3.3 V to 3.6 V, and the power ripple should show no obvious spectral peaks within 100 kHz. Additionally, developers should take EMC design such as ESD and lightning surge into consideration.

9. Important Tips

Maximum Detection Range

The maximum detection range of XenD101MM is 10 m in radical direction. Within this range, the radar reports the direct distance of the detected moving target. Currently, the radar only reports the direct distance of moving human body, and does not support range measurement of motionless human target in close range.

Modifying Firmware Baud Rate

XenD101MM default baud rate 256000. It can be modified through the macro USART0_BAUDRATE defined under engineering directory \platform\py32\inc\py32_uart.h.

Maximum Detection Range and Range Accuracy

Theoretically, the range accuracy of XenD101MM reference design is 0.35 cm. However, the value together with the maximum range may vary according to human target size, pose, and RCS.

Absence Report Delay

When human absence is detected in detection area, the radar will delay the absence report. The delay mechanism works as such: once no human target is detected in detection area, the radar will start a timer whose duration is the parameter absence report delay, and if there is no target showing up during this timing the radar will end the timer and send the non-human report; however, if a human target is detected in detection area during the timing, the radar will end and refresh the timer before sending the target information.

10. Revision History

Revision	Date	Modification
1.1	2023/5/22	Initial release.
1.2	2023/6/1	Align the description of the reference design with the website content, update the description as human micro-motion detection mmWave sensor.
1.3	2023/7/27	Added Chapter 5 Communication Protocol ; The visualization tool added displaying module serial number, version number updated from v1.2.0.0 to v1.2.1.1; The firmware added serial number related functions, version number updated to v1.5.5.
1.4	2023/8/8	Optimized the communication protocol of the visualization tool, the version number updated from v1.2.1.1 to v1.2.1.2; Updated the definitions of radar module relative direction.

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