

### Introduction

This document introduces the reference design of ICLM gesture recognition and control mmWave sensor XenG102ST, including its basic functions, hardware specification, software configuration, installing condition etc.

This document aims to guide users to get started with XenG102ST gesture recognition and control solution quickly and easily so that users can sort out suitable parameters for specified scenarios and can design both precise and customized human detection and gesture recognition sensors.

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## 1. XenG102ST Overview

The XenG102ST is a gesture recognition and control sensor reference design of the ICLM EZ Sensor series. It contains a minimalist 24 GHz radar sensor hardware Xen102 and an intelligent algorithm firmware ST01.

The Xen102 hardware incorporates an AIoT mmWave sensor SoC S3KM111L, high-performance 1T1R microstrip antennas, low-cost MCU, and peripheral circuits. Intelligent algorithm firmware ST01 adopts FMCW waveform and S3KM111L specified advanced signal processing technology. This reference solution is mainly applied to Smart Toilet scenarios with precise human detection and gesture recognition ability. Developers can check the human target distance and gesture information in real-time using a visualization tool provided in this solution.

The Xen102 hardware adopts a wide-narrow beamform design, with azimuth angle (4 patch direction) ranges  $\pm 20^\circ$  and pitch angle ranges  $\pm 40^\circ$ . Users can adjust the installation method of the Xen102 according to practical scenarios. In the Smart Toilet scenario, it is recommended to apply a narrow horizontal beamform to avoid the radar being accidentally triggered by passersby.

## 2. System Characteristics

The XenG102ST is a gesture recognition and control reference solution developed based on ICLM S3KM111L. It detects human presence, recognizes gestures in a specified range, and reports real-time detection results by incorporating FMCW waveform, MCU radar signal processing, and a built-in intelligent human detection algorithm. With this reference solution, developers can quickly develop customized human detection and gesture recognition products with high precision.

The systematic characteristics of XenG102ST are shown in Table 2-1.

**Table 2-1 XenG102ST characteristics**

Parameter	Min.	Typ.	Max.	Unit
Supporting frequency	24.015	-	24.245	GHz
Sweeping bandwidth	-	0.23	-	GHz
Max. EIRP	-	12	-	dBm
Power supply	4.6	5	5.4	V
Size	-	28 × 24	-	mm <sup>2</sup>
Ambient temperature	-40	-	85	°C
Average operating current	-	50	-	mA
Detection range	0.3	-	2.2	m
Azimuth	-	$\pm 40$	-	°
Pitch	-	$\pm 20$	-	°
Range deviation	-	-	$\pm 10$	cm

## 3. Hardware Overview

The hardware module of XenG102ST is Xen102. Figure 3-1 shows the device maps of Xen102. Xen102 hardware reserves 5 pins (default without contact pin) called J2 for power supply and communication; 4 pins called J3 for programming the MCU. When programming the module, please pay attention to J3 pin names. Due to hardware-compliant, the firmware for adopting GD32F310 will be developed in the future. (J1 is a reserved USB interface and will not be introduced in this document.)

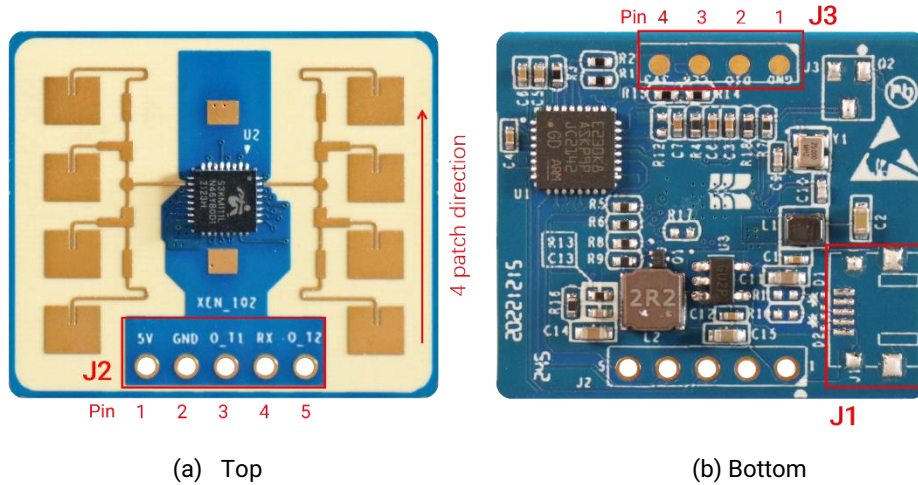


Figure 3-1 Xen102 device map

Details of J2 and J3 pins are listed in Table 3-1 and Table 3-2.

Table 3-1 J2 pin description

J#PIN#	Name	Function	Operating Range
J2Pin1	5V	Power input	4.6 V ~ 5.4 V, Typ. 5 V
J2Pin2	GND	Ground	-
J2Pin3	O_T1	UART_TX	0 ~ 3.3 V
J2Pin4	RX	UART_RX	0 ~ 3.3 V
J2Pin5	O_T2	UART_TX (reserved)	0 ~ 3.3 V

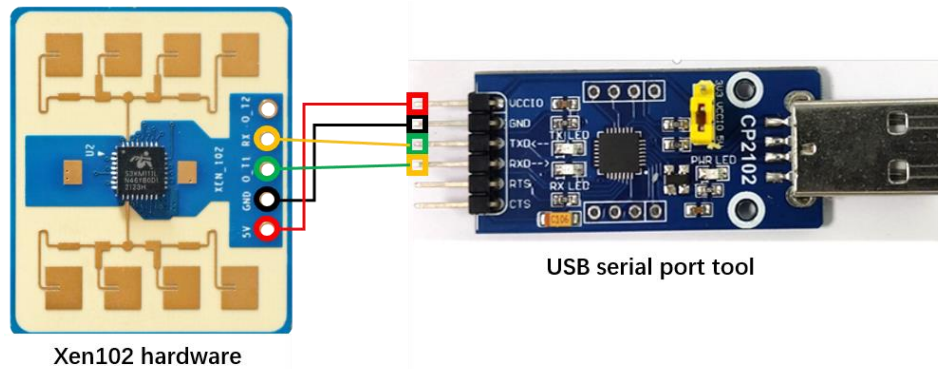
Table 3-2 J3 pin description

J#PIN#	Name	Function	Operating Range
J3Pin1	GND	Ground	-
J3Pin2	DIO	Data port	0 ~ 3.3 V
J3Pin3	CLK	Clock signal	0 ~ 3.3 V
J3Pin4	3V3	Power input	3.3 V

XenG102ST supports Keil5 IDE programming, either hex or firmware file is acceptable. XenG102ST supports common RW programmers such as J-Link (revisions no earlier than V9), CMSIS-DAP etc. Make sure the Keil5 IDE has installed [GigaDevice.GD32E23x\\_DFP.1.0.1.pack](#) and [ARM.CMSIS.5.7.0.pack](#) (or a later version of CMSIS pack).

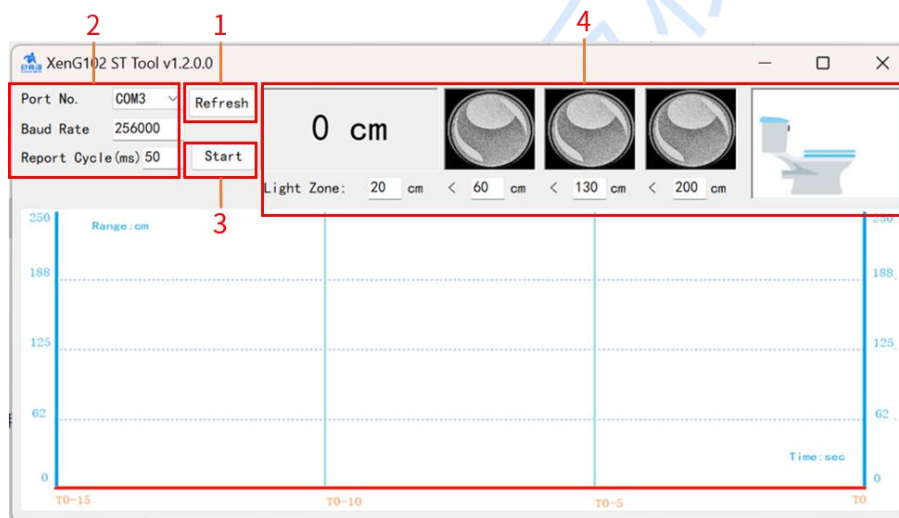
## 4. Software Overview

Xen102 hardware requires a 5 V power supply. When connecting the hardware to the serial port tool, as shown in Figure 4-1, the connection of pins should follow these requirements: the TX pin of Xen102 connects to the RX pin of the serial port tool, the RX of Xen102 connects to the TX of the serial port tool, and the 5 V pin of Xen102 connects to VCCIO. If another type of serial port tool is used, make sure the power supply is 5 V.


**Figure 4-1 Connection of Xen102 and serial port tool**

After connecting the radar module with a host PC through a serial port tool, developers can configure the module through the visualization tool [XenG102STTool](#), and the steps are introduced as follows.

- Step 1: In XenG102STTool directory, double click the **ICLM\_XenG102\_STTool.exe** to open the visualization tool.
- Step 2: Click the **Refresh** button (in Zone 1, as shown in Figure 4-2). If the connection between the radar and the host PC is successful, the Port No. drop-box will display the serial port number of the radar.
- Step 3: Select the serial port number of the radar, type in the baud rate (Zone 2), and type in the reporting cycle. The default reporting cycle is 50 ms in the released firmware.
- Step 4: Click the **Start/Stop** toggle button (Zone 3), and the visualization tool starts receiving data from the radar and displaying the target's distance and the toilet's state (Zone 4).


**Figure 4-2 ICLM\_XenG102 ST Tool**




The detection range is separated into 3 gears and can be modified by users. Each gear is represented by a colored light. By default setting, the lights work as follows:

- When the human target distance is between 0 to 60 cm, the red light on the left is on, and the rest two are grey;
- When the human target distance is between 60 cm to 130 cm, the yellow light in the middle is on, and the rest two are grey;
- When the human target distance is between 130 cm to 200 cm, the green light on the right is on, and the rest two are grey.

An illustration of the lights on/off state with respect to target distance is shown in Table 4-1. The distance

range definition of each gear can be modified on the visualization tool.

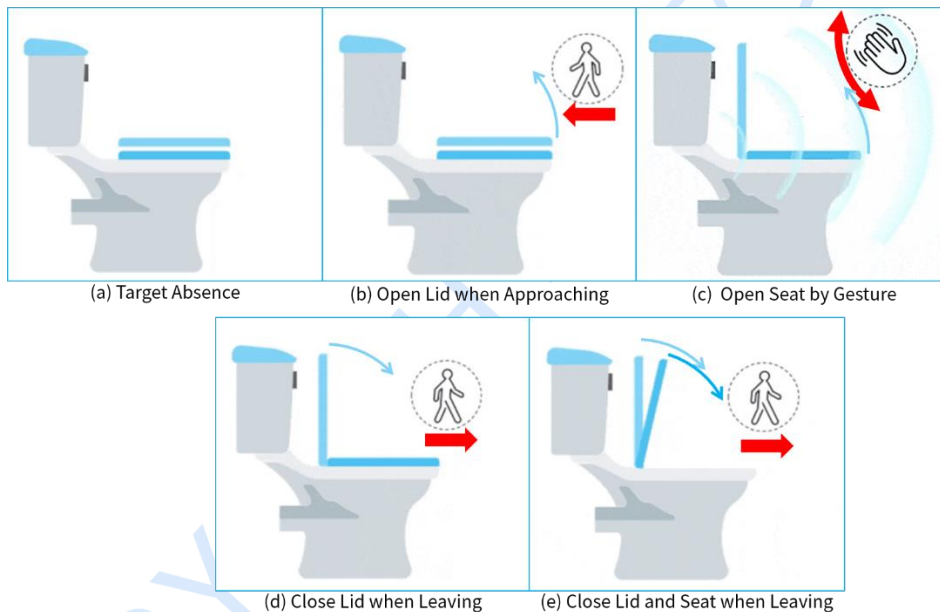
**Table 4-1 Mapping between target distance and light color**

Target Distance Range (cm)	Light Display
0 ~ 60	
60 ~ 130	
130 ~ 200	

There are 5 different states for the toilet:

- Target absence (both the lid and the seat are default closed);
- Open lid when approaching (if the lid is previously closed);
- Open seat by gesture (if the lid is previously open);
- Close lid when leaving (only if the lid is previously open);
- Close lid and seat when leaving (if both lid and seat are previously open).

An illustration of these states is shown in Figure 4-3.



**Figure 4-3 Illustration of toilet states**

Absence Report Delay refers to the duration from the radar first detecting the absence of the target to reporting the absence. Developers can change this value by modifying the parameter NobodyDebounceTime in the XenG102 ST Tool/appConfig.xml file under the visualization tool directory, it is defaulted as 1000 ms.

## 5. Communication Protocol

This communication protocol is mainly for users who need to develop products without the visualization tool. Xen102 hardware communicates via a serial port which transmits radar data processed by a built-in algorithm in frames. The data format for each frame is defined as:

AA + distance information (2 bytes, unit cm) + gesture information (1 byte) + 55

Distance information adopts the little-endian format. An example of radar data is shown in Figure 5-1. The delay of the gesture result report is 0.25 s.

```

1 frame radar data
AA 1E 00 00 55 AA 1D 00 00 55 AA 1D 00 00 55 AA 1E 00 00 55 AA 1E 00 00
55 AA 1F 00 00 55 AA 1E 00 00 55 AA 1E 00 00 55 AA 1C 00 00 55 AA 1C 00
00 55 AA 1C 00 00 55 AA 1C 00 00 55 AA 1C 00 00 55 AA 1D 00 00 55 AA 1F
00 00 55 AA 28 00 00 55 AA 25 00 00 55 AA 1E 00 00 55 AA 1F 00 00 55 AA
1F 00 00 55 AA 1F 00 00 55
    
```

Figure 5-1 Example radar data transmitted via serial port

Examples of parsing radar data are as follow:

AA 1E 00 00 55, distance = 001E = 30 cm, gesture = 00, meaning no gesture detected;

AA 4B 00 01 55, distance = 004B = 75 cm, gesture = 01, meaning gesture is detected.

The target distance is displayed in the visualization tool, as shown in Figure 5-2. On the top right corner of the GUI, there is a small window presenting the toilet state, and the red wave on the lower part of the GUI displays the target distance in the past 15 s.

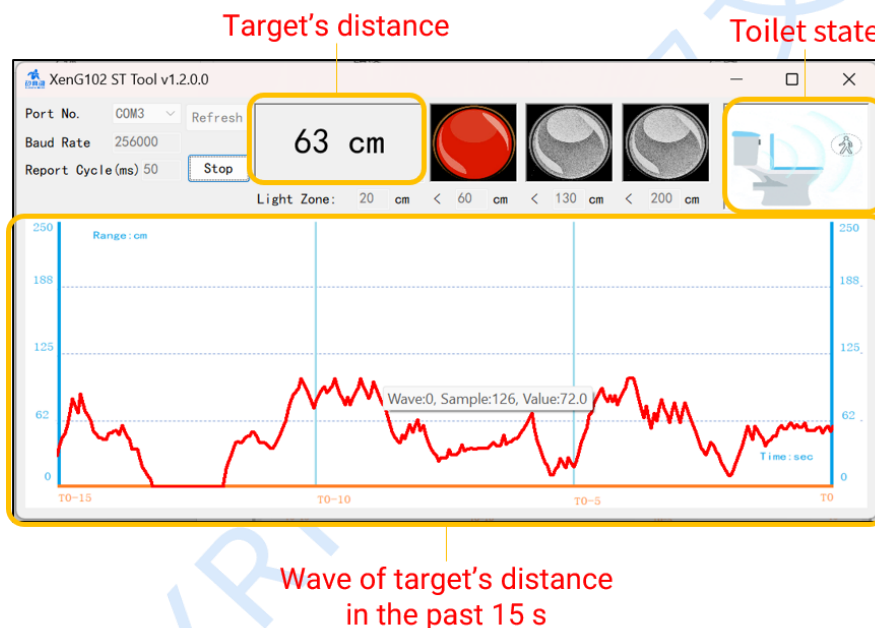


Figure 5-2 XenG102ST GUI

## 6. Installation Requirements

When installing the radar module, the height should be 45 cm above the floor, and the elevation angle should be 45°, as shown in Figure 6-1. Please make sure that the antenna 4 patch is horizontal.

If the radar module is installed inside a toilet, the elevation angle should also be 45°.



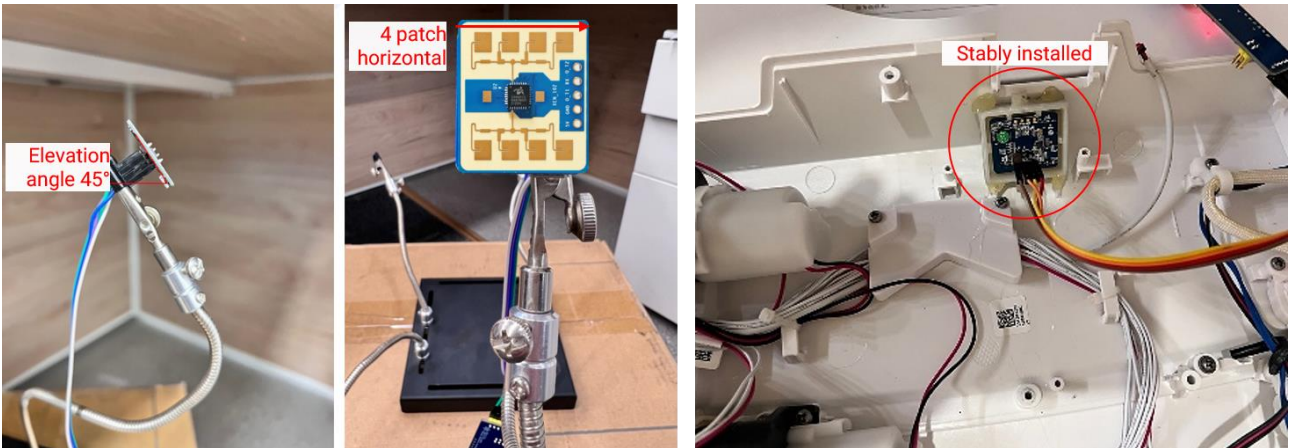


Figure 6-1 Example of installing XenG102ST

If there is a need to install a radome, the material selected must have good transparency for 24 GHz wave, and not contain any material that may block electromagnetic wave such as metal. For more details please refer to [Guide of mmWave Sensor Antenna Radome Design](#)<sup>1</sup>.

Make sure the installation position of the sensor is solid and stable. The motion of the radar itself can hugely impact signal processing.

Make sure 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 interfering with detection accuracy. It is recommended to use a radome or a backplane to reduce interference.

When multiple 24 GHz radars are installed in close areas, make sure their beamforming does not face each other, and try to separate them as far as possible to avoid interference.

## 7. Detection Range

After installation, the radar detection area is a cubic fan-shaped area with the radar module be the original point,  $\pm 40^\circ$  in the H plane, and  $\pm 20^\circ$  in the E plane. An illustration of radar H and E planes is shown in Figure 7-1. The radar detection ability diagram is shown in Figure 7-2. The human motion detection range is a fan-shaped area with an azimuth angle of  $\pm 20^\circ$  and a radius range of 0.3~2.2 m; the gesture recognition and micro-motion detection range is a fan-shaped area with an azimuth angle of  $\pm 30^\circ$  and a radius range of 0.5~1 m. The gesture recognition area in the smart toilet application is shown in Figure 7-3.

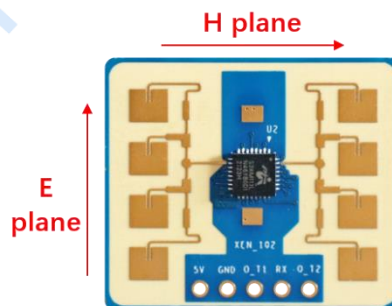


Figure 7-1 H plane and E plane of the radar module

<sup>1</sup> Currently, only Chinese version is available.



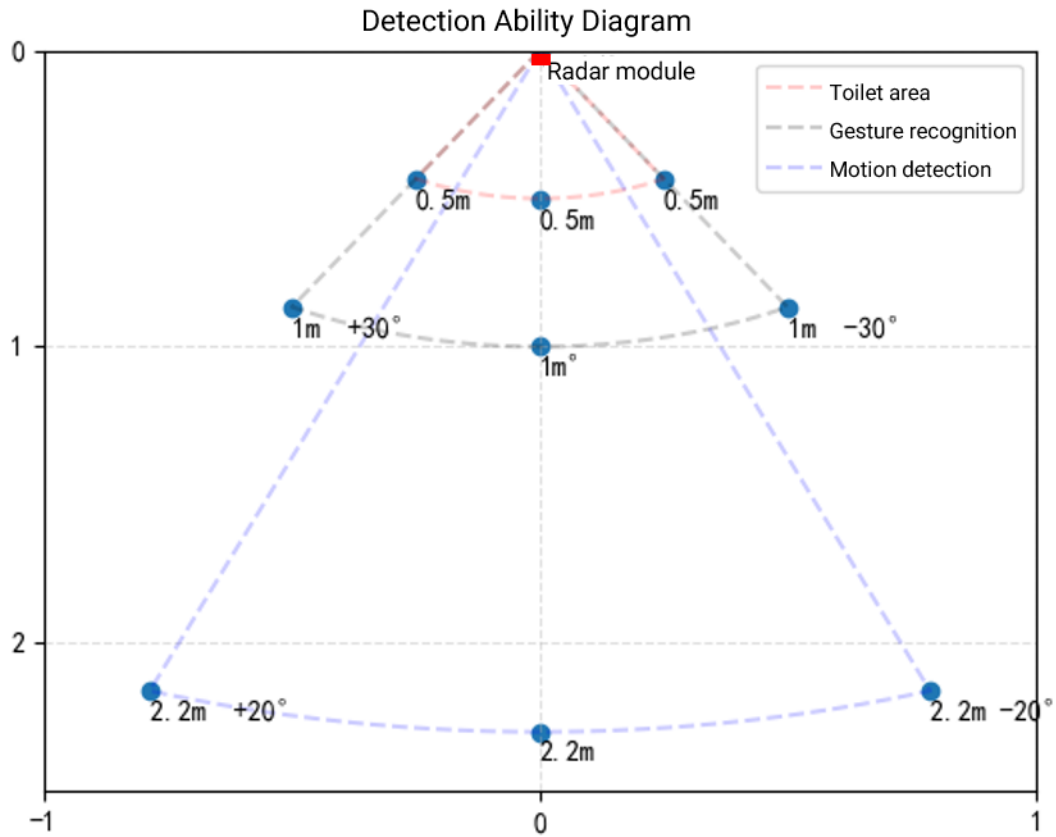


Figure 7-2 Radar detection ability diagram

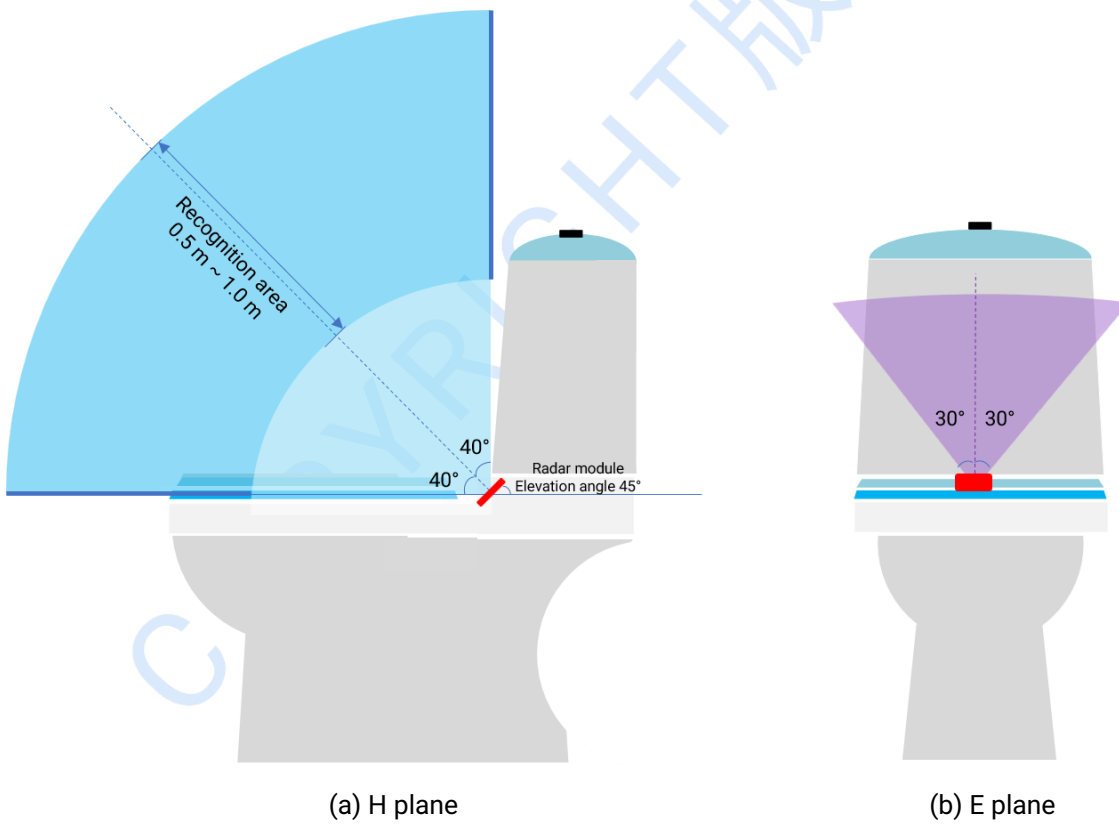


Figure 7-3 Illustration of radar gesture recognition area

## 8. Mechanical Size

Figure 8-1 presents the mechanical size of Xen102 hardware. The board thickness is 1.2 mm with a tolerance of  $\pm 10\%$ .

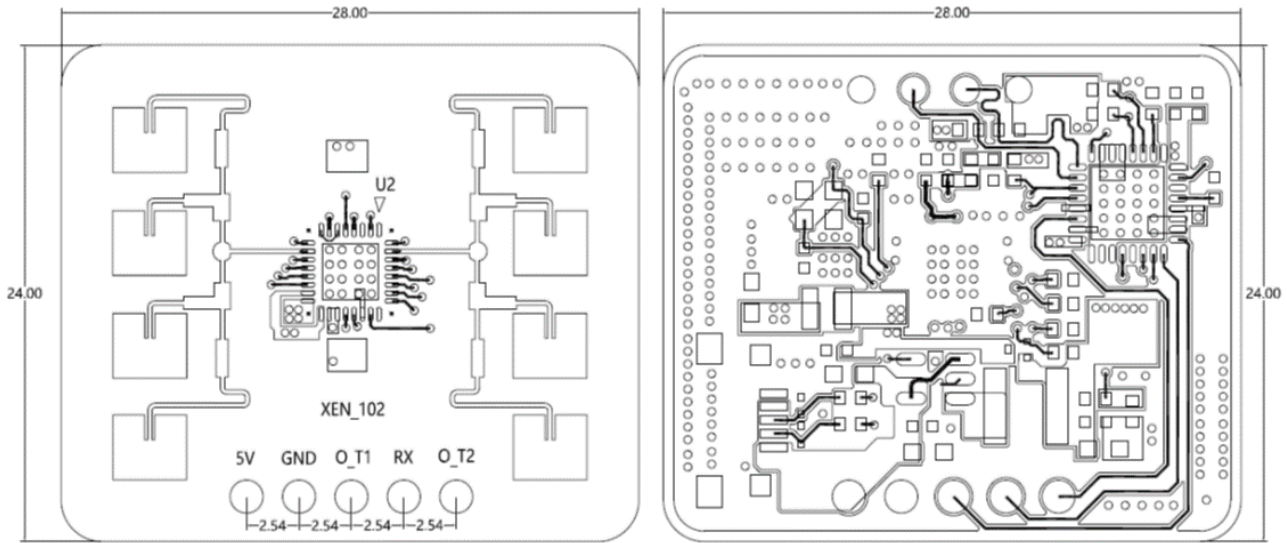


Figure 8-1 Xen102 mechanical size (mm)

## 9. Gesture Description

### 9.1 Definition of Gesture

When waving to the radar, users should stand facing the radar. It is suggested to change the waving hand according to the users' relative position to the radar to ensure the waving hand is closer to the radar, as shown in Figure 9-1.

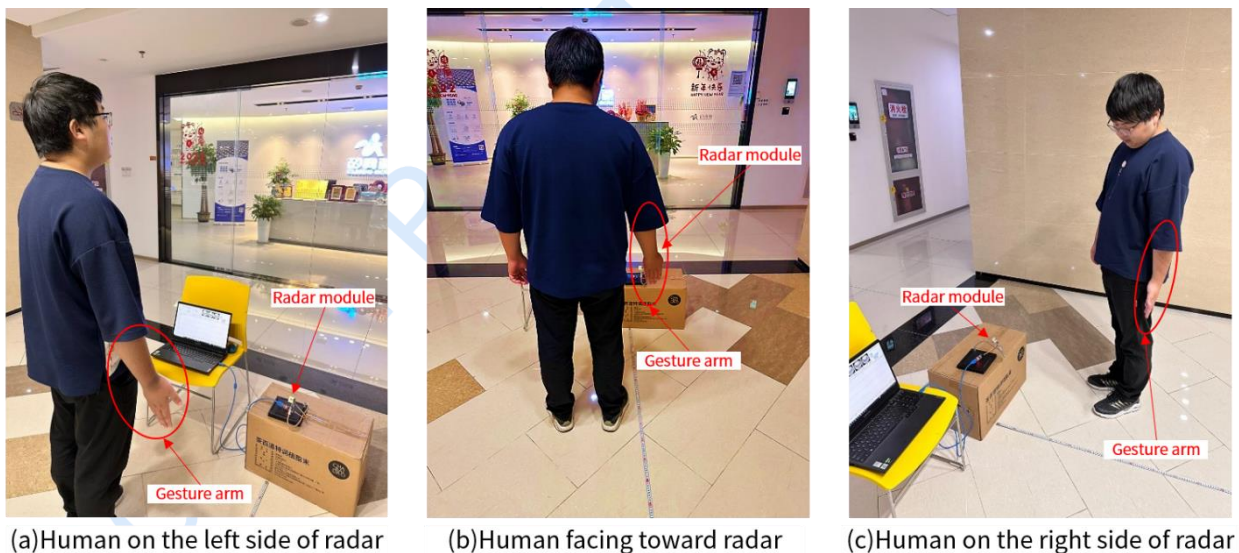


Figure 9-1 Possible user-radar relative positions when waving

Before waving, the hand stays down naturally. Users should first raise the arm up with the palm facing upward till the forearm is vertical to the ground, then let the arm drop down naturally with the palm still facing upward/forward. An example of one waving cycle is shown in Figure 9-2. To ensure the waving gesture is

correctly recognized, do not move the arm to the left or the right during the whole waving process. This means that users should only wave their arms upside down. The interval between two waving movements should be at least 1.5 s. When testing a radar installed on the toilet, it is suggested that the waving trajectory should pass the area right above the center of the toilet seat (i.e., the flushing hole of the toilet).



Figure 9-2 An example of one waving cycle

## 9.2 Speed of Gesture

Users should wave the arm at a constant speed of around 1.5 s per waving cycle.

## 9.3 Parameters of Gesture

Table 9-1 lists the values and descriptions of gesture parameters.

Table 9-1 Description of gesture parameters

Parameter	Default Value	Description
GESTURE_DISTANCE_LIMIT	120	Distance limit of gesture (cm)
PARAM_SLIDEFRAMECNT	5	Slide frame size
PARAM_DOPPLERHEIGHT_P	4	Positive Doppler benchmark value
PARAM_DOPPLERHEIGHT_N	-4	Negative Doppler benchmark value
PARAM_DOPPLERNUM_P	1	Amount of positive Doppler
PARAM_DOPPLERNUM_N	1	Amount of negative Doppler
PARAM_HIGHSPEED_DOPPLERVALUE	9	High speed Doppler value
PARAM_INVALID_FRAME	14	Amount of invalid frame
PARAM_TARGET_RNGBIN	3	Range bin of gesture
PARAM_NOISE_COEF	2.2	Base noise coefficient
PARAM_HIGHSPEED_DOPPLERNUM	0	Amount of highspeed Doppler
PARAM_WAVECNT_THD	3	Amount of waving cycle
PARAM_PNNUM_CNT	2	Amount of positive-negative pair
PARAM_WAVENUM_THD	50	Frame threshold
PARAM_GESTURECNT_THD	2	Threshold of halfway waving number

## 10. Important Tips

- Currently, test cases have been run in three different ways, they are bare module, module with ICLM radome, and module with ICLM radome & toilet seat. Due to the variations of toilet seats of different brands or models, users may encounter abnormal situations when testing this reference module for

ranging or gesture recognition. If so, please print out the 1DFFT or rdmap data, and adjust the chain gain or detection parameters accordingly.

- This firmware supports continuous ranging and gesture recognition and does not support being triggered by electrical level or PWM (Pulse Width Modulation). Users can develop these independently based on the released SDK if needed.

## 11. Revision History

Revision	Date	Modification
1.1	2023/4/17	Initial release.
1.2	2023/6/1	Add EULA to the visualization tool, update the figures of the visualization tool.

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