Radar Sensor in Ceiling Lighting Application

60 GHz Radar system with Alexa

About this document

Scope and purpose

This application note is intended to provide a proof-of-concept (POC) for an embedded platform that is a sensor system capable of transmitting sensor-generated data to Amazon Web Services (AWS) in order to control room lighting. The embedded platform starts with Infineon's Connected Sensor Kit (CSK) which uses a sensor board mounted to provide the complete IoT sensor system. This specific POC is a ceiling-mounted radar sensor that is used for detecting human presence and occupancy for lighting control. The CSK-based POC uses Infineon's XENSIV™ BGT60LTR11AIP 60GHz radar sensor shield stacked onto the Rapid IoT CYSBSYKIT-01 feather board. Utilizing the Wi-Fi capability on the feather board, detection information is sent to the AWS IoT platform and is handled by an AWS Lambda function to interact with an Alexa device via an Alexa Smart Home skill to control lighting.

Intended audience

This document is intended for users who would like to evaluate the radar sensor system in a ceiling-mounted application for detecting people and monitoring the human presence in a room to control smart home lighting and potentially other smart home devices or applications.

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1 Introduction

1.1 System overview

This application provides an example of a smart home lighting system using Infineon's BGT60LTR11AIP autonomous 60GHz radar sensor paired with Infineon's Connected Sensor Kit (CSK) IoT development kit connected to a Smart Home Skill in Amazon's Alexa mobile app.

The XENSIV™ BGT60LTR11AIP is a fully integrated radar sensor that includes Antennas in Package (AIP), built-in detectors for motion, and a state machine that allows operation in autonomous mode without any external microcontroller (see https://www.infineon.com/cms/en/product/evaluation-boards/shield_autonom_bgt60/). The Connected Sensor Kit's CYCBSYSKIT-01 Feather Board contains a Post 6 microcontroller and Wi-Fi and Bluetooth® Combo (see https://www.infineon.com/cms/en/product/promopages/connectedsensorkit/). It connects with Amazon Web Services (AWS) to pass the motion detection data from the BGT60LTR11AIP to a function hosted on AWS Lambda (https://docs.aws.amazon.com/lambda/), a serverless compute service on AWS. This AWS Lambda function connects to the Smart Home Skill, which acts as an application within the Alexa mobile app to interact with devices connected to Alexa (https://developer.amazon.com/en-US/docs/alexa/ask-overviews/what-is-the-alexa-skills-kit.html). The AWS Lambda function serves as the central component communicating with the radar system as well as Alexa. Alexa is used to control a smart bulb connected to the Alexa mobile app as configured by a user-created routine.

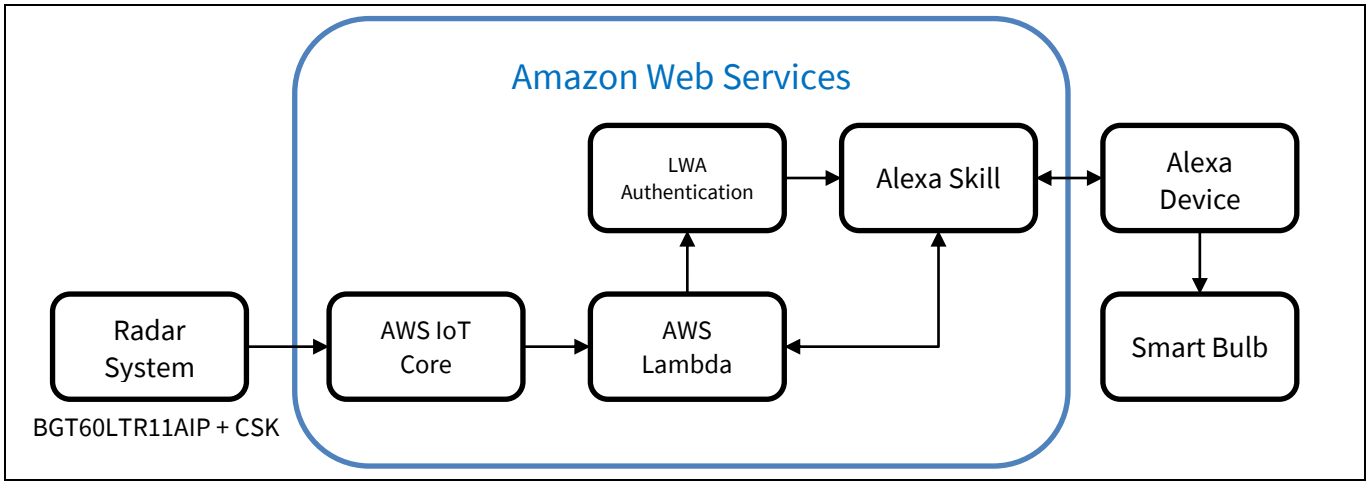
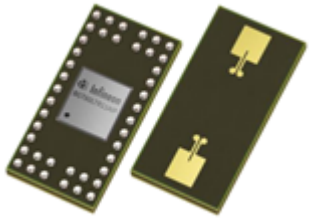


Figure 1 System overview

1.2 Radar system

The XENSIV™ BGT60LTR11AIP MMIC is a 60 GHz Doppler motion sensor, it is a fully integrated Monolithic Microwave Integrated Circuit (MMIC) that includes Antennas in Package (AIP), built-in detectors for motion, and a state machine that allows operation in autonomous mode without any external microcontroller. With the autonomous mode using the internal detector, this radar sensor can be integrated into smart buildings, smart home devices, smart appliances, smart lighting systems, security systems, and screen-based interface systems as a "plug and play" solution that does not require expertise in RF, antenna design, or radar signal processing. This compact radar solution is a cost-effective replacement for conventional Passive Infrared (PIR) sensors in low-power or battery-powered applications. A block diagram of the BGT60LTR11AIP is shown in Figure 2.



BGT60LTR11AIP MMIC
Radar Chipset

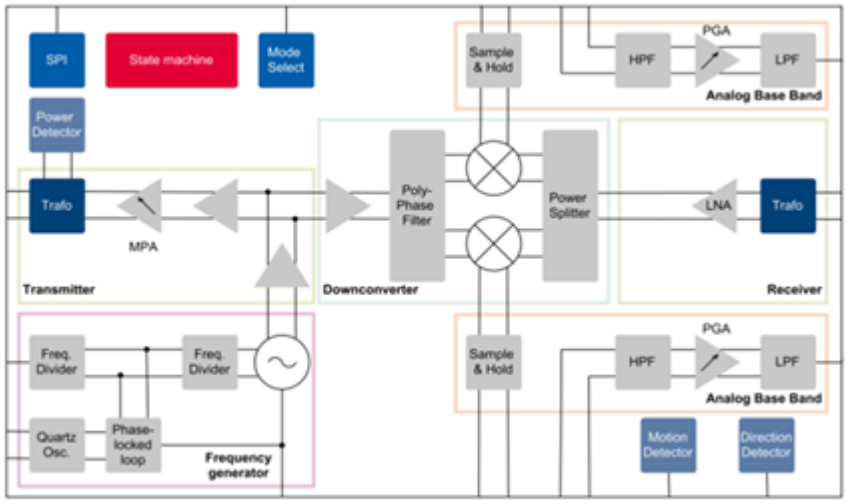


Figure 2 BGT60LTR11AIP MMIC 60 GHz radar and block diagram

The BGT60LTR11AIP autonomous shield (SHIELD_AUTONOM_BGT60) is a small 20 x 6.25 mm PCB optimized for fast prototyping designs and system integrations as well as initial product feature evaluations. Mounted on top of the PCB is a BGT60LTR11AIP MMIC with integrated antennas. It can detect a human target within a range of 5 m with less than 2 mW power consumption in its default autonomous mode. The bottom side of the shield has board-to-board connectors for a CSK compatible carrier board called a Wing Board. The castellated holes on the edges of the PCB provide additional access to the detector outputs and power supply signals of the shield. On the top side of the shield is a marker that must be aligned with the marker on the Wing Board for correct orientation, Figure 4 shows the correct alignment of the shield and position of the switches on the Wing Board.

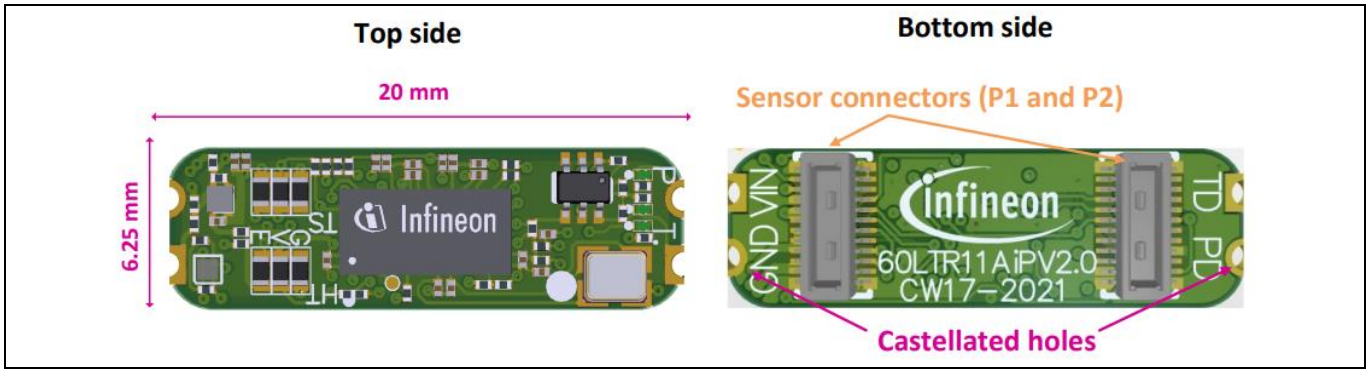


Figure 3 BGT60LTR11AIP Shield (SHIELD_AUTONOM_BGT60)

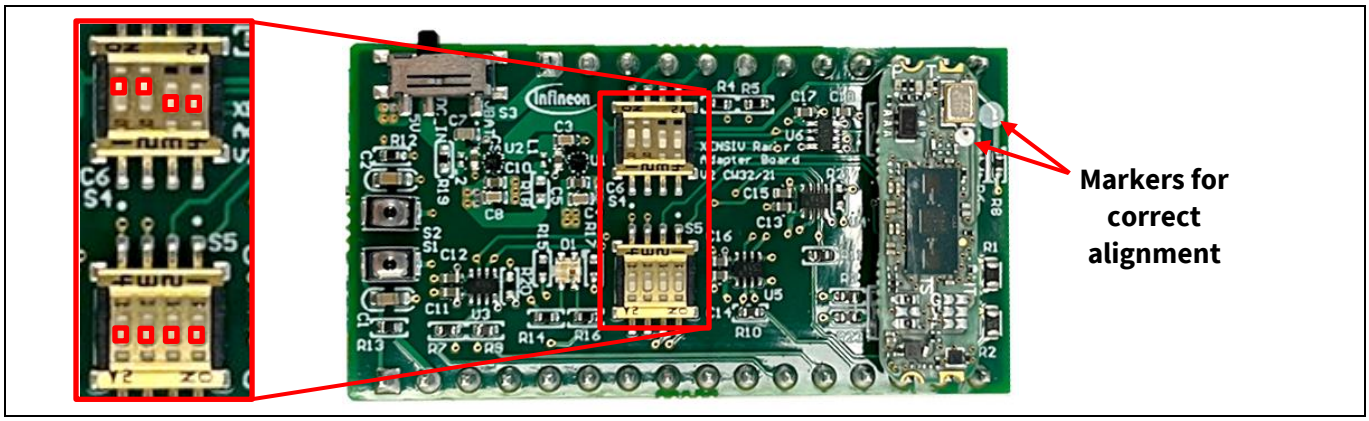


Figure 4 BGT60LTR11AIP Wing Board

The Wing Board is stacked on the Rapid IoT CYSBSYKIT-01 Feather Board, which is configured with firmware that continuously monitors the target detection pin status from the BGT60LTR11AIP radar for presence/absence status and transmits this information using Wi-Fi via a MQTT IoT messaging protocol (https://mqtt.org/) library configured to publish data on the AWS IoT Core platform. Since the firmware requires Wi-Fi connectivity, it is configured for a pre-defined SSID and password. Further details are provided in Section 3.1.

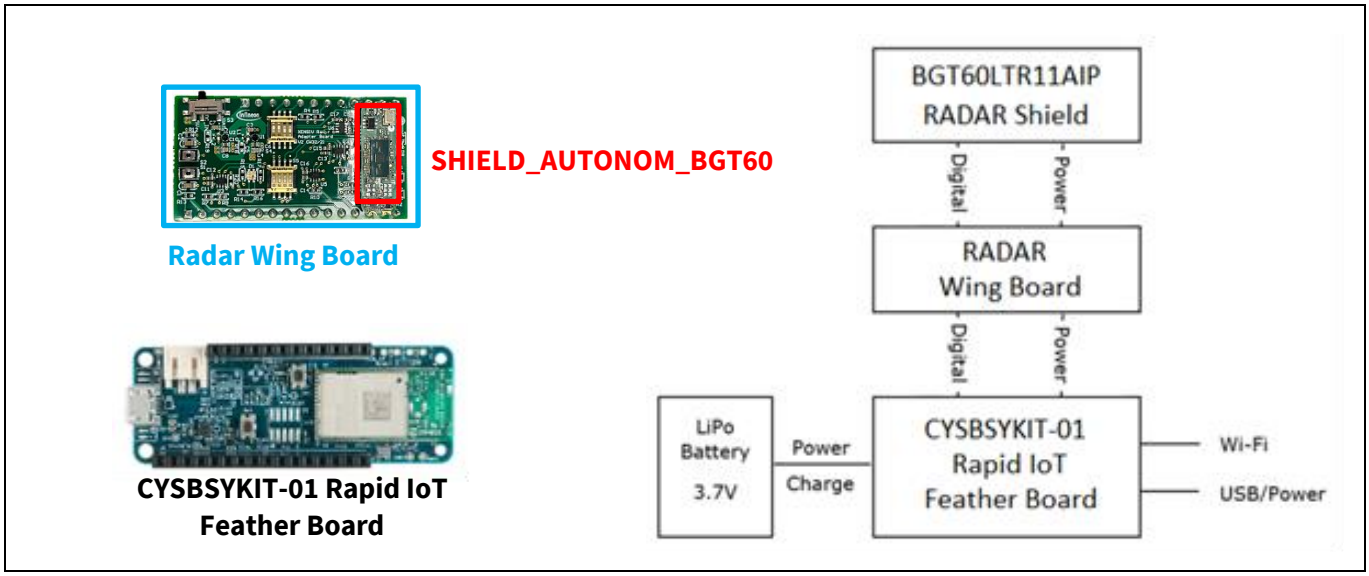


Figure 5 BGT60LTR11AIP Wing Board, CYSBSYKIT-01 Feather Board, and CSK block diagram

1.3 AWS IoT Core

AWS IoT Core receives messages published on the message topic configured in the Firmware (FW) running on the CSK and sends this information to AWS Lambda for further processing. With the existing implementation, no messages are sent back to the FW from the IoT Core. The FW acts only as a publisher and the IoT Core acts only as a subscriber.

1.4 AWS Lambda

AWS Lambda is a serverless, event-driven compute service that lets you run code for virtually any type of application or backend service without provisioning or managing servers. The Lambda function consists of Python code that is configured to receive messages from AWS IoT core and transfer it to the Alexa service.

1.5 Alexa

AWS Lambda is responsible for information exchange with the Alexa service. The response from Lambda can be observed from an Alexa app via an Alexa Smart Home skill. An Alexa Skill acts as an app within the Alexa service and allows interaction with devices connected to Alexa. This project has its own unique skill that can be enabled for a user. The skill is in a beta release form, not publicly visible within the Alexa app, and requires invitation via email for access. Once the invitation has been accepted, the CSK Smart Home Demo Skill appears in the Alexa app as shown in Figure 6.

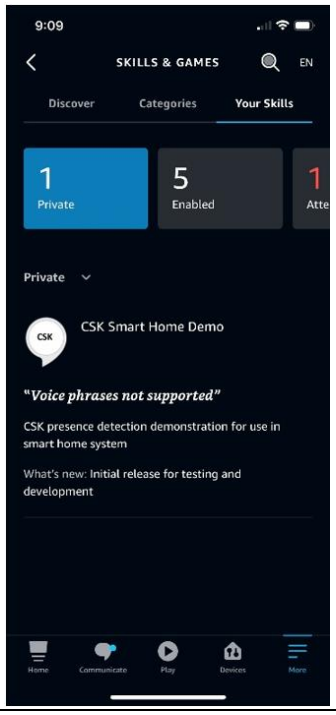


Figure 6 The CSK Smart Home Demo Skill as it appears in the Alexa app

1.6 Authentication

Every time an Alexa Smart Home skill is enabled on the Alexa app, an authentication is carried out for account linking. Once done, the skill is ready to be used. The authentication uses the “Login With Amazon” (LWA) service and requires an Amazon account.

2 Hardware setup

The following hardware (HW) components are required to get started with the demo:

- An Alexa-compatible Wi-Fi smart bulb along with a bulb stand. Please follow the installation instructions provided by the vendor of the smart bulb. The following smart bulb has been tested with the demo: https://www.amazon.com/LUMIMAN-Changing-Compatible-Assistant-Multicolor/dp/B07XYXY5QR
- Rapid IoT CYSBSYKIT-01 Feather Board from the Connected Sensor Kit (CSK). The CSK is not packaged with a power supply. The user will need to provide their own power supply and ensure that it is adequate for powering the CSK. Micro-USB type B with 5V, 1.5A rating is recommended. For more details on the CSK, please see https://www.infineon.com/cms/en/product/promopages/connectedsensorkit/
- BGT60LTR11AIP radar configured for autonomous mode. For further details, please refer to https://www.infineon.com/cms/en/product/evaluation-boards/shield_autonom_bgt60/
- Hotspot or other wireless HW that allows for user-configurable SSID and password, and WPA2 AES PSK security. Please note that smart bulbs may have other requirements for the Wi-Fi networks and/or require other related hardware (e.g. LUMIMAN smart bulb linked above requires 2.4GHz Wi-Fi network).

2.1 Mounting

The radar system is recommended to be mounted at the center of a room's ceiling, at a height of approximately 3 m (9.8 ft) from the floor, directly facing downwards without any tilting. The radar system is mounted in the position and orientation shown in Figure 7, within an unobstructed 9.1 m (30 ft) by 7.3 m (24 ft) area to test the detection area. The field of view covered by the test area is approximately 113.7° along the y-axis and 101.5° along the X-axis.

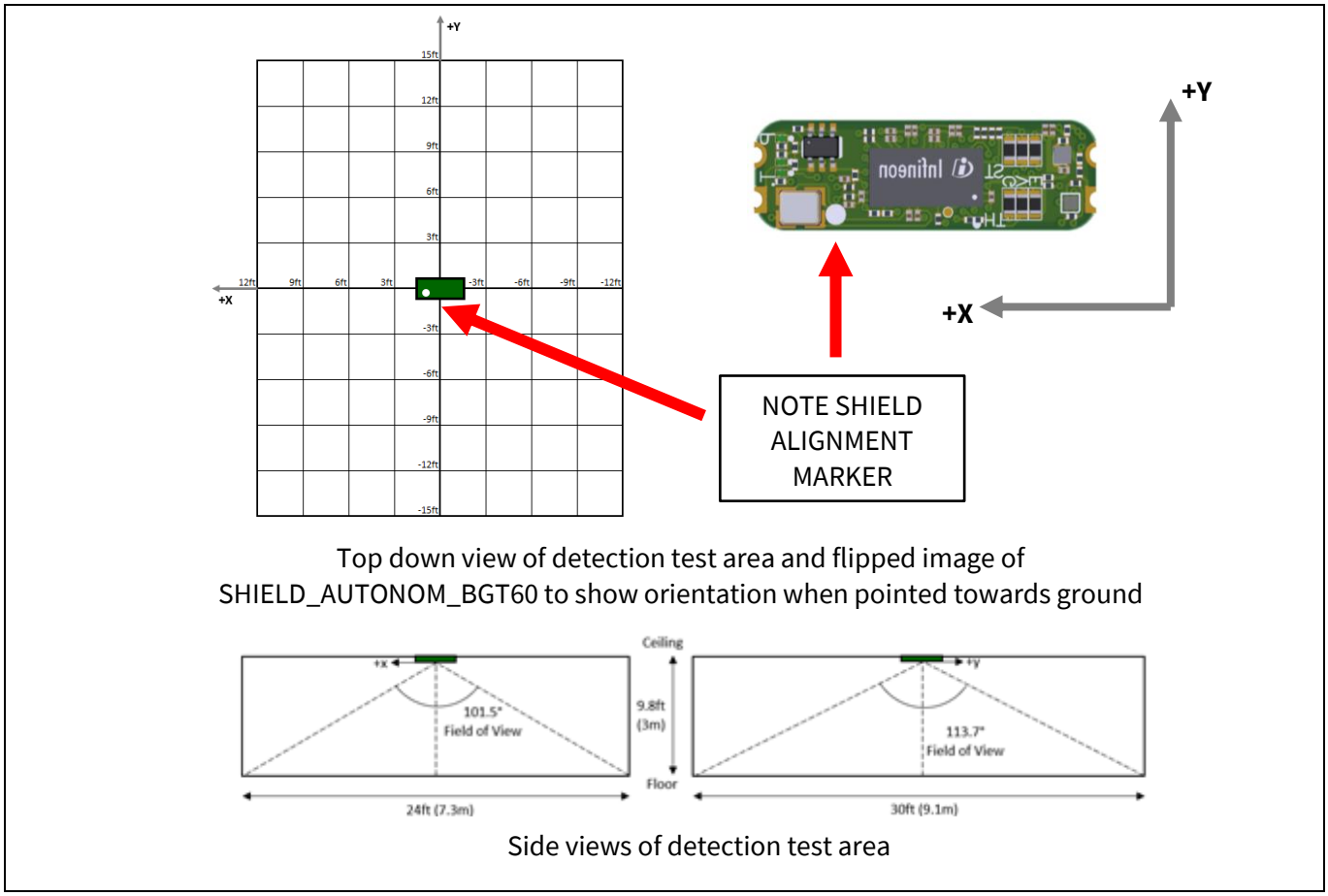


Figure 7 BGT60LTR11AIP radar in a ceiling mounted position, detection area, and field of view

3 Software setup

3.1 Hotspot or Wi-Fi

The FW on CSK is already configured with the following SSID, password, and security settings for connectivity, hence, users are recommended to create a hotspot with the same settings:

- SSID: ***IFX_CSKRCL***
- Password: ***LTR11AIP2022***
- Security: ***WPA2 AES PSK***

The CSK will attempt to connect to the Wi-Fi network for 10 minutes after powering on. If the above Wi-Fi settings are not available within that time duration, the CSK will need to be restarted once Wi-Fi has been set up. When the radar sensor on the CSK is connected and active, a green LED on the BGT60LTR11AIP shield will light up to show presence is detected and turn off when no presence is detected. There is a red LED on the shield which indicates the direction of motion, it is not used for this demo. Please refer to the App Note on the BGT60LTRAIP for more details: https://www.infineon.com/cms/en/product/evaluation-boards/demo-bgt60ltr11aip/

3.2 Alexa app and Alexa Smart Home skill

Please install Alexa app on your phone and login with your Amazon account. As outlined in Section 2, you will need to ensure that installation of an Alexa compatible smart bulb is already completed and the smart light bulb can be controlled using the Alexa app before proceeding forward. The **CSK Smart Home Demo** skill is distributed as a beta test and cannot be found via the Alexa app itself, to access the skill your email account must be provided to Infineon and an invitation will be sent a shown in Figure 8. Once your email address has been registered with Infineon, a separate link will be sent to the email address providing instructions to install the CSK Smart Home Demo skill.

Note: The smart bulb and Alexa app do not need to be connected to the same network.

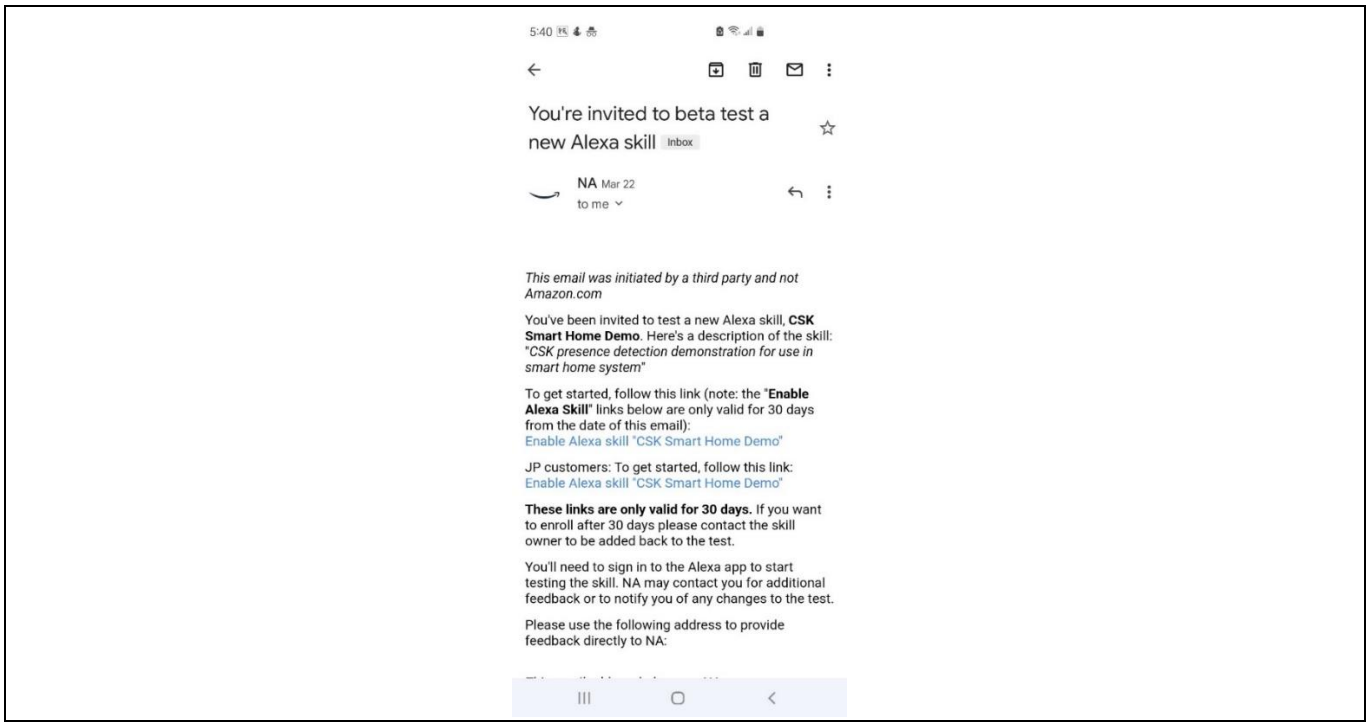


Figure 8 Email invitation for accessing Smart Home skill

Please click on the “Enable Alexa Skill” link to install the skill. This will open the Alexa app and provide an option as shown in Figure 9.

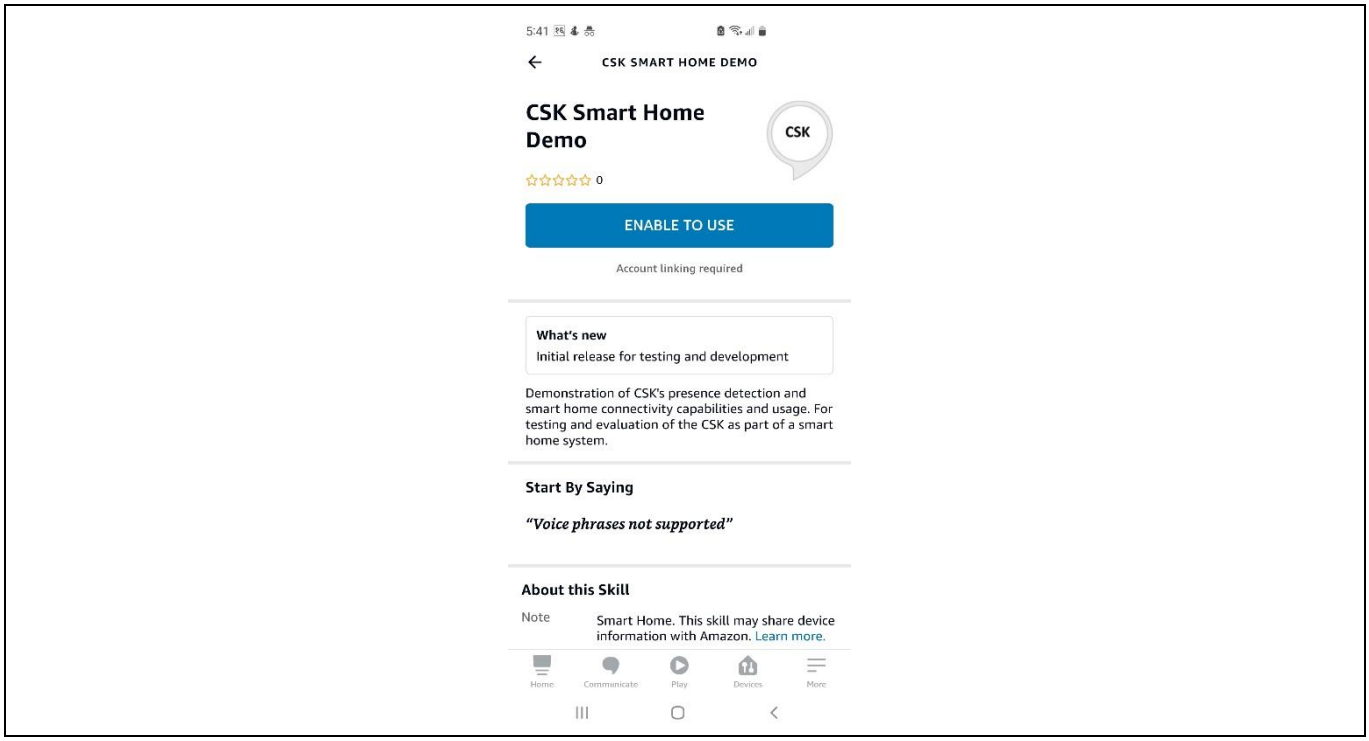


Figure 9 Smart Home skill installation on Alexa app

To enable the skill in the app, you will need to log in with your Amazon credentials to “skills” using “Login With Amazon” (LWA) which provides account linking for authentication as shown in Figure 10. Once completed, a success message is displayed as shown in Figure 11.

Selecting “Discover Devices” will add the CSK Smart Home device to the Alexa app. The app will show “1 motion sensor found and connected” and lead to an optional device setup. Once the setup is completed or skipped, the app will show “CSK Smart Home is set up and ready to use”.

Note that the Alexa app may show “No new devices found” after device discovery if the CSK Smart Home device has been previously added to the Alexa app. Select “Check if your device is already set up” to view all devices. The CSK Smart Home device should be listed and show whether motion is detected or not, as shown in Figure 12. If the status of the device is not updating as expected, please ensure that the CSK and its Wi-Fi network outlined in Section 3.1 has been successfully set up.

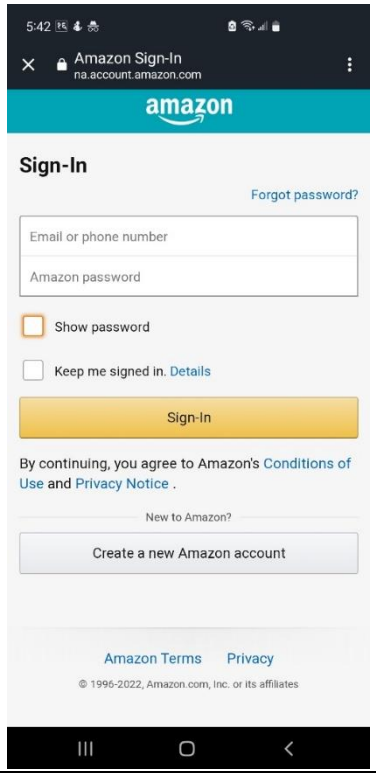


Figure 10 Account linking for Smart Home skill

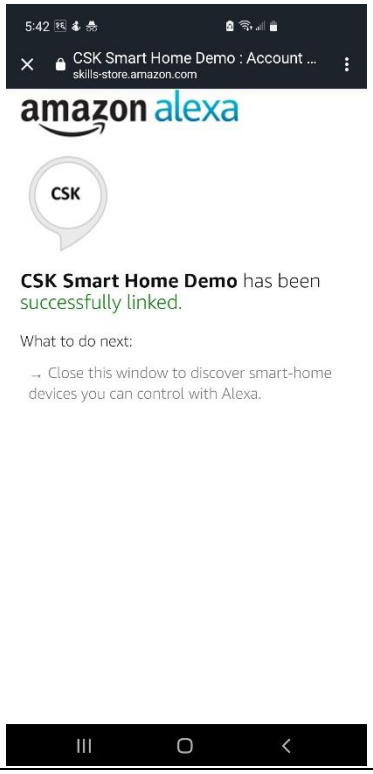


Figure 11 Confirmation for account linking

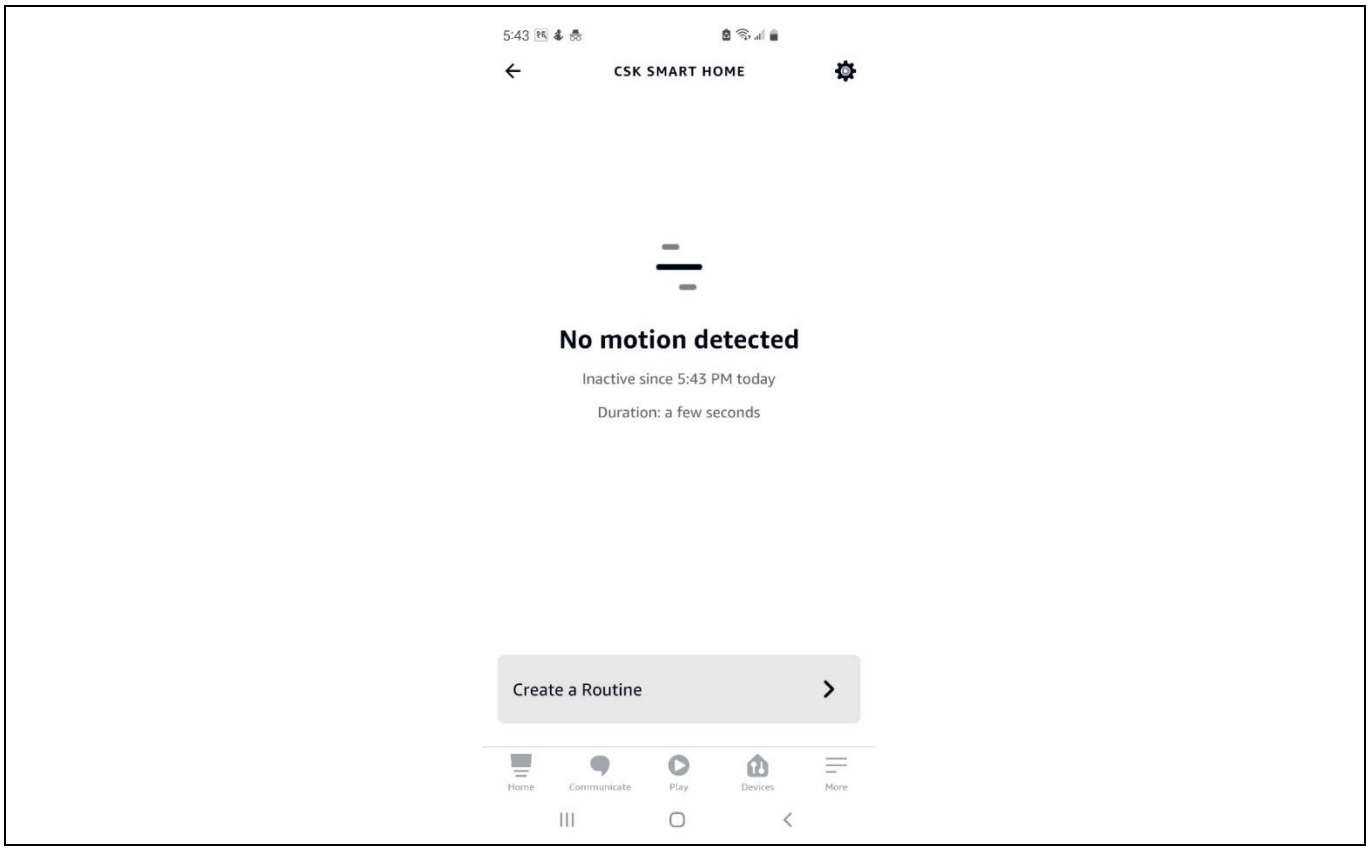


Figure 12 Status on presence/absence

A routine can now be created to use the status of the CSK Smart Home to control another smart home device, such as a smart bulb, as shown in Figure 13 and Figure 14. Please click on Create a Routine option to get started and make sure all routines are enabled once created. Other devices linked to the Alexa app may also be similarly connected via routines.

Two routines need to be created in the Alexa app to control the smart bulb: **Presence** and **Absence**. For Presence, set the routine trigger to the CSK Smart Home devices detecting motion and the action to power on the smart light bulb. For Absence, set the routine trigger to the CSK Smart Home devices detecting no motion for 0 minutes and the action to power off the same smart light bulb. Enabling both routines will allow the light to turn on or off depending on the radar sensor's presence detection. The Alexa app will store and show when each routine has been triggered under "Activity".

If the smart bulb is not behaving as expected, check that routines are successfully triggering under "Activity". The CSK Smart Home Demo skill currently supports routine triggering with only one linked account. If the skill has been enabled but routines using the CSK Smart Home device are not being triggered, disable then re-enable the skill to link your account, the skill will be listed in "Your Skills" under "Private" in the Alexa app. If the routines are successfully triggered, but the smart bulb is not behaving accordingly, please ensure that the smart bulb along with its associated skill and app are set up correctly.

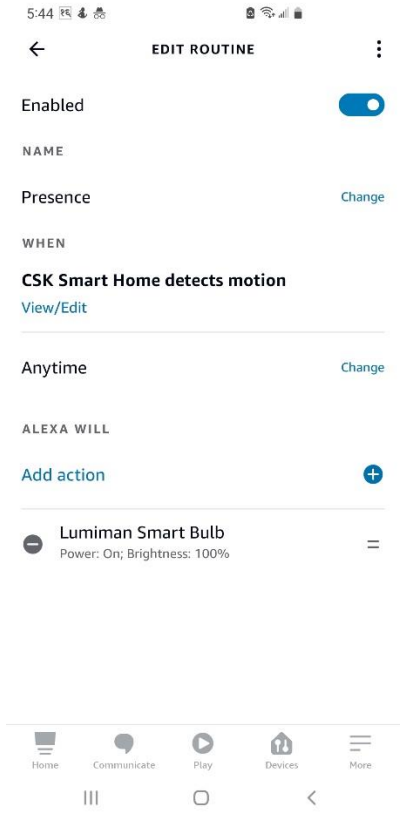


Figure 13 Routine to handle presence: turn on smart bulb with 100% brightness

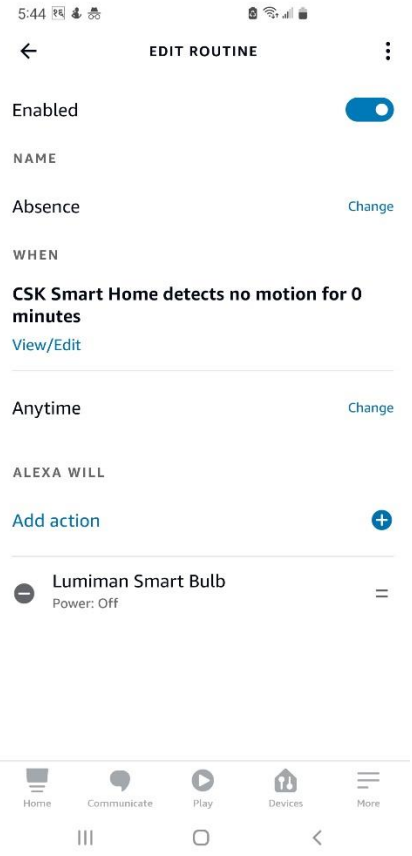


Figure 14 Routine to handle absence: turn off smart bulb

4 Testing observations

The detection area of the BGT60LTR11AIP with the default settings in the pulsed Doppler autonomous mode for major and minor motion was tested in an open area of a large room to provide a sample detection heatmap, additional testing is recommended for the intended use cases and setups. The default settings for autonomous mode on the shield are 61.1 GHz operating frequency, sensitivity level of 13 (corresponding detector threshold of 80), detection hold time of 1 second, and Pulse Repetition Time of 500 microseconds.

Four trials for the major and minor motion tests were performed based on the test procedure in the NEMA WD-7 standard for occupancy motion sensors (https://www.nema.org/Standards/view/Occupancy-Motion-Sensors-Standard). The radar system was mounted directly on the ceiling with double-sided tape, pointing straight down towards the ground, and powered via a USB cable attached to the ceiling. The radar was at point (0, 0) in a grid of 0.9 m (3 ft) by 0.9 m (3 ft) cells. As the coverage area exceeded the available testing area, the alternate method outlined in the NEMA WD-7 standard was used, where half the detection area is tested before the sensor is rotated 180° to test the other half.

- Major motion tested a person walking from one edge of a cell to another parallel to either the X-axis or Y-axis of the grid, with a two-second pause at each edge to find the areas where detection is triggered or maintained.
- The minor motion tested a person seated in the middle of each cell and moving a forearm in four vertical 90° sweeps to trigger detection after an absence state. Figure 15 and Figure 16 show the detection heatmaps in a confidence level for detection based on the results of four test trials.

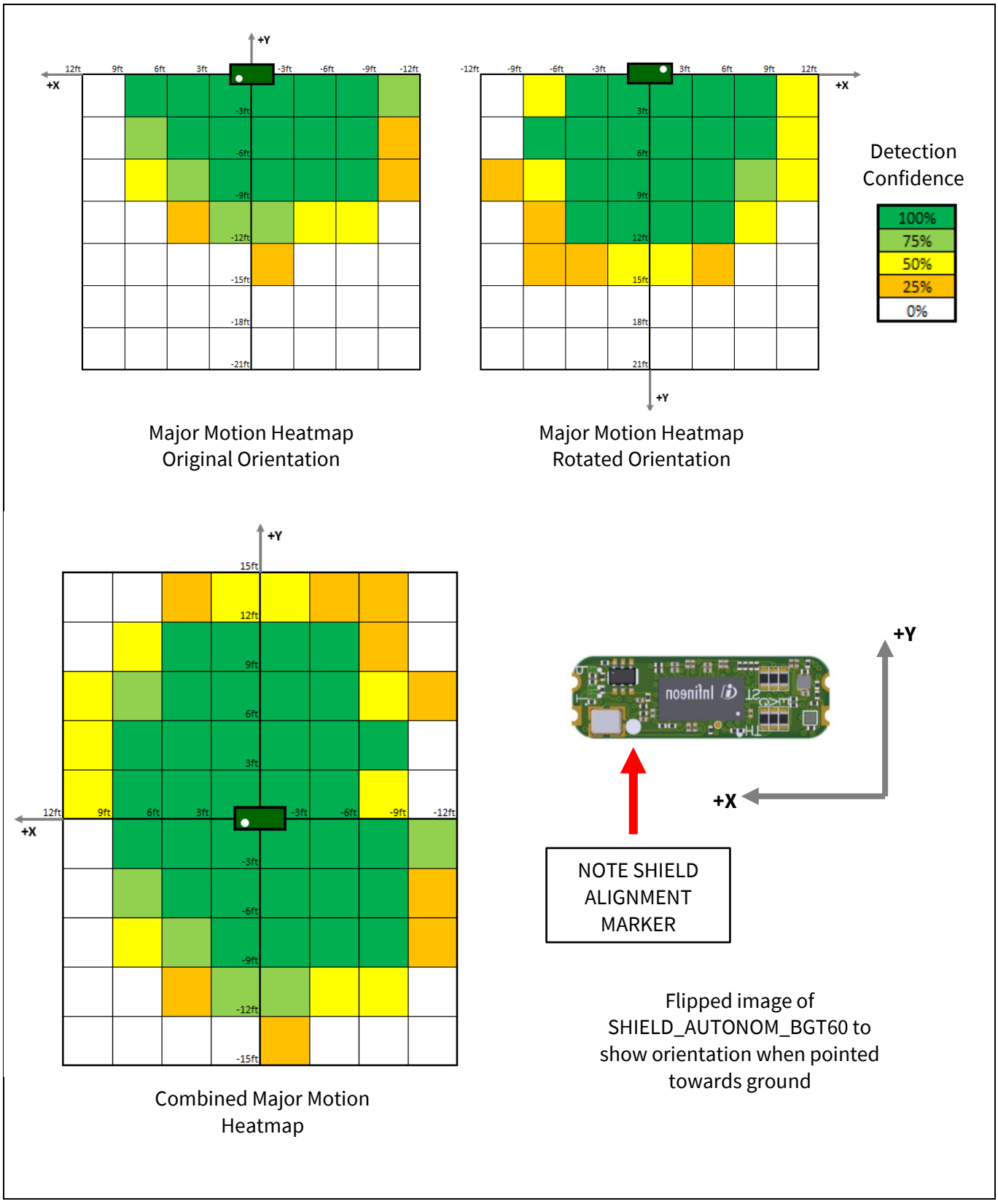


Figure 15 BGT60LTR11AIP radar heatmaps for major motion detection

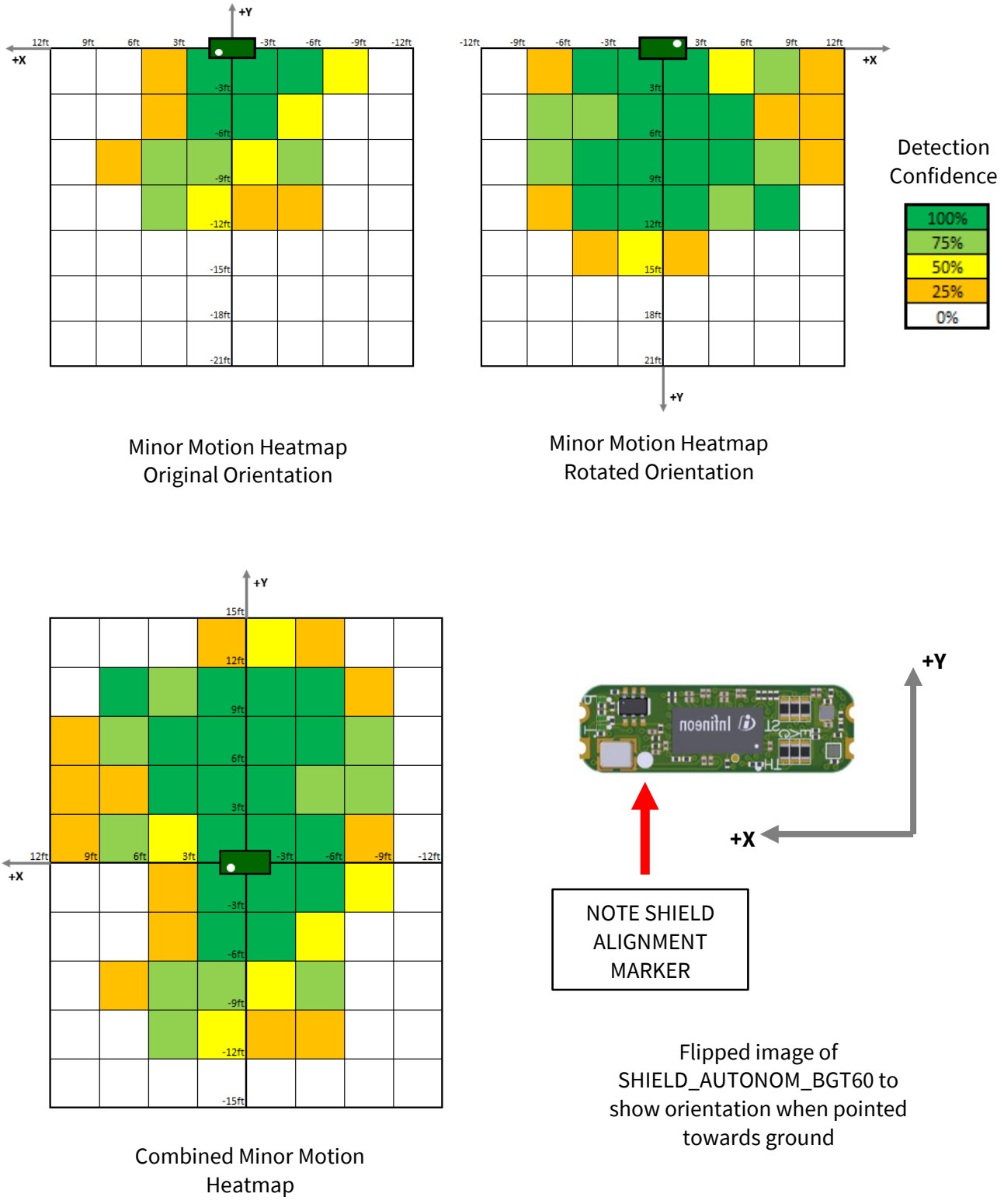


Figure 16 BGT60LTR11AIP radar heatmaps for minor motion detection

5 Future upgrades and capabilities

The radar sensor is intended to detect people within a room. Other moving objects such as fans, open windows with blinds, curtains, etc. may be detected at this time. Infineon is developing an algorithm that will allow detection of human presence only, which can be installed onto the embedded radar sensor system when the algorithm is available. False positives can be minimized when the sensor intelligence is increased to only detect human presence and occupancy. Future implementations of the radar sensor system will have a BGT60TR13C or updated BGT60LTR11AIP radar carrier board, which will be equipped with sophisticated algorithms for human localization and positioning. The sensor system will enable intelligent room monitoring, where people can be detected in certain areas or zones in the room. Such capabilities can allow for customized room lighting or environmental conditions depending on where people are in the room.

6 References

[1] SHIELD_AUTONOM_BGT60. See information at https://www.infineon.com/cms/en/product/evaluation-boards/shield_autonom_bgt60/

[2] Connected Sensor Kit. See information at https://www.infineon.com/cms/en/product/promopages/connectedsensorkit/

[3] AWS Lambda. See information at https://docs.aws.amazon.com/lambda/

[4] Alexa Skills. See information at https://developer.amazon.com/en-US/docs/alexa/ask-overviews/what-is-the-alexa-skills-kit.html

[5] MQTT messaging protocol for IoT. See information at https://mqtt.org/

[6] Alexa Smart Home Skills. See information at https://developer.amazon.com/en-US/docs/alexa/smarthome/understand-the-smart-home-skill-api.html

[7] NEMA Occupancy Motion Sensor Standard WD 7-2011 (R2016, R2021). See information at https://www.nema.org/Standards/view/Occupancy-Motion-Sensors-Standard

Revision history

Document version	Date of release	Description of changes
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