REF_BGT60LTR11AIP_M0

XENSIV™ 60 GHz radar reference board

Board version V 1.0

About this document

Scope and purpose

This application note describes the function, circuitry, and performance of the BGT60LTR11AIP M0 radar reference board (REF_BGT60LTR11AIP_M0). The board provides the supporting circuitry to the XENSIV™ BGT60LTR11AIP monolithic microwave integrated circuit (MMIC) in an Antenna in Package (AIP).

This reference board offers an SPI digital interface for configuration and transfer of the acquired radar data to an Arm® Cortex®-M0 based microcontroller.

Intended audience

This document is intended for design engineers, technicians, and developers of electronic systems, working with Infineon's XENSIV™ 60 GHz radar sensors.

Reference Board/Kit

Product(s) embedded on a PCB with a focus on specific applications and defined use cases that may include software. PCB and auxiliary circuits are optimized for the requirements of the target application.

Note: Boards do not necessarily meet safety, EMI, quality standards (for example UL, CE) requirements.

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Safety precautions

Note: *Please note the following warnings regarding the hazards associated with development systems*

Table 1 Safety precautions

	Warning: *The DC link potential of this board is up to 1000 VDC. When measuring voltage waveforms by oscilloscope, high voltage differential probes must be used. Failure to do so may result in personal injury or death.*
	Warning: *The evaluation or reference board contains DC bus capacitors which take time to discharge after removal of the main supply. Before working on the drive system, wait five minutes for capacitors to discharge to safe voltage levels. Failure to do so may result in personal injury or death. Darkened display LEDs are not an indication that capacitors have discharged to safe voltage levels.*
	Warning: *The evaluation or reference board is connected to the grid input during testing. Hence, high-voltage differential probes must be used when measuring voltage waveforms by oscilloscope. Failure to do so may result in personal injury or death. Darkened display LEDs are not an indication that capacitors have discharged to safe voltage levels.*
	Warning: *Remove or disconnect power from the drive before you disconnect or reconnect wires, or perform maintenance work. Wait five minutes after removing power to discharge the bus capacitors. Do not attempt to service the drive until the bus capacitors have discharged to zero. Failure to do so may result in personal injury or death.*
	Caution: *The heat sink and device surfaces of the evaluation or reference board may become hot during testing. Hence, necessary precautions are required while handling the board. Failure to comply may cause injury.*
	Caution: *Only personnel familiar with the drive, power electronics and associated machinery should plan, install, commission and subsequently service the system. Failure to comply may result in personal injury and/or equipment damage.*
	Caution: *The evaluation or reference board contains parts and assemblies sensitive to electrostatic discharge (ESD). Electrostatic control precautions are required when installing, testing, servicing or repairing the assembly. Component damage may result if ESD control procedures are not followed. If you are not familiar with electrostatic control procedures, refer to the applicable ESD protection handbooks and guidelines.*
	Caution: *A drive that is incorrectly applied or installed can lead to component damage or reduction in product lifetime. Wiring or application errors such as undersizing the motor, supplying an incorrect or inadequate AC supply, or excessive ambient temperatures may result in system malfunction.*
	Caution: *The evaluation or reference board is shipped with packing materials that need to be removed prior to installation. Failure to remove all packing materials that are unnecessary for system installation may result in overheating or abnormal operating conditions.*

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1 Introduction

1.1 Overview

The BGT60LTR11AIP MMIC is a fully integrated Antenna in Package (AIP) microwave motion sensor with built-in motion and direction of motion detectors. This small-sized radar solution is a compelling, smart, and cost-effective replacement for conventional passive infrared (PIR) sensors in low-power or battery-powered applications. The MMIC is designed to operate as a Doppler motion sensor in the 60 GHz ISM band.

The MMIC supports multiple operation modes, including autonomous mode and SPI mode. The MMIC has four quad-state (QS1–4) input pins that provide flexibility in performance parameters even when it is running in autonomous mode. See Section 4.

The BGT60LTR11AIP M0 reference board works in SPI mode, which is set using the QS1 pin. SPI mode offers full flexibility in the configuration of radar MMIC parameters such as detection threshold, hold time, and operation frequency. In this mode, the required configuration can be programmed into the MMIC registers using an external MCU and the integrated detectors also deliver digital outputs indicating motion and direction of motion. If further signal processing is required, the radar raw data can be extracted and sampled from BGT60LTR11AIP MMIC and then used for developing customized algorithms for maximum performance.

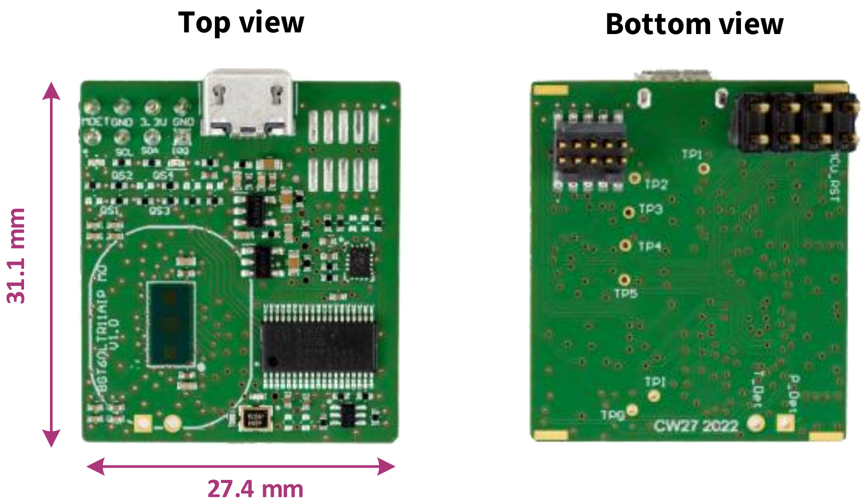


Figure 1 Top and bottom views of BGT60LTR11AIP M0 reference board

1.2 Key features

The BGT60LTR11AIP M0 reference board is optimized for initial product feature evaluation, fast prototyping design, and system integration. In addition, the sensor can be integrated into systems like laptops, tablets, TVs, and speakers to 'wake' them up based on motion (or direction of motion) detection, or to put them to sleep or auto-lock when no motion is detected for a defined amount of time. This way, it can be a smart power saving feature for these devices and might also eliminate the need for keyword-based activation of systems. Radar sensors can be concealed inside the end product because they operate through non-metallic materials.

Some key features of the BGT60LTR11AIP M0 reference board are as follows:

- 31 mm x 28 mm form factor
- Features an AIP MMIC of small size (6.7 mm x 3.3 mm x 0.56 mm), thereby eliminating antenna design complexity at the user end
- Detects motion and direction of movement (approaching or departing) for a human target
- Works standalone (autonomous mode) or also with SPI mode to interface with an external Cortex®-M0 microcontroller to do further signal processing
- Configurable settings like operation mode, detector threshold, hold time, and operating frequency

2 System specifications

Table 2 BGT60LTR11AIP M0 reference board specifications

Parameter	Unit	Min.	Typ.	Max.	Comments
System performance					
Maximum detection range	m	–	10	14	Typical motion detection range for human target at high sensitivity (in both E-plane and H-plane orientation)
Power supply					
Supply voltage	V	–	5.0	–	–
Current consumption	mA	–	13	–	At 5 V supplied via USB PRT = 500 µs, pulse width = 5 µs (LEDs off) (9.2 mA M0 MCU + 3 mA MMIC)
Antenna characteristics (measured)					
Antenna type		–	1 x 1	–	Antenna-in-package (AIP)
Horizontal – 3 dB beam width (HPBW)	Degrees	–	80	–	At frequency = 61.25 GHz
Elevation – 3 dB beam width (HPBW)	Degrees	–	80	–	At frequency = 61.25 GHz

3 Hardware description

This section provides an overview of the board's hardware building blocks, such as BGT60LTR11AIP MMIC, microcontroller, power supply, crystal, and board interfaces.

3.1 Key features

The BGT60LTR11AIP M0 reference board is a 26 x 28 mm PCB as shown in Figure 2. Mounted on top of the PCB is an Infineon XENSIV™ BGT60LTR11AIP 60 GHz radar sensor. The antennas are integrated into the chip package; therefore, the PCB can be manufactured using a standard FR4 laminate. The board can be powered up by using the USB port or the 3.3 V pins. Two Onsemi LDOs are used for providing a clean supply to the components on the board. The board has a XMC1302-T038X0200 Arm® Cortex® M0 microcontroller to apply different settings to the MMIC and to perform further signal processing and algorithm implementation using the output signals of the MMIC.

The communication between the MMIC and MCU is mainly performed via SPI. These signals need to be level-shifted using a level shifter to interface with the SPI block of the MCU. BSD84N (Q1A) and SN74AVC4T245RSVR (U5) are used for level shifting. The MMIC uses a 38.4 MHz crystal (Y1) as an oscillator source with a stable reference clock. The Cortex® debug connector can be placed on the top side or the bottom side of the board and is used to connect an XMC™ Link (J-Link based debug probe). The connectors provide access to other important signals of the board. The board has two LEDs (D1 and D2) to output the results from the MCU. The block diagram of the board is shown in Figure 3.

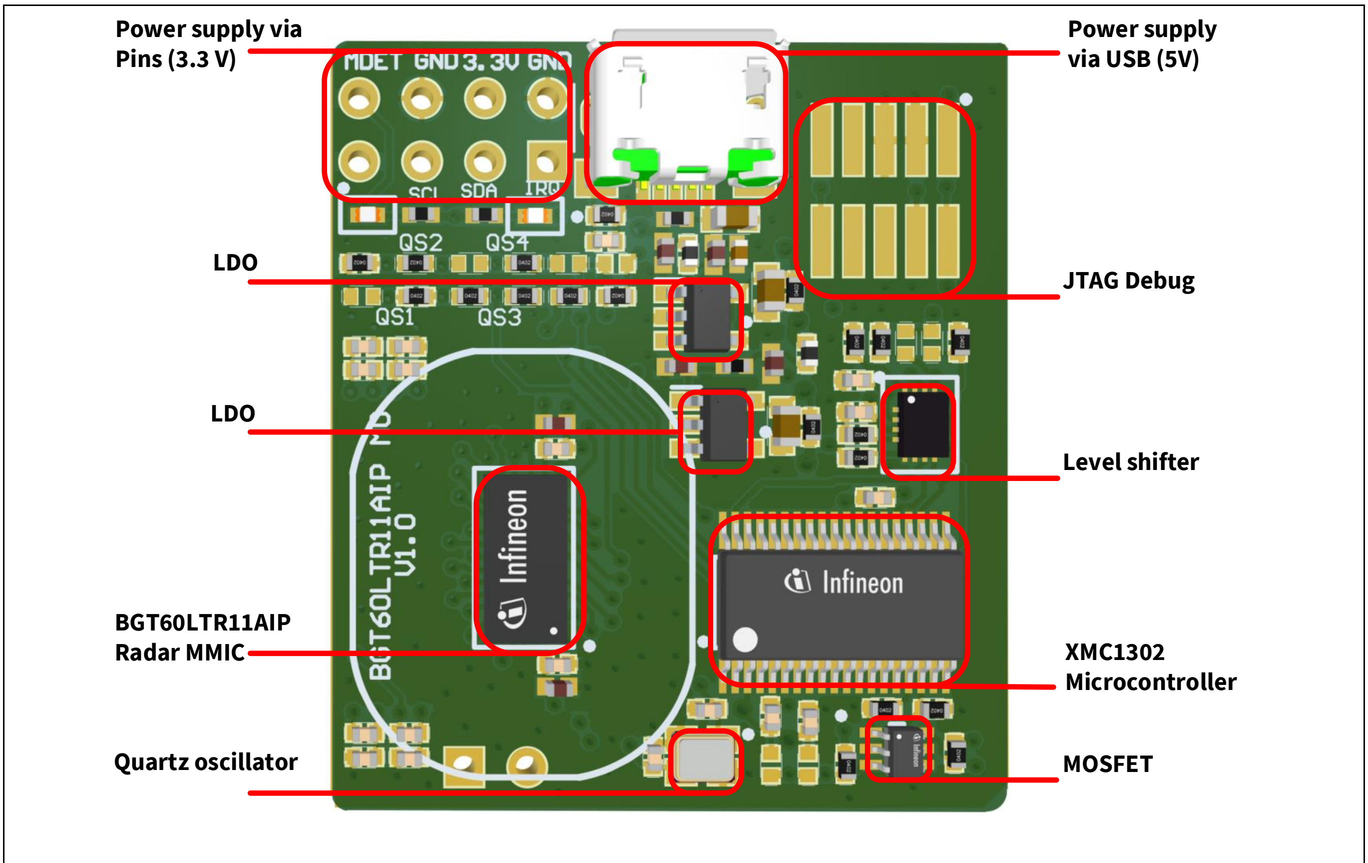


Figure 2 Components on BGT60LTR11AIP M0 reference board

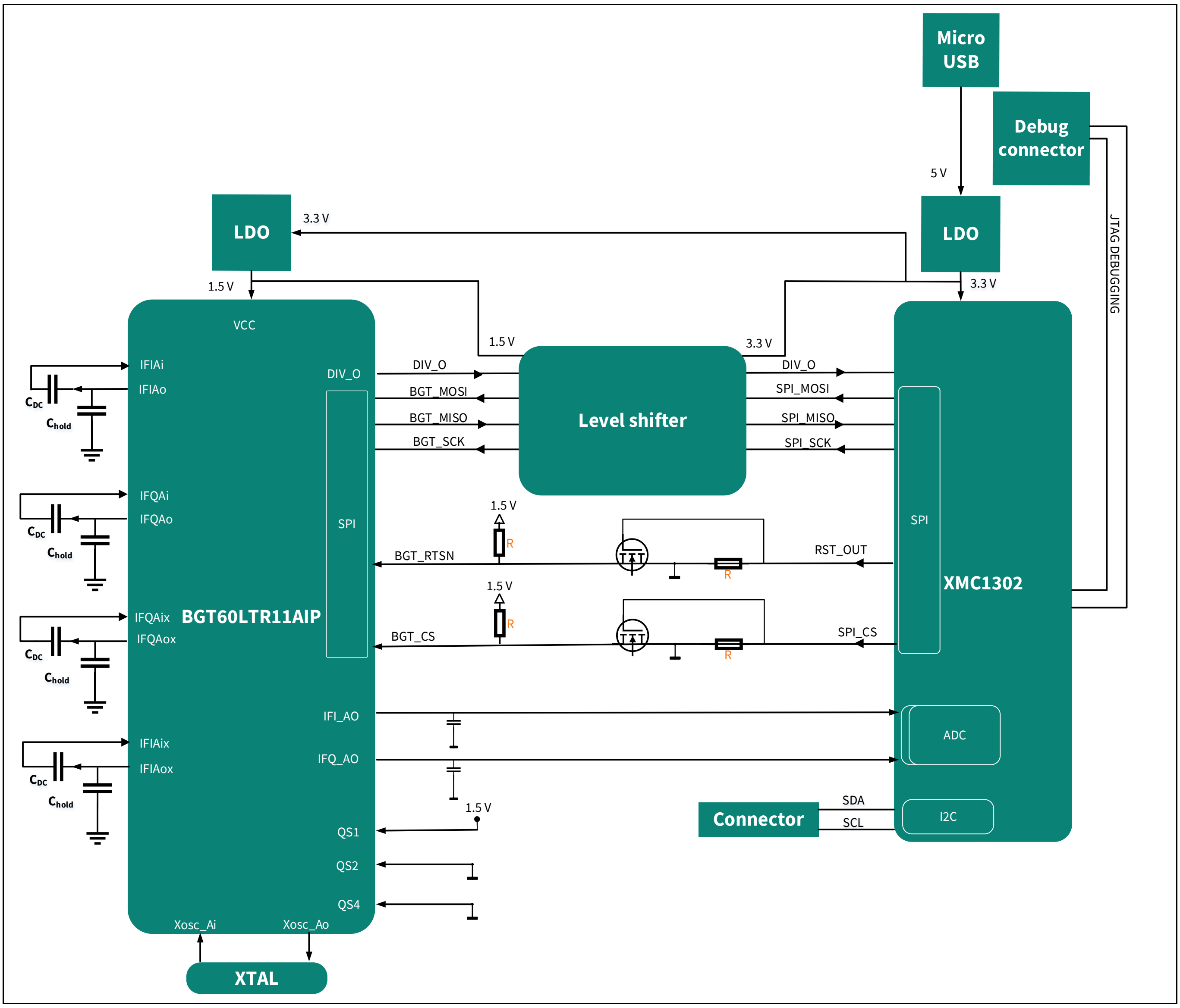


Figure 3 **Block diagram of BGT60LTR11AIP M0 reference board**

3.2 BGT60LTR11AIP MMIC

The BGT60LTR11AIP MMIC (Figure 4) is the main element on the BGT60LTR11AIP M0 reference board. The MMIC has one transmit antenna and one receive antenna integrated into the package, as shown in Figure 5.
The package dimensions are 6.7 mm x 3.3 mm x 0.56 mm, as shown in Figure 6.

The MMIC has an integrated voltage-controlled oscillator (VCO) and PLL for high-frequency signal generation. The transmit section consists of a medium power amplifier (MPA) with configurable output power, which can be controlled via SPI.

The chip features a low-noise quadrature receiver stage. The receiver uses a low-noise amplifier (LNA) in front of a quadrature homodyne down-conversion mixer to provide excellent receiver sensitivity. Derived from the internal VCO signal, an RC poly-phase filter (PPF) generates quadrature LO signals for the quadrature mixer.

The analog baseband (ABB) unit consists of an integrated sample-and-hold circuit for low-power duty-cycled operation. This is followed by an externally configurable high-pass filter, a variable gain amplifier (VGA) stage, and a low-pass filter.

The integrated target detector circuits in the MMIC use two digital signals (BGT_TARGET_DET and BGT_PHASE_DET) to indicate the detection of movement in front of the radar and the direction of movement. See Section 3.9 for more details. The detector circuit offers a user-configurable hold-time for maximum flexibility.

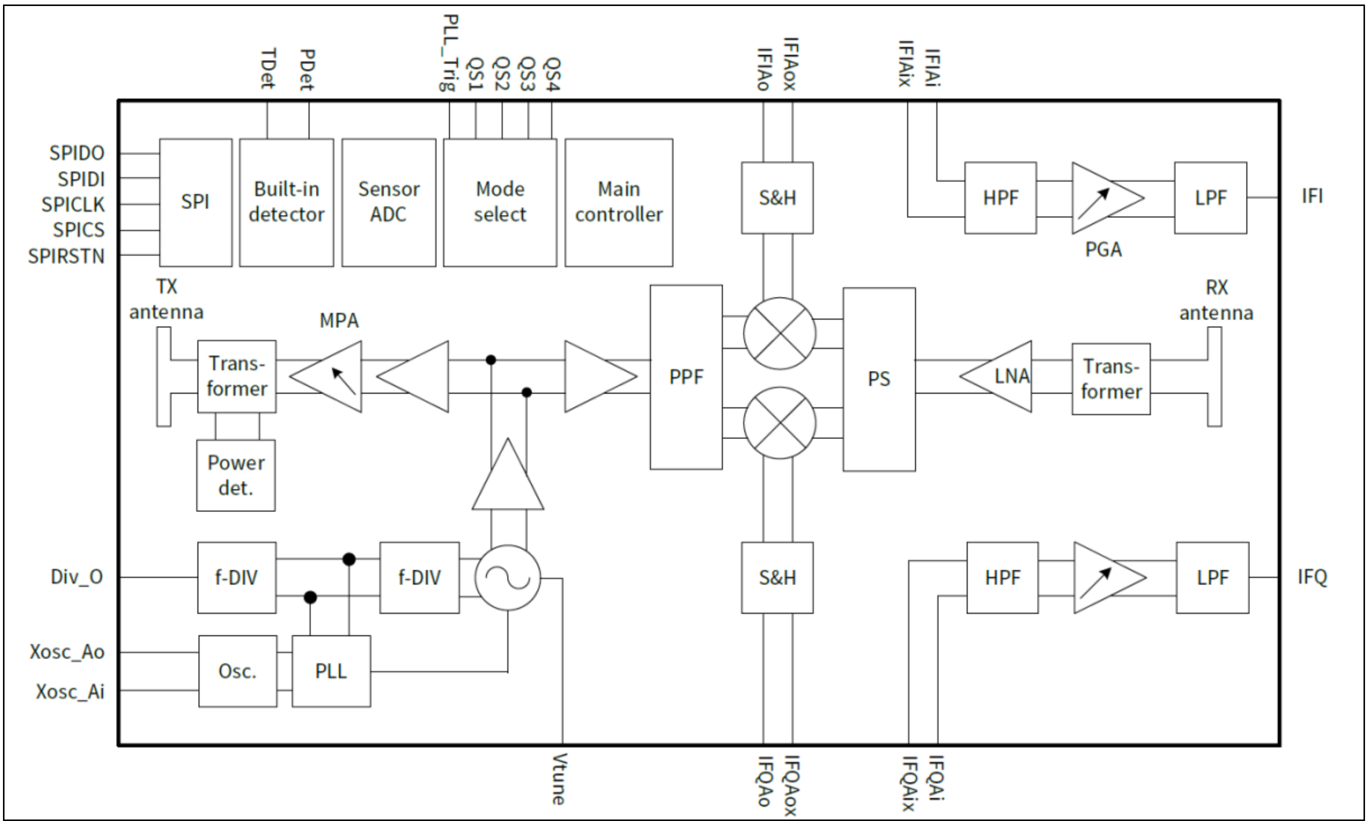


Figure 4 **BGT60LTR11AIP MMIC block diagram**

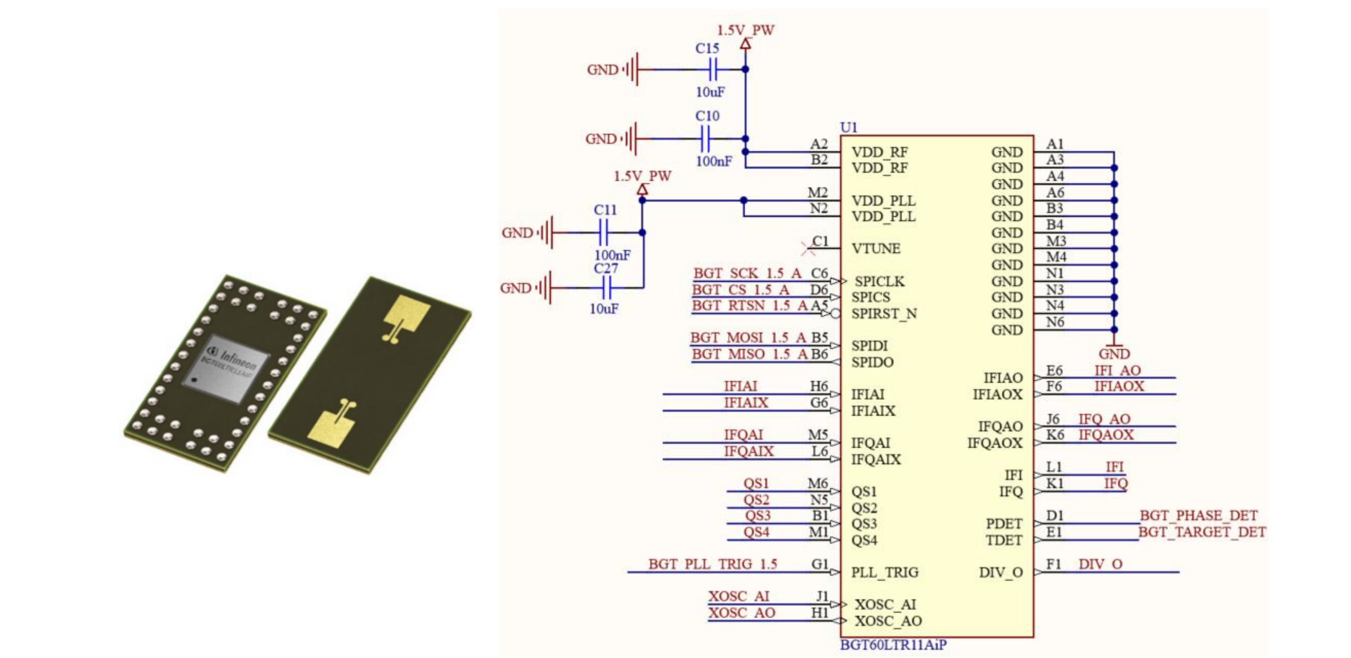


Figure 5 Package and pin-signal assignment of BGT60LTR11AIP MMIC

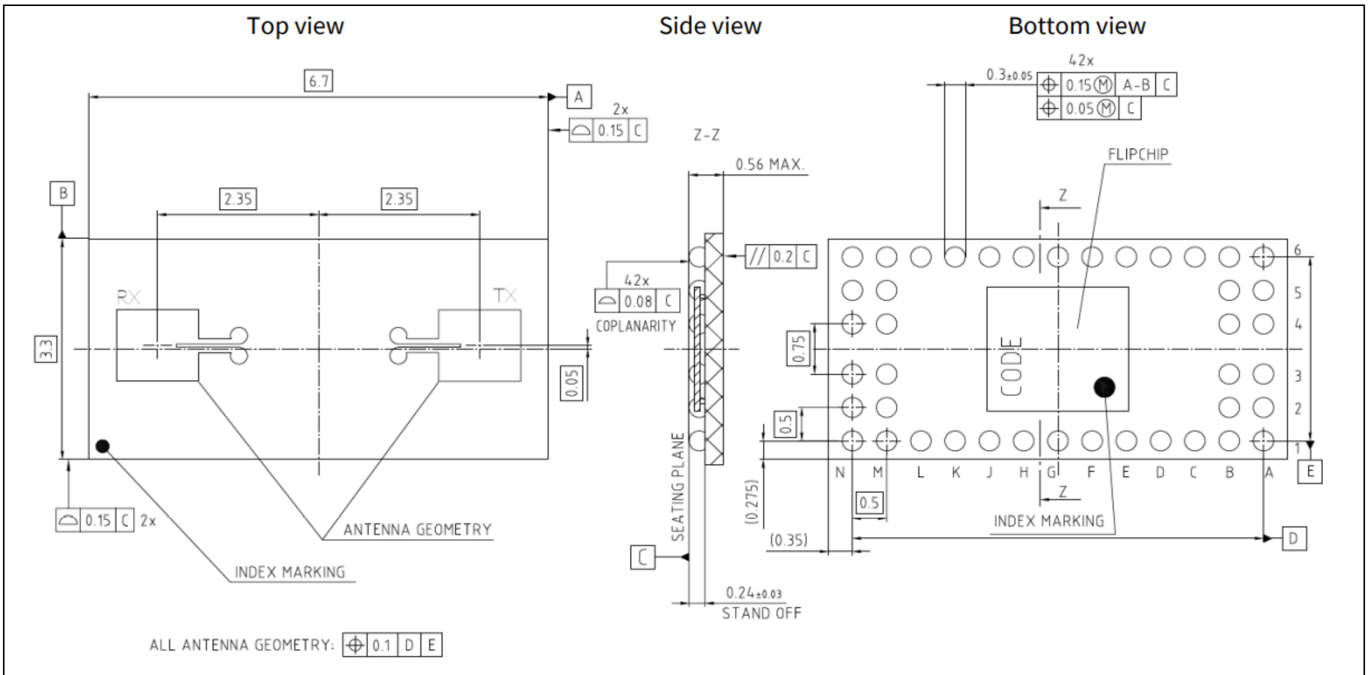


Figure 6 Top, side, and bottom views of BGT60LTR11AIP MMIC package (dimensions in mm)

3.3 Microcontroller unit - XMC1302

The BGT60LTR11AIP M0 reference board uses an Arm® Cortex®-M0 microcontroller to allow flexibility to the users to do their own signal processing and algorithm implementation. Infineon's XMC™ 32-bit industrial microcontroller (XMC1302-T038X0200) is designed for system cost and efficiency for demanding industrial applications. Fast and largely autonomous peripherals can be configured to support individual needs. Highlights include analog-mixed signal, timer/PWM, and communication peripherals powered by an Arm® Cortex®-M0 core.

3.4 Sensor supply

Because radar sensors are sensitive to supply voltage fluctuations or crosstalk between different supply domains, a low-noise power supply and properly decoupled supply rails are vital. Figure 7 shows the schematics of the low-pass filters employed to decouple the supplies of the different power rails in the BGT60LTR11AIP M0 reference board . Two LDOs are used in cascaded implementation to create stable and clean supply voltages of 1.5 V (for the MMIC), and 3.3 V (for the MCU).

R11 and R19 along with test points TP2, TP3, TP4, and TP5 can be used to make accurate current consumption measurements at the output of both the LDOs. You can choose between two different LDO packages; in this board, G1 and G2 are do not populate (DNP).

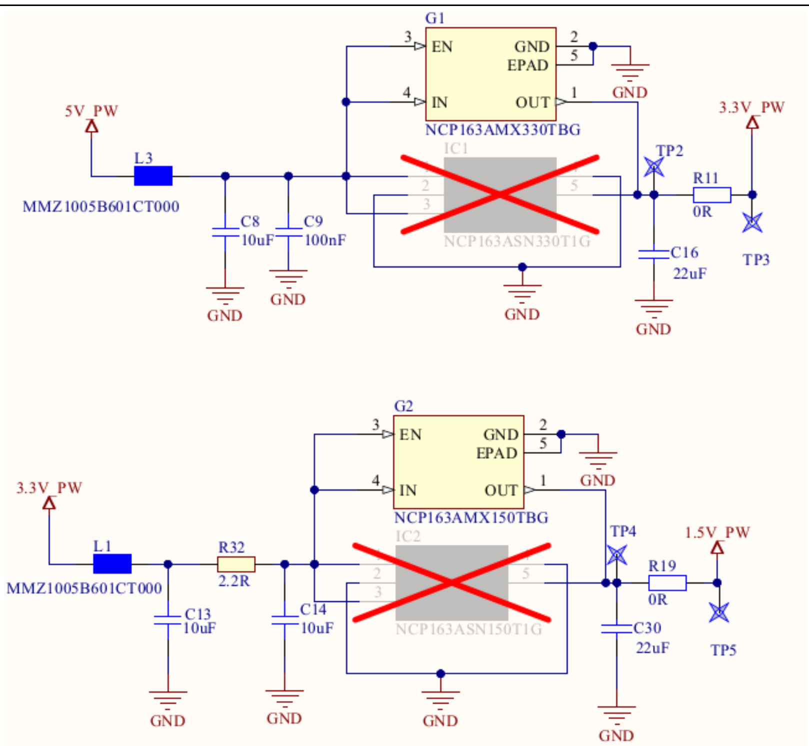


Figure 7 **Schematics of sensor supply and low-pass filters**

3.5 Oscillator

The MMIC requires an oscillator source with a stable reference clock providing low phase jitter and phase noise. The oscillator is integrated inside the MMIC. This saves current consumption because the crystal oscillator consumes only a few milliamperes (mA) and runs continuously. The BGT60LTR11AIP M0 reference board uses a 38.4 MHz crystal oscillator, as shown in Figure 8.

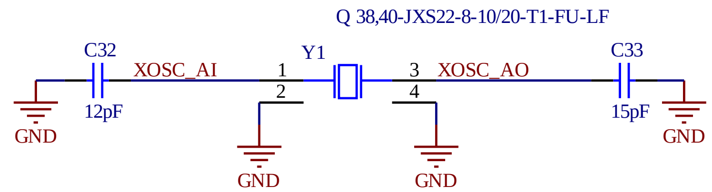


Figure 8 **Crystal circuit on BGT60LTR11AIP M0 reference board**

3.6 External capacitors

The BGT60LTR11AIP MMIC is duty-cycled and performs a sample-and-hold (S/H) operation for lower power consumption. The S/H switches are integrated in the chip at each differential IQ mixer output port. They are controlled synchronously via the internal state machine. The capacitors between the S/H and the high-pass filter (HPF) are external (Figure 9). C21, C22, C23, and C24 are 5.6 nF capacitors used as "hold" capacitors for the S/H circuit. They can be configured for different pulse width settings, as shown in Table 3. C17, C18, C19, and C20 are the DC blocking (or high-pass) capacitors. They are 10 nF to get a high pass of 4 Hz (if internal high pass resistor, R_{HP} = 4 MΩ).

Do not use higher values because it affects the analog base band (ABB) settling time. The DC blocking capacitors are important because the mixer output has a different DC voltage than the internal ABB. In Figure 9, the external hold (C_{hold}) and high-pass capacitors (C_{HP}) are shown for all four branches in the differential IQ configuration.

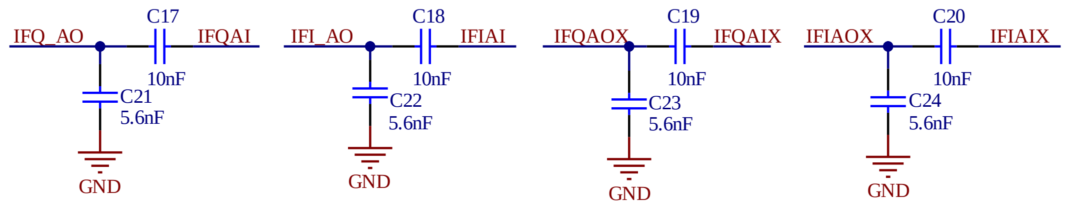


Figure 9 External capacitors

Table 3 Recommended hold capacitors (C21, C22, C23, and C24) for different pulse widths

Pulse width (µs)	Hold capacitor value (nF)
3	4.7
4	5.6
5 (default)	5.6 (default)
10	15

The charging time of the hold capacitor (C_{hold}) is limited to the selected pulse width. Shorter pulse widths require smaller C_{hold} to get it ~ 90% charged during one pulse. The rise time is controlled by C_{hold} itself and the internal mixer output resistance (R_{mixer_out}) of 300 Ω in each branch.

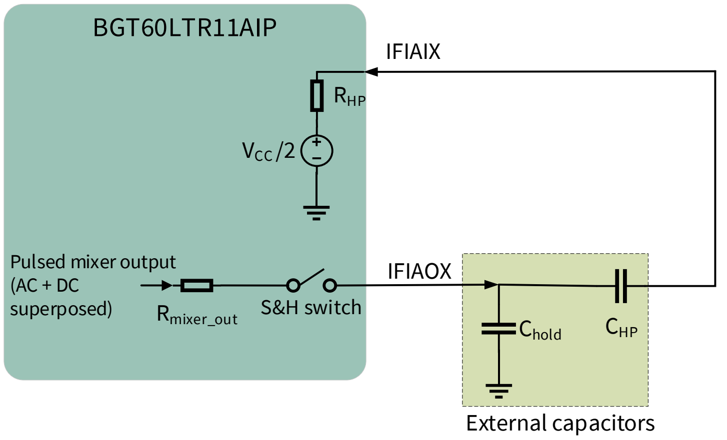


Figure 10 External capacitors for BGT60LTR11AIP

A longer pulse width can have a higher C_{hold} value. This leads to a reduced bandwidth (BW) of the RC filter (R_{mixer_out} and C_{hold}). Consequently, there will be lower baseband noise because of reduced noise folding bandwidth.

For this RC structure, the low-pass 3 dB cutoff frequency ($f_{LP_{3dB}}$) can be calculated under the following conditions:

$$t_{rise} = \frac{10\%}{90\%} = \text{S/H } ON\ time = 4\ \mu\text{s}$$

$$Pulse\ width = 5\ \mu\text{s}$$

$$R_{mixer\_out} = 300\ \Omega$$

$$f_{LP_{3dB}} = \frac{0.35}{t_{rise}} = \frac{0.35}{4\mu s} = 87.5\ kHz$$

Equation 1

This can also be calculated based on the following formula:

$$f_{LP_{3dB}} = \frac{1}{2\pi \times R_{mixer\_out} \times C_{hold}}$$

$$C_{hold} = 6.1\ nF \rightarrow 5.6\ nF\ \text{(closest E12 series value)}$$

Equation 2

The high-pass 3 dB cutoff frequency ($f_{HP_{3dB}}$) can be calculated under the following conditions:

$$C_{HP} = 10\ \text{nF}$$

$$R_{HP} = 4\ \text{M}\Omega$$

$$f_{HP_{3dB}} = \frac{1}{2\pi \times R_{HP} \times C_{HP}} = \frac{1}{2\pi \times 4M\Omega \times 10nF} = 4\ Hz$$

Equation 3

3.7 Connectors

The BGT60LTR11AIP M0 reference board has a Cortex® Debug (10-pin) connector (J2) to easily allow debugging the XMC1302 MCU and provide flexibility for your own implementation. Connectors P2 and P3 provide access to other important signals of the board such as the I²C signals (SCL and SDA) and the outputs of the internal detectors of the MMIC (BGT_PHASE DET and BGT_TARGET_DET).

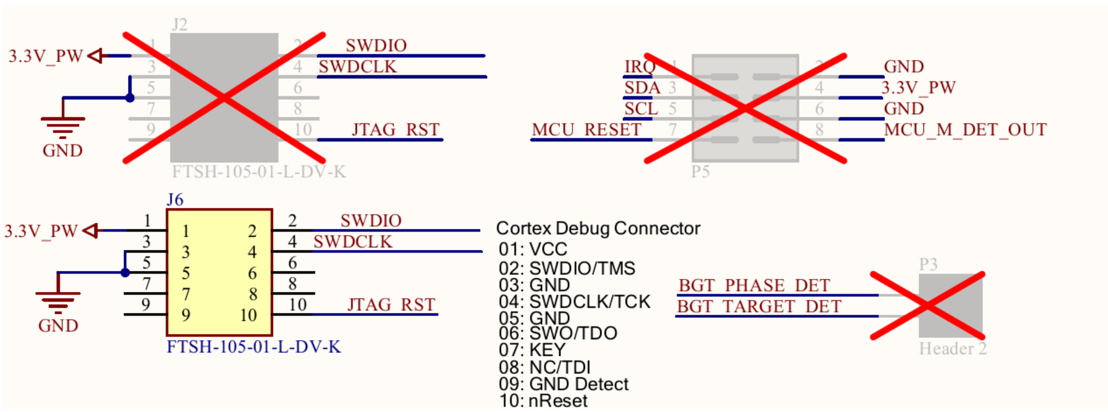


Figure 11 **Connectors on BGT60LTR11AIP M0 reference board, and their pinouts**

3.8 LEDs

The board also has two LEDs (D1 and D2) as shown in Table 4 and Figure 12.

Table 4 **LEDs on BGT60LTR11AIP M0 reference board**

LED	Purpose
D1	Green user LED connected to I/O P1.2 of the XMC1302 MCU.
D2	Red user LED connected to I/O P1.1 of the XMC1302 MCU. By default, this is connected to MCU_M_DET_OUT signal to indicate the detection status of FFT peak algorithm running on the MCU.

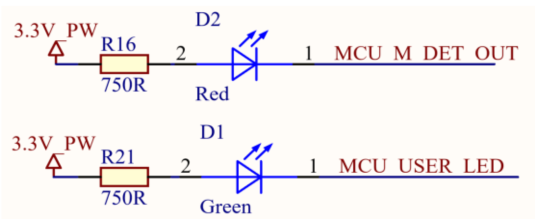


Figure 12 **LED connections**

3.9 Level shifters

The outputs from MMIC are at 1.5 V. They are level-shifted to 3.3 V by using the circuit shown in Figure 13.

BGT_MISO_1.5_A and IRQ signals at 1.5 V are converted to SPI_MISO and BGT_DIV_TRIG_IN at 3.3 V to interface with the MCU. SPI_SCK, SPI_MOSI, SPI_CS, and BGT_RST_OUT are the outputs of the MCU and are converted to the corresponding 1.5 V signals for the MMIC.

BGT_CS_1.5_A and BGT_RTSN_1.5_A should be pulled up with 10 kΩ resistors for the correct operation of the MMIC.

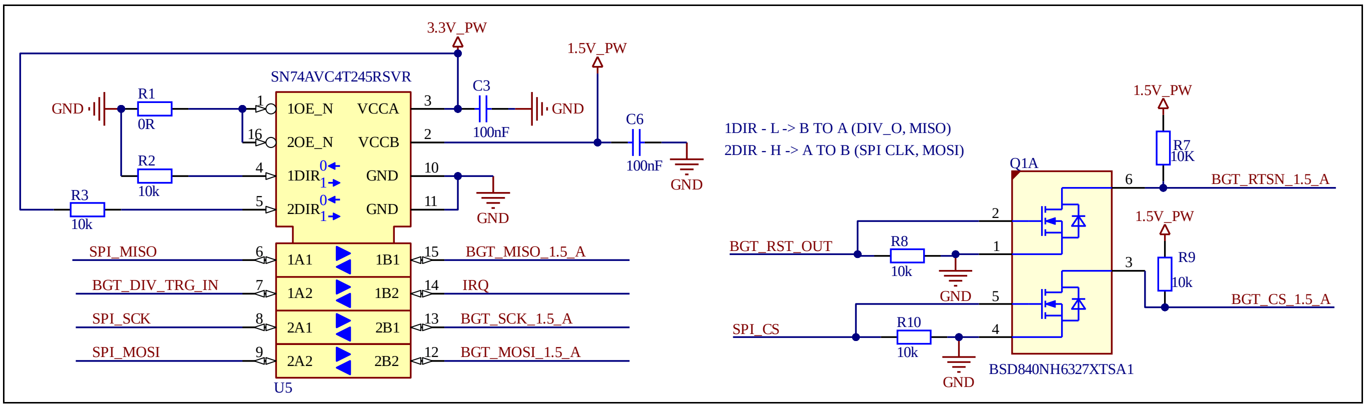


Figure 13 Connections of level shifter

3.10 MMIC quad state inputs

The radar MMIC can be configured in both operation modes. In autonomous mode, the sensor configuration parameters are set via QS pins and external resistors. In SPI mode, the connection to a microcontroller allows setting the sensor configuration parameters by writing in the internal registers through SPI.

The BGT60LTR11AIP MMIC has four quad-state inputs QS1-4. Figure 14 shows the default settings of these QS pins on the board; these can be used as a reference to configure the board with different settings. By default, the board is configured in SPI mode (QS1) to interface with the MCU.

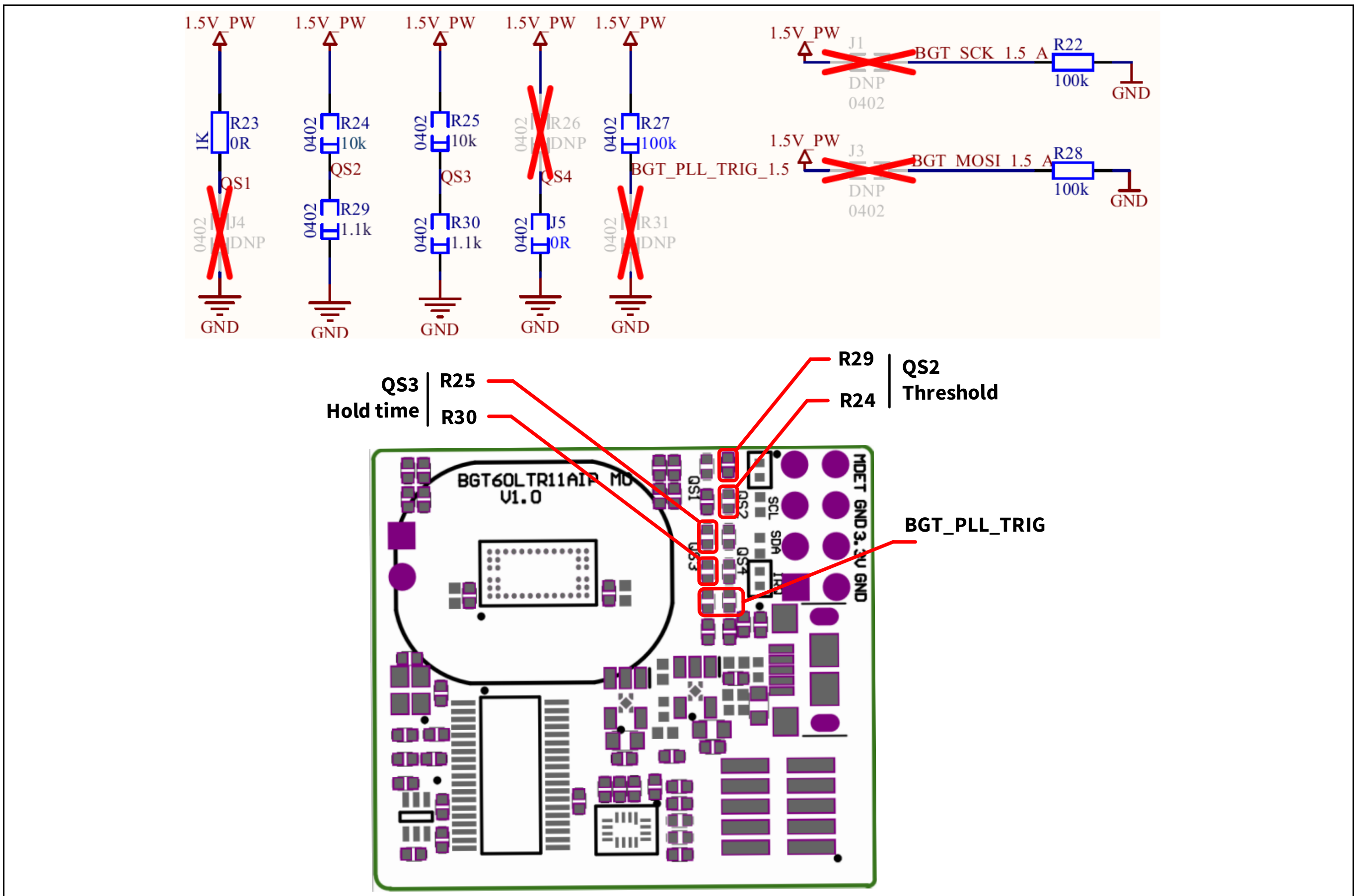
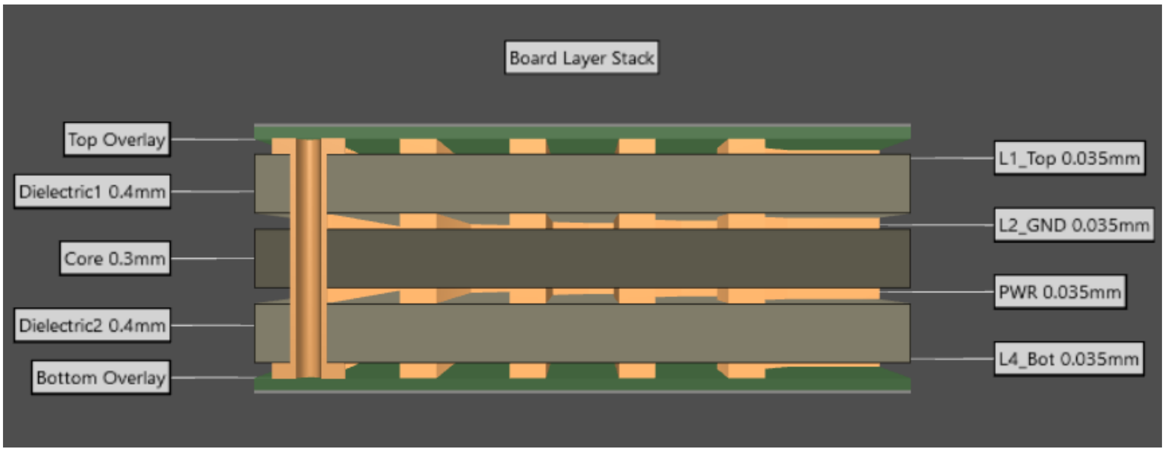


Figure 14 **QS1 to QS4 schematic and layout connections**

Note: *The BGT60LTR11AIP M0 reference board works only in SPI mode. For autonomous mode, see the BGT60LTR11AIP autonomous reference board (REF_BGT60LTR11AIP_AUT).*

3.11 Layer stackup and routing

The PCB is designed with a 4-layer stack up with standard FR4 material. Figure 15 shows the different layers and their respective thicknesses.



#	Name	Material	Type	Weight	Thickness	Dk
	Top Overlay		Overlay			
	Top Solder	Solder Resist	Solder Mask		0.02mm	3.5
1	L1_Top		Signal	1oz	0.035mm	
	Dielectric1	PP-006	Prepreg		0.4mm	4.1
2	L2_GND	CF-004	Signal	1oz	0.035mm	
	Core	FR-4	Core		0.3mm	4.2
3	PWR	CF-004	Signal	1oz	0.035mm	
	Dielectric2	PP-006	Prepreg		0.4mm	4.1
4	L4_Bot		Signal	1oz	0.035mm	
	Bottom Solder	Solder Resist	Solder Mask		0.02mm	3.5
	Bottom Overlay		Overlay			

Figure 15 QS1 to QS4 schematic and layout connections

In the routing on the PCB, the VTUNE pin on BGT60LTR11AIP MMIC should be left floating. Any components added to the line, or a long wire connected can result in spurs.

4 Radar MMIC settings

In SPI mode, the radar sensor MMIC configuration parameters are initially set via the QS pins and external resistors. The FW running on the microcontroller allows overwriting or setting the sensor configuration parameters by writing to the internal registers through SPI.

4.1 Operation mode

The QS1 pin allows choosing the operation mode of the radar MMIC, as shown in Table 5.

Table 5 QS1 settings

QS1	Operation mode of the MMIC	PCB configuration	
Ground	Autonomous continuous wave (CW) mode	J4 = 0 Ω	R23 = DNP*
Open	Autonomous pulsed mode	J4 = DNP*	R23 = DNP*
100 kΩ to V_{DD}	SPI mode with external 9.6 MHz clock enabled	J4 = DNP*	R23 = 100 kΩ
V_{DD} (default)	SPI mode	J4 = DNP*	R23 = 0 Ω

*DNP: Do Not Populate/Do Not Place

The BGT60LTR11AIP M0 reference board is originally configured for SPI mode applications.

4.2 Detector threshold

The internal detector threshold is the minimum signal strength that must be reached to trigger a detection event. The lower the threshold set, the higher the sensitivity and therefore the higher the detection range. In the current FW running on the BGT60LTR11AIP M0 reference board, two algorithms detection thresholds are used that depend mainly on the defined algorithm, and not related to the internal detector threshold.

4.3 Detector hold time

The internal detector hold time is the time for which the internal detector outputs remain active after target detection. In SPI operation mode, you can set the internal detector hold time by writing to the hold (Reg10[15:0]) bitfield of MMIC SPI registers.

4.4 Operating frequency

In SPI operation mode, you can set the device operation frequency by writing to the pll_fcw (Reg5[11:0]) bitfield of MMIC SPI registers. The BGT60LTR11AIP device operates in the frequency band from 61 GHz to 61.5 GHz.

4.5 Pulse repetition time

The pulse repetition time (PRT) is the duty cycle repetition rate, which is the time until the next pulsing sequence starts in pulsed mode.

In SPI pulsed operation mode, you can set the PRT value by writing to the dc_rep_rate (Reg7[11:10]) bitfield of MMIC SPI registers. You can also enable adaptive pulse repetition time (APRT) by writing to the aprt (Reg2[6]) bitfield of MMIC SPI registers. The PRT multiplier factor of 2, 4, 8, or 16 can be set by writing to the prt_mult (Reg13[1:0]) bitfield.

5 Running the radar algorithms

This section explains how to customize, build, flash, and debug radar applications using the code generated in the DAVE™ IDE and run them on the BGT60LTR11AIP M0 reference board.

The BGT60LTR11AIP M0 reference board provides two main algorithms to demonstrate the capabilities of the radar MMIC and to develop user applications that detect motion and direction of movement, as well as mitigate interference when multiple radars are used.

Before using this reference board and running the available algorithms, you should download the supporting software from Infineon.

5.1 Infineon Developer Center

To install and use Infineon plugins and tools, and use the full functionality of the 60 GHz radar, you must first download and install the Infineon developer Center (IDC) Launcher. It is the one-stop shop for engineers for downloading and designing of Infineon development tools, embedded software, services, and solutions.

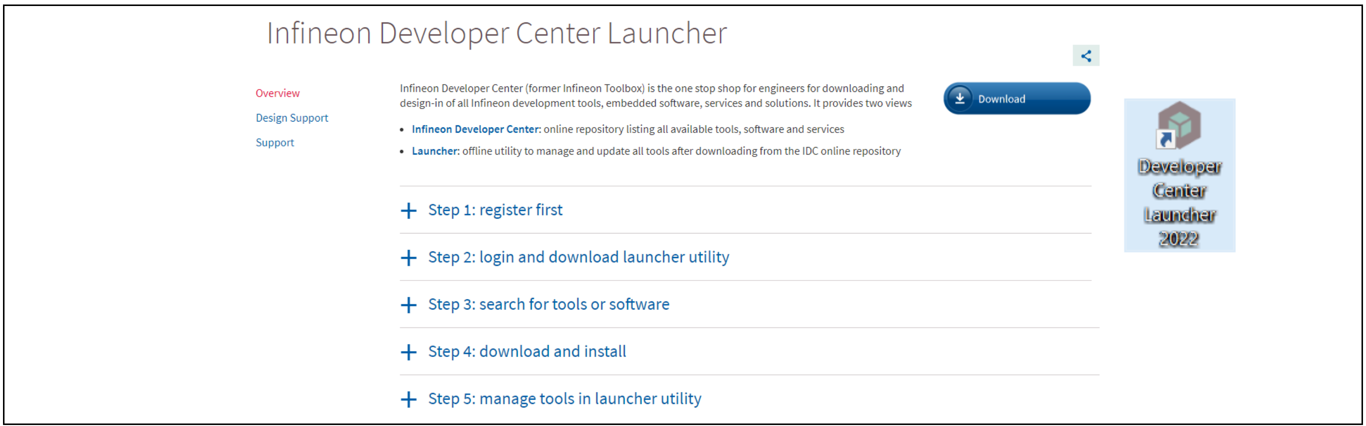


Figure 16 Download and run Infineon Developer Center Launcher

5.2 XMC™ Flasher

The BGT60LTR11AIP M0 reference board firmware is preloaded in the flash memory on the XMC™ microcontroller. This section describes how to use the binary images provided to reprogram the firmware applications. In addition to an XMC™ Flasher, the DAVE™ IDE can also be used to modify, compile, and flash new firmware into the device (see Section 6.1). The dedicated firmware package contains binary images (*.hex) of the applications provided in the */REF_BGT60LTR11AIP_M0/Binary* subfolder.

Note: An XMC™ Link debugger is embedded in the REF_BGT60LTR11AIP_M0 hardware kit.

Figure 17 Connect XMC™ Link debug probe

The XMC™ Flasher tool can be used for on-chip flash programming to reprogram the radar board using a binary image as follows:

1. Connect the 60 GHz radar board to a PC with USB Type-A to Micro-B cables through the embedded USB connector to power up the board. Two power supply options are available via the USB (5 V) or via one 3.3 V pin.
2. Connect the XMC™ Link debugger to your PC and connect the JTAG debug connector to the board for flashing and debugging.

5.2.1 Reprogram the radar firmware

Use (*.hex) binary with the XMC™ Flasher tool to reprogram the radar firmware:

1. Start the **XMC™ Flasher** tool in Infineon Developer Center.

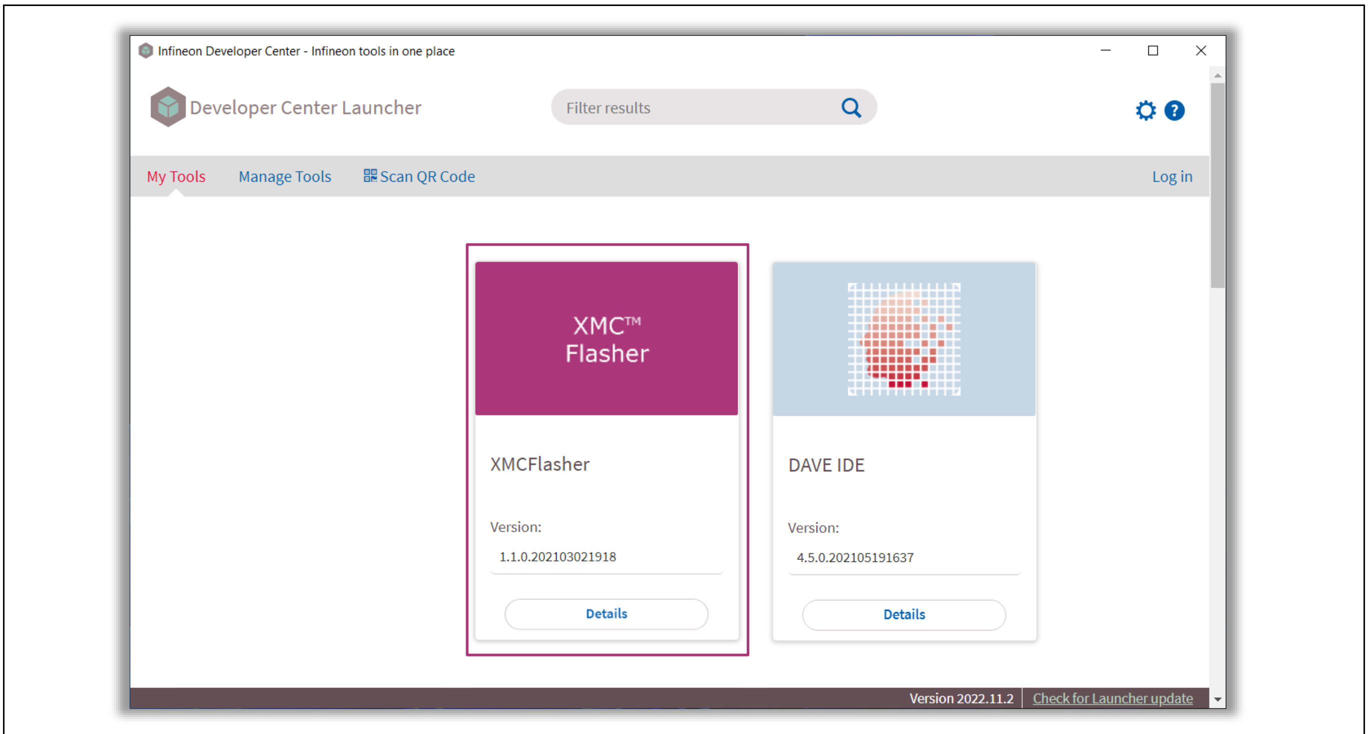


Figure 18 Start XMC™ Flasher tool via Infineon Developer Center

2. Click **Connect**, and then select the device name as “XMC1302-0200”. Click **Ok**.

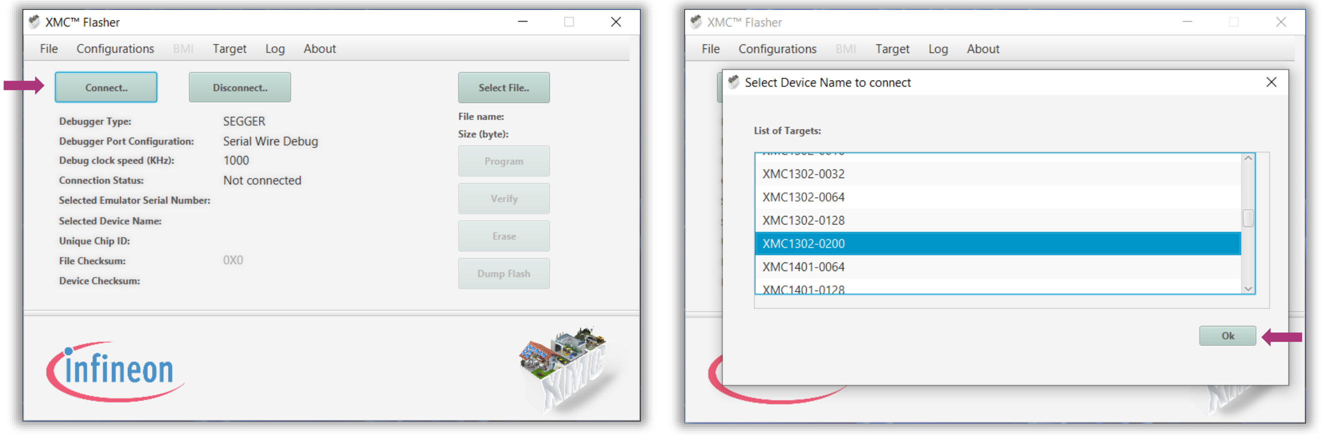
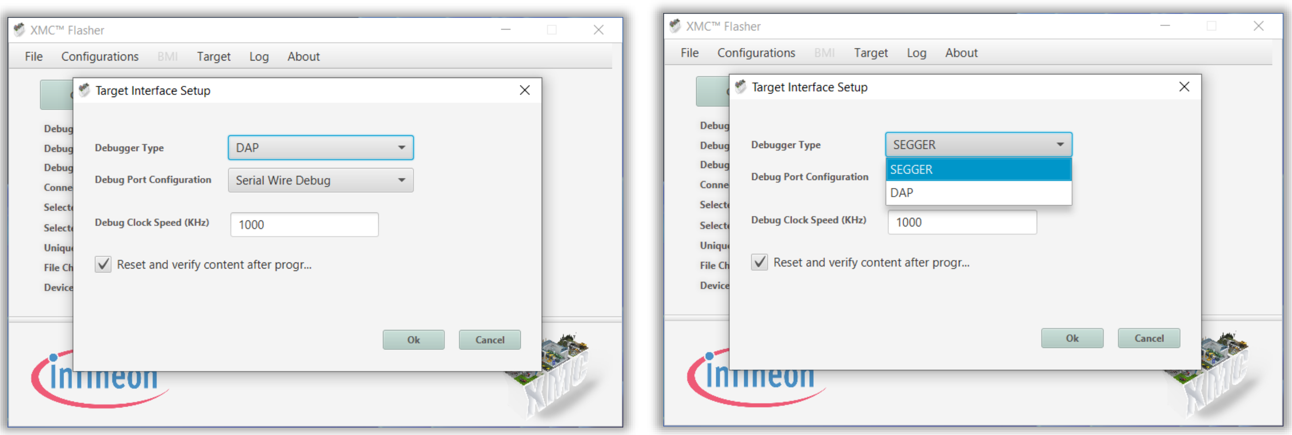


Figure 19 **XMC™ Flasher device selection and connection**

Note: Ensure that SEGGER J-Link drivers are installed before using the XMC™ Flasher tool. Otherwise, the default debugger type under XMC™ Flasher Target Interface Setup will be set to ***DAP****, as shown in Figure 20a. Once installed, you must change the debugger type to* ***SEGGER****, as shown in Figure 20b.*



(a) (b)

Figure 20 **Change debugger type**

3. Note that **Connection Status** turns to **Connected** after the board is connected successfully, and displays the **Unique Chip ID**.
4. Click **Select File…** .

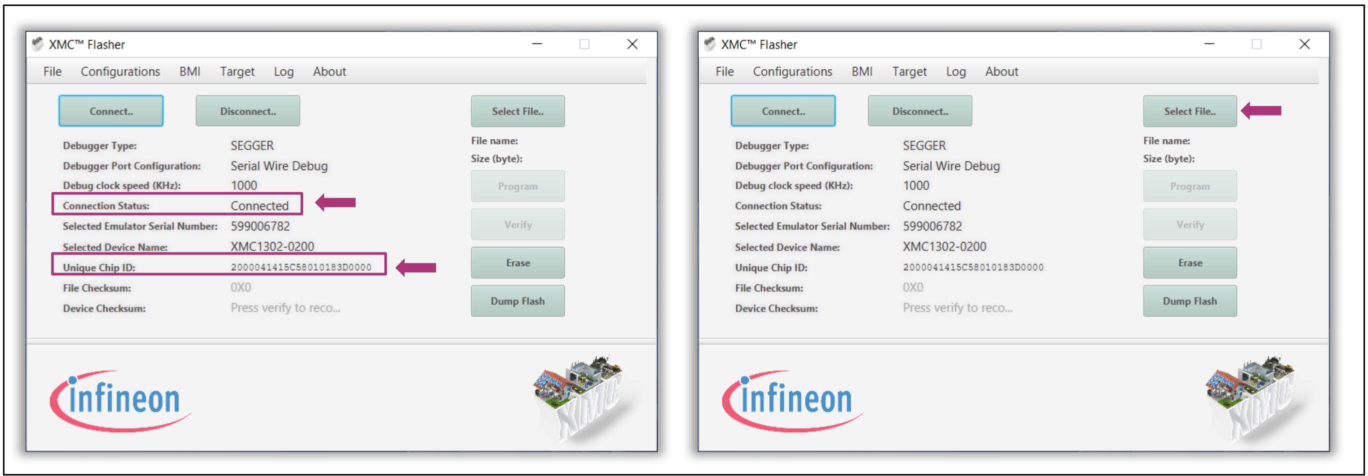


Figure 21 Binary image file selection

5. Navigate to the **Binary** folder and select the (*.hex) file (REF_BGT60LTR11AIP_M0_FW.hex), and then click **Open**.

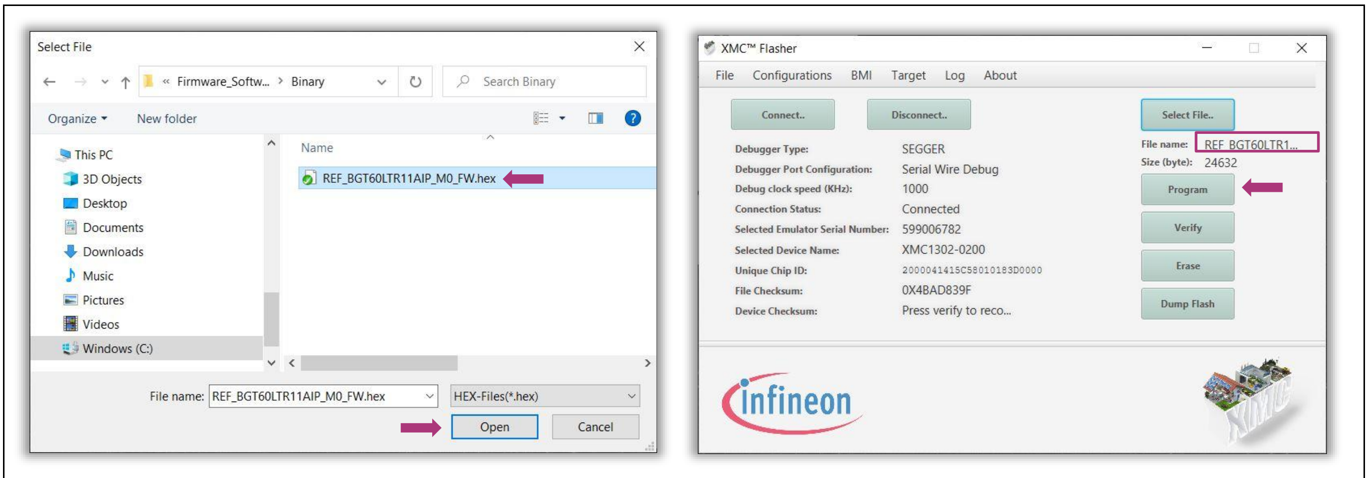


Figure 22 Binary image programming

6. Click **Program**. The SEGGER progress window is displayed, showing the status of the flash operation.
7. If programming succeeds, the message **Programming & verification after reset are successful!** appears.

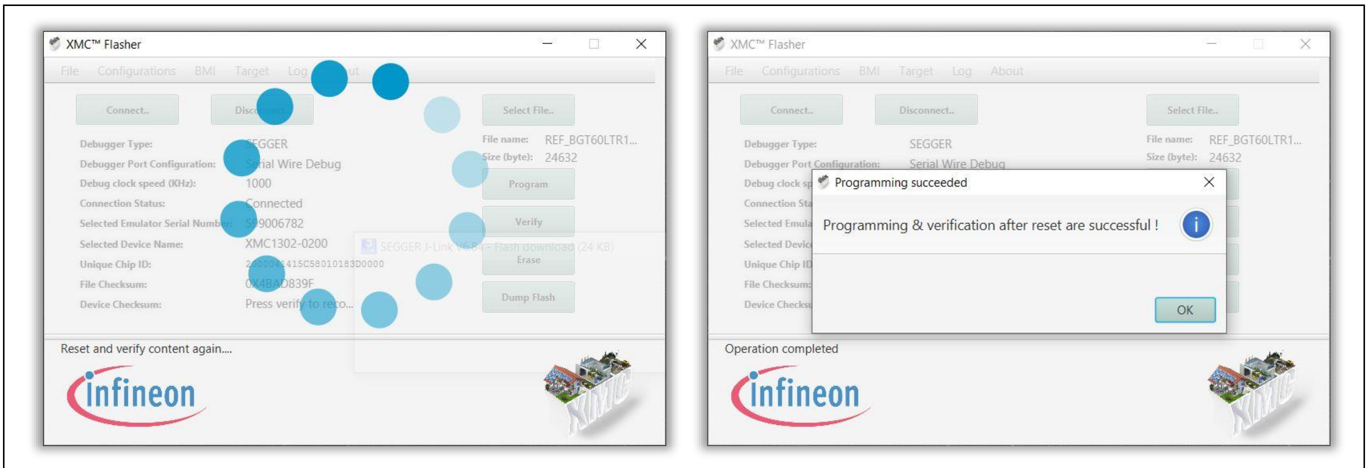


Figure 23 Programming successful

5.3 µC/Probe XMC™ tool

µC/Probe XMC™ from Micrium is a free-of-charge data monitoring and visualization tool to modify and track real-time data on the XMC™ target microcontroller in a non-intrusive way. It enables designing a graphical dashboard with a wide range of widgets to control or fine-tune your XMC™ application. This tool includes an eight-channel digital oscilloscope to visualize real-time data, controlled by a dedicated code that runs on the XMC™ target. It is a Windows application that can be easily connected via the J-Link onboard debugger integrated into most of the XMC™ kits.

The latest version of µC/Probe XMC™ v4.3.0.9 is available for download from the Infineon website.

Note: The BGT60LTR11AIP M0 reference board is supported only by the Micrium-based GUI tool.

To run this Micrium-based GUI project:

1. Go to the */Firmware_Software/GUI* folder inside the locally installed package.
2. Double-click the µC/Probe **REF_BGT60LTR11AIP_M0_GUI.wspx** project to open the GUI.

You need to provide the XMC™ compiling and linking process output file (ELF file) to the tool. This file contains the name, data type, and address of all firmware global variables, and is parsed by the µC/Probe project.

A precompiled *.elf* file is already available in the */Firmware_Software/GUI* folder called *REF_BGT60LTR11AIP_M0_FW.elf*.

Note: After building a project, object files and an application binary file (typically in ELF format) are present in the Debug *folder in the Project Explorer. Ensure that you have imported the* .elf *file into your Micrium-based GUI project each time you modify and build your DAVE™ project.*

After opening the project has opened, do the following:

1. Click **Run** to start the GUI.

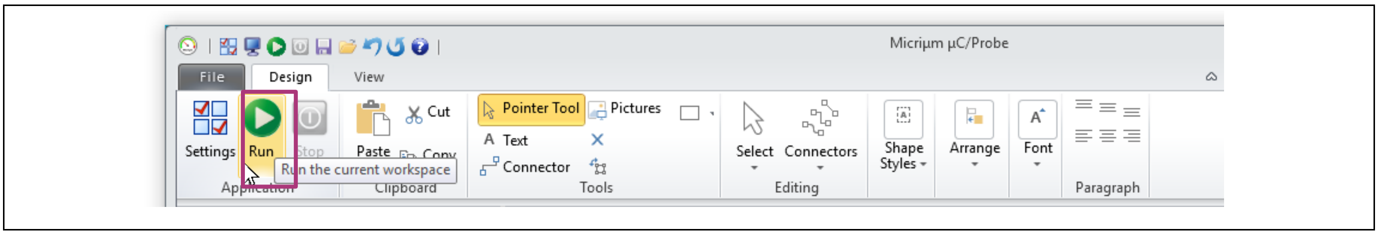


Figure 24 Run REF_BGT60LTR11AIP_M0_GUI

The GUI interface shown in Figure 25 should appear.

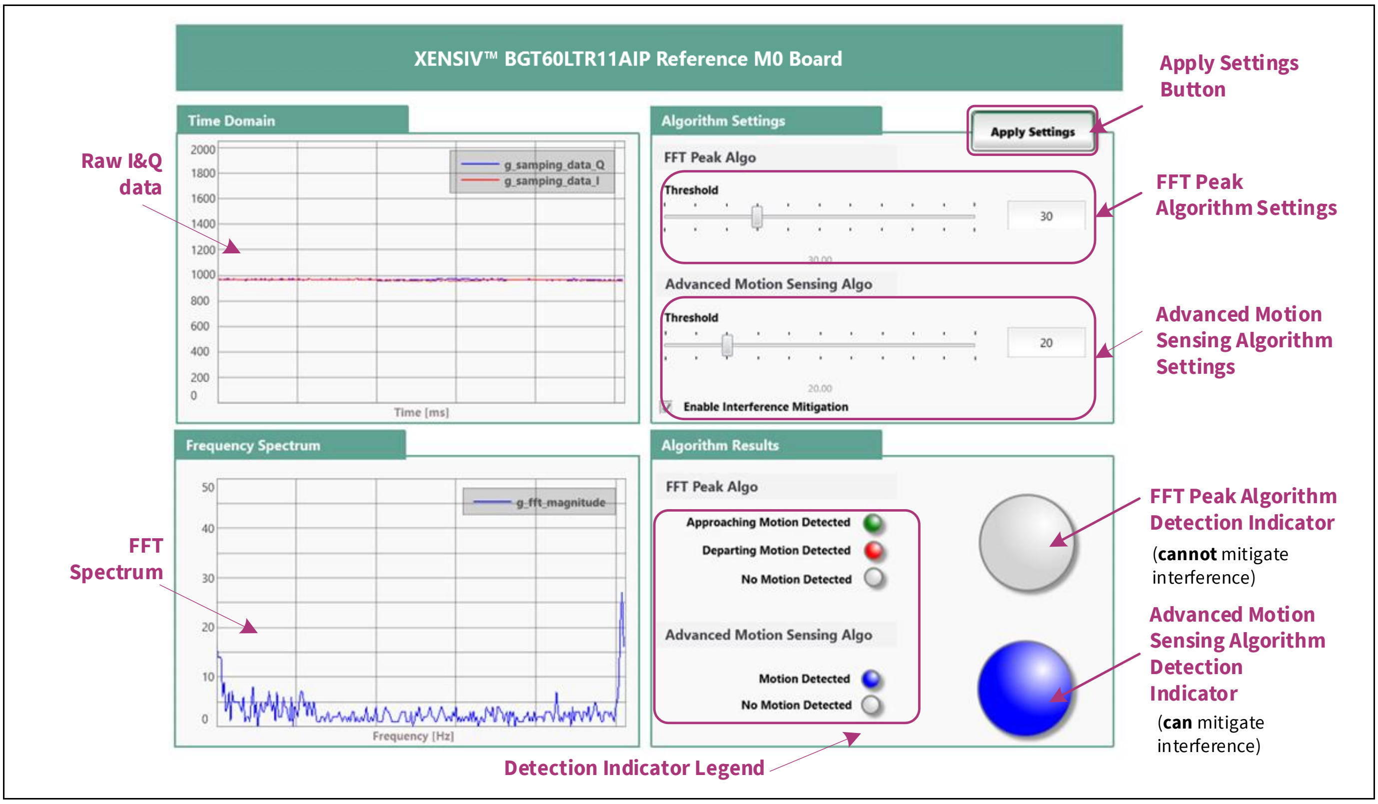


Figure 25 Data display on Micrium-based GUI

The radar should now detect movement and display the following data on the GUI:

- Time and frequency plots
- Algorithm settings (e.g., detection threshold, enable/disable interference mitigation)
- Algorithm results (e.g., detection status, direction of movement)

2. If you change algorithm parameters, click **Apply Settings**.

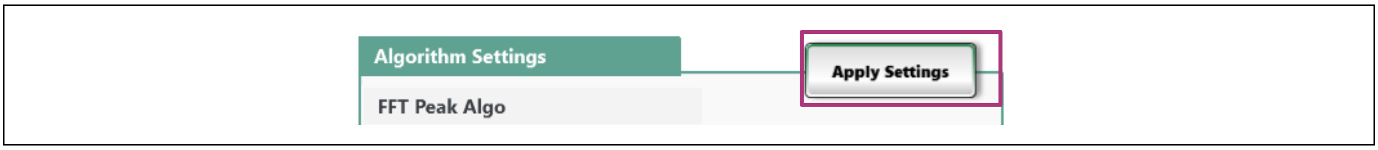


Figure 26 Apply settings

6 Firmware description

6.1 DAVE™ IDE

DAVE™ (Digital Application Virtual Engineer), is a free-of-charge Eclipse-based IDE using a GNU C-compiler that provides an extensive, configurable, and reusable code repository for an XMC™ industrial microcontroller powered by Arm® Cortex®-M processors and can be used to configure MCU peripherals (ADC, DMA, CCU4…). This reduces the development time and allows for quick porting of the firmware across XMC™ series MCUs.

You need to install DAVE™ v4.4.2 or higher from the Infineon Developer Center (IDC).

6.2 Firmware project overview

The radar firmware is a ready-to-run DAVE™4 project, where the source files are generated based on the DAVE™ APPs used, which are configurable application-oriented software components that enable quick reuse and customization. Figure 27 shows a top-level view of the project file structure.

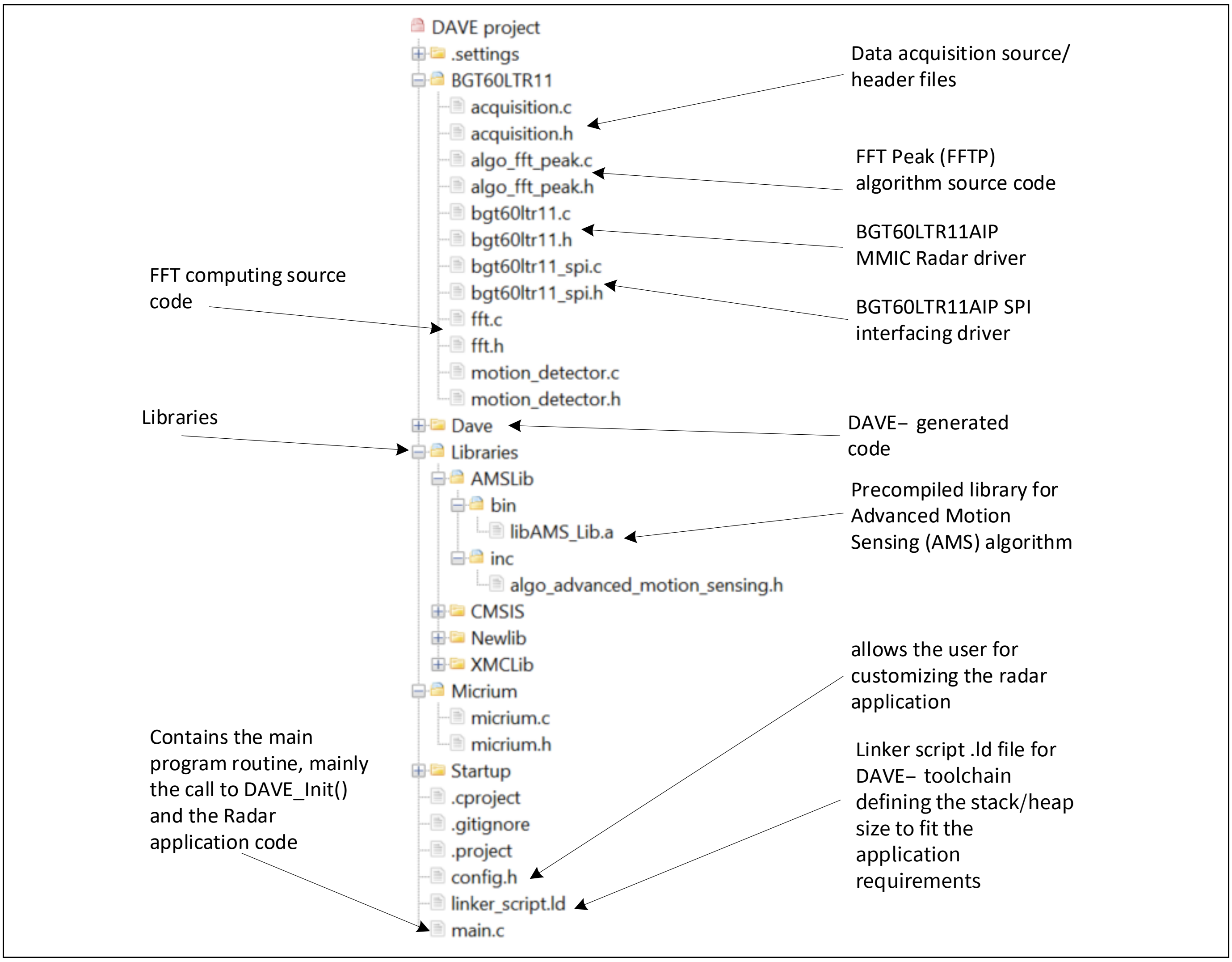


Figure 27 Package folder structure

6.3 Footprint

The following sections provide the memory requirements for all the firmware modules, including device drivers, algorithms, and main radar applications. This helps in estimating the fixed and customizable memory requirements if a module or feature is removed or added. The footprint data is provided for the following environments:

- Board – REF_BGT60LTR11AIP_M0 (v1.0)
- Firmware – REF_BGT60LTR11AIP_M0_FW
- Toolchain – DAVE™ v4.4.2

After building a project, the build result is displayed in the console window, where the code size is listed. The values are organized according to memory areas, arranged by the linker file (*.ld) into the text, data, and bss sections. Table 6 shows the build memory utilization for the radar firmware configurations, main modules, and algorithms. The information has been gathered by analyzing the corresponding (*.elf) file.

Table 6 Total firmware footprint

DAVE project	Optimization	text[1] [bytes]	data [bytes]	bss[2] [bytes]	Total [bytes]
REF_BGT60LTR11AIP_M0_FW	Optimize (-O1)	24472	148	6428	31048 bytes (0x7948)

Table 7 Advanced motion sensing (AMS) algorithm precompiled library

Library	Optimization	text[1] [bytes]	data [bytes]	bss[2] [bytes]	Total [bytes]
libAMS_Lib.a	Optimize (-O1)	1464	0	0	1464 bytes (0x5b8)

Note: Because the libAMS_Lib.a library does not utilize any instructions specific to Cortex®-M0, this library can be used with any Cortex®-M and other compatible processor architectures.

[1] text: code.

[2] bss: statically allocated variables that are not explicitly initialized to any value.

6.4 Firmware customization and configuration

The configuration files allow for customizing the drivers (*config.h*) and algorithms (*algo_fft_peak.h/algo_advanced_motion_sensing.h***)** for the radar application. The following parameters can be configured by modifying the values of the related define statements, as described in Table 8.

Table 8 Define statements used for radar firmware configuration

Parameter	Description	Default	Valid range
General configurations			
FRAME_INTERVAL_TIME_MS	Time period between two consecutive frames (in ms)	300	
SAMPLING_FREQ_HZ	Sampling frequency (in Hz)	2000	
FFT Peak algorithm configurations			
THRESHOLD_FFT_PEAK	Minimum threshold value to trigger a detection event	30	[30 to ...]
BIN_NUMBER_START	Minimum bin number to consider for peak search	3	[0 to 255]
BIN_NUMBER_END	Maximum bin number to consider for peak search	253	[0 to 255]
Advanced Motion Sensing algorithm configurations			
THRESHOLD_AMS	Minimum threshold value to trigger a detection event	30	[30 to ...]

The AMS algorithm requires two input data arrays, each consisting of 256 elements, obtained from the radar sensor's acquired and sampled raw data.

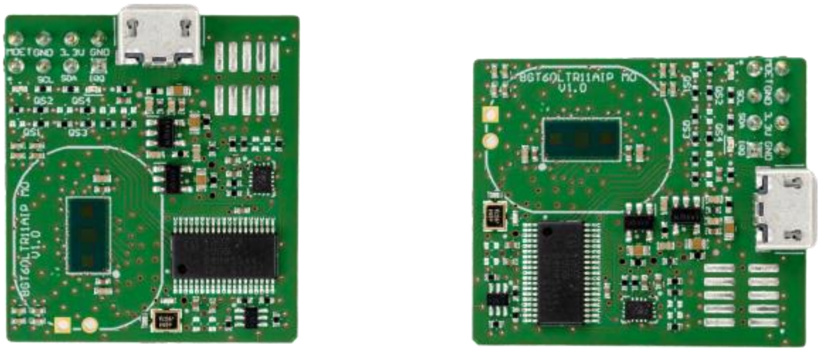
Code Listing 1

```
unsigned short If_I_sample[256];
unsigned short If_Q_sample[256];
```

These two arrays are declared within the *acquisition.c* file and are used by the `algo_advanced_motion_sensing_run()` API to run the AMS algorithm.

7 Simulation results

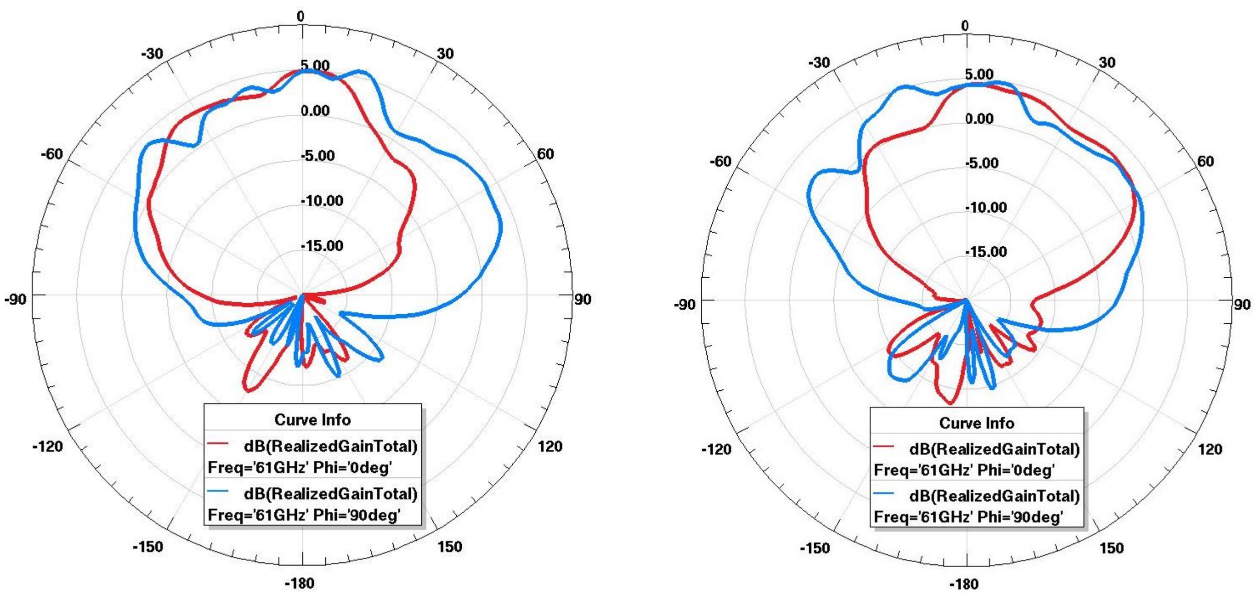
To analyze the sensor radiation characteristics, the radiation pattern of the BGT60LTR11AIP M0 reference board is simulated along the H-plane and E-plane of the sensor.



E-plane **H-plane**

Figure 28 E-plane and H-plane orientations of BGT60LTR11AIP M0 reference board

The realized gain of the transmitting antenna in H-plane and E-plane at a frequency of 61 GHz is shown in Figure 29a. The antenna characteristics of the receiving antenna in H-plane and E-plane at a frequency of 61 GHz is illustrated in Figure 29b.



(a) TX – H/E plane at f = 61 GHz (b) RX – H/E plane at f = 61 GHz

Figure 29 Radiation pattern simulations of BGT60LTR11AIP M0 reference board

8 Measurement results

Both the FFT peak and AMS algorithms process the I&Q raw data in parallel in the time domain, and both algorithms display the detection status simultaneously.

Attention: ***The interference mitigation feature is applicable only to the AMS algorithm.***

8.1 FFT peak algorithm

- **Scenario**
  Measure the max. detection range of a human target along the H-plane and E-plane of the sensor for different angles with the default configuration and with an algorithm set threshold value of 30, which can be selected from the Micrium-based GUI.
- **Height**: Board is placed at 1.2 m.
- **Detection status**
  It is driven from the FFT peak detection algorithm running on the embedded microcontroller of the BGT60LTR11AIP M0 reference board. Figure 30 shows the measurement results in H-plane and E-plane.

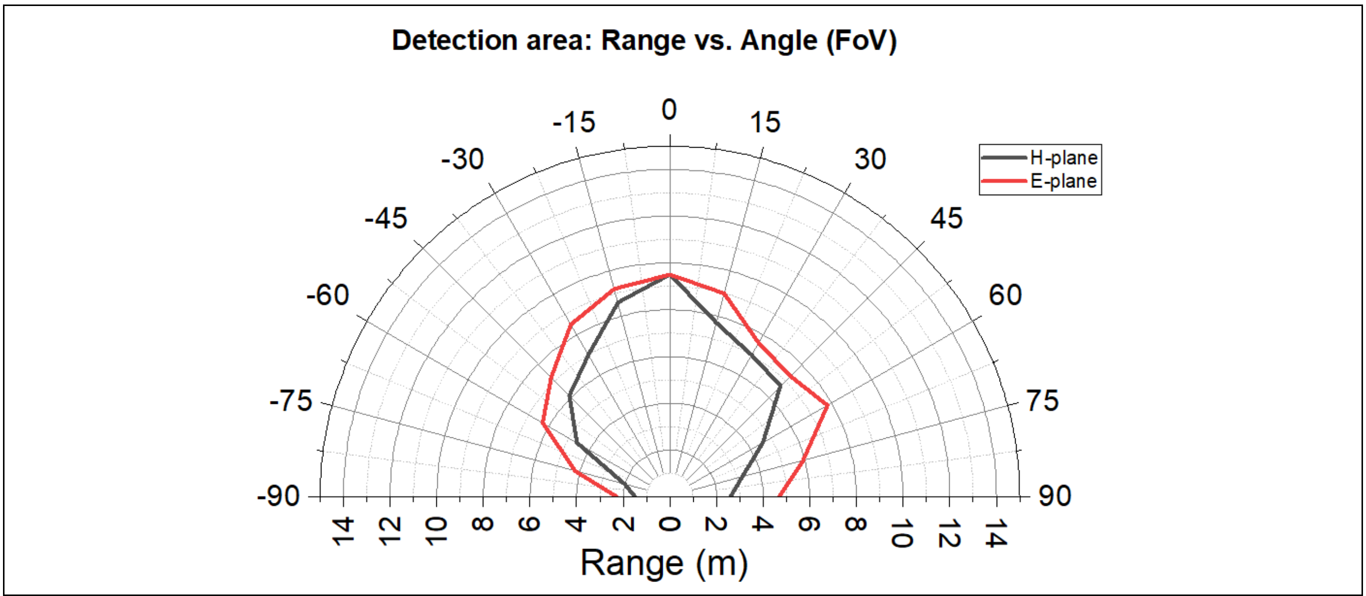


Figure 30 **Detection area of FFT peak algorithm**

8.2 Advanced Motion Sensing (AMS) algorithm

- **Scenario**
  Measure the max. detection range of a human target along the H-plane and E-plane of the sensor for different angles with the default configuration and with an algorithm set threshold value of 40, which can be selected from the Micrium-based GUI.
- **Interference mitigation**: Disabled
- **Height**: Board is placed at 1.2 m.
- **Detection status**
  It is driven from the advanced motion detection algorithm running on the embedded microcontroller of the BGT60LTR11AIP M0 reference board. Figure 30 shows the measurement results in H-plane and E-plane.

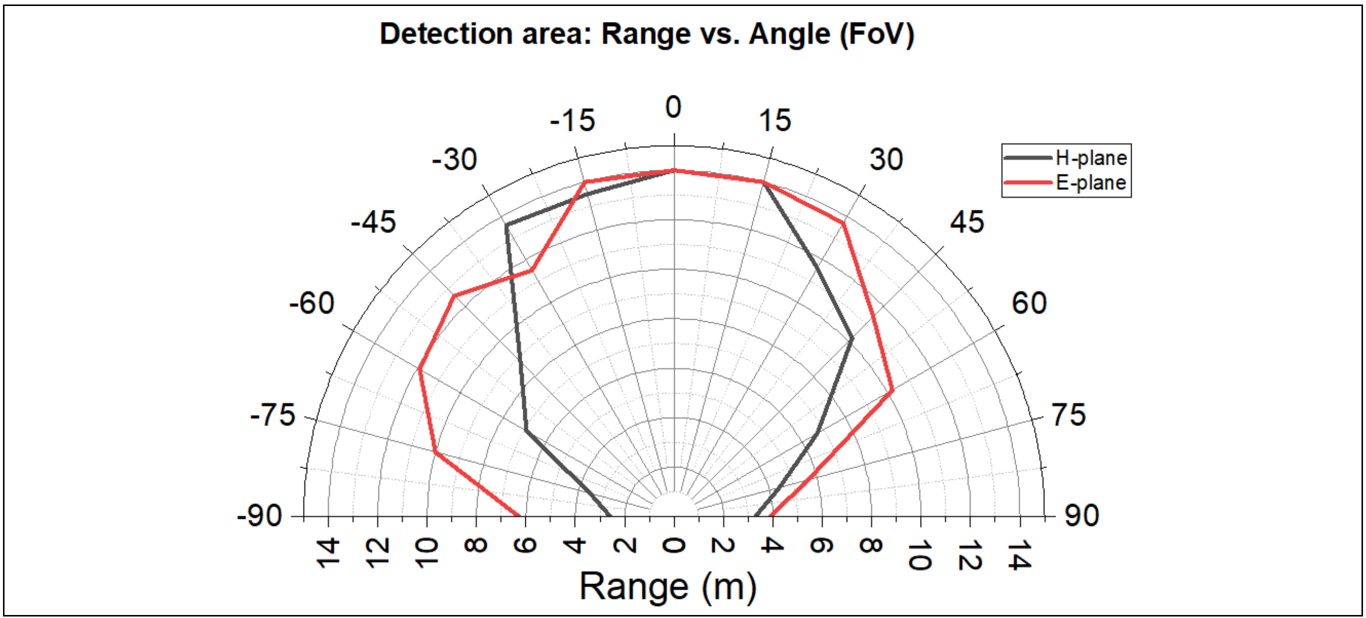


Figure 31 **Detection area of Advanced Motion Sensing algorithm**

References

[1] Infineon Technologies AG. *BGT60LTR11AIP MMIC datasheet;* Available online

[2] Infineon Technologies AG. *User guide to BGT60LTR11AIP;* Available online

Revision history

Document revision	Date	Description of changes
1.00	2023-02-14	Initial release
1.10	2024-05-08	Added AMS algorithm library footprint under section 6.3
1.20	2024-09-17	Changed document ID Updated Figure 7, Figure 11, and Figure 14

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