BGT60LTR11AIP shield

60 GHz radar system platform

Board version 1.5

About this document

Scope and purpose

This application note describes the function, circuitry, and performance of the 60 GHz radar BGT60LTR11AIP shield. The shield provides the supporting circuitry to the on-board BGT60LTR11AIP MMIC, Infineon's 60 GHz radar chipset with Antenna in Package (AIP). In addition to the autonomous sensing configuration, the shield offers a digital interface for configuration and transfer of the acquired radar data to a microcontroller board, e.g. Radar Baseboard MCU7.

Intended audience

This document is intended for anyone working with Infineon's 60 GHz radar system platform.

Disclaimer

The platform serves as a demonstrator to perform simple motion sensing. The test data in this document shows typical performance of demonstrator. However, board performance may vary depending on the PCB manufacturer, specific design rules they may impose and components they may use.

Table of contents

1 Introduction

1.1 Overview

The BGT60LTR11AIP MMIC is a fully integrated microwave motion sensor including Antennas in Package (AIP) as well as built-in motion and direction of motion detectors. A state machine enables operation of the MMIC without any external microcontroller. In its autonomous mode, it detects a human target up to 5 m with a low power consumption of less than 5 mW. These features make the small sized radar solution a compelling smart and cost-effective replacement for conventional PIR sensors in low power or battery-powered applications.

The BGT60LTR11AIP Shield demonstrates the features of the BGT60LTR11AIP MMIC and gives the user a "plug and play" radar solution. The MMIC is designed to operate as a Doppler motion sensor in the 60 GHz ISM-band. Two integrated detectors provide two digital output signals – one indicating motion and the other indicating the direction of motion (approaching or departing) of a human target.

The MMIC has four quad-state (QS1-4) input pins that give the performance parameters flexibility even when it is running in autonomous mode. For instance, the user can easily select between four threshold values at QS2 to increase or reduce the detector sensitivity.

For experienced radar users, the MMIC also supports a semi-autonomous and a SPI mode by changing the operation mode with QS1 pin. In these modes, the radar raw data can be extracted from BGT60LTR11AIP for signal processing on PC or an external microcontroller unit (MCU) using SPI. This sampled radar data can be used for developing customized algorithms. The shield can also be attached to an Arduino MKR board or an Infineon Radar Baseboard MCU7. Infineon's Toolbox supports this platform with a demonstration software and a radar graphical user interface (Radar GUI) to display and analyze acquired data in time and frequency domain.

This application note focuses on the BGT60LTR11AIP shield. Detailed documentation on the Radar Baseboard MCU7 can be found in reference (RS, 2019).

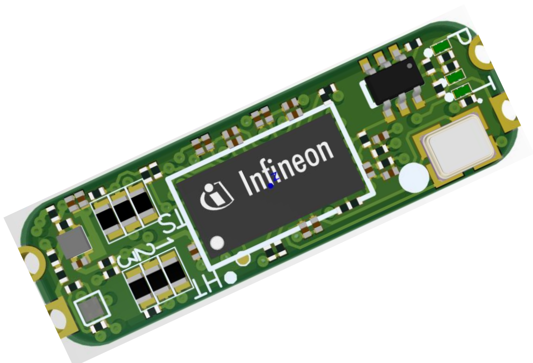


Figure 1 BGT60LTR11AIP Shield using BGT60LTR11AIP MMIC

1.2 Key features and system benefits

The BGT60LTR11AIP MMIC is a fully integrated microwave motion sensor including antenna elements, configurable built-in detectors and a state machine allowing fully autonomous operation of the device. The chip is designed to operate as a Doppler motion sensor. In the fully autonomous mode, the integrated detectors deliver digital outputs indicating motion and direction of motion. An integrated frequency divider with a Phase-Locked Loop (PLL) provides VCO frequency stabilization. The MMIC supports multiple operation modes: fully autonomous, semi-autonomous and SPI mode. The different modes can be selected via hardware preset pins (Section 3.9).

The BGT60LTR11AIP shield is optimized for fast prototyping designs and system integrations as well as initial product feature evaluations. In addition, the sensor can be integrated into systems like laptops, tablets, TVs, speakers etc. to 'wake' them up based on motion (or rather direction of motion) detection, 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 key-word based activation of systems. Radar sensors offer the possibility to hide them inside the end product since they operate through non-metallic materials. Therefore, it enables a seamless integration of technology in our day-to-day lives.

Some key features of the BGT60LTR11AIP shield are as follows:

- Form factor of 20 mm x 6.25 mm for the BGT60LTR11AIP shield
- 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 retreating) for a human target
- Option to solder onto other PCBs such as Arduino MKR for extra flexibility
- Low power consumption and different modes of operation with QS pins

2 System specifications

2.1 BGT60LTR11AIP shield parameters

Table 1 lists the various parameters of the BGT60LTR11AIP shield.

Table 1 BGT60LTR11AIP shield specifications

Parameter	Unit	Min.	Typ.	Max.	Comments
System performance					
Maximum detection range	m	–	5	10	Typ. range for human target (in autonomous mode) Max. range with MCU (FFT)
Power supply					
Supply voltage	V	1.5	3.3	5.0	
Antenna characteristics (measured)					
Antenna type			1 x 1		Antenna in Package (AIP)
Horizontal – 3 dB beamwidth	Degrees		65		At frequency = 60.6 GHz
Elevation – 3 dB beamwidth	Degrees		65		At frequency = 60.6 GHz

2.2 Typical current consumption

The platform can be powered directly through the castellated holes, VIN and GND (Figure 2) on the sides of the shield or through a baseboard platform like the Radar Baseboard MCU7 (Figure 3).

In Continuous Wave (CW) mode the MMIC is always active as configured with quad-state inputs.In pulsed Doppler mode, the MMIC is active only for a short time, followed by a time where the internal VCO, RF and PLL are off. Analog Base Band (ABB) and internal detectors keep running all the time. On/off timing can be configured in the MMIC registers. The pulsed Doppler mode features lower power consumption.

Table 2 Typical current consumption of the BGT60LTR11AIP MMIC

Operation mode	Current consumption	Comments
Continuous Wave mode	120 mA	
Pulsed Doppler mode	2.9 mA	Default mode Pulse on-time = 5 µs and pulse off-time = 500 µs

3 Hardware description

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

3.1 Overview

The BGT60LTR11AIP shield is a very small PCB of 20 mm x 6.25 mm size. Mounted on top of the PCB is a BGT60LTR11AIP (U1 in Figure 2), Infineon's 60 GHz radar sensor with integrated antennas. The antennas are integrated into the chip package; therefore, the PCB can be manufactured using a standard FR4 laminate. The bottom side of the shield has the connectors to the Radar Baseboard MCU7 [1] (P1 and P2 in Figure 2). The castellated holes on the edges of the PCB provide additional access to the detector outputs and power supply signals of the shield. By using these castellated holes and removing P1 and P2, the BGT60LTR11AIP shield can be soldered onto other PCBs. On the top side of the shield is a marker that must be aligned with the marker on the radar baseboard MCU7 for correct alignment, as shown in Figure 3.

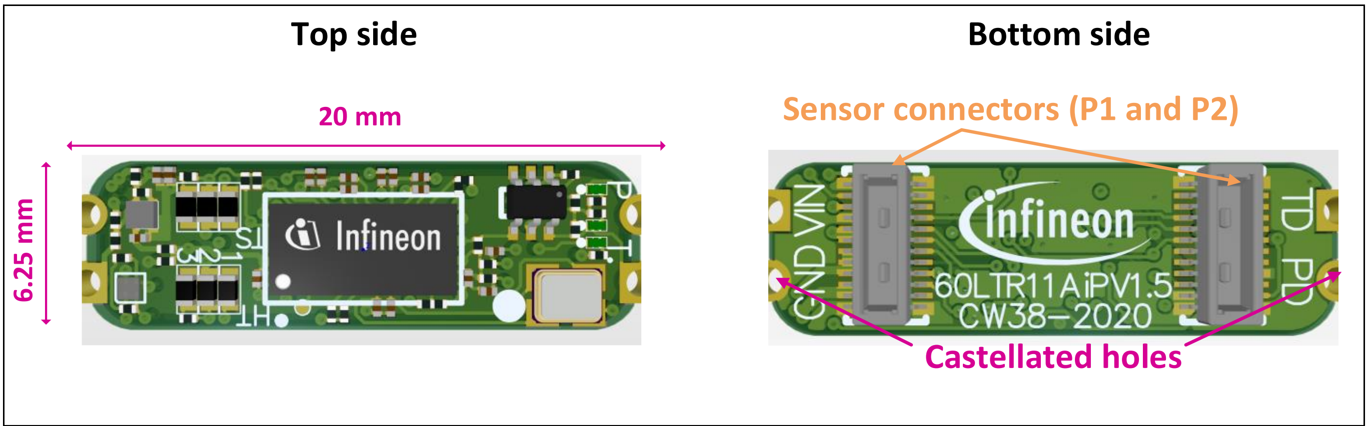


Figure 2 Top and bottom view of BGT60LTR11AIP shield

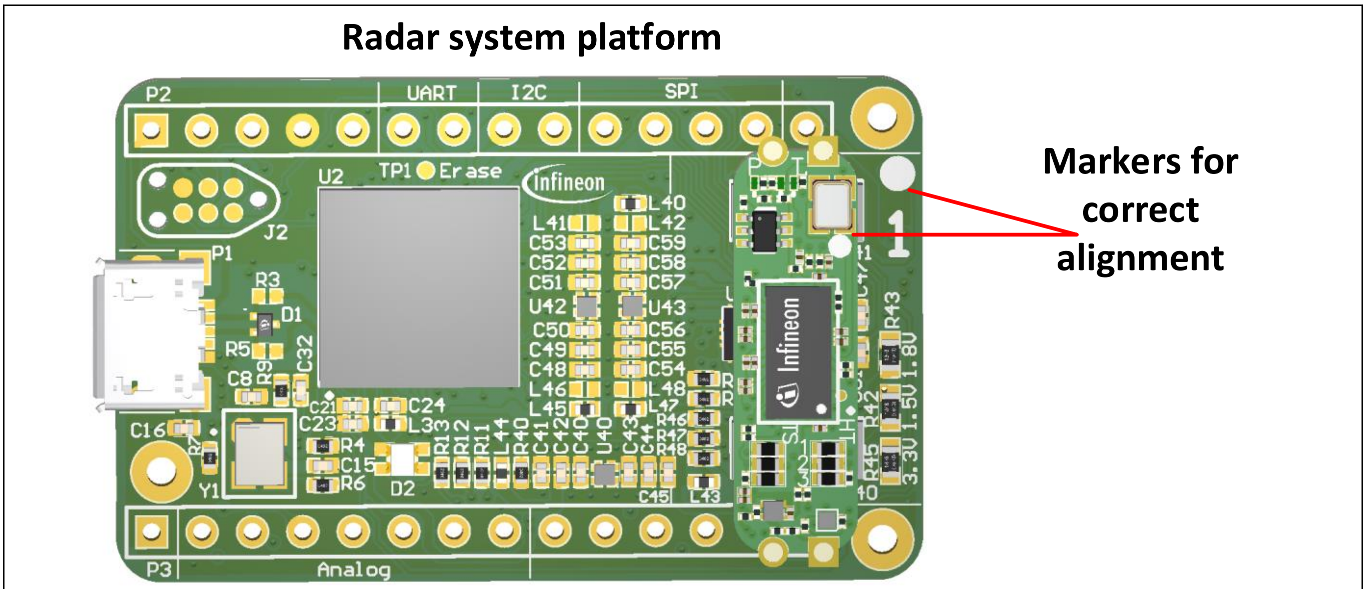


Figure 3 Markers on Radar Baseboard MCU7 and BGT60LTR11AIP shield for alignment

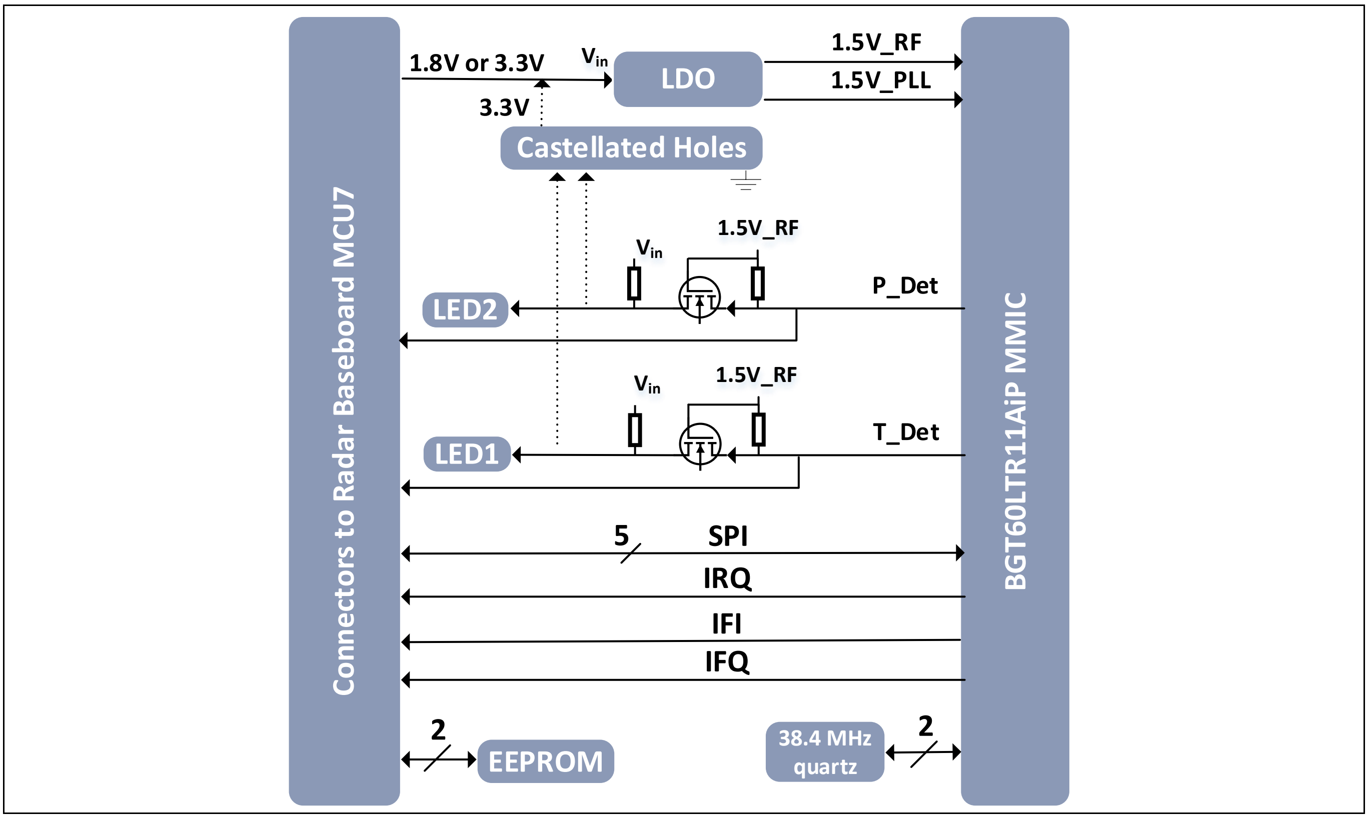


Figure 4 **Block diagram of the BGT60LTR11AIP shield**

The block diagram in Figure 4 depicts the configuration of the shield. When the shield is plugged into the Radar Baseboard MCU7, the MMIC's supplies are initially deactivated. Only the EEPROM is powered. The MCU reads the content of the EEPROM's memory to determine which shield is plugged into the connectors. Only when the shield has been correctly identified, are the MMIC's supplies activated.

Communication with the MMIC is mainly performed via a Serial Peripheral Interface (SPI). The BGT_RTSN allows the MCU to perform a hardware reset of the MMIC. The BGT_SELECT and BGT_RTSN lines of the SPI are also pulled up with 10 kΩ resistors. The interrupt request (IRQ) line signals the MCU when new data needs to be fetched.

3.2 BGT60LTR11AIP MMIC

The BGT60LTR11AIP MMIC (Figure 5) serves as the main element on the BGT60LTR11AIP shield. The MMIC has one transmit antenna and one receive antenna integrated into the package. The package dimensions are 6.7 mm (± 0.1 mm) x 3.3 mm (± 0.1 mm) x 0.56 mm (± 0.05 mm), as illustrated in Figure 6 and Figure 7.

The MMIC has an integrated Voltage Controlled Oscillator (VCO) for high-frequency signal generation. The transmit section consists of a Medium Power Amplifier (MPA) with configurable output power, which can be controlled via the 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 in order 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 Base Band (ABB) unit consists of an integrated sample and hold circuit for low-power duty-cycled operation 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 indicate the detection of movement in front of the radar and the direction of movement with two digital signals (BGT_TARGET_DET and BGT_PHASE_DET). See section 3.8 for more details. The detector circuit offers a user-configurable hold-time for maximum flexibility.

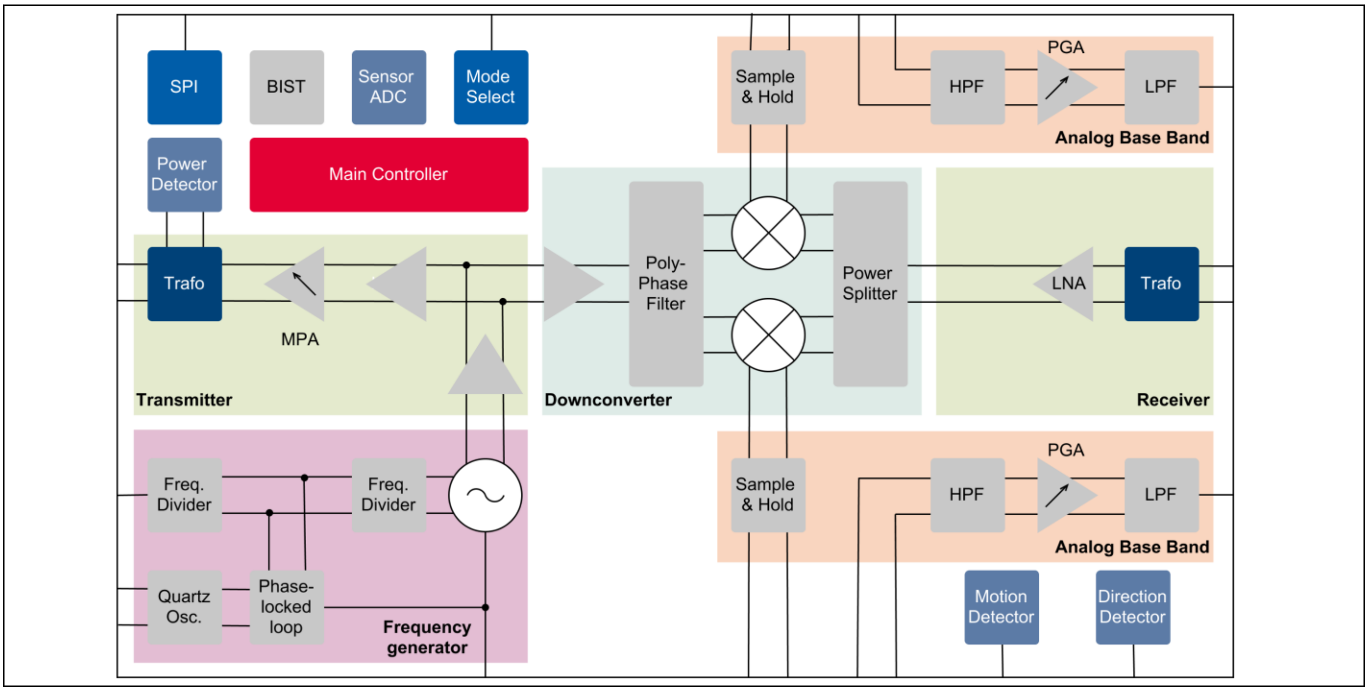


Figure 5 **BGT60LTR11AIP MMIC block diagram**

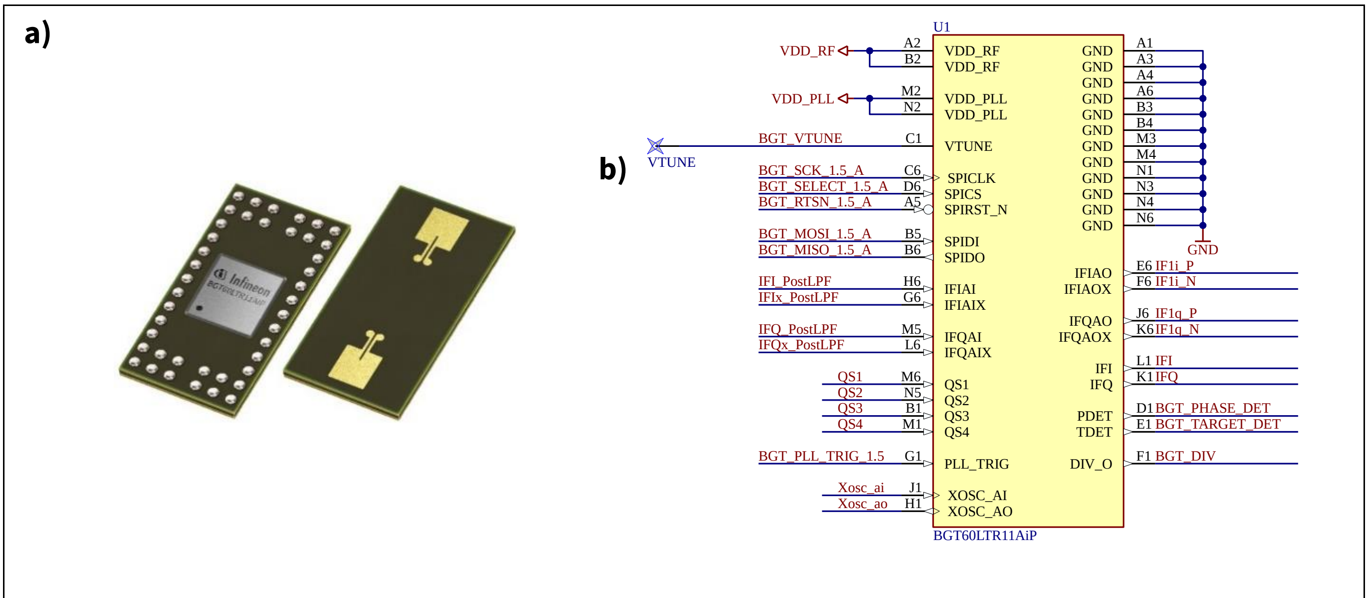


Figure 6 **Package outline (a) and pin-signal assignment (b) of the BGT60LTR11AIP MMIC**

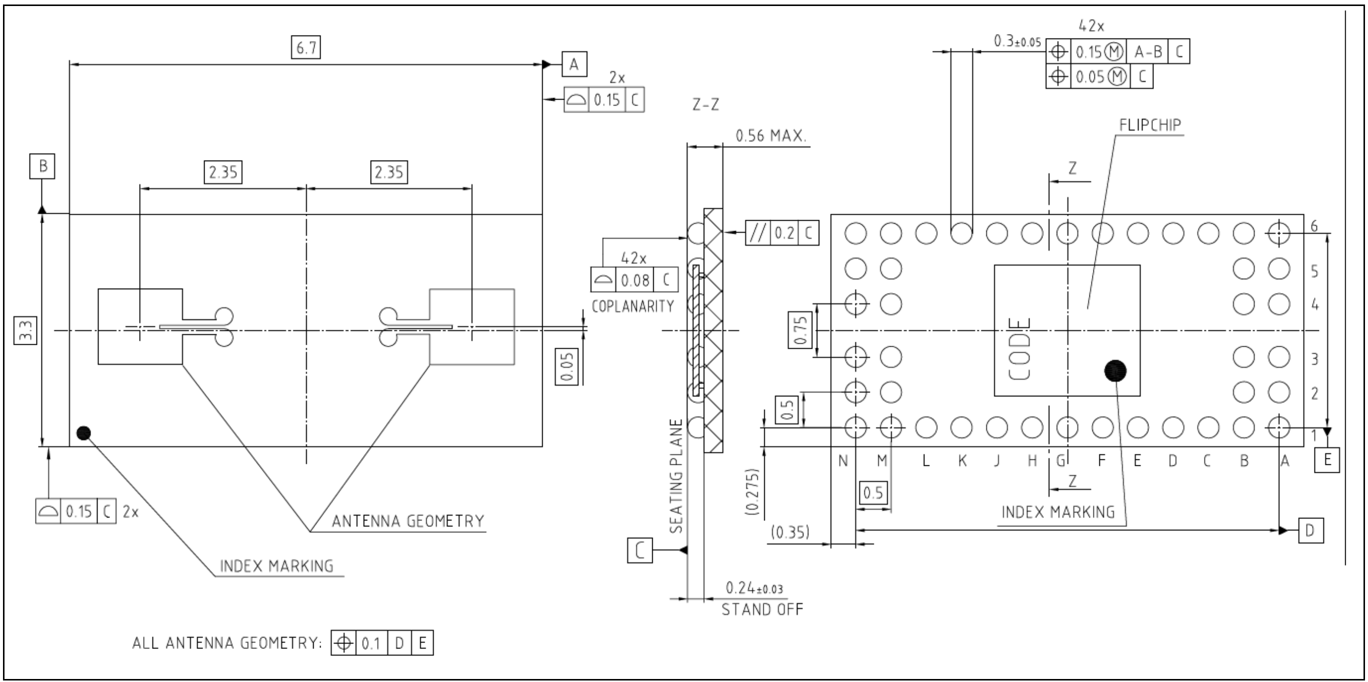


Figure 7 **Top and side view of the BGT60LTR11AIP MMIC package – all dimensions in mm**

3.3 Sensor supply

Since radar sensors are very sensitive to supply voltage fluctuations or cross-talk between different supply domains, a low-noise power supply as well as properly decoupled supply rails are vital. The Radar Baseboard MCU7 provides a low-noise supply. Figure 8 depicts the schematics of the low-pass filters employed to decouple the supplies of the different power rails in the BGT60LTR11AIP shield. High attenuation of voltage fluctuations in the MHz regime is provided by ferrite beads (L1, L3 and L5). For example, the SPI which runs up to 50 MHz, induces voltage fluctuations on the digital domain, which would then couple into and interfere with the analog domain without the decoupling filters. The ferrite beads are chosen such that they can handle the maximum current of the sensor with a low DC resistance (below 0.25 Ω) and an inductance as high as possible. The high inductance will reduce the cut-off frequency of the low-pass filter, which provides better decoupling for lower frequencies.

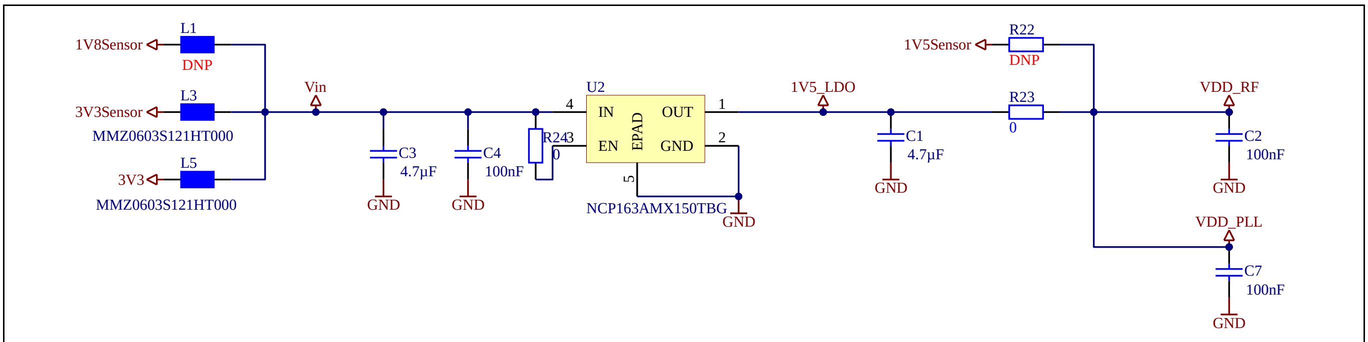


Figure 8 **Schematics of the sensor supply and low-pass filters**

3.4 Crystal

The MMIC requires an oscillator source with a stable reference clock providing low phase jitter and low phase noise. The oscillator is integrated inside the MMIC. This saves current consumption, as crystal oscillators consume only a few milli-amperes and run continuously. The BGT60LTR11AIP shield uses a 38.4 MHz crystal oscillator, as shown in Figure 9.

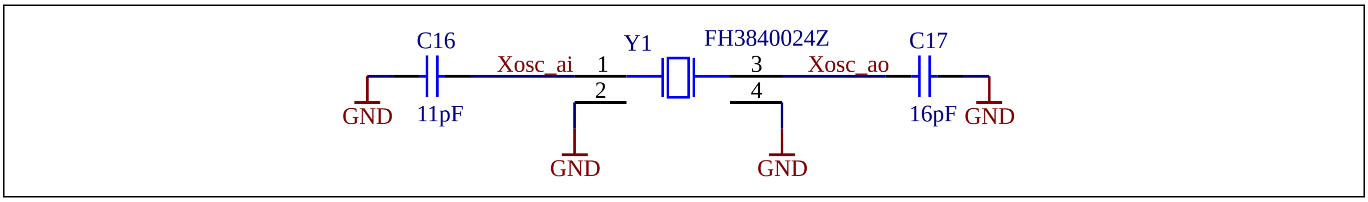


Figure 9 The crystal circuit on the BGT60LTR11AIP shield

3.5 Capacitors

The BGT60LTR11AIP MMIC performs a sample and hold operation for lower power consumption. The capacitors between sample and hold and the high-pass filter are external. C10, C11, C14 and C15 are 5.6 nF capacitors used as "hold" capacitors for the sample and hold circuitry. C8, C9, C12 and C13 are the DC blocking capacitors. They are 10 nF to get a high-pass of 4 Hz. It is not recommended to use higher values as it will cause issues with 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.

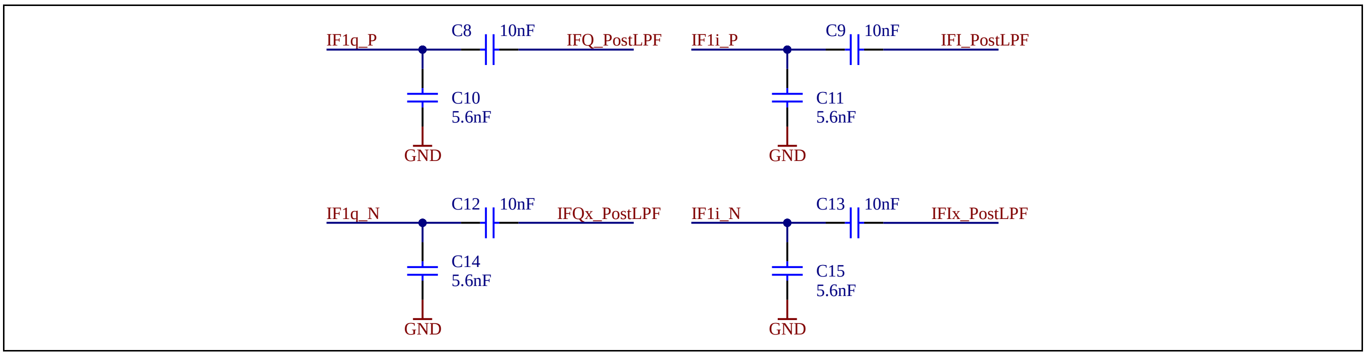


Figure 10 Capacitors

3.6 Connectors

The BGT60LTR11AIP shield can be connected to an MCU board, like the Radar Baseboard MCU7 with the P1 and P2 connectors. Visible on the top and bottom side of the PCB are the castellated holes (P3 and P4). TD and PD pins of the castellated holes correspond to the internal detector outputs of the MMIC.

The shield contains two Hirose DF40C-20DP-0.4V connectors, P1 and P2. The corresponding DF40C-20DS-0.4V connectors are on the Radar Baseboard MCU7. Figure 11 illustrates the pin-out of the Hirose connectors of the BGT60LTR11AIP shield.

There is a risk of the Hirose connectors wearing out when regularly plugged into and unplugged from the shield. To prevent this, do not lift the board on the short side out of the connector. Instead simply pull on the long side of the board, thereby tilting the short side. This will significantly increase the lifetime of the connectors.

The signal IRQ is connected with a R5 resistor (0 Ω) to the divider output (BGT_DIV) of the MMIC. In pulsed mode, BGT_DIV generates a signal that acts as an interrupt signal for the MCU to start ADC acquisition. This BGT_DIV is not used in CW mode.

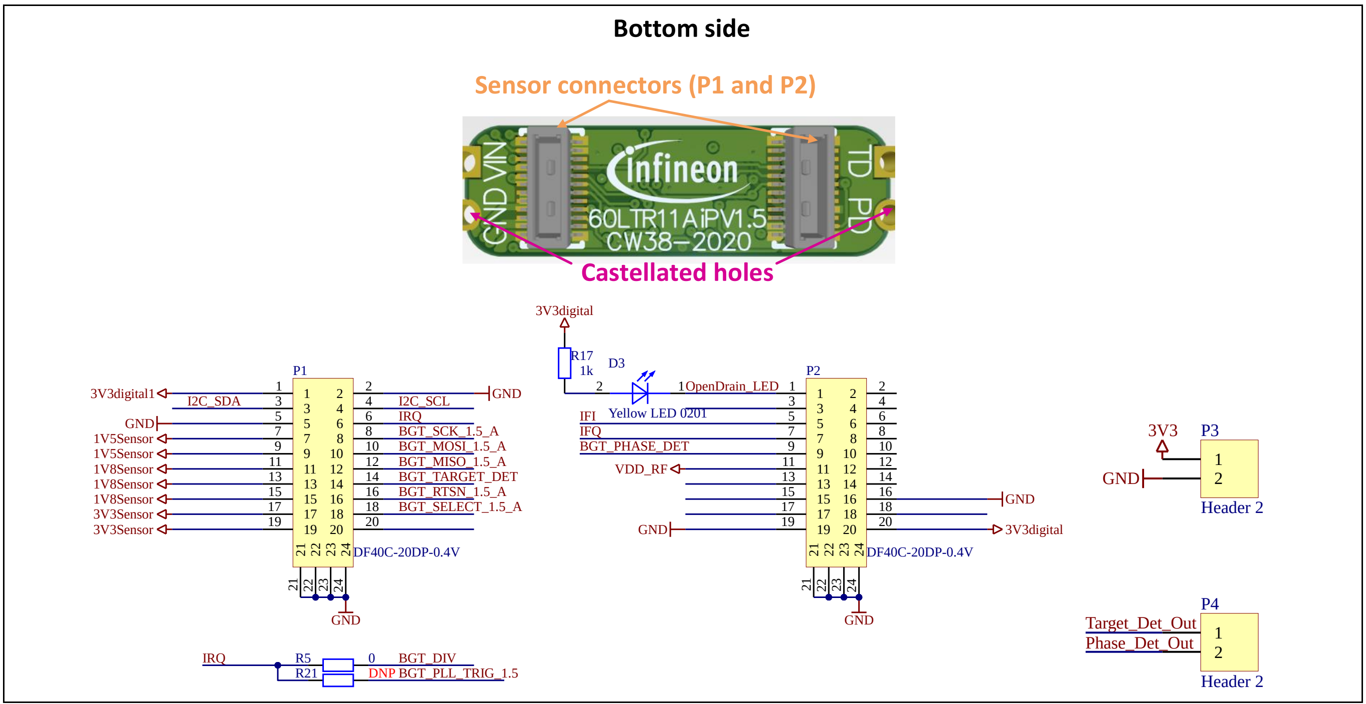


Figure 11 Connectors on the BGT60LTR11AIP shield, and their pin-outs

3.7 EEPROM

The BGT60LTR11AIP shield contains an EEPROM connected via an I^{2}C interface to store data like a board identifier. Its connections can be seen in Figure 12. This EEPROM contains a descriptor indicating the type of the shield board and MMIC. This is used by the firmware to communicate properly with the shield. The EEPROM can be removed when the shield is intended to be used independently in the autonomous mode.

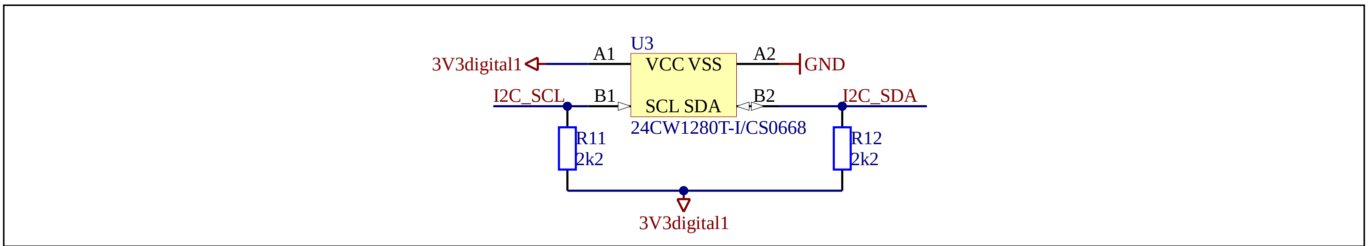


Figure 12 Connections of the EEPROM

3.8 LEDs and level shifting

The shield has two LEDs to indicate the motion detection (green) and target's direction of motion (red), as shown in Figure 13. R1 and R2 are limiting resistors. The digital block within the detector in the MMIC evaluates and sets the Target_detect/Phase_detect outputs of the BGT60LTR11AIP MMIC. Target detected (T_{det}) output is active low. It is set to L when enough events on the pulse train are counted. Phase detected (P_{det}) output is used to show the direction of the detected target. It is only valid in case of a detected target and it is set to H for approaching targets and set to L for departing targets.

The outputs from MMIC are at the voltage level of 1.5 V. They are level-shifted to the voltage level of Vin by using the circuit shown in Figure 13. In the circuit, BGT_TARGET_DET and BGT_PHASE_DET are outputs of MMIC (1.5 V voltage level). V_{DD_RF} is 1.5 V and V_{in} is 3.3 V (when connected with Radar Baseboard MCU7).

- When BGT_TARGET_DET is high (1.5 V), NMOS is off (V_{gs} = 0 V), and Target_Det_Out is 3.3V through the R14 pull-up resistor.
- When BGT_TARGET_DET is low (0 V), NMOS is on (V_{gs} = 1.5 V), and Target_Det_Out is pulled down to 0 V.

The same applies to the BGT_PHASE_DET signal.

Table 3 LED detection

LED	Mode	Comments
Green	On – target detected Off – target not detected	Target_Det_Out is an active low signal
Red	On – depart departing Off – target approaching	Triggered when Target_Det_Out is low

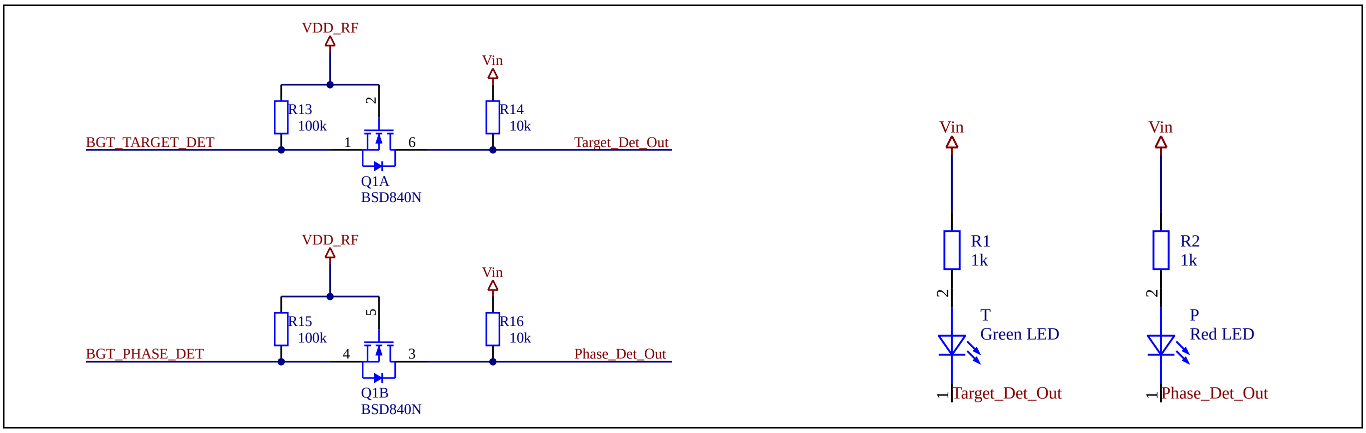


Figure 13 Connections of the LEDs and level shifter

3.9 MMIC operation modes and settings

The BGT60LTR11AIP MMIC has four quad-state inputs (QS1 to QS4). They allow configuration of four different states with one input pin (Figure 14). These can be configured in different ways to change the settings of the MMIC, as shown in Figure 14, Table 4, Table 5, Table 6 and Table 7.

For QS2 and QS3, there are labels 1, 2 and 3 to denote GND, V_{DD} and 100 kΩ to V_{DD} connections respectively. It is a simplified way to quickly change the settings of these quad-state inputs.

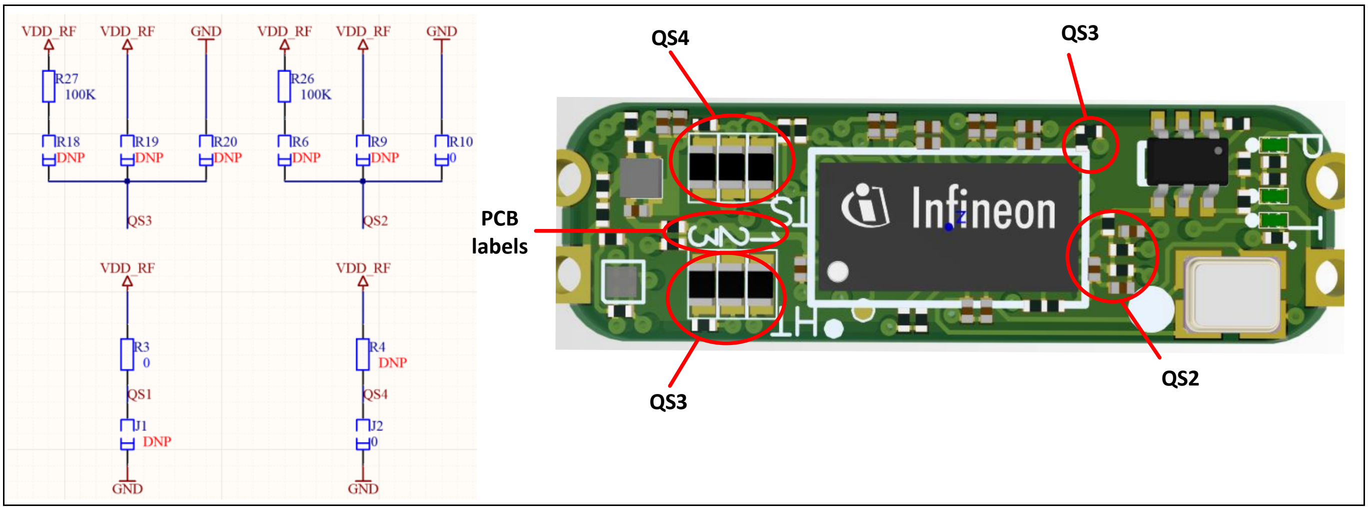


Figure 14 QS1 to QS4 schematic and layout connections

Table 4 QS1 settings: operation modes of the MMIC

QS1	Mode	PCB components
GND	Continuous Wave	J1 = 0 Ω; R3 = DNP
OPEN	Pulsed Mode	J1 = DNP; R3 = DNP
100 kΩ to V_{DD}	SPI with 9.6 MHz	J1 = DNP; R3 = 100 kΩ
V_{DD} (default)	SPI	J1 = DNP; R3 = 0 Ω

Table 5 QS2 settings: detector comparator threshold voltage

QS2	PCB label	Mode	PCB components
GND (default)	1	787.5 mV	R6 = DNP; R26 = DNP; R9 = DNP; R10 = 0 Ω
OPEN	–	937.5 mV	R6 = DNP; R26 = DNP; R9 = DNP; R10 = DNP
100 kΩ to V_{DD}	3	1087.5 mV	R6 = 0 Ω; R26 = 100 kΩ; R9 = DNP; R10 = DNP
V_{DD}	2	1237.5 mV	R6 = DNP; R26 = DNP; R9 = 0 Ω; R10 = DNP

Table 6 QS3 settings: hold-time of the "target detect" output

QS3	PCB label	Mode	PCB components
GND	1	10 ms	R18 = DNP; R27 = DNP; R19 = DNP; R20 = 0 Ω
OPEN (default)	-	1 s	R18 = DNP; R27 = DNP; R19 = DNP; R20 = DNP
100 kΩ to V_{DD}	3	10 s	R18 = 0 Ω; R27 = 100kΩ; R19 = DNP; R20 = DNP
V_{DD}	2	60 s	R18 = DNP; R27 = DNP; R19 = 0 Ω; R20 = DNP

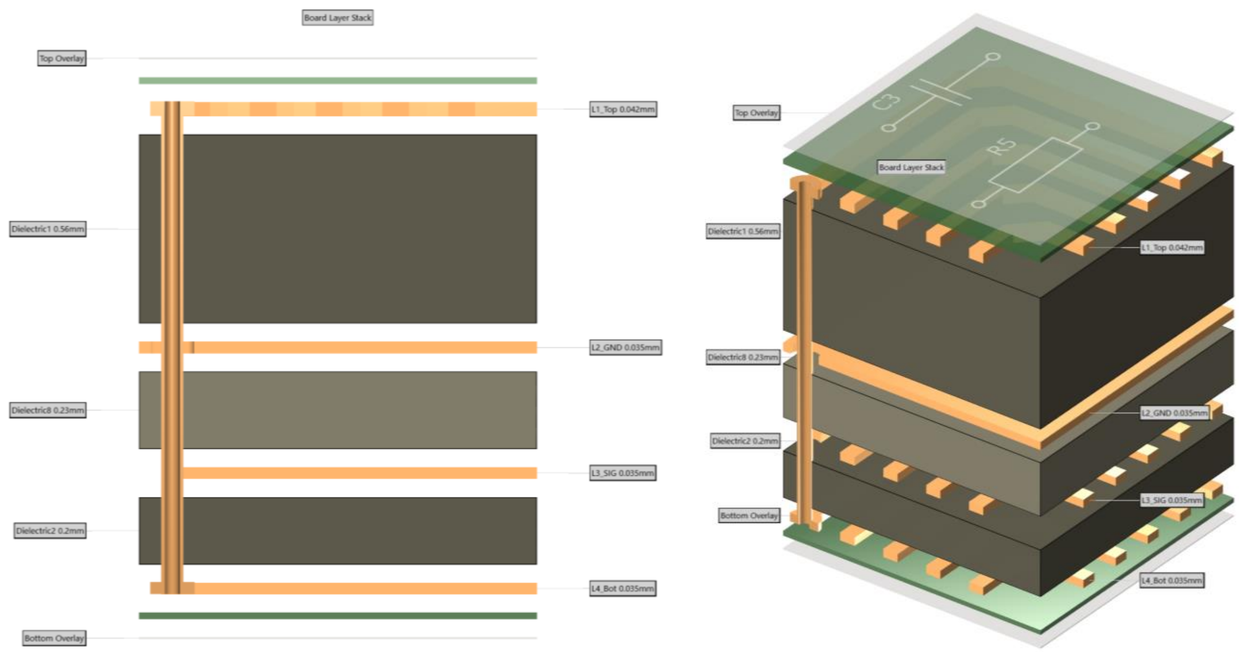
Table 7 QS4 settings: device operating frequency

QS4	Japan e-fuse	Mode	PCB components
GND (default)	1	61.1 GHz	J2 = 0 Ω; R4 = DNP
OPEN	1	61.2 GHz	J2 = DNP; R4 = DNP
100 kΩ to V_{DD}	1	61.3 GHz	J2 = DNP; R4 = 100kΩ

QS4	Japan e-fuse	Mode	PCB components
V_{DD}	1	61.4 GHz	J2 = DNP; R4 = 0 Ω
GND (default)	0	60.6 GHz	J2 = 0 Ω; R4 = DNP
OPEN	0	60.7 GHz	J2 = DNP; R4 = DNP
100 kΩ to V_{DD}	0	60.8 GHz	J2 = DNP; R4 = 100 kΩ
V_{DD}	0	60.9 GHz	J2 = DNP; R4 = 0 Ω

3.10 Layer-stack up and routing

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



#	Name	Material	Type	Thickness	Dk
	Top Overlay		Overlay		
	Top Solder	Solder Resist	Solder Mask	0.02mm	3.5
1	L1_Top		Signal	0.042mm	
	Dielectric1	FR-4	Core	0.56mm	4.2
2	L2_GND		Plane	0.035mm	
	Dielectric8	FR-4	Prepreg	0.23mm	4.2
3	L3_SIG		Signal	0.035mm	
	Dielectric2	FR-4	Core	0.2mm	4.3
4	L4_Bot		Signal	0.035mm	
	Bottom Solder	Solder Resist	Solder Mask	0.02mm	3.5
	Bottom Overlay		Overlay		

Figure 15 PCB layer stack-up in 2D and 3D view

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 Measurement results

4.1 Radiation pattern

To analyze the radar radiation pattern, the BGT60LTR11AIP shield is characterized along the E-plane and the H-plane of the antenna. The measurement is performed in an anechoic RF chamber.

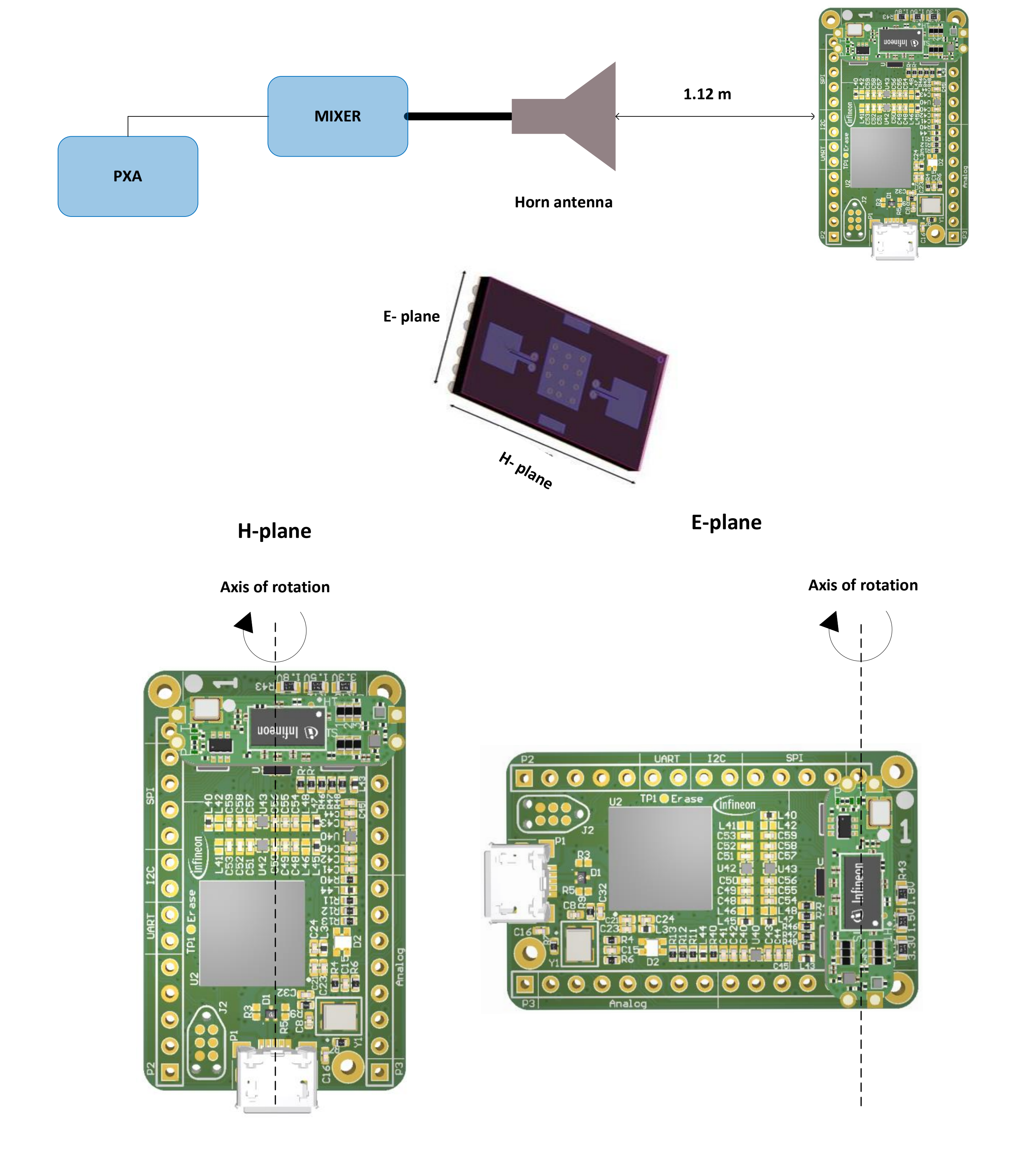


Figure 16 Set-up for radiation pattern measurement

Figure 16 shows the measurement set-up. The board is placed at a distance of 1.12 m from the horn antenna in an anechoic chamber. The board is rotated by ±90 degrees along the E-plane and the H-plane. The results for the E-plane can be seen in Figure 17 and the ones for the H-plane in Figure 18.

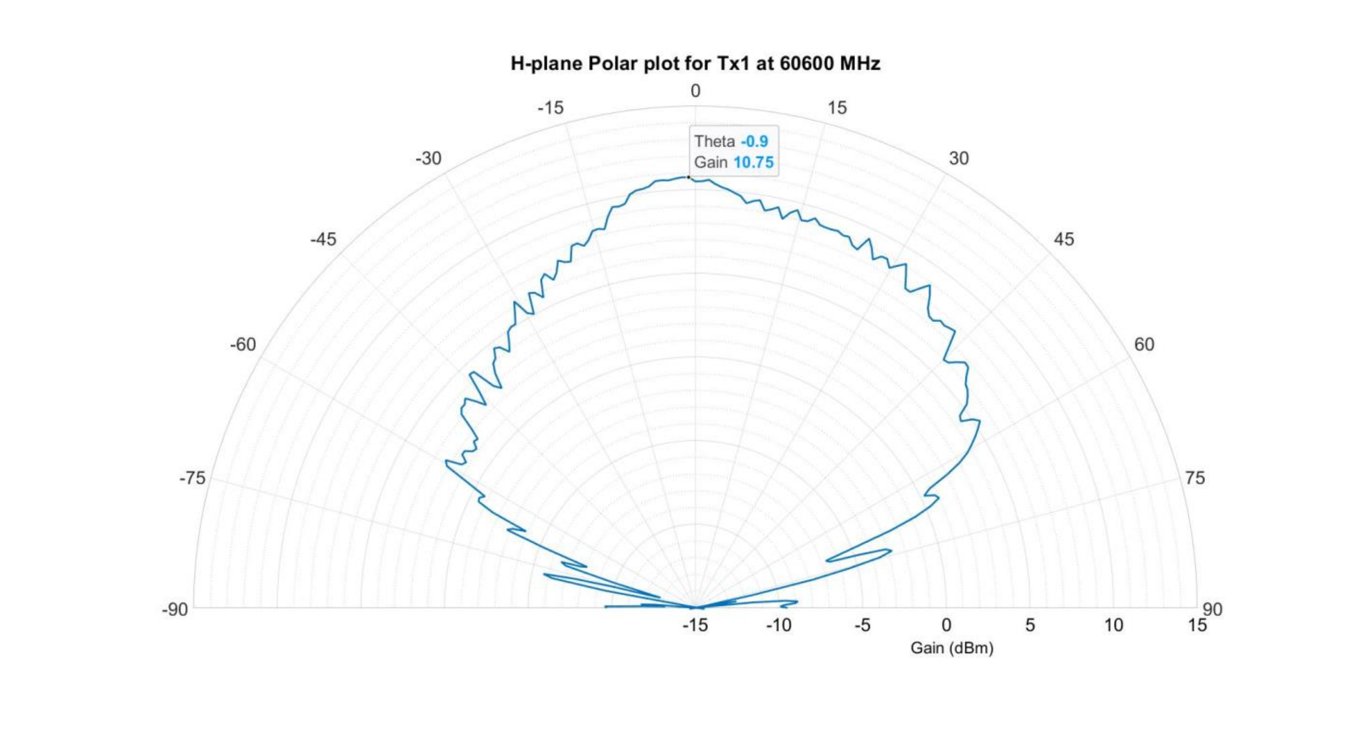


Figure 17 Radiation pattern measurement result along the H-plane of the MMIC (at 60.6 GHz) for the Tx antenna

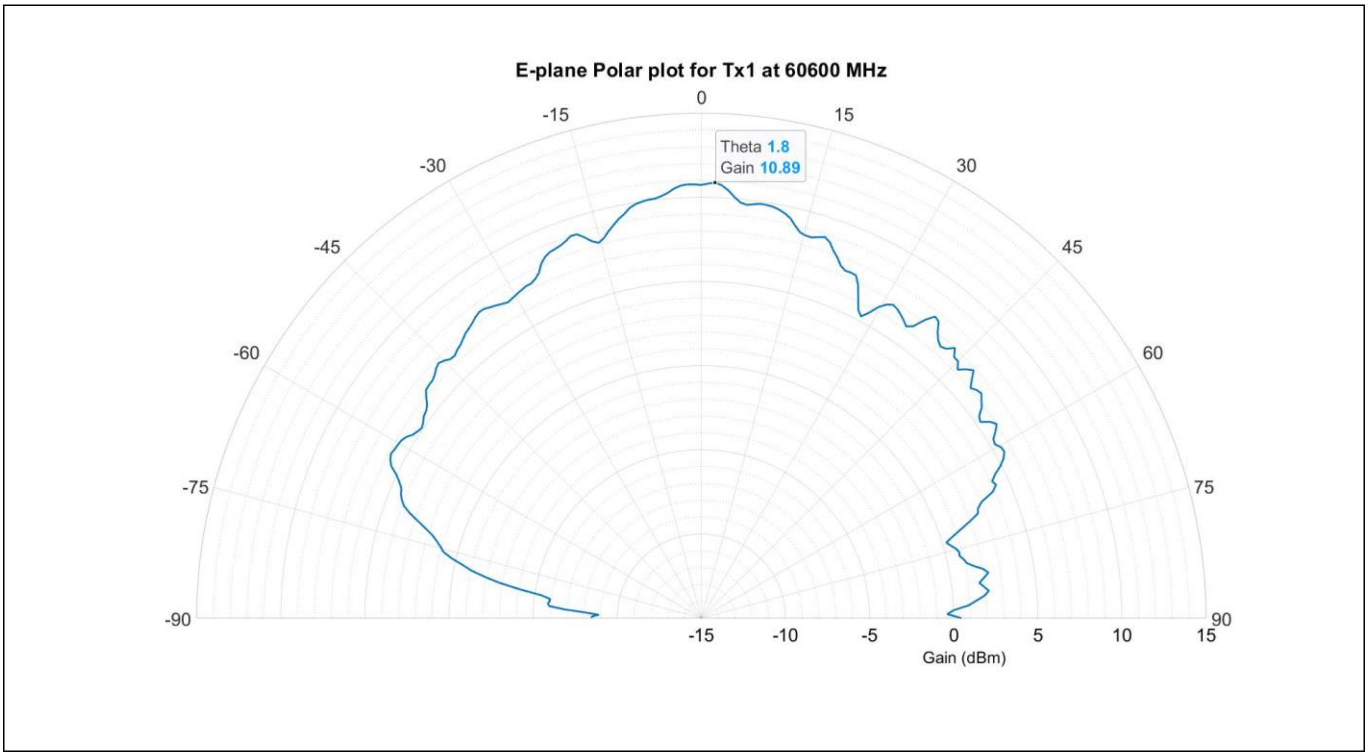


Figure 18 Radiation pattern measurement result along the E-plane of the MMIC (at 60.6 GHz) for the Tx antenna

4.2 Motion detection

Figure 19 shows the detection of a moving human target in the +/- 90° field of view (FoV) with respect to the BGT60LTR11AIP shield in the autonomous mode of operation. The detection range is maximum in 0° and reduces along the angles.

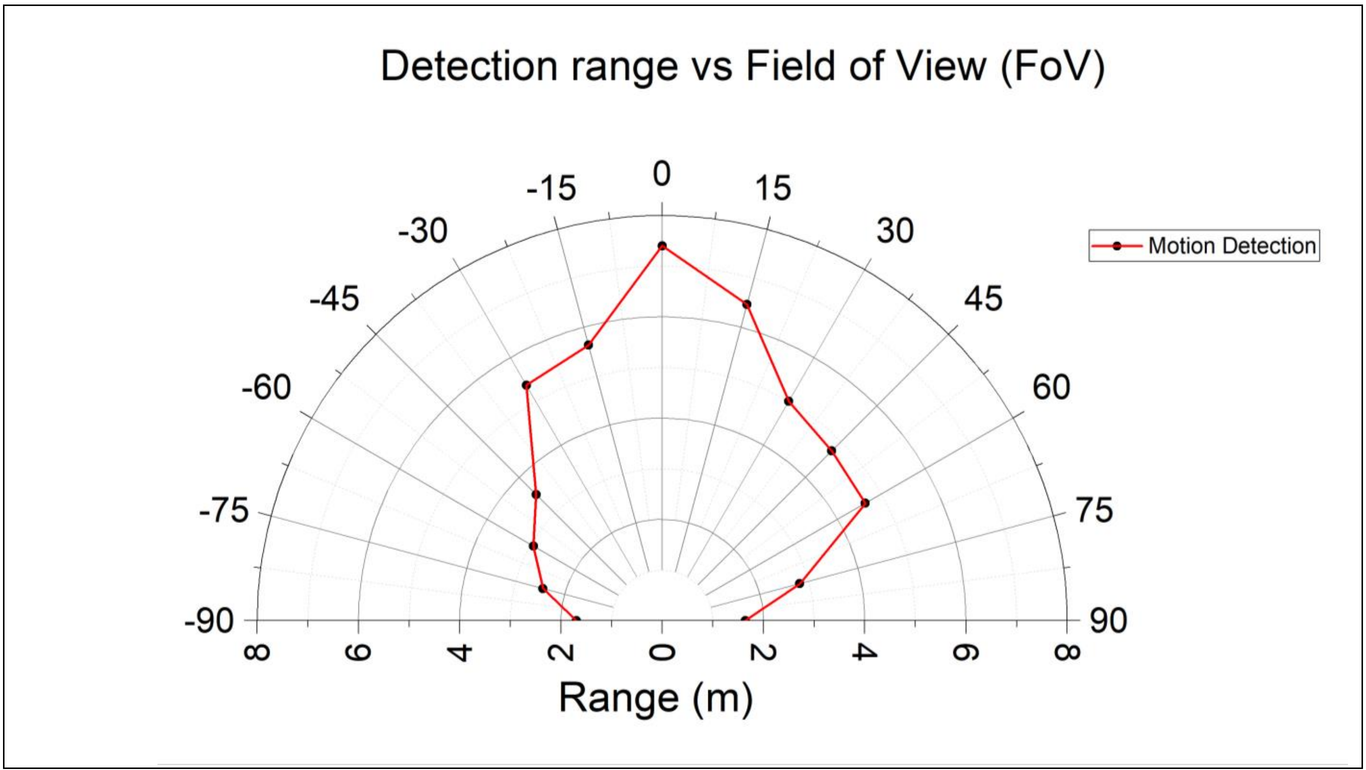


Figure 19 **Human target motion detection over the angles**

5 Autonomous mode operation

In the autonomous mode operation, the MMIC uses internal detectors for motion and direction of motion indication. The detector output signals are connected to LEDs which glow according to target movement.

A shield working in autonomous mode can be used as a plug-on radar module. The MMIC only needs power supply with the castellated holes and generates outputs on TD and PD castellated holes depending on the movement of the target. In Figure 20 a shield is shown working independently with a battery that supplies 3.7 V to the VIN, GND pins of the castellated holes.

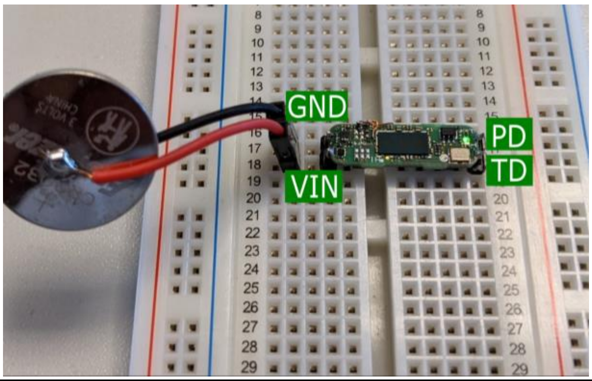


Figure 20 Shield working independently with a 3.7 V battery power supply

The shield has dimensions such that it can be mounted onto an Arduino MKR series board as shown in Figure 21 as a plug-on motion sensor.

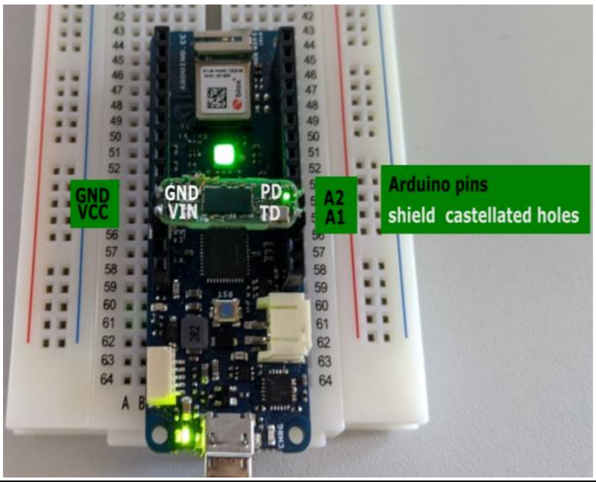


Figure 21 Shield mounted on an Arduino MKR Wifi1010 board

6 References

AN599 - Radar Baseboard MCU7. Neubiberg: Infineon Technologies.

Revision history

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V1.0	2020-06-03	First version – preliminary
V1.1	2020-10-20	Mass market version

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