BGT60UTR11AIP shield

XENSIV™ 60 GHz radar system platform

Board version V2.2

About this document

Scope and purpose

This user guide describes the function, circuitry, and performance of the BGT60UTR11AIP shield, part of Infineon's XENSIV™ 60 GHz radar system platform. The shield provides the supporting circuitry to the on-board BGT60UTR11AIP monolithic microwave integrated circuit (MMIC) Infineon's 60 GHz radar chipset with antenna-in-package (AIP). The shield offers a digital interface for configuration and transfer of the acquired radar data to a microcontroller board, e.g., "Radar Baseboard MCU7 Plus".

Intended audience

The intended audience for this document is 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**

	**Caution:** *The 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.*

Table of contents

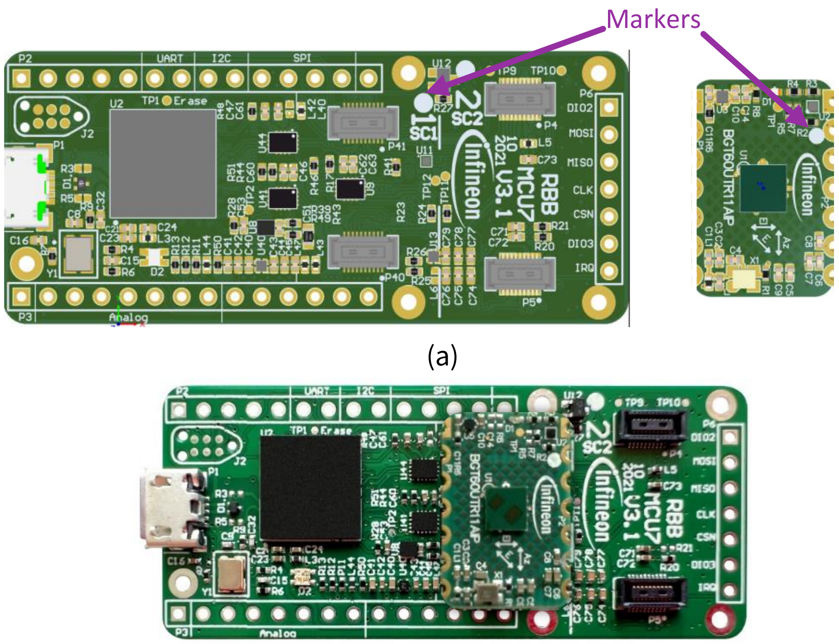
1 Introduction

1.1 Radar system platform

The 60 GHz radar system platform is the demo platform for Infineon's 60 GHz radar solutions. It consists of the "Radar Baseboard MCU7 Plus" as the microcontroller board and a radar sensor board, like the BGT60UTR11AIP shield for Infineon's 60 GHz radar sensor chip.

The BGT60UTR11AIP shield demonstrates the features of the BGT60UTR11AIP MMIC and gives you a "plug-and-play" radar solution. The shield can also be attached to an Arduino MKR board or an Infineon Radar Baseboard. A graphical user interface (GUI) is available via the Developer Center to display and analyze the acquired data in the time and frequency domains.

Figure 1 shows the "Radar Baseboard MCU7 Plus" with the BGT60UTR11AIP shield. Both boards have markers. These markers must be aligned to correctly plug in a sensor board.



(b)

Figure 1 Radar Baseboard MCU7 Plus with the BGT60UTR11AIP shield (a) unplugged or (b) plugged in

1.2 Key features

The BGT60UTR11AIP shield is optimized for fast prototyping designs and system integrations, as well as initial product feature evaluations. The board offers developers the flexibility to choose their own platform depending on their preferred use cases. The sensor supports various use cases, serving a broad application spectrum such as presence detection, proximity sensing or distance measurement. These use cases target applications such as notebooks, TVs, smart speakers, wearables, smart home and automations for comfort, energy savings and security/safety functions.

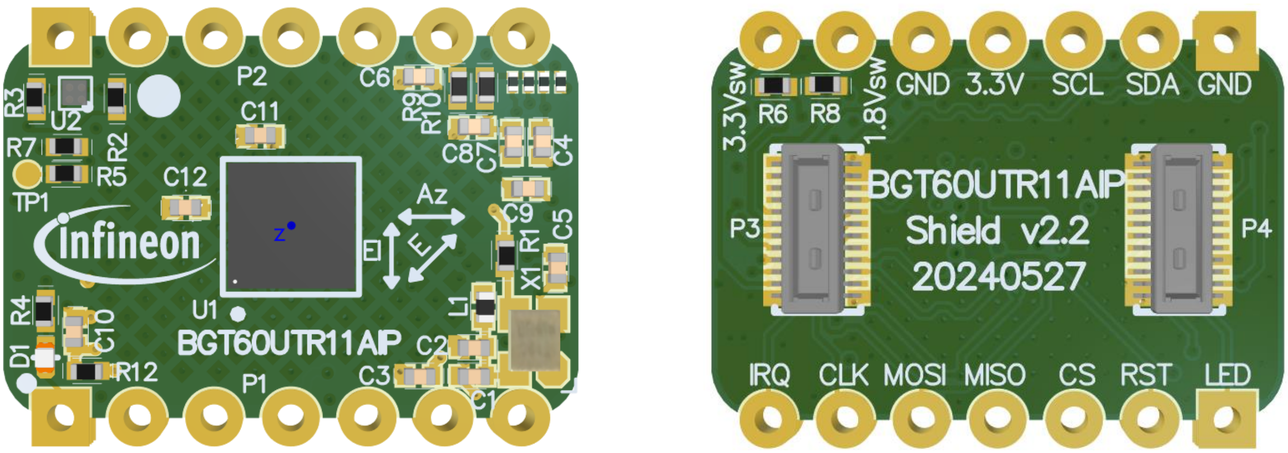
Some key features of the BGT60UTR11AIP shield are as follows:

- Minimized form factor of 19 mm x 12.7 mm^2 RF board with Antenna-in-Package (AIP) of 4.05 x 4.05 x 0.86 mm^3
- Flexible platform selection
- Variable connector options, and option to solder onto other PCBs
- Highly flexible configuration on FMCW modulation
- Power consumption can be optimized according to the use case

2 Hardware description

This section of the document presents a detailed overview of the BGT60UTR11AIP shield hardware specifics, such as BGT60UTR11AIP considerations, power supply, crystal oscillator, and board interfaces.

2.1 Overview



(a) Top view (b) Bottom view

Figure 2 The BGT60UTR11AIP shield

The dimensions of the BGT60UTR11AIP shield printed circuit board (PCB) are 19 mm x 12.7 mm. The radar sensor BGT60UTR11AIP is the central component on the top side of the PCB (U1 in Figure 2a). Because the antennas are integrated into the BGT60UTR11AIP chip package, the PCB can be manufactured using a standard FR4 laminate. The bottom side of the PCB features the main interfaces to the “Radar Baseboard MCU7 Plus” (P3 and P4 in Figure 2b). The castellated holes on the edges of the PCB (P1 and P2 in Figure 2a) provide additional access to the most important signals of the BGT60UTR11AIP. By using these side connectors and removing P3 and P4, the BGT60UTR11AIP shield can be soldered onto other PCBs as a radar module.

The block diagram in Figure 3 depicts the concept behind the board. Each of the signals on the castellated holes’ side connectors corresponds to a signal on the sensor connector. To provide the correct level shifter voltage for the MCU board, the 1.8 V sensor supply line is connected with $V_{digital}$. When the shield is plugged into the “Radar Baseboard MCU7 Plus”, the sensor’s supplies are initially deactivated. The MCU will read the chip ID from the radar chip to determine which sensor is plugged into the sensor interface. Only when the board has been correctly identified, the sensor’s supplies are activated.

Radar sensors are very sensitive to noise and crosstalk on the supply domains. Therefore, the different supply domains must be decoupled. On the BGT60UTR11AIP shield, this is realized by a capacitor on each supply domain (and the oscillator supply). Communication with the radar sensor is mainly performed via a serial peripheral interface (SPI) bus. Additionally, two more digital lines are required for operation. One line (IRQ) signals the MCU when new data needs to be fetched. The other (RST) allows the MCU to perform a hardware reset of the sensor. Furthermore, an MCU-controllable LED is mounted on the board. This allows the MCU to indicate to the user, for example, if the sensor is activated or deactivated.

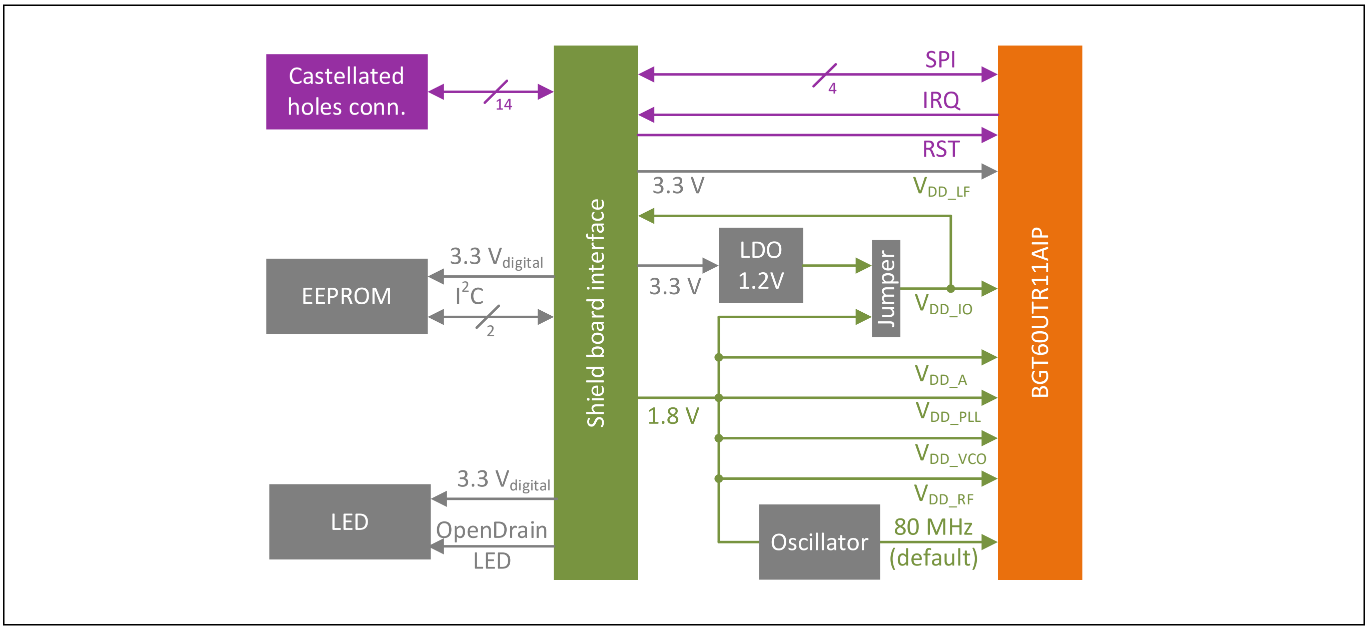


Figure 3 **Block diagram of the BGT60UTR11AIP shield**

2.2 BGT60UTR11AIP MMIC

The BGT60UTR11AIP is a 60 GHz radar sensor with one transmitting and one receiving U-slotted patch antenna in the package. The 5.5 GHz ultra-wide bandwidth allows Frequency-Modulated Continuous Wave (FMCW) operations with extremely high resolution. This enables precise range measurements, 1D gestures and the measurement of vital signs such as breathing rate or heart rate.

The BGT60UTR11AIP provides the following digital signal lines: oscillator input, four SPI signals, hardware reset line (RST) and interrupt request output (IRQ) to the MCU. Furthermore, there is a divider output signal. It must be enabled in the chip and outputs a 1:16 fraction of the RF generated by the radar sensor.

2.3 Sensor power supply

The BGT60UTR11AIP has four 1.8 V power domains: analog, Radio Frequency (RF), Phase-Locked Loop (PLL) and the Voltage Controlled Oscillator (VCO) circuitry. Additionally, there is a 3.3 V domain for the Loop Filter (LF). The digital domain (V_{DD_IO}) is compatible with both 1.8 V and 1.2 V power supply.

2.4 Oscillator

Infineon's BGT60UTR11AIP radar sensor requires an oscillator source with a stable reference clock providing low phase jitter and low phase noise. Therefore, the BGT60UTR11AIP shield employs a Kyocera KC2016K quartz oscillator, which is supplied by 1.8 V as depicted in Figure 4. This oscillator source will output a stable 1.8 V digital signal. The most important parameters for choosing an oscillator are phase jitter and phase noise. Other oscillators should have similar phase jitter and phase noise as the Kyocera KC2016K. Furthermore, the radar sensor will work most efficiently if the reference oscillator signal is neither too strong nor too weak. The series resistor R1 reduces the RF level at the sensor so that it is at the ideal range for the BGT60UTR11AIP. If a redesign of the board contains a different signal source or a vastly different layout is designed, the value of R1 (150 Ω) may have to be adjusted. A higher resistance results in a lower signal at the radar sensor. If the signal level is too low, the phase noise of the sensor will deteriorate. With a low resistance, the signal level at the sensor will be high, and in the Range-Doppler illustration of the radar data, a peak (or ghost target) will appear for low distances.

For this reason, the phase noise needs to be measured as well as the radar data needing to be illustrated with a Range-Doppler plot to optimize the series resistance of the layout. The series resistance can be varied by soldering different resistors into the circuit. An optimized series resistance will show the ideal phase noise behavior of the sensor, paired with a clean Range-Doppler plot. If the phase noise behavior is non-ideal, the resistance value must be lower. If a peak appears in the Range-Doppler plot, the resistance must be higher.

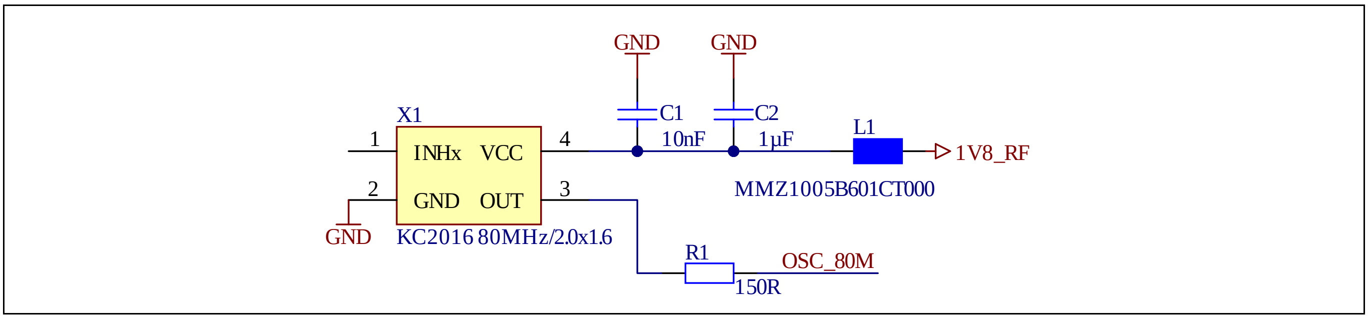


Figure 4 The oscillator circuit on the BGT60UTR11AIP shield

2.5 Connectors

The BGT60UTR11AIP shield is an extension board of Infineon's 60 GHz radar system platform without a microcontroller. The shield must be connected to an MCU board, like the "Radar Baseboard MCU7 Plus". The BGT60UTR11AIP shield contains two different types of connectors to interact with an MCU board, as depicted in Figure 2a. Visible on the top and bottom side of the PCB are the castellated holes. The contacts on this connector give access to all signals required for operation of the BGT60UTR11AIP. The pinout of the connectors as shown in Figure 5.

The main connector interface of the BGT60UTR11AIP shield contains two Hirose DF40C-20DP-0.4V connectors. On the MCU side, the "Radar Baseboard MCU7 Plus" contains the corresponding DF40C-20DS-0.4V connectors. Figure 5 shows the pin map of the Hirose connectors of the BGT60UTR11AIP shield. On the top side of the shield, there is a marker that must be aligned with the marker on the MCU board for correct shield alignment, as depicted in Figure 1a.

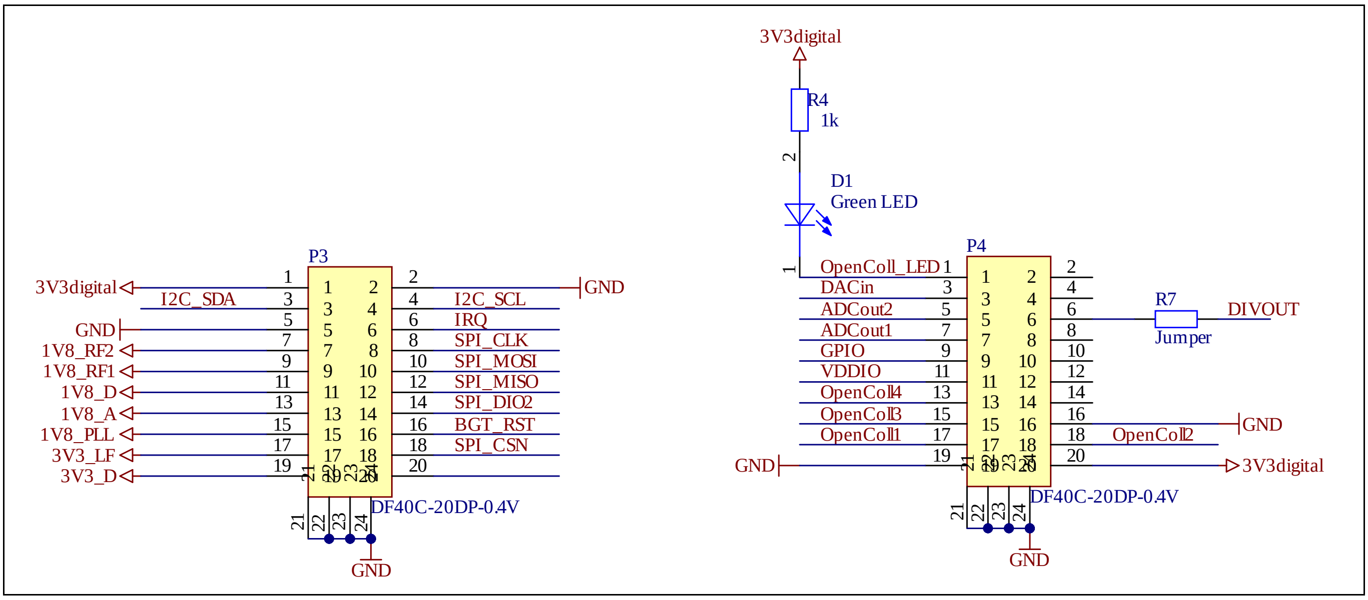


Figure 5 Pin map of the sensor connectors on the BGT60UTR11AIP shield

2.6 PCB design recommendation

The size of ground plane for the antennas-in-package is limited by the BGT60UTR11AIP chip dimension. It results that there will always be a portion of the RF signal interacting with the PCB structures around the BGT60UTR11AIP chip. In some cases, this interaction will have an impact on the antenna radiation pattern. In the cases requiring reducing this interaction, some special PCB design may be adopted, such as the Electromagnetic Band-Gap (EBG) structure.

Reflections of an electromagnetic wave travelling perpendicular to the surface of the EBG structure will behave similar like reflections from a regular metallic plane, but without the 180° phase shift. Hence, the reflected wave has the in-phase effect on superposition of the original radiated waves from the antenna, which results in less deviations of the initial antenna radiation pattern.

The EBG structure in general consists of multiple identical elements placed in a uniform grid. The literature provides various EBG element designs utilizing different geometries. The geometry of the EBG element together with the PCB substrate defines the inductance and capacitance between neighboring elements, which will result in a specific operating frequency band of the individual EBG design.

The structure of the EBG element design used for the BGT60UTR11AIP RF shield can be seen in Figure 6. The EBG structure consists of a rectangular patch with a centered via connection to the internal PCB GND layer. The size of the patch ($w = 0.55\ mm$) and the periodicity ($w + g = 0.85\ mm$) are designed for an operation frequency around 61 GHz on an FR4 substrate with a thickness "l" of the first laminate layer of 0.36 mm and the via diameter "d" of 0.2 mm. The first inner metal layer forms a continuous ground plane underneath the EBG structure. Therefore, only the thickness of the first laminate layer is relevant for this EBG design, and the thickness of the other layers can be customized.

At least three rows of EBG elements in every direction around the sensor are recommended to provide a significant effect. Additional rows of EBG elements will further decrease the sensitivity of the radiation pattern towards the remaining PCB layout. This results in a trade-off between the area occupied by the EBG elements and radiation performance.

The EBG structure has not necessarily to be part of every design. For many applications, reasonable performance has been demonstrated without EBG structure.

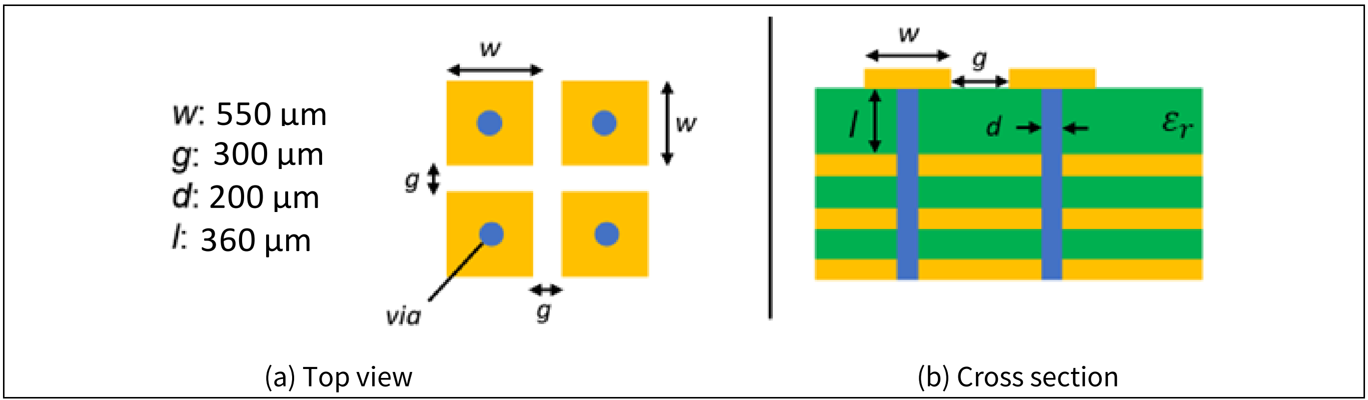


Figure 6 EBG geometry designed for 61 GHz on FR4 laminate

The transmitter antenna and the receiver antenna are located in a compact dimension of the radar package. A certain coupling level between transmitter channel and receiving channel usually cannot be avoided. The coupling path may be formed both inside the radar chip and on the external PCB vicinity. If the coupled signals from two main coupling paths have a similar amplitude but inverted phase at a certain frequency, the coupled signal may cancel each other. This effect can be adopted in the PCB design to further optimize the coupling behavior.

As presented in Figure 7, with the direct connections between PCB landing pads A1 and H8, together with the direct connection between pads A5 and D8, the Tx-Rx coupling of BGT60UTR11AIP shield V2.2 improves.

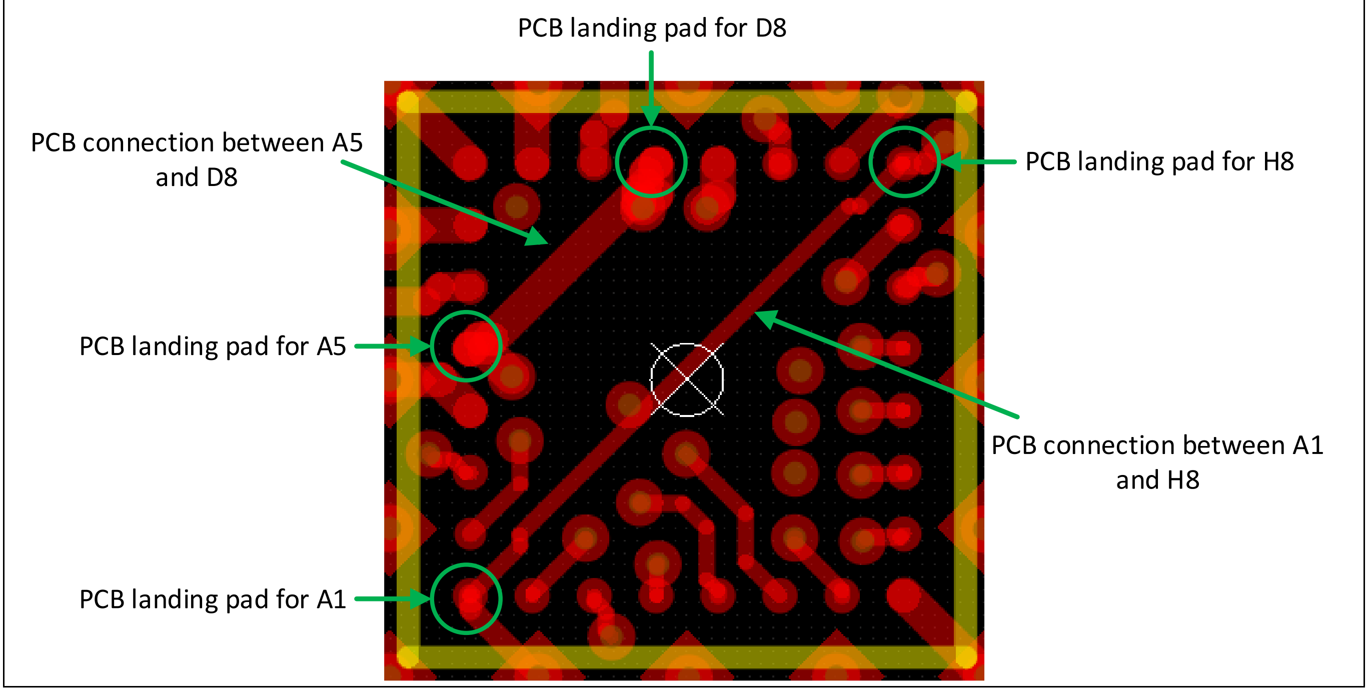


Figure 7 **Ground landing pad connections underneath the BGT60UTR11AIP to improve Tx-Rx coupling**

The cancellation of coupling relates to the inverted phase from different coupling paths. Hence, the variation in assembly and production may have an impact on the cancellation effect. The suggestion is to do pre-production evaluation to define the radar setting boundaries, like the parameters of high-pass filter, baseband gain.

3 Firmware

The “Radar Baseboard MCU7 Plus” comes with a default firmware, which is intended to serve as a bridge between a host (typically a PC) and the BGT60UTR11AIP RF shield, which is mounted on the sensor connectors.

When the firmware detects a BGT60UTR11AIP shield, it automatically configures the driver layer for the BGT60UTR11AIP sensor. This includes configuring the chip, as well as setting up the MCU to initiate a serial peripheral interface (SPI) transfer when the BGT signals the availability of new data via the IRQ line. The firmware will also configure the communication layer so that radar and BGT60UTR11AIP specific messages are understood.

For more details, please refer to the UG091519: Radar Baseboard MCU7 Plus user guide [2].

4 Measurement results

4.1 Field of view (FoV) measurements

To analyze the radar FoV, the BGT60UTR11AIP shield is characterized along the azimuth plane and elevation plane of the shield board. A corner reflector is placed opposite to the radar board. The radiation emitted by the radar sensor is reflected by the corner reflector and measured with the receiver antennas of the radar board. In order to avoid clutter, the measurement is typically performed in an anechoic RF chamber. The measurement characterizes the chip in radar operation. Thus, both transmit and receive antennas are part of the measurement. For the measurement, the standard FMCW radar scheme is followed and the signal at the receive antenna is recorded. The gimbal sweeps the predefined angles in the azimuth plane and elevation plane and generates the 2D radiation pattern.

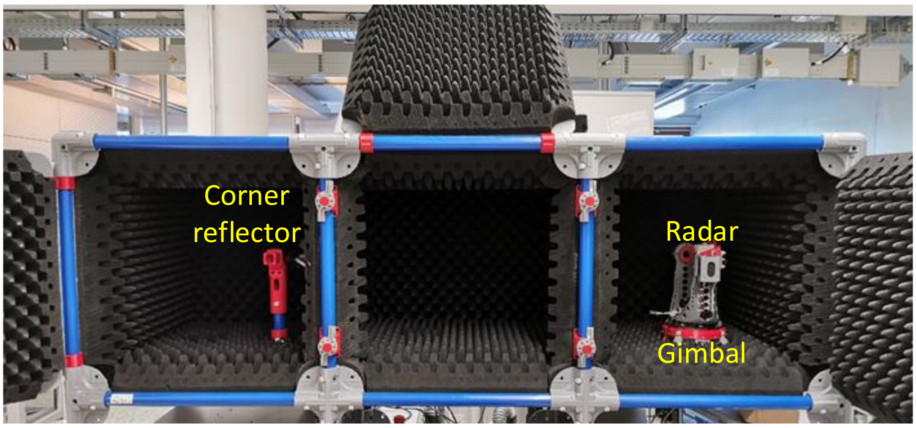


Figure 8 Photo of the chamber set-up for radiation pattern measurement

Figure 8 shows the measurement set-up that is used. The corner reflector is placed at a distance of 1.2 m from the BGT60UTR11AIP shield in an anechoic chamber. The radar board is mounted on the gimbal, which can rotate by ±60 degrees along the azimuth plane and elevation plane respectively. A typical board was measured with the chirp frequency ranges of 61-61.5 GHz and 60.5-61 GHz. The reference planes of the measurements are described in Figure 9. The results for the 2D plots can be seen in Figure 10 and Figure 11. The dash-lines in purple are the 6-dB contours. The plots of azimuth and elevation planes are presented in Figure 12 to Figure 15 respectively.

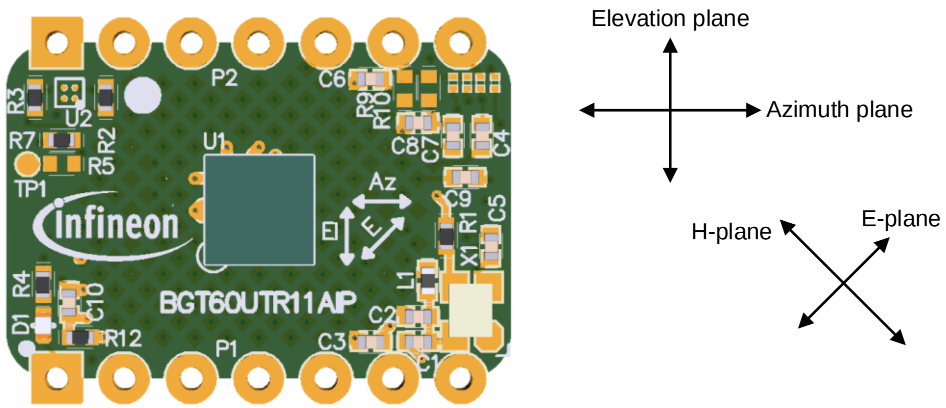


Figure 9 Reference planes of the radiation pattern measurement

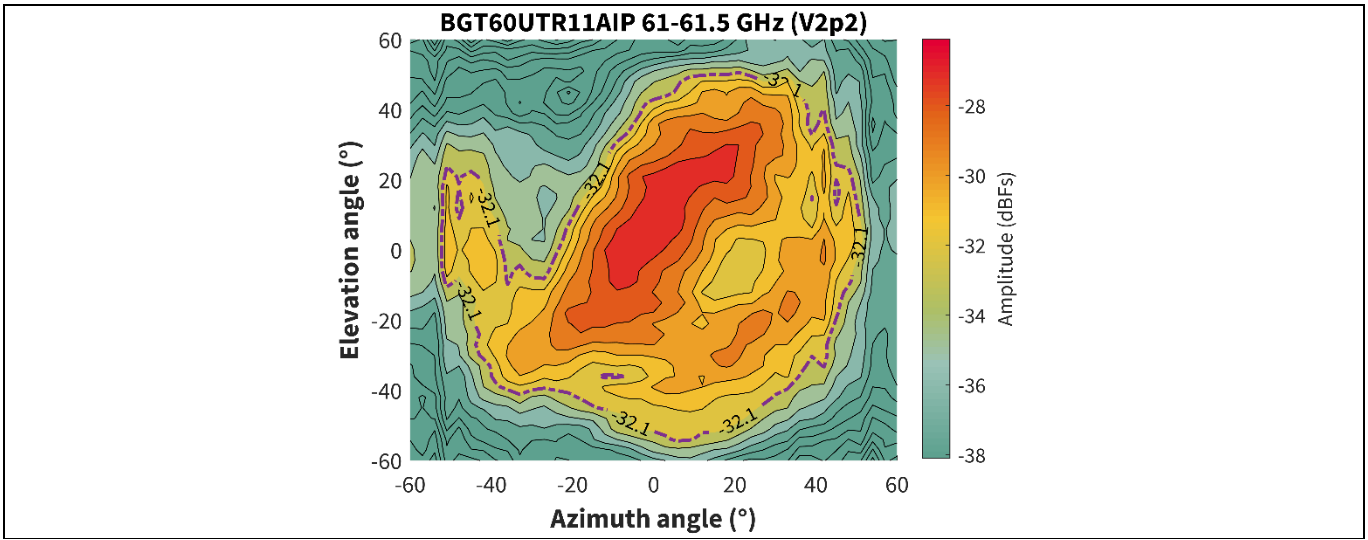


Figure 10 2D plot of FoV with chirp frequency from 61 GHz to 61.5 GHz

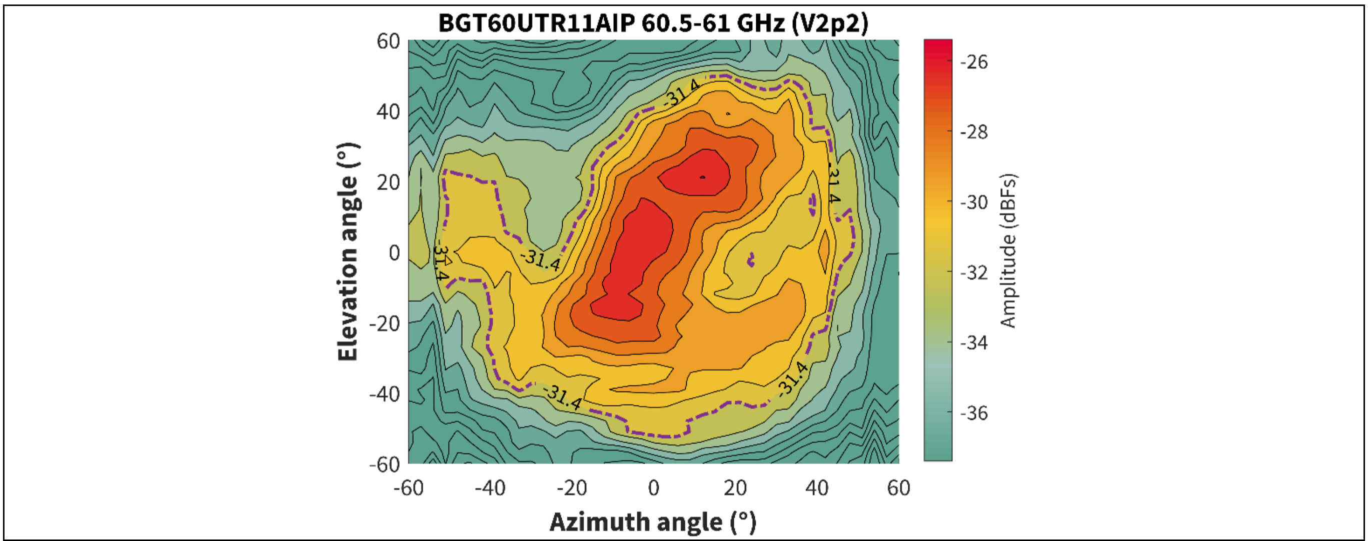


Figure 11 2D plot of FoV with chirp frequency from 60.5 GHz to 61 GHz

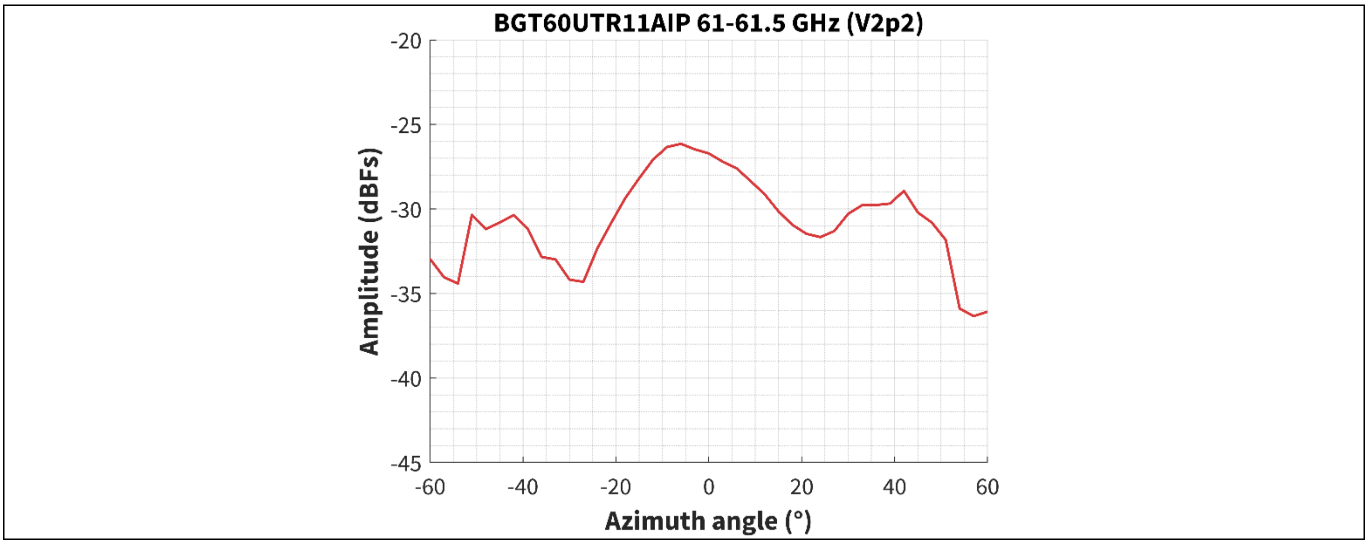


Figure 12 FoV on azimuth plane with chirp frequency from 61 GHz to 61.5 GHz

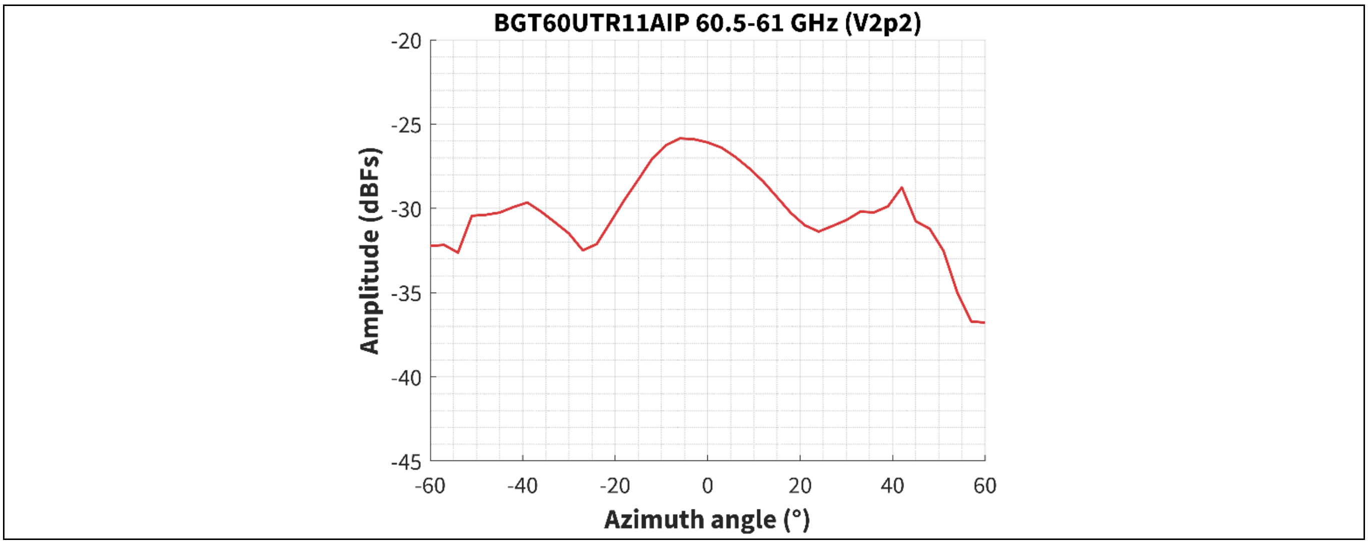


Figure 13 FoV on azimuth plane with chirp frequency from 60.5 GHz to 61 GHz

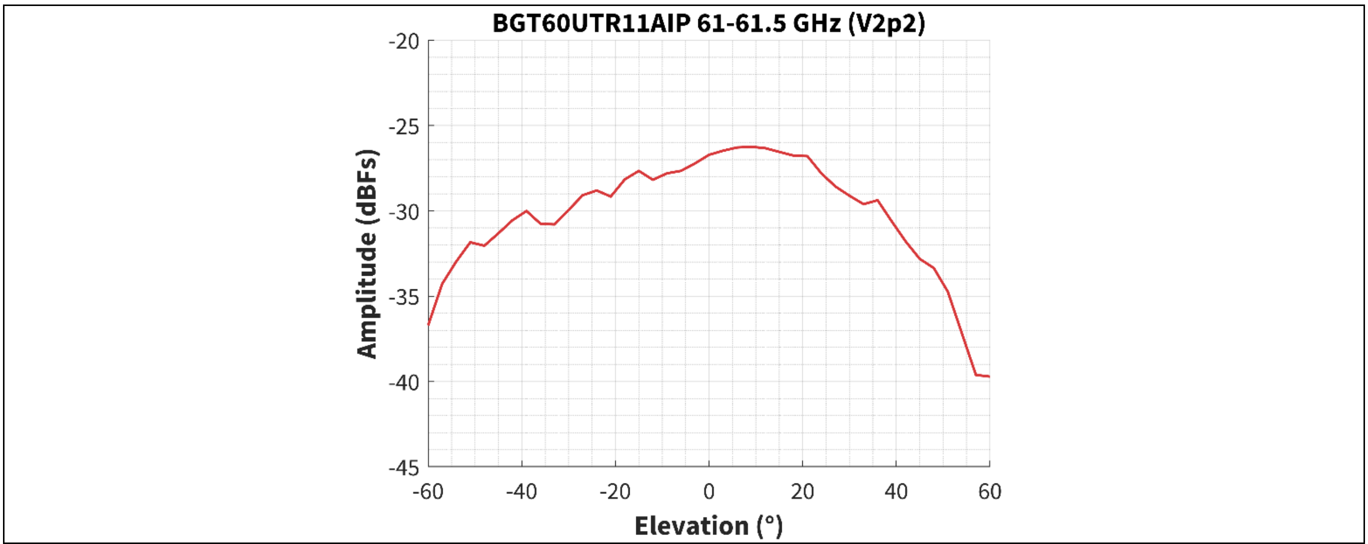


Figure 14 FoV on elevation plane with chirp frequency from 61 GHz to 61.5 GHz

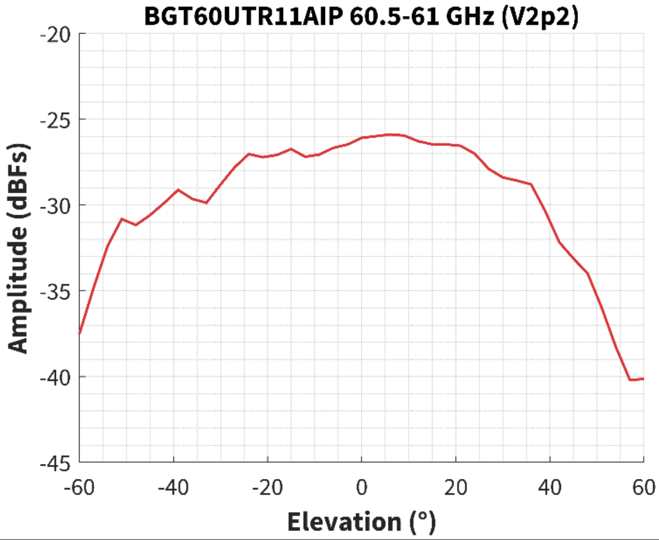


Figure 15 **FoV on elevation plane with chirp frequency from 60.5 GHz to 61 GHz**

4.2 Transmitter path Equivalent Isotropic Radiated Power (EIRP) measurements

The EIRP measurement set-up is similar as the FoV measurement set-up but with a spectrum analyzer instead of the corner reflector. The axes of the measurements refer to the H-plane and E-plane, which are shown in Figure 9. Figure 16 to Figure 18 show the EIRP measurement results in 2D plots at carrier frequency of 58 GHz, 61 GHz, and 63 GHz. The dash-lines in purple are the 3-dB contours, while the dash-lines in red are the 6-dB contours.

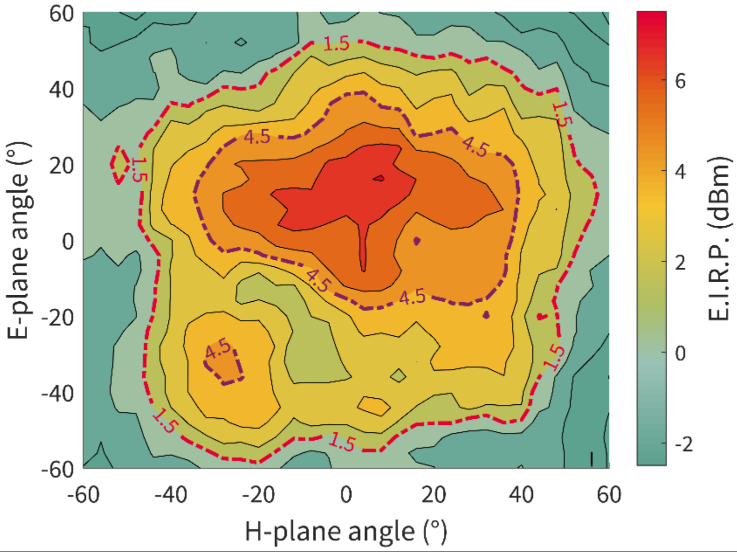


Figure 16 **EIRP measurement result at carrier frequency of 58 GHz**

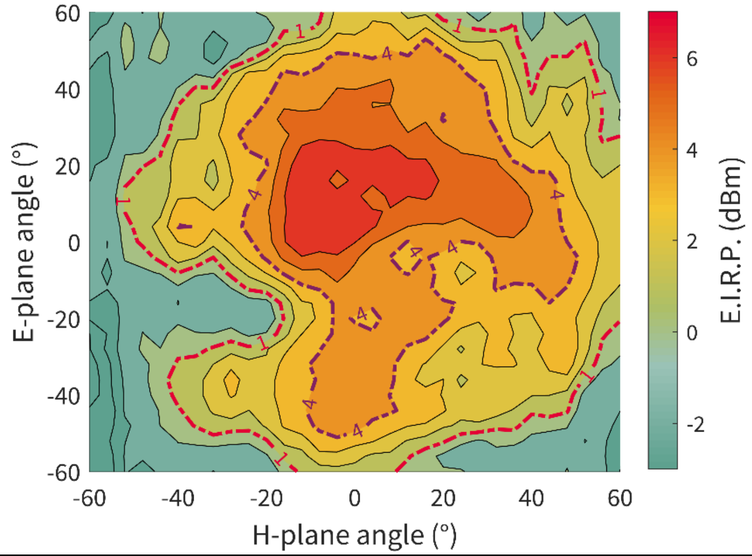


Figure 17 **EIRP measurement result at carrier frequency of 61 GHz**

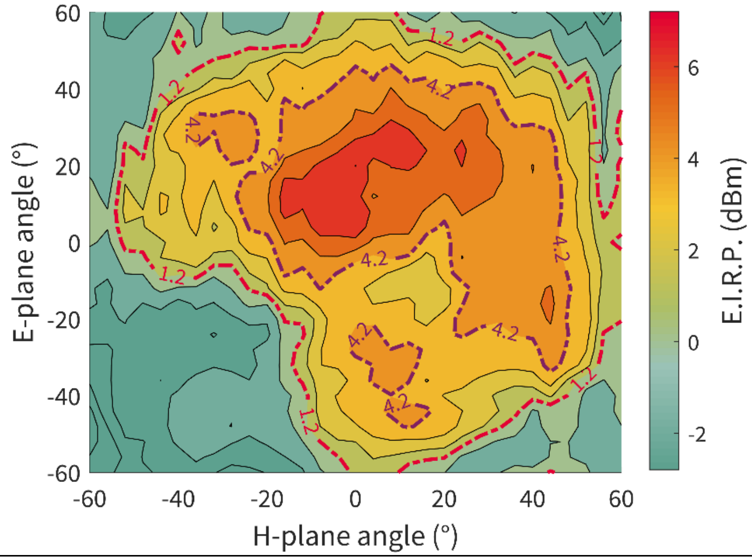


Figure 18 **EIRP measurement result at carrier frequency of 63 GHz**

4.3 Phase noise measurements

The phase noise is a way to characterize the RF signal. Thereby, the signal with an offset from the carrier signal is put in relation with the carrier itself. In radar data processing with BGT60UTR11AIP, the typical IF frequencies are in a range from about 10 kHz to 1 MHz. Therefore, the phase noise has to be investigated within this range as well.

The phase noise can be measured directly at the radar frequency. A horn antenna placed in front of the sensor receives the radiation emitted by the BGT60UTR11AIP. Then, the RF signal is transferred to a harmonic mixer, which in combination with a signal analyzer enables measurement of the RF signal level emitted by the radar sensor. A typical set-up for this measurement could consist of:

- Keysight signal analyzer PXA N9030A
- Keysight M1970V waveguide harmonic mixer

- Dorado international GH-15-20 horn antenna

Figure 19 to Figure 21 show the phase noise measurement of a typical BGT60UTR11AIP shield over three carrier frequencies, 59 GHz, 61 GHz, and 63 GHz. The measurement was performed directly at the RF signal with a harmonic mixer. The phase noise is clean for all tested frequencies.

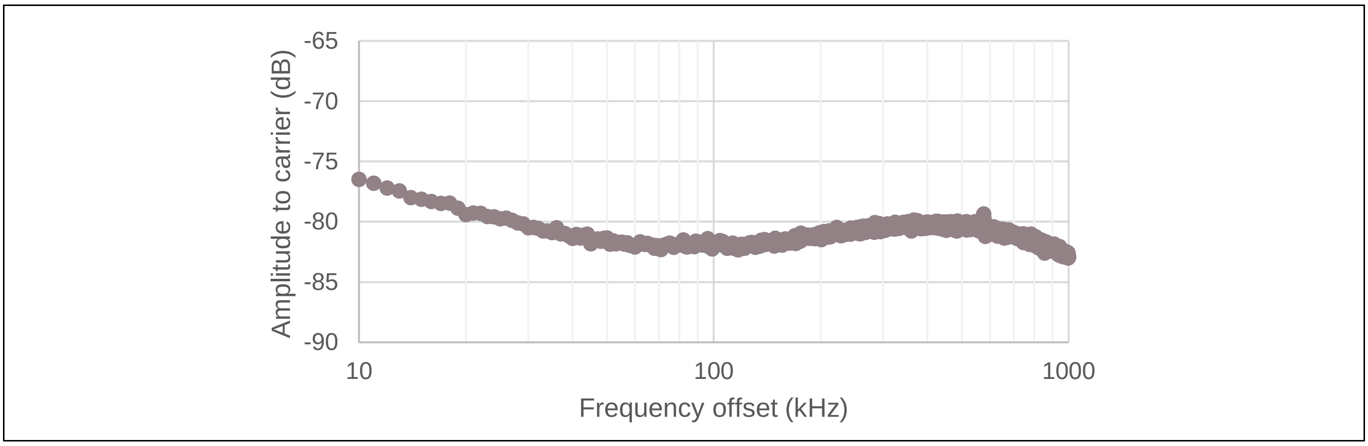


Figure 19 Carrier phase noise at 59 GHz

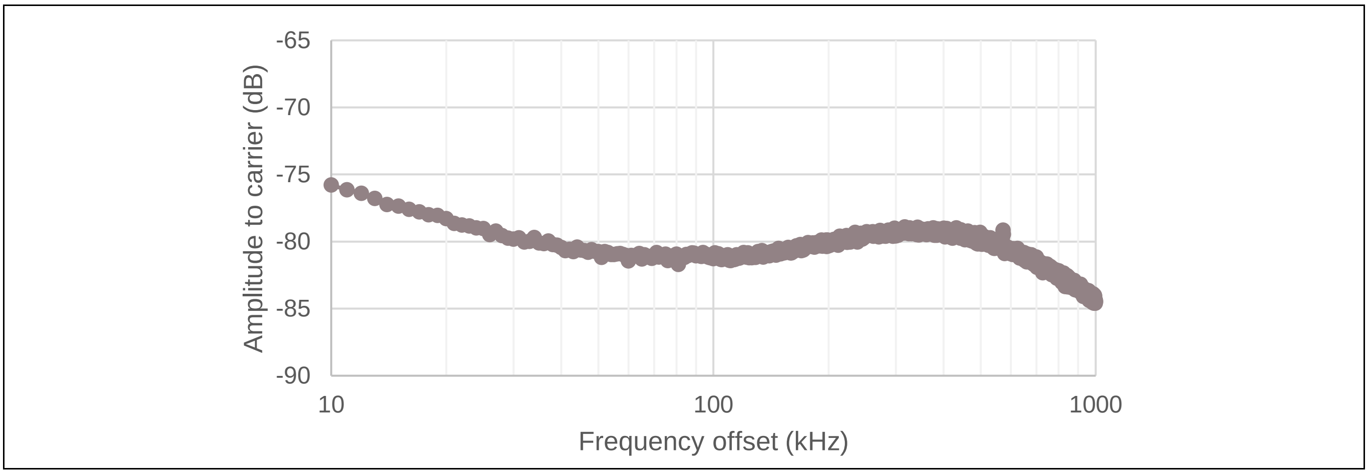


Figure 20 Carrier phase noise at 61 GHz

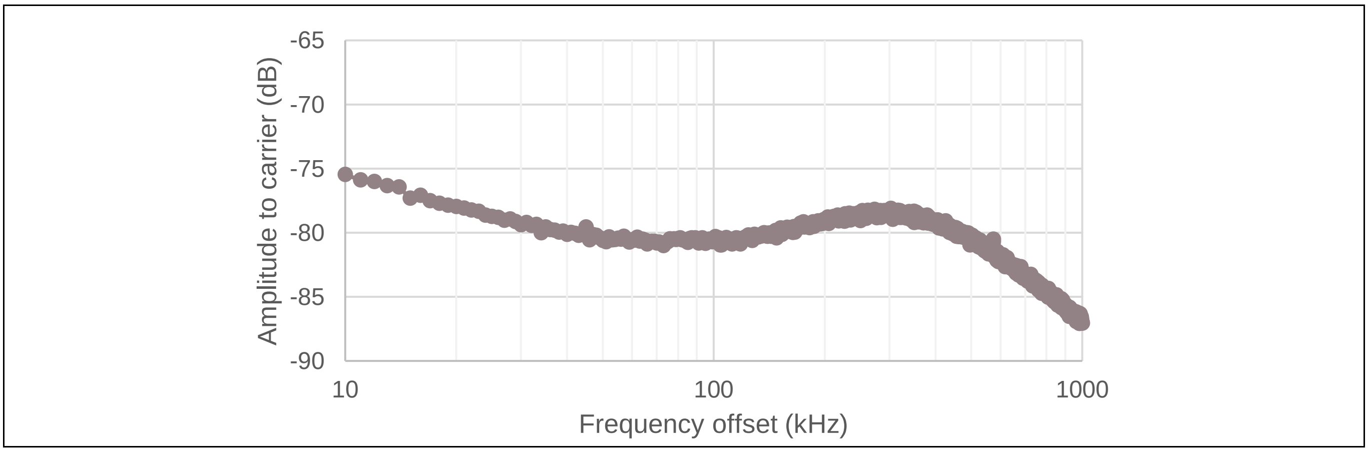
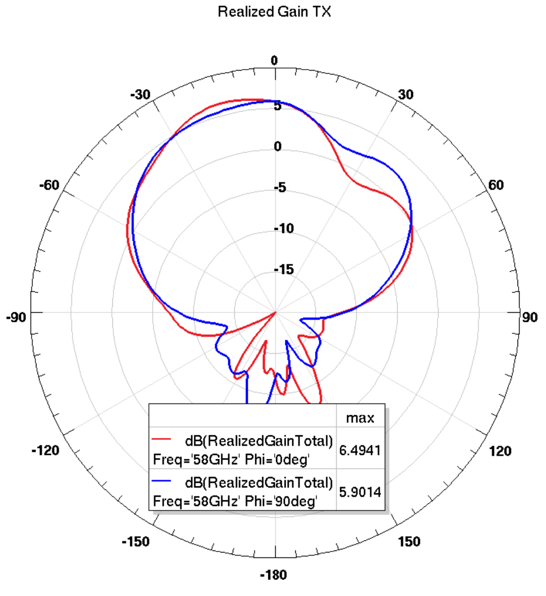


Figure 21 Carrier phase noise at 63 GHz

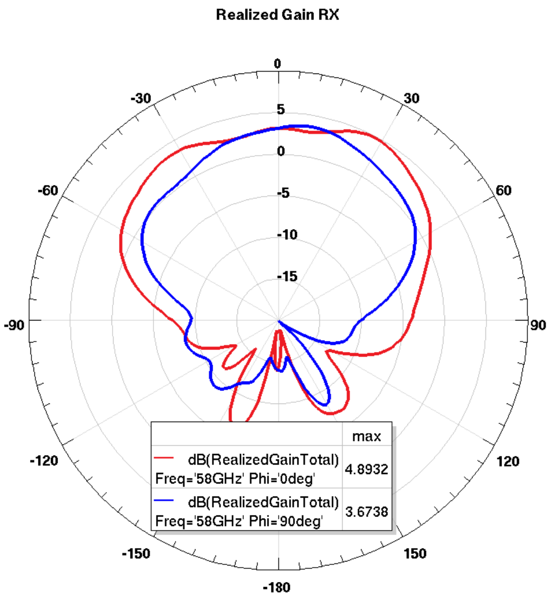
5 Simulation results

5.1 Radiation pattern

The radiation pattern of a BGT60UTR11AIP shield (V2.2) is simulated along the H-plane and E-plane of the radar MMIC. Figure 22a and Figure 22b show the realized gain of, respectively, the transmitting and receiving antennas in both the H-plane and E-plane at a frequency of 58 GHz.



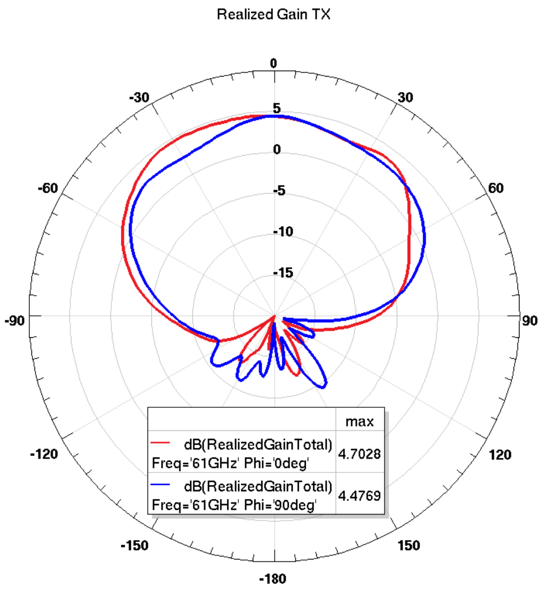
(a) TX – H/E plane at f = 58 GHz



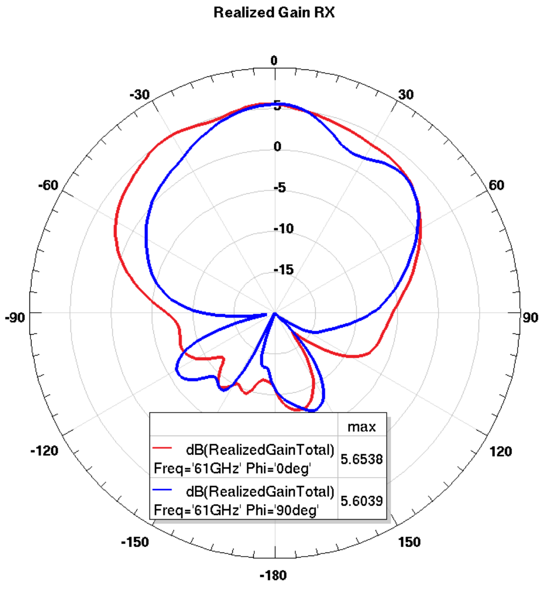
(b) RX – H/E plane at f = 58 GHz

Figure 22 Radiation pattern simulations at 58 GHz

Figure 23a and Figure 23b show the realized gain of, respectively, the transmitting and receiving antennas in both the H-plane and E-plane at a frequency of 61 GHz.



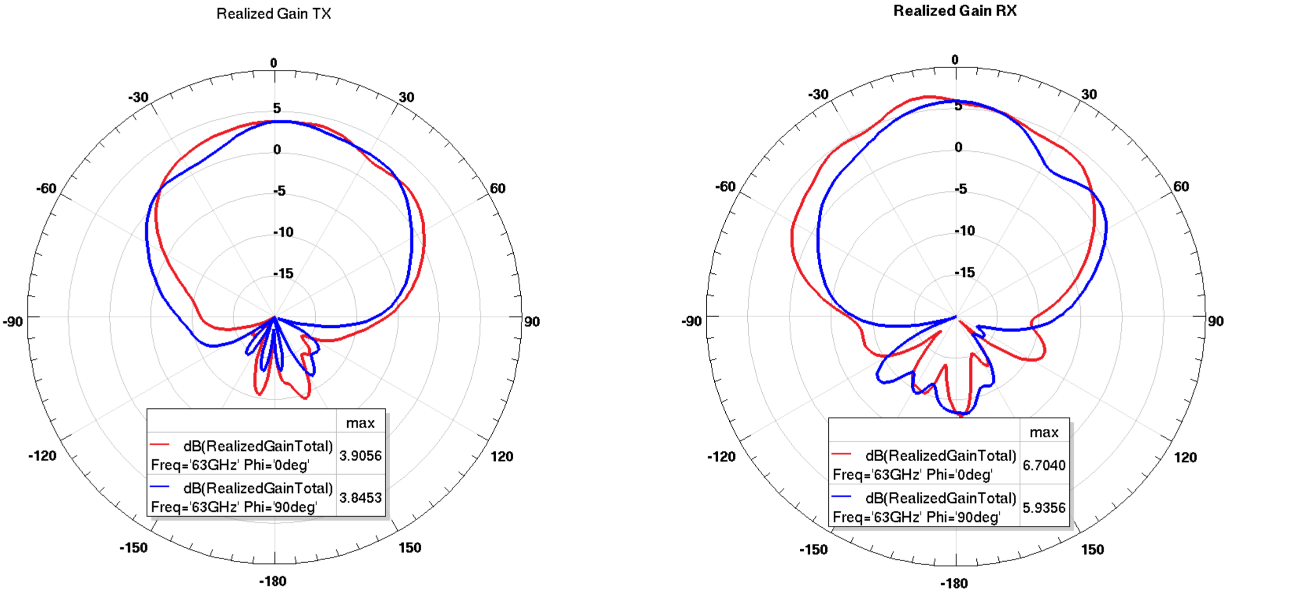
(a) TX – H/E plane at f = 61 GHz



(b) RX – H/E plane at f = 61 GHz

Figure 23 Radiation pattern simulations at 61 GHz

Figure 24a and Figure 24b show the realized gain of, respectively, the transmitting and receiving antennas in both the H-plane and E-plane at a frequency of 63 GHz.



(a) TX – H/E plane at f = 63 GHz

(b) RX – H/E plane at f = 63 GHz

Figure 24 Radiation pattern simulations at 63 GHz

References

[1] Infineon Technologies AG. *BGT60UTR11AIP MMIC datasheet*; Available online

[2] Infineon Technologies AG. *UG155750: Radar Baseboard MCU7 Plus user guide*; Available online

Revision history

Document revision	Date	Description of changes
1.00	2024-06-26	Initial version
2.00	2024-07-11	Updated support shield v2.2 (instead of v2.0)
2.10	2025-01-28	Added Simulated results section

Trademarks

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