

BGT60TR13C shield

60 GHz radar system platform

Board version 2.2

About this document

Scope and purpose

This application note describes the BGT60TR13C shield, part of Infineon's 60 GHz radar system platform. The shield is the evaluation platform for the BGT60TR13C sensor, Infineon's 60 GHz radar sensor with integrated antennas. The sensor simply contains a digital interface for configuration and transfer of the acquired radar data to a microcontroller board. Detailed information about the radar baseboard MCU7 can be found in the corresponding application note **(RS, 2019)**.

Intended audience

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

Disclaimer

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

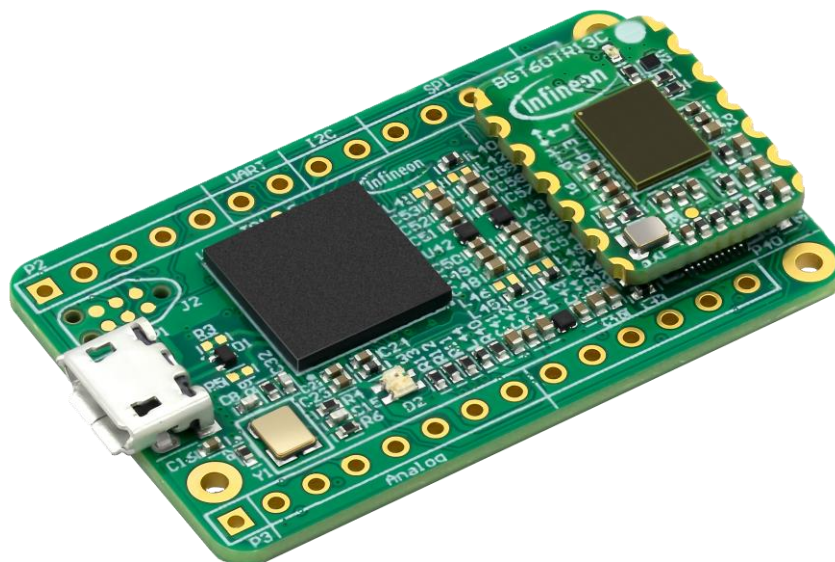


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1 Introduction

1.1 60 GHz 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 as the microcontroller board and a radar sensor board, like the BGT60TR13C shield for Infineon's 60 GHz radar sensor, the BGT60TR13C. This application note focuses on the BGT60TR13C shield. Detailed documentation on the radar baseboard can be found in reference (RS, 2019).

Figure 1 illustrates the radar baseboard MCU7 with the BGT60TR13C shield. Both boards have markers. These markers must be aligned to correctly plug in a sensor board.

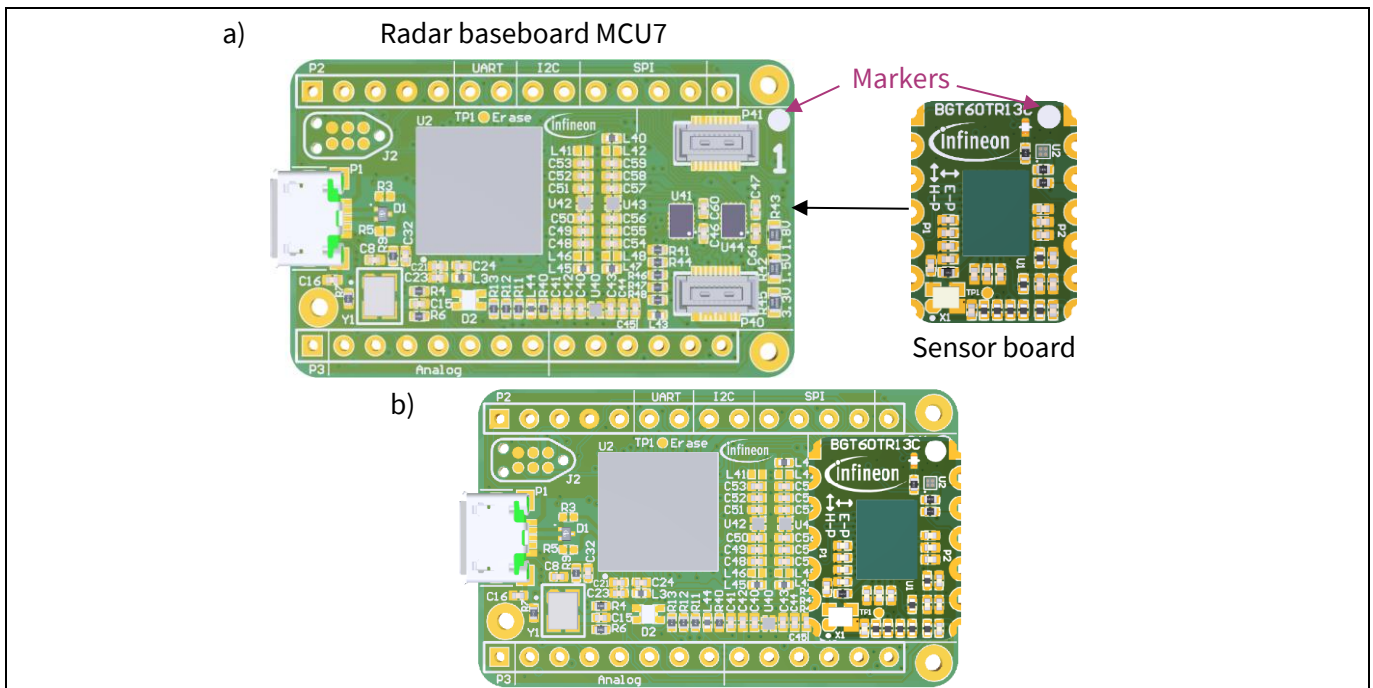


Figure 1 The 60 GHz radar system platform with the BGT60TR13C shield (a) unplugged or (b) plugged in

1.1 Key features and system benefits

The BGT60TR13C 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, people counting and tracking, gesture sensing and material classification. These use cases target applications such as smartphones, notebooks, TVs, smart speakers, wearables, smart home and building automations for comfort, energy savings and security/safety functions. Presence detection may only require 1 mW of power in the sensor under certain circumstances.

- Minimized form factor of 17 x 12.7 mm² RF board with Antenna-in-Package (AIP) of 6.5 x 5.0 x 0.85 mm³
- 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 use case

2 System specifications

2.1 Typical current consumption

The typical current consumption of the whole 60 GHz radar sensor platform, consisting of a radar baseboard MCU7 and a BGT60TR13C shield, can be found in Table 1. When the MCU is in reset, the power consumption stays below 10 mW. Without a sensor, approximately 150 mW are consumed, and with a BGT60TR13C shield, the power consumption can be as high as 1.5 W in continuous wave (CW) operation. The BGT60TR13C radar sensor's share of the total power can reach up to 350 or 400 mW in CW operation. However, the exact value will depend on the operating condition of the radar sensor. As the sensor is typically operated in duty-cycle mode, the actual power consumption figures tend to be much lower. In the design of the radar sensor, the developers take care to optimize power saving in duty-cycle operation. For this reason, most use cases will consume less than 100 mW. Section 7.2 lists the expected power consumption figures for typical configurations.

Table 1 Typical current consumption of the 60 GHz radar sensor platform with the BGT60TR13C shield

Condition	Current consumption	Power consumption	Power consumption BGT60TR13C shield
MCU in reset	~ 2 mA	~ 10 mW	–
No sensor attached	~ 29 mA	~ 150 mW	–
Sensor attached but deactivated	~ 110 mA	~ 550 mW	–
BGT60TR13C shield attached and in CW operation (maximum power consumption)	290 to 300 mA	~ 1.5 W	~ 350 mW

3 Hardware description

This section of the document presents a detailed overview of the BGT60TR13C shield hardware specifics, such as BGT60TR13C considerations, power supply, oscillator and board interfaces.

3.1 Overview

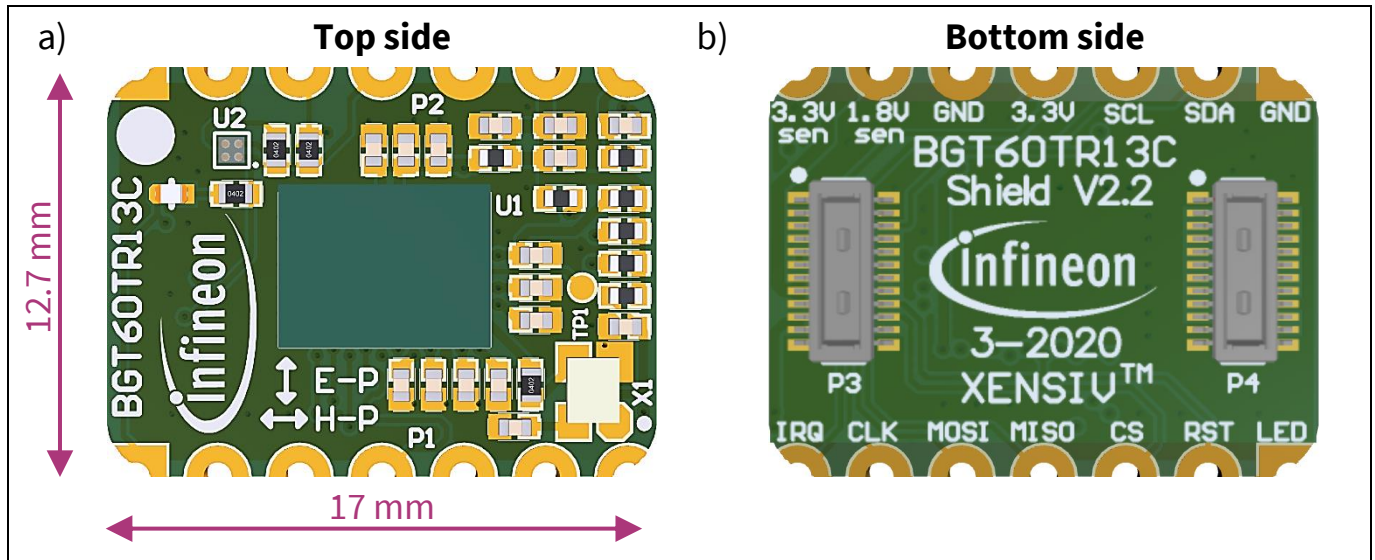


Figure 2 The BGT60TR13C shield

The dimensions of the BGT60TR13C shield printed circuit board (PCB) are 17 mm x 12.7 mm. Mounted on top of the PCB is a BGT60TR13C, Infineon's 60 GHz radar sensor with integrated antennas. Because the antennas are integrated into the chip package, the PCB can be manufactured using a standard FR4 laminate. No special high-frequency (HF) materials are required to build a BGT60TR13C system. The radar sensor is the central element on the top side of the PCB (U1 in Figure 2a). The bottom side of the PCB features the main interfaces to the radar baseboard MCU7 [1] (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 BGT60TR13C. By using these side connectors and removing P3 and P4, the BGT60TR13C shield can be soldered onto other PCBs as a radar module.

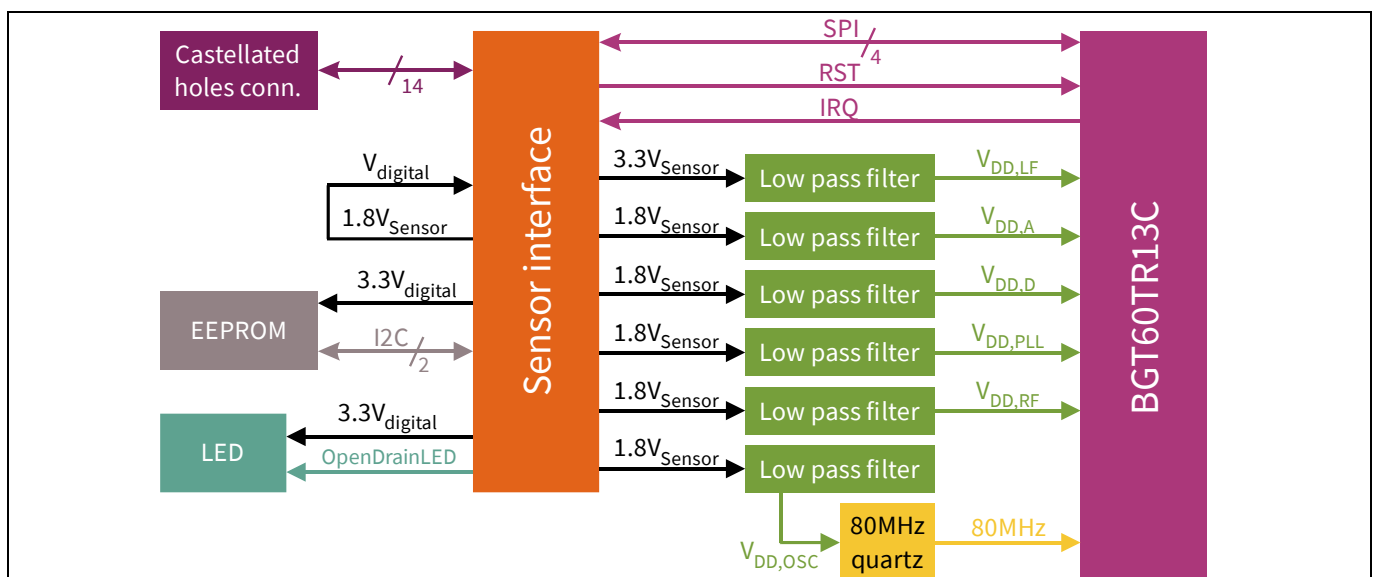


Figure 3 Block diagram of the BGT60TR13C shield

Hardware description

The block diagram in Figure 3 depicts the concept behind the board. Each of the signals on the castellated holes' side connectors corresponds with a signal on the sensor connector – refer to Section 5.5 for details. To provide the correct level shifter voltage for the MCU board, the $1.8 V_{\text{sensor}}$ supply line is connected with V_{digital} – refer to Section 2.3 of (RS, 2019). When the shield is plugged into the radar baseboard MCU7, the sensor's supplies are initially deactivated. Only the EEPROM is powered. The MCU will read the content of the EEPROM's memory to determine which sensor is plugged into the sensor interface. Only when the board has been correctly identified are the sensor's supplies activated.

Radar sensors are very sensitive to noise and cross-talk on the supply domains. Therefore, the different supply domains must be decoupled. On the BGT60TR13C shield, this is realized by a pi-shaped low-pass filter 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 signals the MCU when new data needs to be fetched. The other 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 signal for example if the sensor is activated or deactivated.

3.2 BGT60TR13C overview

Infineon's 60 GHz radar sensor with AIP, the BGT60TR13C, serves as the main element on the BGT60TR13C shield. Integrated into the package chip contains one transmit antenna and three receive antennas. Its dimensions are $6.5 \text{ mm} \pm 0.1 \text{ mm} \times 5.0 \text{ mm} \pm 0.1 \text{ mm}$, as illustrated by the package outline in Figure 4a and in more detail in Figure 5a and 5b. Its height is $0.85 \text{ mm} \pm 0.05 \text{ mm}$. When oriented as in the figure, the radar sensor will emit vertical polarization. Thus, the E-plane is vertical and the H-plane is horizontal. The free-space wavelength of 60 GHz, denoted by λ , is about 5 mm. The horizontal spacing between receive antenna 1 (Rx1) and receive antenna 3 (Rx3) as well as the vertical spacing between receive antenna 2 (Rx2) and Rx3 is λ over 2. This enables angular measurements perpendicular to the chips' surface providing a horizontal range of ± 90 degrees using Rx1 and Rx3 and a vertical range of ± 90 degrees using Rx2 and Rx3 respectively.¹

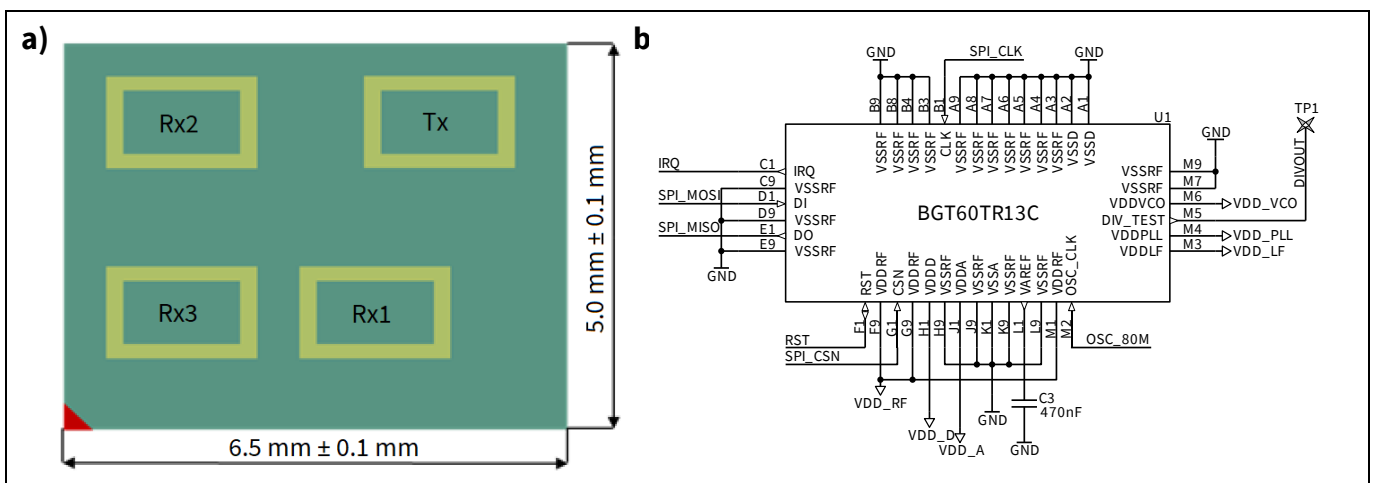


Figure 4 Package outline (a) and schematics (b) of the BGT60TR13C

The BGT60TR13C has five 1.8 V power domains: analog, digital, 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) – see Figure 4b for details. When the chip is operated with a LF supply voltage below 3.3 V, the maximum VCO frequency and thus the sensors's bandwidth will be restricted accordingly.

¹ The signal strength will, of course, decrease with increasing angle – see Section 5.1 for details.

Hardware description

In order to reduce the system phase noise and frequency jitter, it is recommended to short the ground contacts of the different power domains. Therefore, it is essential to have a solid ground plane right underneath the chip with no signal lines. The suggested pad layout is shown in Figure 5c.

The BGT60TR13C provides the following digital signal lines: oscillator input, four SPI signals, hardware reset line and interrupt request output (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. This can be used to measure the phase noise of the sensor – see Section 5.3 for details.

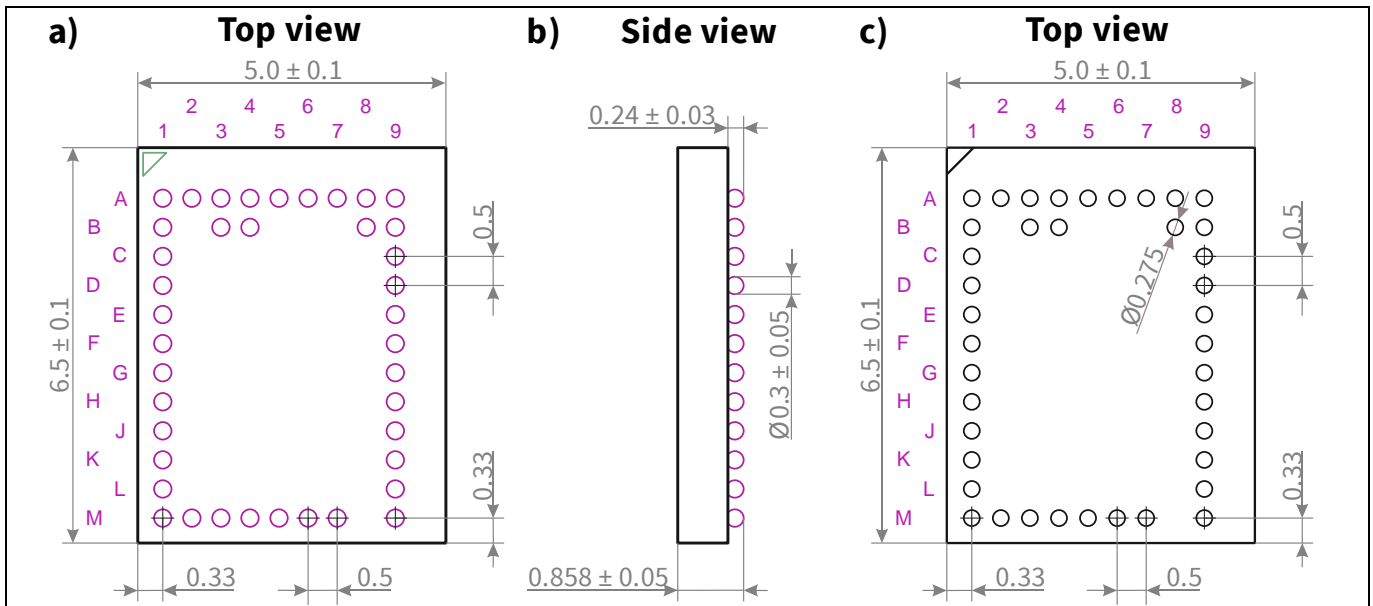


Figure 5 Top (a) and side view (b) of the package and the suggested pad layout of BGT60TR13C (c) – all dimensions in mm

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 (see Section 2.2 of reference (RS, 2019)). Figure 6 depicts the schematics of the pi-shaped low-pass filters employed to decouple the supplies of the different power rails in the chip. High attenuation of voltage fluctuations in the MHz regime is provided by ferrite beads. For example, the SPI, which runs at up to 50 MHz, induces voltage fluctuations on the digital domain, which would then transfer into the analog domain if not for the decoupling filters. The ferrite beads are chosen such that they can handle the maximum current of the sensor of about 200 mA with a low DC resistance (below 0.25Ω) 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.

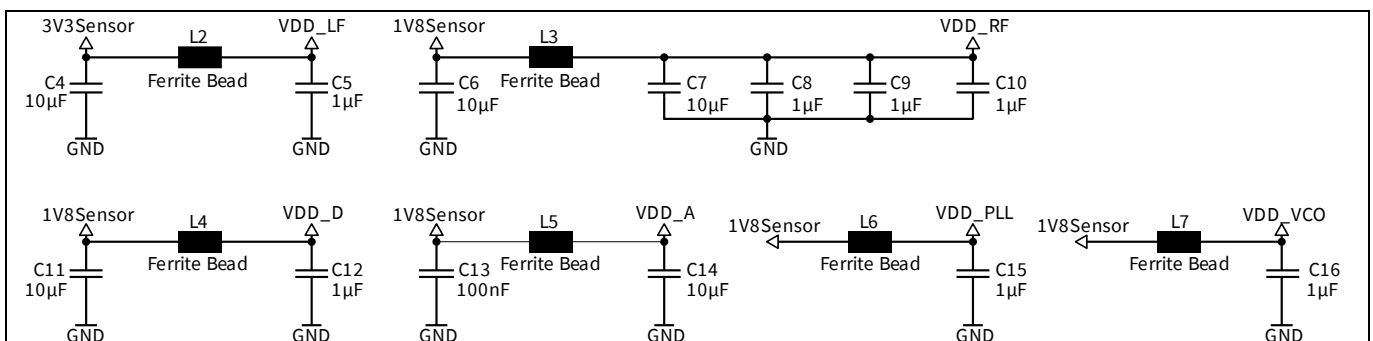


Figure 6 Schematics of the low-pass filters

Hardware description

3.4 Oscillator

Infineon's BGT60TR13C radar sensor requires an oscillator source with a stable reference clock providing low phase jitter and low phase noise. Therefore, the BGT60TR13C shield employs a Kyocera KC2016 quartz oscillator, which is supplied with 1.8 V as depicted in Figure 7. 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 KC2016. 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 BGT60TR13C. 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 – see Section 5.3 for details of phase noise measurement. 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.

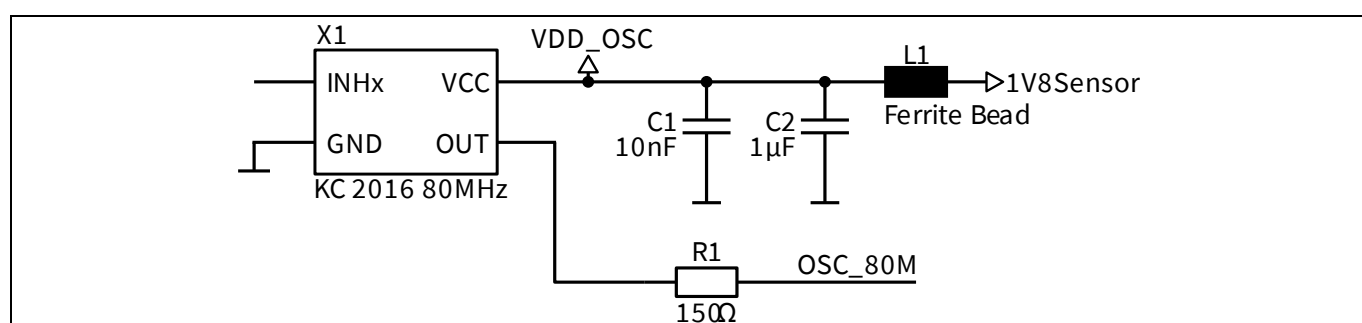


Figure 7 The oscillator circuit on the BGT60TR13C shield

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 must be varied by soldering different resistors into the circuit. An optimized series resistance will show 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.

3.5 Connectors

The BGT60TR13C 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 (RS, 2019). The BGT60TR13C shield contains two different type of connectors to interact with an MCU board, as depicted in Figure 8a. 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 BGT60TR13C. The pin-out of the connectors can be seen in Figure 8b as well as on the silkscreen on the bottom side of the PCB (Figure 8a).

The main connector interface of the BGT60TR13C shield contains two Hirose DF40C-20DP-0.4V connectors. On the MCU side, the radar baseboard MCU7 contains the corresponding DF40C-20DS-0.4V connectors. Figure 9 illustrates the pin-out and the pad layout of the Hirose connectors of the BGT60TR13C shield. To provide the information of the correct digital signal level to the host board, the line V_{digital} is shorted with the 1.8 V supply. On the top side of the shield is a marker that must be aligned with the marker on the MCU board for correct shield alignment, as depicted in Figure 1.

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, as illustrated in Figure 10a. Instead simply pull on the long side of the board, thereby tilting the short side, as shown in Figure 10b. This will significantly increase the lifetime of the connectors.

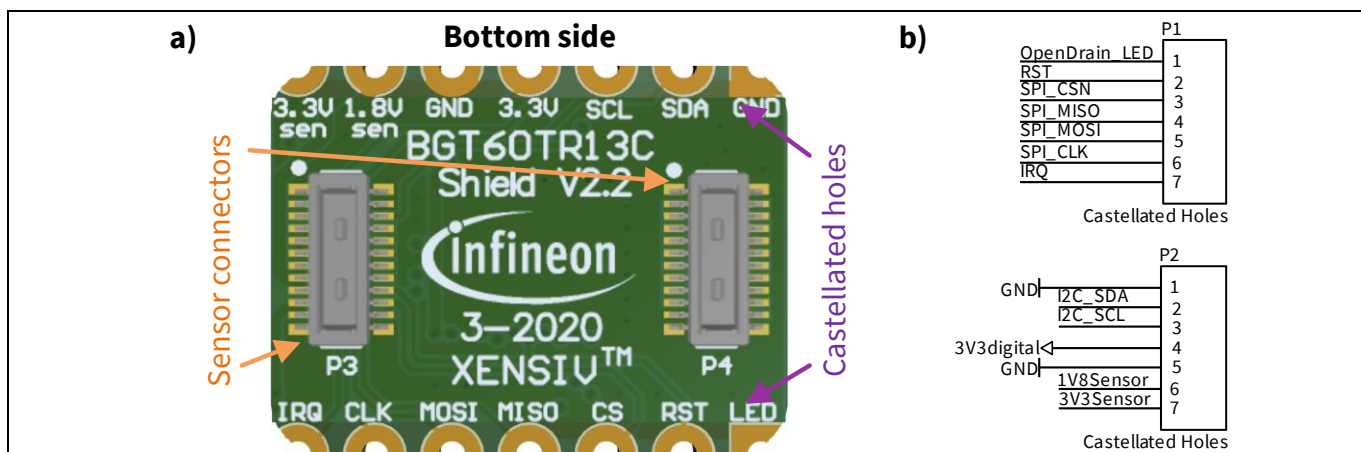


Figure 8 Connectors on the bottom side of the BGT60TR13C shield (a) and the pin-out of the castellated hole connectors (b)

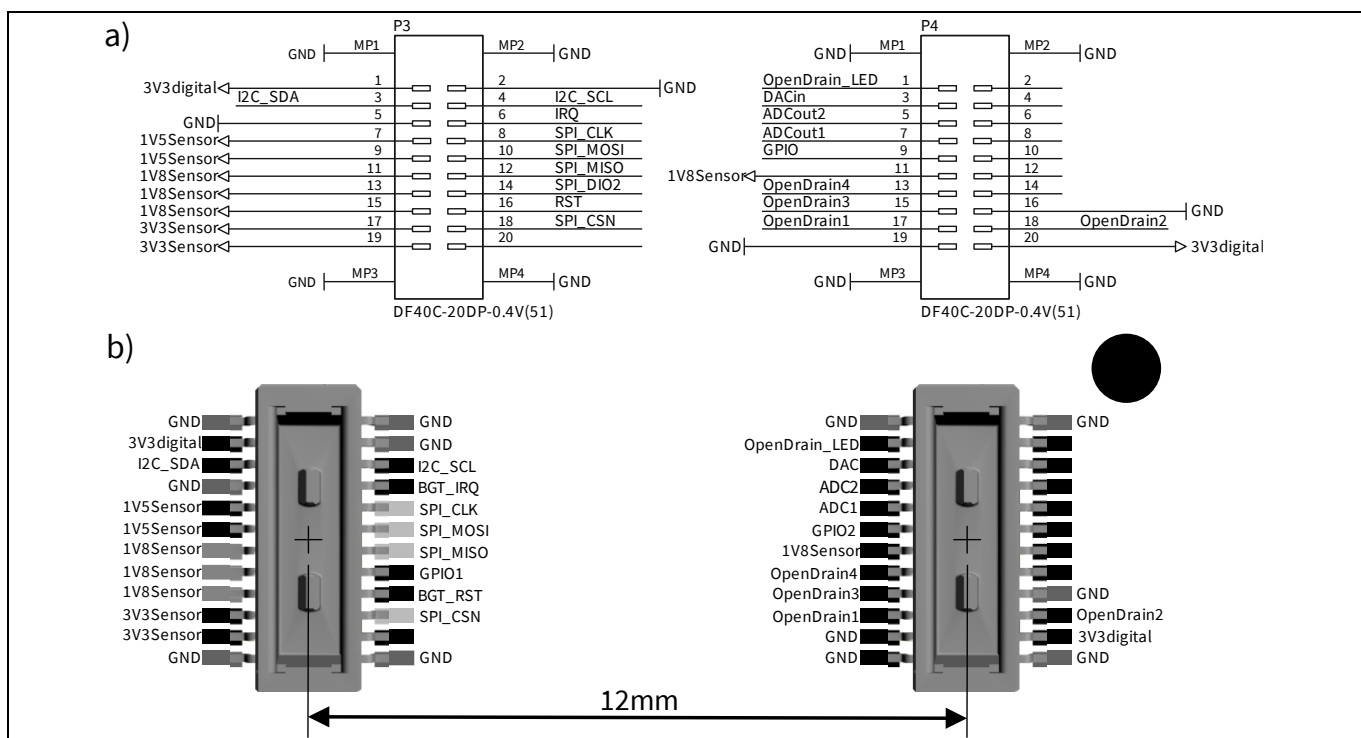


Figure 9 Pin-out (a) and pad layout (b) of the sensor connectors on the BGT60TR13C shield

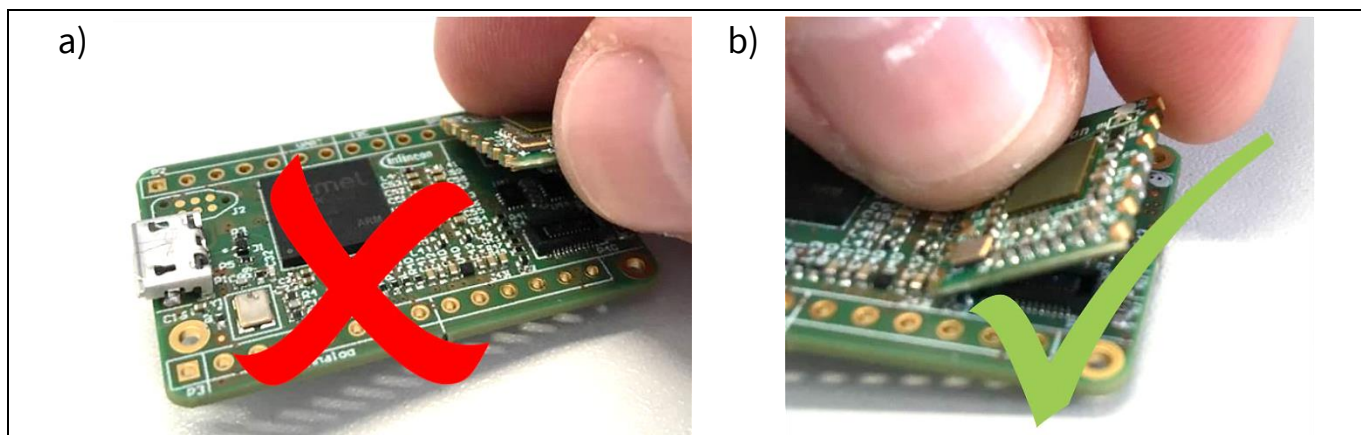


Figure 10 How to unplug the sensor-to-sensor connectors of the radar baseboard MCU7

3.6 EEPROM

The BGT60TR13C shield contains an EEPROM to store data like a board identifier. Its schematics can be seen in Figure 11.

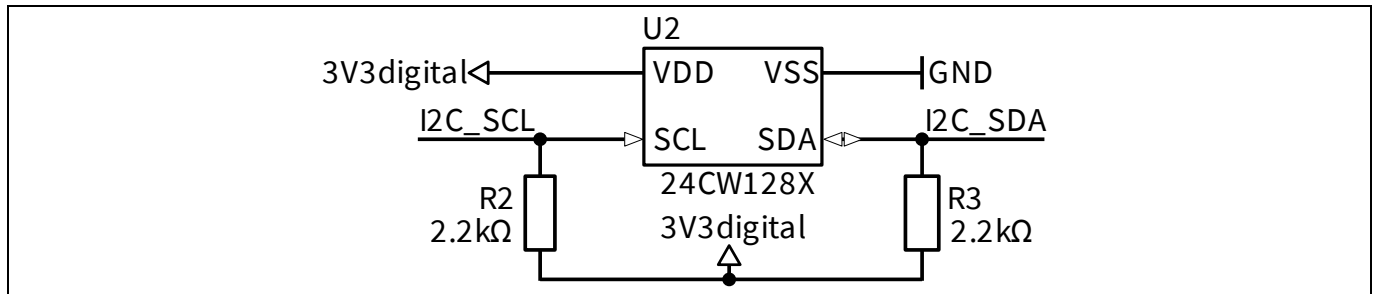


Figure 11 Schematics of the EEPROM

4 Firmware

When the firmware detects a BGT60TR13C shield, it automatically configures the driver layer for the BGT60TR13C sensor. This includes configuring the chip as well as setting up the MCU to initiate an 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 BGT60TR13C specific messages are understood. For general details of the firmware see (RS, 2019).

5 Measurement results

5.1 Radiation Pattern

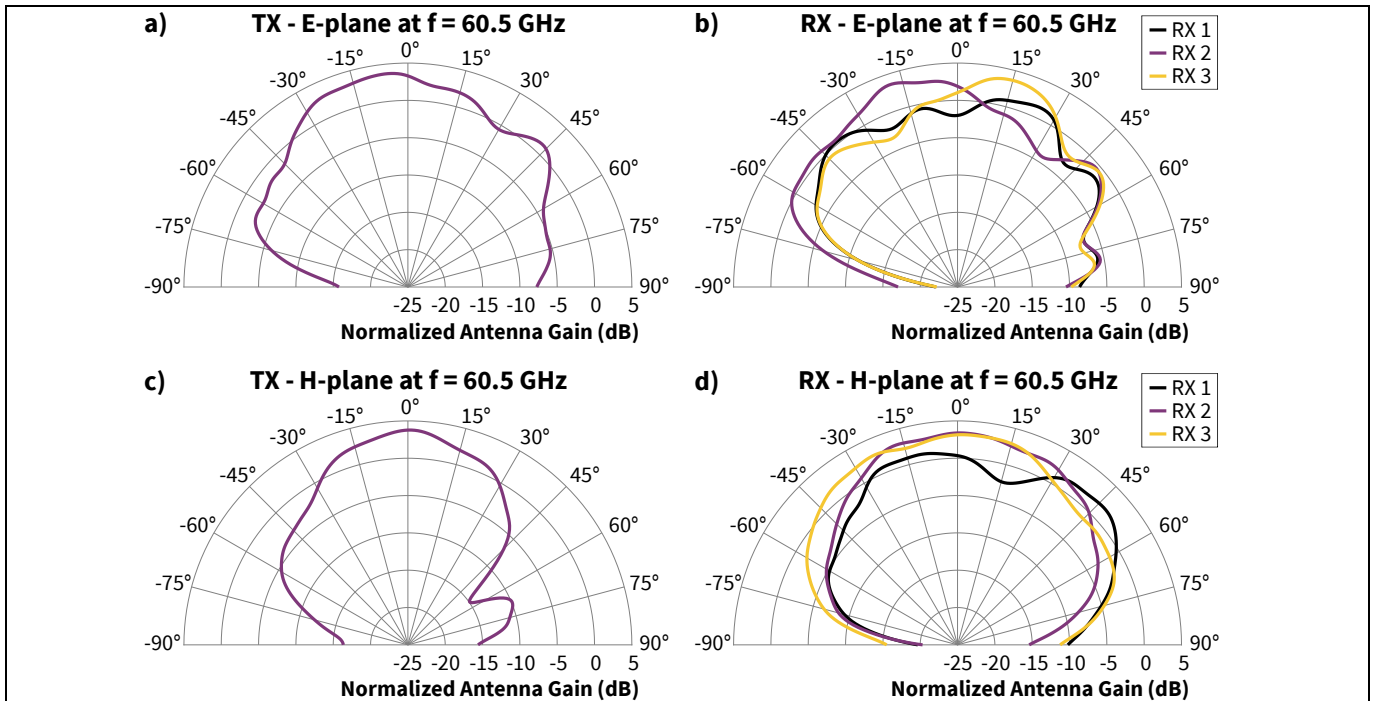


Figure 12 Radiation Pattern of a typical BGT60TR13C

The datasheet of the BGT60TR13C only shows the 3-dB values for transmit and receive antenna characteristics. This subsection shows the radiation pattern of a typical BGT60TR13C radar sensor. Figure 12a and c show the EIRP of the transmit antenna in E-plane and H-plane at a frequency of 60.5 GHz. Figure 12b and d illustrate the antenna characteristics of the three receive antennas in E-plane and H-plane at a frequency of 60.5 GHz.

5.2 Radar radiation pattern

To analyze the radar radiation pattern, the BGT60TR13C shield is characterized along the E-plane and H-plane of the sensor. A corner reflector is placed opposite 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 all three receive antennas is recorded. Then the sensor is rotated into different angles and the measurement is repeated for each angle, resulting in an angle dependence of the received signal for all three receiver antennas.

Figure 13a shows the measurement set-up that is used. The corner reflector is placed at a distance of 0.4 m from the BGT60TR13C shield in an anechoic chamber. The board is rotated by ± 90 degrees along the E-plane (Figure 13b) and H-plane (Figure 13c). The results for the E-plane can be seen in Figure 14a and the ones for the H-plane in Figure 14b. Thereby, a typical board was measured with a frequency chirp from 60.5 to 61.5 GHz and the results of all three receive antennas are plotted. In the E-plane, a side lobe is visible and the main lobe is not perpendicular to the chip surface but rotated by about 25 degrees. This effect is due to the close proximity of the antennas in the package and it is stronger for electric fields than for magnetic fields. In the H-plane, no side lobes are visible and the main lobe is perpendicular to the chip surface. Figure 14c shows the dependence of the received signal strength on the used center frequency of the chirp for the direction 0° in E-plane and 0° in H-plane. The strongest signal can be received at around 59.5 GHz and it decreases towards the edges of the band.

Measurement results

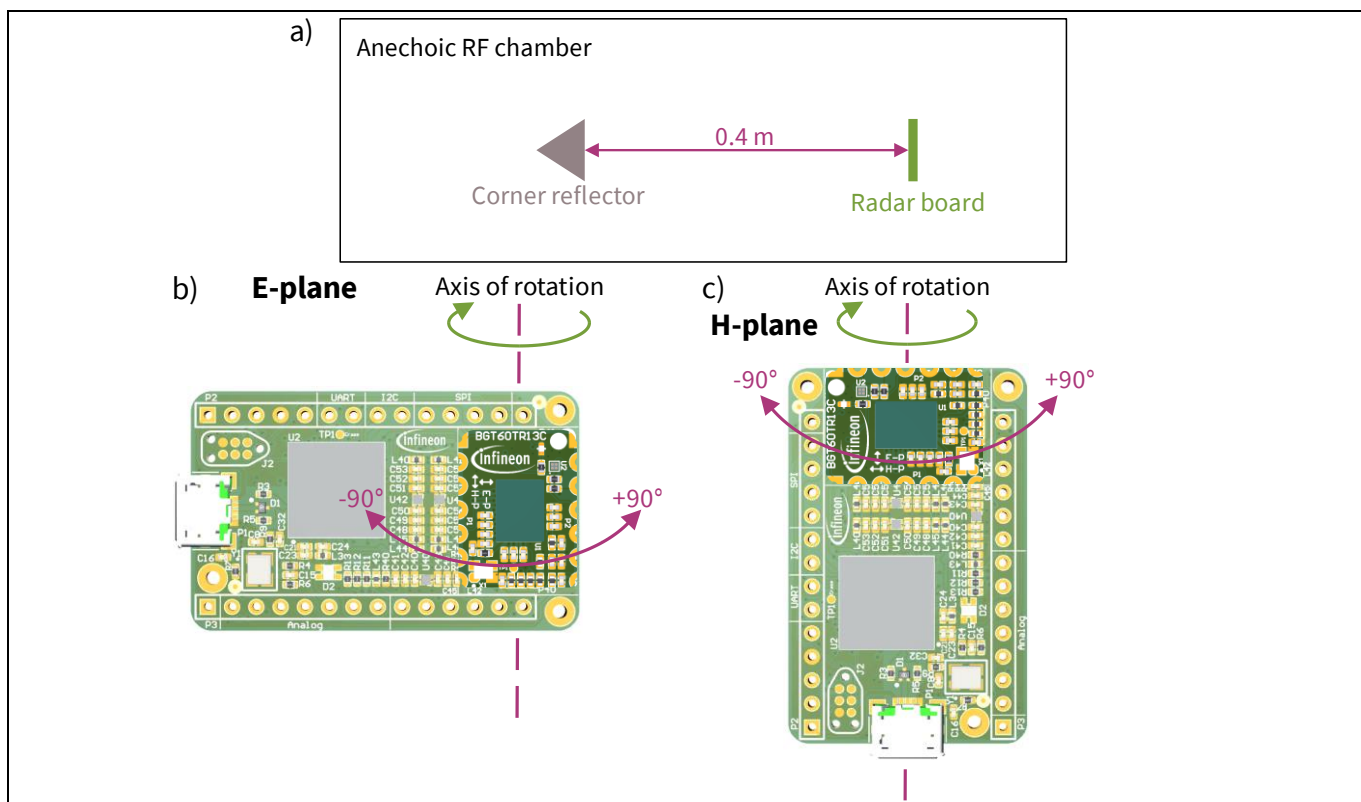


Figure 13 Set-up for radiation pattern measurement

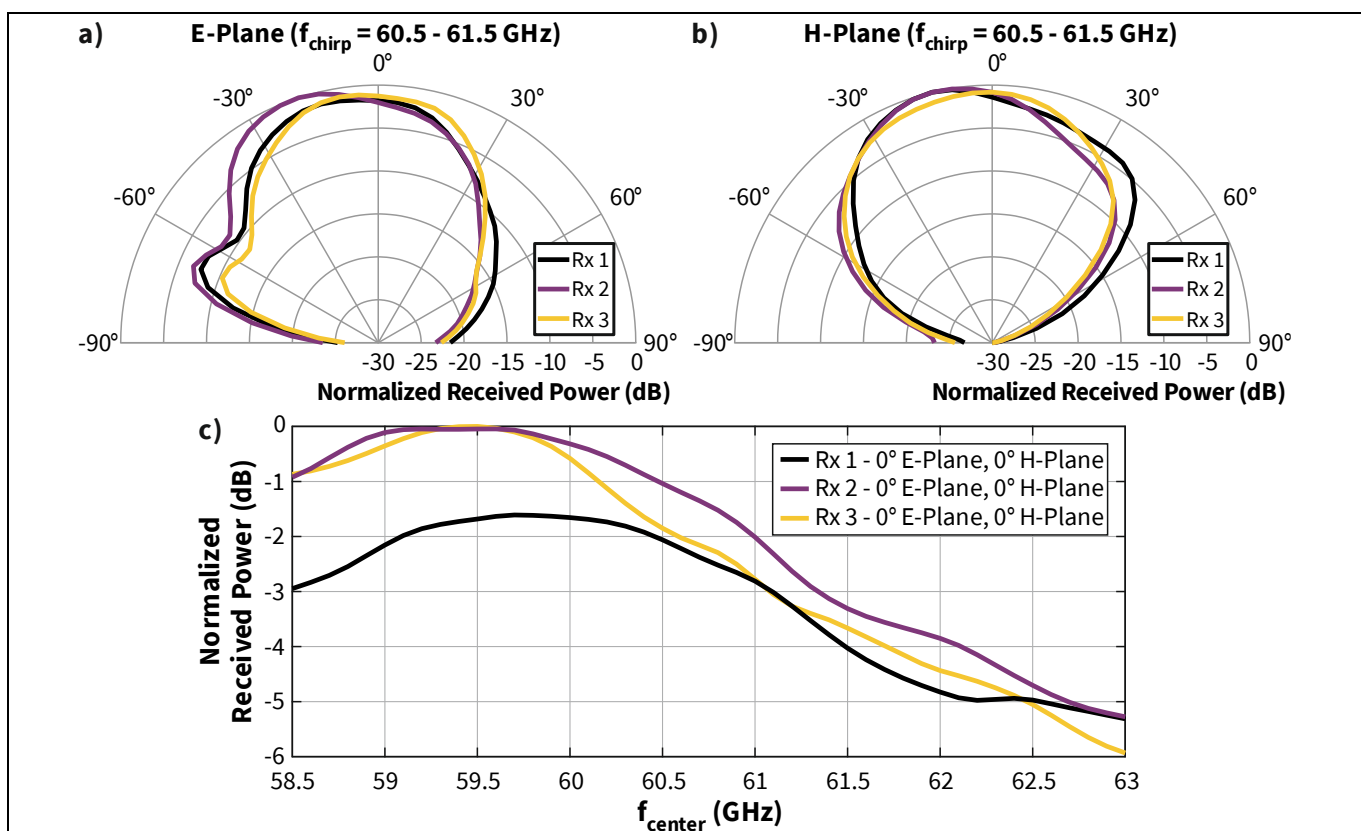


Figure 14 Radiation pattern measurements of a typical sample for a chirp from 60.5 to 61.5 GHz of E-plane (a) and H-plane (b) as well as the received power in dependence of the frequency (c).

Measurement results

5.3 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 BGT60TR13C, 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, as illustrated in Figure 15a. A horn antenna placed in front of the sensor receives the radiation emitted by the BGT60TR13C. Then, via a waveguide, the RF signal is transferred to a harmonic mixer, which in combination with a signal analyzer enables measurement of the RF signal emitted by the radar sensor. A typical set-up for this measurement could consist of:

- Keysight Signal Analyzer PXA N9030A (with phase noise measurement software)
- Keysight M1970V waveguide harmonic mixer
- Dorado International GH-15-20 horn antenna

The BGT60TR13C also has the option to emit the 1:16 divided RF signal at the DIV_TEST pin, shown in Figure 4b. The access to the divided RF signals provides another way to characterize the phase noise of the radar sensor. For measurement, the user must solder a coaxial cable to test point 1 and a GND pad of the BGT60TR13C, depicted in Figure 15b. This coaxial cable can then be connected to a signal analyzer like the Keysight N9030A and the phase noise can be measured with phase noise measurement software.

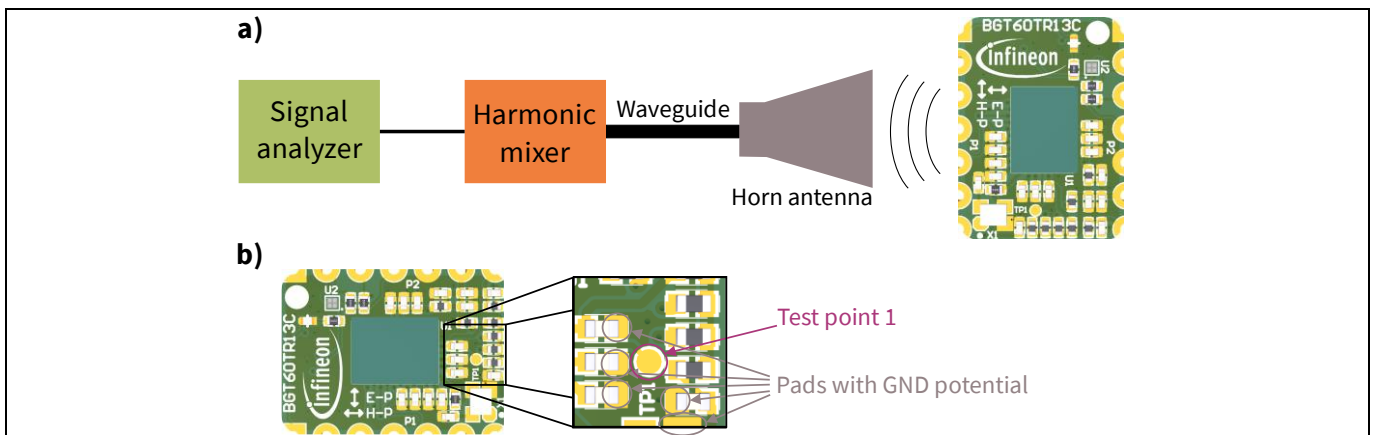


Figure 15 Measurement set-ups for phase noise measurement. Direct RF measurement with a harmonic mixer (a) and with a divided signal at test point 1 (b).

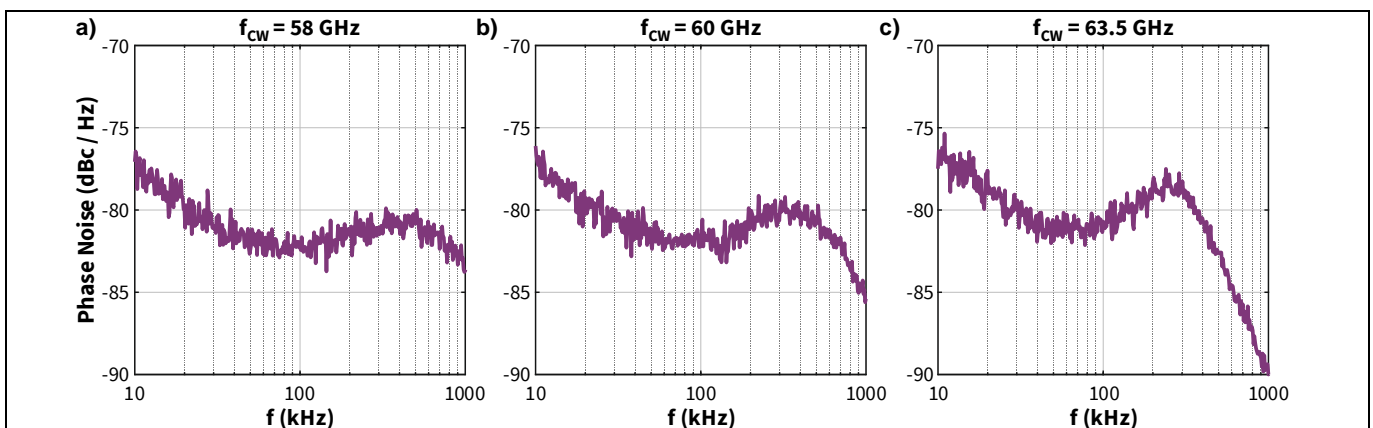


Figure 16 Phase noise measurements of a typical device with three test frequencies (58 GHz, 60 GHz, 63 GHz)

Measurement results

Figure 16 shows the phase noise measurement of a typical BGT60TR13C shield over three frequencies (58 GHz, 60 GHz, 63.5 GHz). The measurement was performed directly at the RF signal with a harmonic mixer. The phase noise is clean for all tested frequencies.

To characterize possible differences between sensor interface 1 and sensor interface 2 of the radar baseboard MCU7, the phase noise of the board was measured at both sensor interfaces with a direct RF measurement and a harmonic mixer. The results are depicted in Figure 17 and they show that there is no difference between the different sensor interfaces for different sensor frequencies.

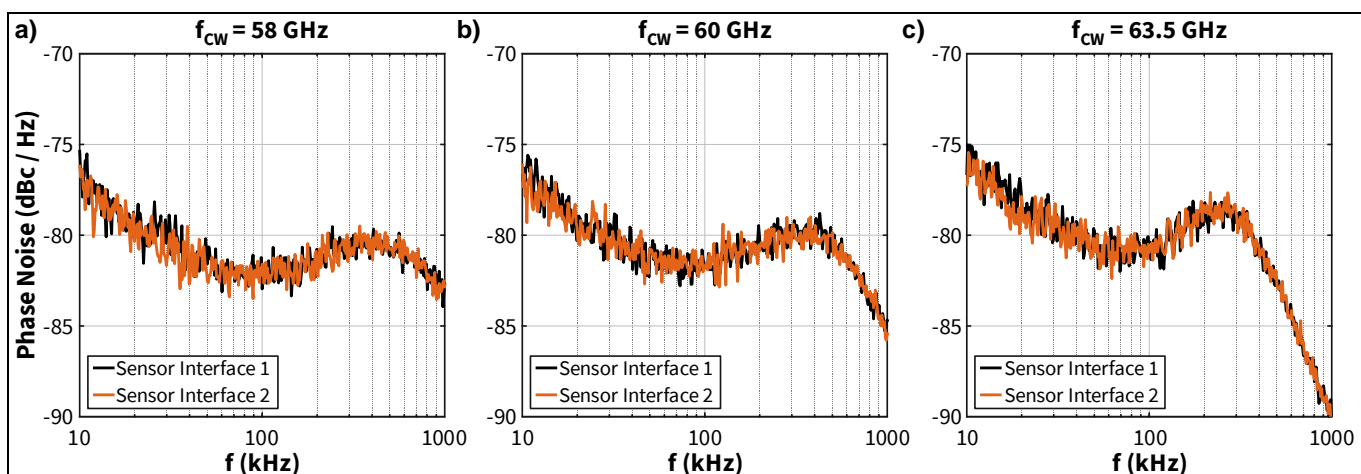


Figure 17 Phase noise measurements of a typical board on sensor interface 1 and sensor interface 2 with three test frequencies (58 GHz, 60 GHz, 63 GHz)

6 Frequency band and regulations

Infineon's BGT60TR13C radar sensor operates in the globally available 60 GHz bands. Typically, there is a wide band (WB) from 57 to 64 GHz and within it, there is an Industrial, Scientific and Medical (ISM) band from 61.0 to 61.5 GHz. However, each country may have differing regulations in term of occupied bandwidth, maximum allowed radiated power, conducted power, spurious emissions, etc. Therefore, it is strongly recommended to check the local regulations before designing an end product.

6.1 Regulations in Europe

In Europe, the European Telecommunications Standards Institute (ETSI) (European Telecommunications Standards Institute, n.d.) defines the regulations. They allow operation of non-specific short-range devices within the 57 to 64 GHz WB with certain limitations. For more details on the ETSI standards, please refer to document EN 305 550 (Institute, n.d.) as well as the Electronic Communications Committee's recommendations (Committee, n.d.). Note that some countries do not follow harmonized European standards. For this reason, it is recommended to check national regulations for operation within specific regions and monitor regulatory changes.

6.2 Regulations in the United States of America

In the USA, the Federal Communications Commission (FCC) (Federal Communications Commission, n.d.) defines standards and regulation. The unlicensed WB covers 57 to 64 GHz and you can operate a field disturbance sensor anywhere within this band within allowed power limits for certain applications. For details, refer to FCC section number 15.255 (Regulations, n.d.).

7 Applications and use cases

7.1 Radar GUI

The tool to evaluate the BGT60TR13C on the 60 GHz radar system platform is called Radar GUI. It is installed in the Infineon Toolbox when following the “Getting Started” instructions. Detailed documentation on how to work with Radar GUI can be found in the help section of Radar GUI. To open help, click on the question mark icon in the top right-hand corner of the application. In the help section, there is an introduction to Radar GUI as well as detailed documentation on the individual parts of the app.

7.2 Typical generic settings

In order to simplify the first operation of the BGT60TR13C sensor, this section will introduce some generic settings to configure how the sensor works in certain applications.

7.2.1 Short-range measurement

This section presents a configuration that can be used for short-range applications below 1 m.

- Range configuration
 - Range resolution: 3 cm
 - Resulting sampling bandwidth: 5 GHz
 - Resulting total bandwidth: 5.39 GHz
 - Maximum range: 96 cm
 - Resulting number of samples: 64
 - Resulting chirp time: 64 μ s
- Speed configuration
 - Maximum speed: 10.2 km/h = 2.84 m/s
 - Resulting pulse repetition time: 440 μ s
 - Speed resolution: 0.32 km/h = 0.089 m/s
 - Resulting number of chirps: 64
 - Frame repetition rate: 26 Hz
- Antenna configuration
 - Tx power: 4
 - Active Rx antennas: 1, 2, 3
 - IF gain: 40 dB

This configuration results in the following parameters:

- Duty cycle of the BGT60TR13C: 11.3 percent
- Power consumption of the BGT60TR13C: ~ 93 mW
- Current consumption of the 60 GHz platform: ~ 150 mA
- Power consumption of the 60 GHz platform: ~ 750 mW

7.2.2 Long-range measurement

This section presents a configuration that can be used for long-range applications up to 10 m.

- Range configuration
 - Range resolution: 15 cm
 - Resulting sampling bandwidth: 1 GHz
 - Resulting total bandwidth: 1.04 GHz
 - Maximum range: 9.6 m
 - Resulting number of samples: 128
 - Resulting chirp time: 128 μ s
- Speed configuration
 - Maximum speed: 14.7 km/h = 4.08 m/s
 - Resulting pulse repetition time: 306 μ s
 - Speed resolution: 0.46 km/h = 0.13 m/s
 - Resulting number of chirps: 64
 - Frame repetition rate: 12 Hz
- Antenna configuration
 - Tx power: 31
 - Active Rx antennas: 3
 - IF gain: 50 dB

This configuration results in the following parameters:

- Duty cycle of the BGT60TR13C: 10.58 percent
- Power consumption of the BGT60TR13C: ~ 67.72 mW
- Current consumption of the 60 GHz platform: ~ 140 mA
- Power consumption of the 60 GHz platform: ~ 700 mW

7.2.3 Low-power short-range measurement

This section presents a configuration that can be used for short-range applications below 0.5 m.

- Range configuration
 - Range resolution: 3.2 cm
 - Resulting sampling bandwidth: 4.7 GHz
 - Resulting sampling bandwidth: 5.46 GHz
 - Maximum range: 48 cm
 - Resulting number of samples: 32
 - Resulting chirp time: 32 μ s
- Speed configuration

Applications and use cases

- Maximum speed: 12.2 km/h = 3.38 m/s
→ Resulting pulse repetition time: 370 μ s
- Speed resolution: 0.76 km/h = 0.211 m/s
→ Resulting number of chirps: 32
- Frame repetition rate: 64 Hz
- Antenna configuration
 - Tx power: 16
 - Active Rx antennas: 1, 2, 3
 - IF gain: 23 dB

This configuration results in the following parameters

- Duty cycle of the BGT60TR13C: 3.6 percent
- Power consumption of the BGT60TR13C: ~ 30.25 mW
- Current consumption of the 60 GHz platform: ~ 125 mA
- Power consumption of the 60 GHz platform: ~ 625 mW

8 References

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Revision history

Revision history

Document version	Date of release	Description of changes
V1.0	2019-04-01	First version
V2.0	2019-07-01	Added V _{digital} for level shifter supply of the host board
V2.1	2019-10-21	Typo in section 2.1 Changed schematics (symbol) in Figure 9 Added section 5.1 for antenna radiation pattern Changed figures 17 and 18 with the correspond text in section 5.3
V2.2	2021-11-15	Update BGT60TR13C shield to version 2.2

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Edition 2021-11-15

Published by

Infineon Technologies AG

81726 Munich, Germany

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Document reference

AN600

AN_1907_PL32_1907_091722

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