DEMO DISTANCE2GOL

XENSIV™ 24 GHz radar system platform

Board version V3.0

About this document

Scope and purpose

This application note describes the key features of Infineon's BGT24LTR11 Software-Controlled FMCW shield, part of DEMO DISTANCE2GOL radar system platform, equipped with the XENSIV™ 24 GHz BGT24LTR11 low-power MMIC, and helps the user quickly get started with the demonstration board.

1. The application note describes the hardware configuration and specifications of the sensor module in detail.
2. The document also provides a guide to configuring the hardware and implementing simple radar applications with the firmware/software developed.

Intended audience

The intended audience for this document are design engineers, technicians, and developers of electronic systems, working with Infineon's XENSIV™ 24 GHz radar sensors.

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1 Introduction

The DEMO DISTANCE2GOL is a demonstration platform for Infineon's 24 GHz silicon-germanium (SiGe) BGT24LTR11 radar chipset. It consists of two boards – the microcontroller board: Radar Baseboard MCU4, and a radar front-end board: BGT24LTR11 shield. This document focuses on the BGT24LTR11 shield assembled for a software-controlled Frequency Modulated Continuous Wave (FMCW) implementation. Detailed information about the Radar Baseboard MCU4 can be found in the corresponding application note (AN602).

The system is designed to enable customers to carry out prototyping and system integrations as well as initial product feature evaluations. The platform is a low-power solution for tracking human presence and detecting range. These features of the board make it suitable for various applications such as presence sensing, proximity sensing and motion detection. These use cases target applications such as outdoor security cameras, smart-home devices and lighting control.

The main radar technique used on the platform is FMCW for range estimation. In FMCW, the time delay between the transmitted and received chirp is used for measuring the distance to the target(s). The transmitted and received signals are mixed and then quantized for further processing. A Software-Controlled loop performs the frequency control and ramp generation. This eliminates the need for a high-cost PLL IC, hence reducing system cost. The circuitry is designed for low-power consumption. Two-stage low-noise baseband amplification stages are used for enhanced target detection. The baseband section is configurable for different cut-off frequencies and gain requirements of different applications. The module also offers the possibility of using a battery for operation.

The module provides a complete radar system evaluation platform, including demonstration software and a basic graphical user interface (GUI), which can be used to display and analyze acquired data in time and frequency domains. An onboard debugger with licensed firmware from SEGGER enables easy debugging over USB. Infineon's powerful, free-of-charge toolchain DAVE™ can be used for programming the XMC4700 microcontroller. The system also features integrated micro-strip patch antennas on the PCB with design data, thereby eliminating antenna design complexity at the user end.

This application note describes the key features and hardware configuration of the BGT24LTR11 shield in detail.

1.2 Key features

The primary features of the Distance2GoL radar system are as follows:

- Detects distance of a human in a user-configurable range (1 to 15 m)
- Detects distance and velocity of the closest human or moving target
- Low power consumption
- Two-board topology for RF section and microcontroller sections
- Two customizable analog amplifier stages for the RX channel
- Micro-strip patch antennas with 10 dBi gain and 29 x 80 degrees Field of View (FoV)
- Multiple power supply possibilities – micro-USB, external power supply or LiPo battery
- Compatible with Arduino for ease of use and prototyping
- Operates in different weather conditions, including rain, fog, etc.
- Can be hidden in the end application as it detects through non-metallic materials

Note: The platform serves as a demonstrator platform with the software to perform simple motion sensing. The test data in this document show typical performance of Infineon-produced platforms. However, board performance may vary depending on the PCB manufacturer and specific design rules imposed and components used.

1.3 Overview

The platform is a stack-up of two boards – BGT24LTR11 shield (radar front-end) and Radar Baseboard MCU4 (for signal processing).

The Distance2GoL radar system consists of the following key components:

- BGT24LTR11 – highly integrated 24 GHz transceiver MMIC with one transmitter (TX) and one receiver (RX)
- XMC4700 – 32-bit Arm® Cortex®-M4 based microcontroller for signal processing
- IRLHS2242 – 20 V single P-channel MOSFETs for duty-cycle operation
- MCP73831T – battery manager for charging and using the battery
- CW1280T – EEPROM to store board identifier information
- MOLEX 047571001 – SD card reader for storing raw data
- XMC4200 – 32-bit Arm® Cortex®-M4 based microcontroller for debugging

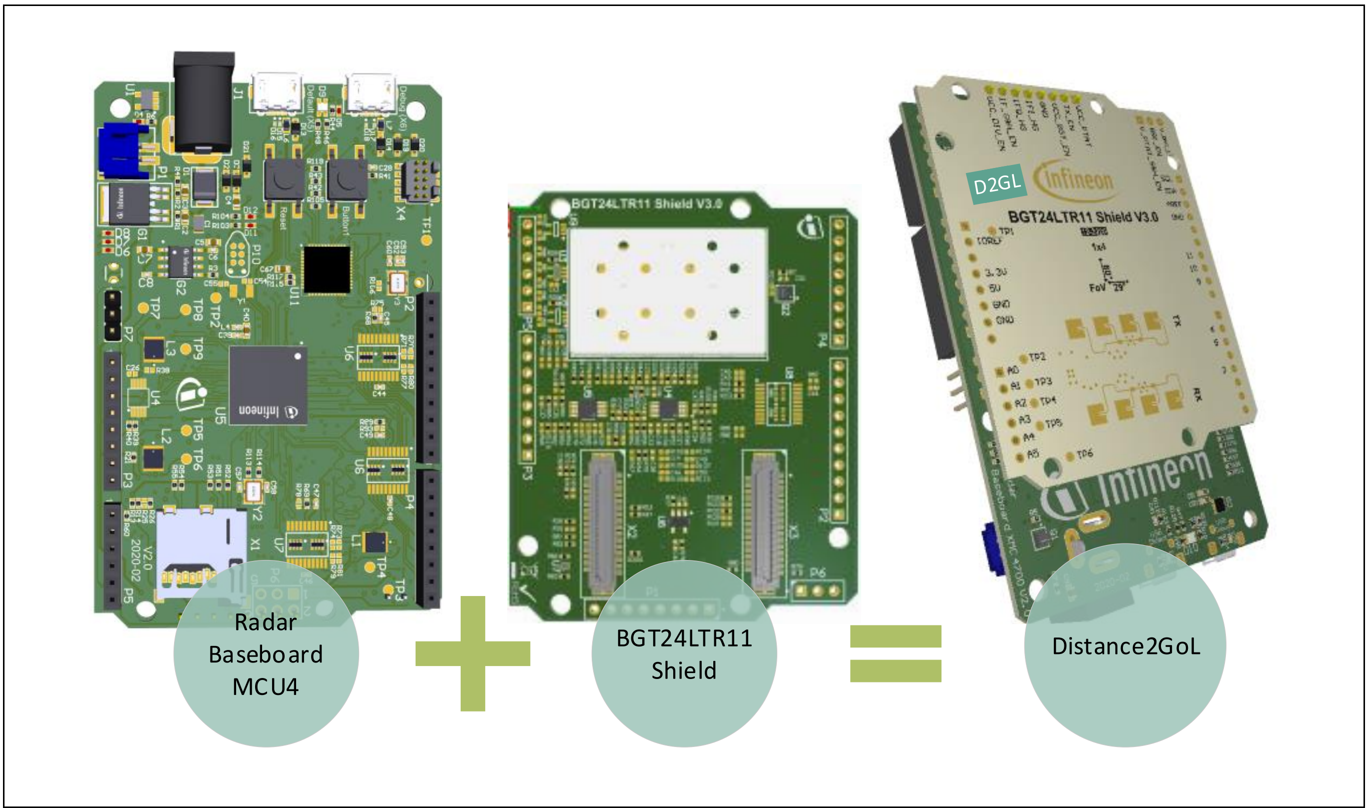

Figure 1 Distance2GoL demo platform

Note: The BGT24LTR11 shield in Distance2GoL platform is assembled for Software-Controlled FMCW operation.

The circuitry for the BGT24LTR11 shield (Software-Controlled FMCW) is designed to perform human target range detection and tracking with low-power consumption. In this approach, the BGT24LTR11 MMIC is controlled using a software-based open-loop concept. Frequency is measured periodically and VCO is tuned accordingly. This implementation has the advantage of reducing the PCB space, BOM cost and power consumption by eliminating the external (Phase Locked Loop) PLL IC. System performance might be lower than an external PLL, but can address a lot of applications like smart lighting, motion sensing or proximity detection, etc.

2 System specifications

Table 1 gives the specifications of the Distance2GoL (Software-Controlled FMCW) radar system.

Table 1 Distance2GoL (Software-Controlled FMCW) module performance specifications

Parameter	Unit	Min.	Typ.	Max.	Comments
System performance					
Detection Speed	km/h	0	-	10	
Detection Distance	m	1	15	25	Human target
Power supply					
Supply voltage	V	3.3	5	5.5	Supplied via the Baseboard
Supply current	mA		50		All blocks on (only the shield)
Transmitter characteristics					
Transmitter frequency	GHz	24.025	24.125	24.225	
Effective isotropic radiated power (EIRP)	dBm		+14		**Conditions:** BGT P_{OUT}: +6 dBm Loss (TX_{OUT} to ant. input = 2 dB) Simulated ant. gain = +10 dBi
Receiver characteristics					
Receiver frequency	GHz	24.025	24.125	24.225	
IF conversion gain – (stage 1)	dB		30		Customizable by re-soldering baseband section (Table 3)
IF conversion gain – (stage 1 + stage 2)	dB		57		Customizable by re-soldering baseband section (Table 3)
-3 dB bandwidth – (stage 1 + stage 2)	kHz	7		15	Customizable by re-soldering baseband section (Table 3)
Antenna characteristics (simulated)					
Antenna type			1 x 4		
Horizontal – 3 dB beamwidth	Degrees		80		
Elevation – 3 dB beamwidth	Degrees		29		
Horizontal sidelobe level suppression	dB	13			
Vertical sidelobe level suppression	dB	13			

Note: The above specifications are indicative values based on typical datasheet parameters of BGT24LTR11 and simulation of several other parameters (antenna characteristics and baseband section) and can vary from module to module. The numbers above are not guaranteed indicators for module performance for all operating conditions.

3 Hardware description – BGT24LTR11 shield

This section presents a detailed overview of the BGT24LTR11 shield hardware specifications, including the MMIC considerations, power supply and board interfaces.

3.1 Overview

The radar shield is shown in Figure 2. It contains the following sections:

- RF part – consists of the Infineon 24 GHz radar MMIC BGT24LTR11 and includes micro-strip patch antennas for the TX and RX sections
- Analog amplifier part – amplifies the in-phase and quadrature-phase signals from the MMIC for the digital part
- EEPROM part – stores data such as board identifier information

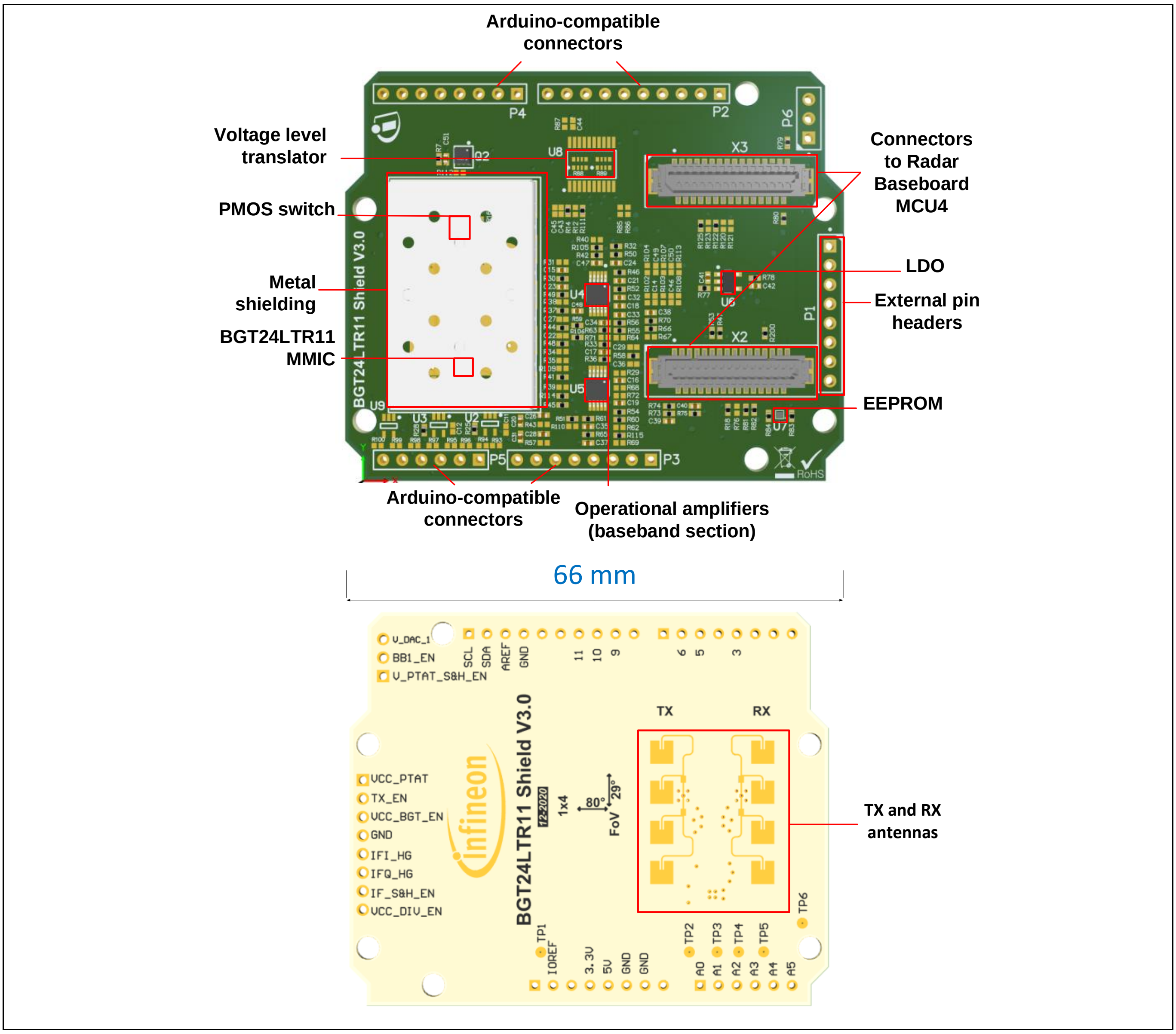

Figure 2 BGT24LTR11 shield with main components and dimensions

The shield demonstrates the features of the BGT24LTR11 RF front-end chip and gives the user a customizable radar solution. The board enables implementation of different baseband settings, VCO control, etc. to get closer to a custom-fit solution for the use case. It also makes it possible to quickly gather sampled radar data that can be used to develop radar signal processing algorithms on a PC or implement target detection algorithms directly on the microcontroller using DAVE™.

3.2 Block diagram

Figure 3 shows the block diagram of the Distance2GoL system. It consists of the highly integrated 24 GHz transceiver MMIC BGT24LTR11 with 1 TX and 1 RX antenna. The hardware consists of two main parts: one Software-Controlled FMCW BGT24LTR11 shield and one microcontroller unit with XMC4700.

In order to keep the output frequency within the industrial, scientific and medical (ISM) band and generate the frequency ramp, the tuning voltage (V_TUNE) is software-controlled via a Digital-to-Analog Converter (DAC) in the microcontroller unit. The DAC output (V_TUNE_IN) is smoothed by two RC low-pass filters and fed to the V_TUNE input of the BGT24LTR11. The IF outputs (I/Q signals) are first bandpass filtered by two stages of op-amps and then sampled by four synchronized Analog-to-Digital Converters (ADC), which are built into the XMC4700 MCU. The user can select the output of the first amplification stage (low-gain output) for sampling for low-range applications. The op-amps are also duty-cycled for a low-power consumption using control signals (BB1_EN and BB2_EN).

An initial RF within the ISM band at the start-up of the radar system is ensured by utilizing the built-in voltage source V_PTAT (Proportional-to-Absolute Temperature). After enabling VCC_PTAT, the output voltage is sampled by an ADC and set by the DAC as V_TUNE. The Capture-and-Compare Unit (CCU) of the XMC4700 measures the divider output (DIV_OUT) of the BGT24LTR11 MMIC to supervise the current RF and (re)calibrate the start and stop frequencies if required. During this process, VCC_PTAT is also enabled to set the correct divider frequency.

For optimizing the power consumption of the system, the BGT24LTR11 MMIC is duty-cycled, along with the building blocks of divider and PTAT using control signals from the MCU (VCC_BGT_EN, VCC_DIV_EN and VCC_PTAT_OUT).

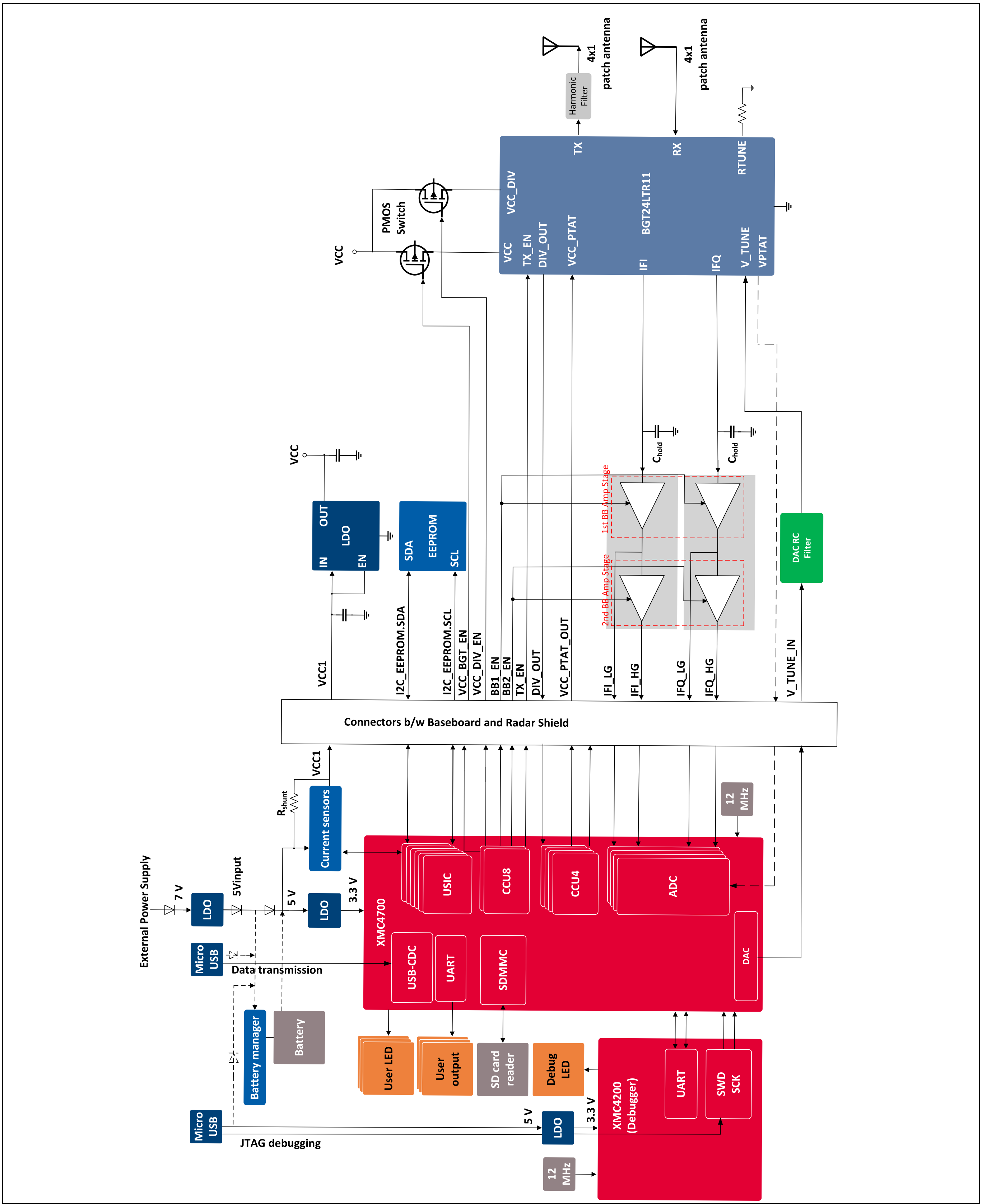

Figure 3 Block diagram – Distance2GoL

3.3 Power supply

The Radar Baseboard MCU4 is powered via micro-USB connector, external 7 V power supply or LiPo battery. It also provides the supply for the BGT24LTR11 shield via the connectors. An LDO (U6) is used on the BGT24LTR11 shield to supply all the components. Figure 4 shows the power supply concept used in the system.

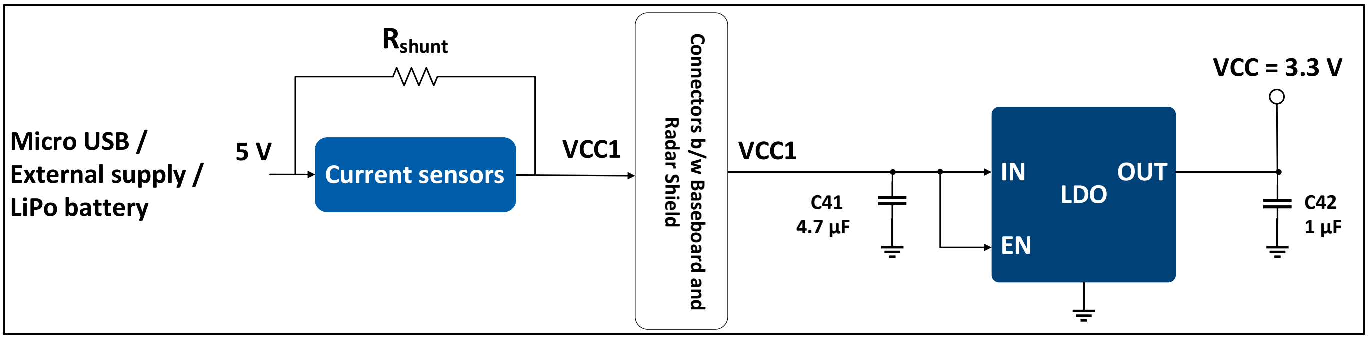

Figure 4 Block diagram – power supply concept

3.4 EEPROM

The BGT24LTR11 shield contains an EEPROM (U7) to store data such as a board identifier. The Serial Data (SDA) is a bi-directional pin that is used to transfer addresses and data into and out of the device. The Serial Clock (SCL) is an input that is used to synchronize the data from and to the device.

When the shield is plugged into the Radar Baseboard MCU4, the sensor'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 interface. Only when the board has been correctly identified are the sensor's supplies activated.

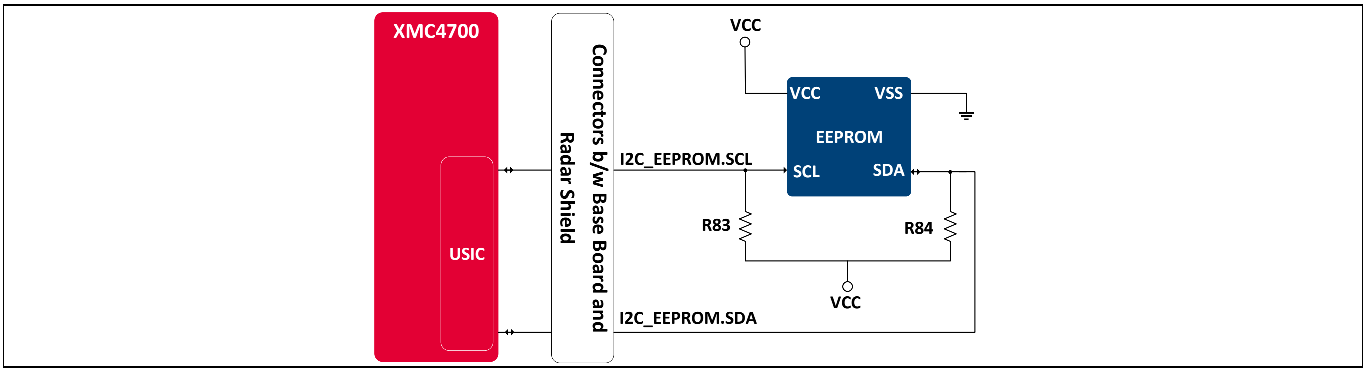

Figure 5 EEPROM block diagram

3.5 RF front-end

Figure 6 shows the top view of the RF front-end. The RF front-end has a cover with absorber material to get the best RF performance. The transmitter and receiver inputs of the BGT24LTR11 are single-ended. The TX output and RX input are connected over a matching structure, a DC block and a feed-through via to the antennas on the other side of the board. The isolation between the RX and TX ports is improved by adding a grounded length of line at the ground pins next to the TX output pin, as shown in Figure 6.

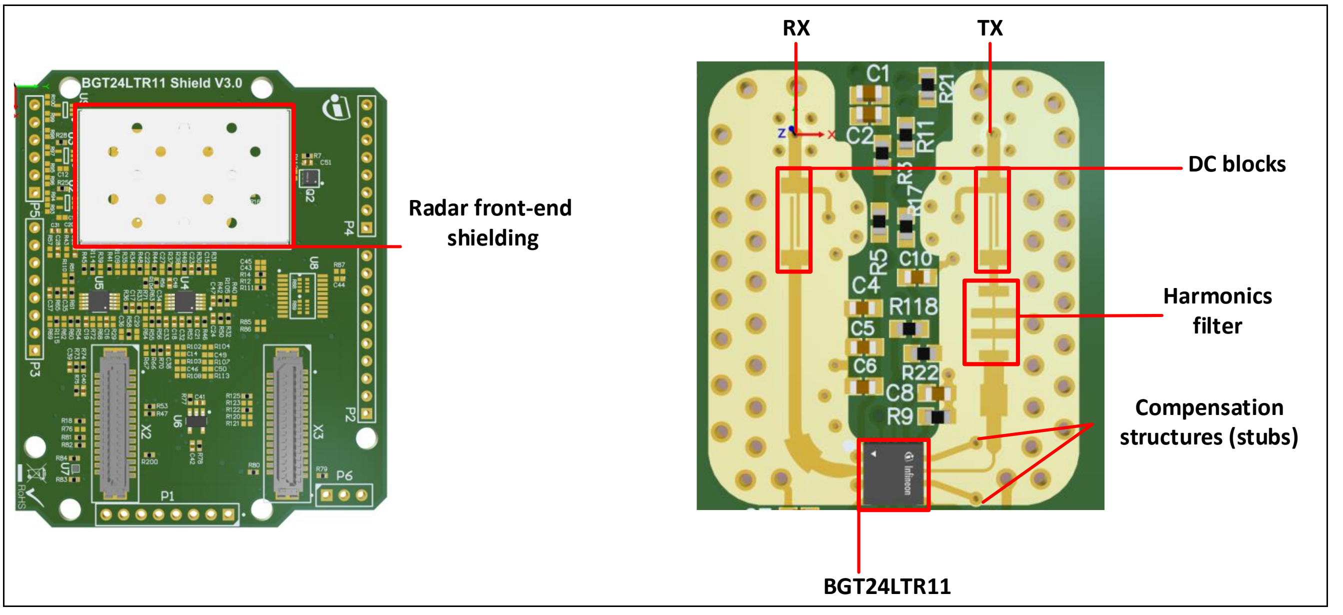

Figure 6 RF front-end overview (top)

3.6 BGT24LTR11 MMIC

The heart of the sensor module is the highly integrated BGT24LTR11 24 GHz transceiver IC. Figure 10 shows the detailed block diagram of the MMIC. BGT24LTR11 is a radar MMIC for signal generation and reception, operating in the 24.000 GHz to 24.250 GHz ISM band. It is based on a 24 GHz fundamental Voltage Controlled Oscillator (VCO).

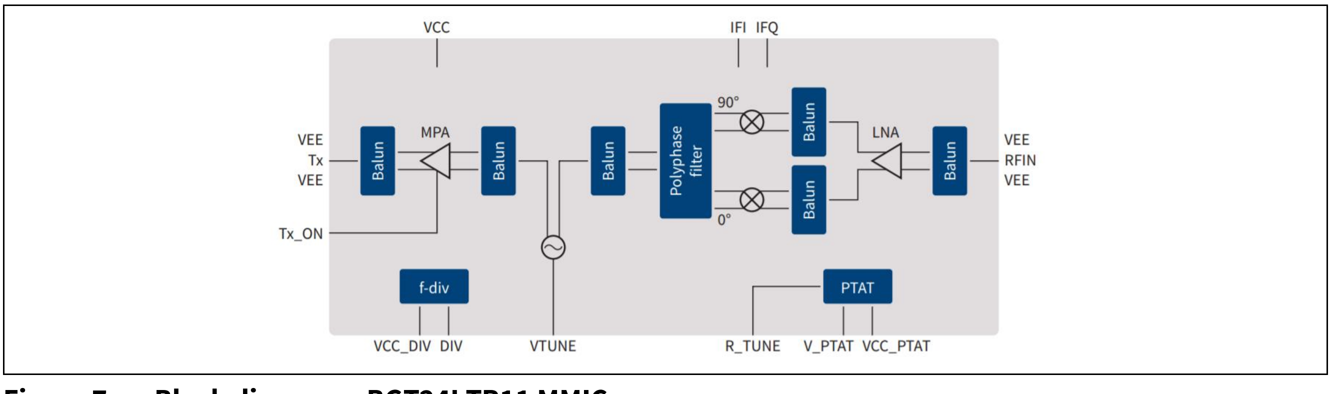

Figure 7 Block diagram – BGT24LTR11 MMIC

A built-in voltage source delivers a VCO PTAT tuning voltage. When connected to the VCO tuning pin, it compensates for the inherent frequency drift of the VCO overtemperature, thus stabilizing the VCO within the ISM band and eliminating the need for a PLL/microcontroller.

The receiver section 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, a RC Poly-Phase Filter (PPF) generates quadrature LO signals for the quadrature mixer. I/Q IF outputs are available through single-ended terminals.

3.7 Antennas

The BGT24LTR11 shield features a 4 x 1 array antenna for the transceiver and receiver sections. The antenna has a gain of 9.6 dBi and an opening angle of 28.5 x 81.8 degrees. Figure 8 shows the simulated 2D and 3D radiation pattern.

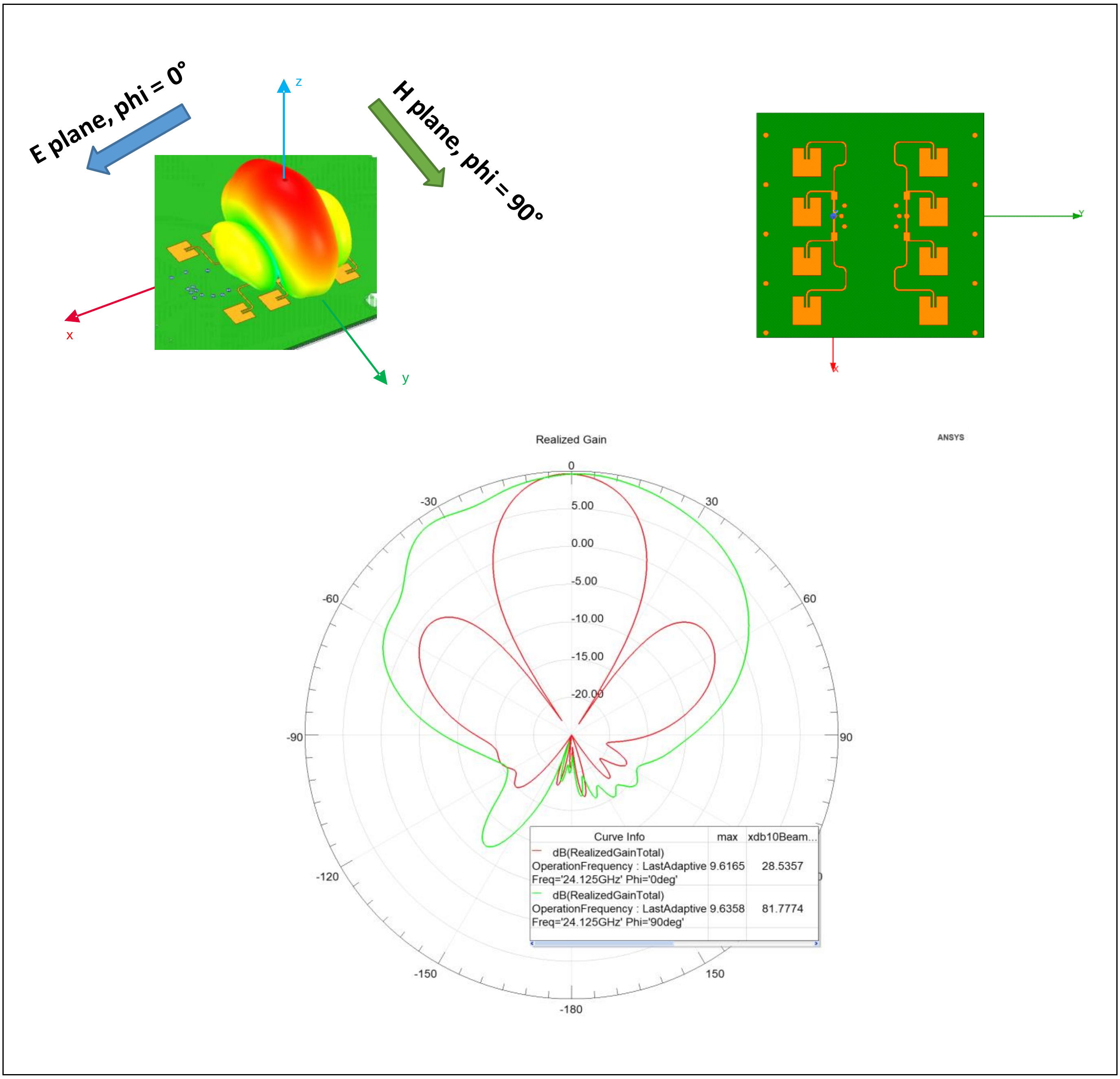

Figure 8 Simulated radiation pattern for 4x1 antennas

3.8 Analog baseband section

The BGT24LTR11 provides both in-phase and quadrature-phase Intermediate Frequency (IF) signals from its receiver. Depending on the target in front of the radar antennas, the analog output signal from the BGT24LTR11 chipset can be very low in amplitude (µV to mV range). To process these low-amplitude signals, it is necessary to amplify the IF signals.

The BGT24LTR11 shield offers two stages of signal amplification using low-noise op-amps. As shown in Figure 9 and Figure 10, the I/Q outputs of the BGT are filtered and amplified in the first gain stage. The second gain stage consists of a multiple-feedback active filter topology, which provides additional gain and bandpass filtering to the output of the first gain stage. The low-gain and high-gain output signals are low-pass filtered to avoid aliasing. A voltage divider is used to create the 1.65 V reference voltage. Both stages of op-amps are duty-cycled for low-power consumption.

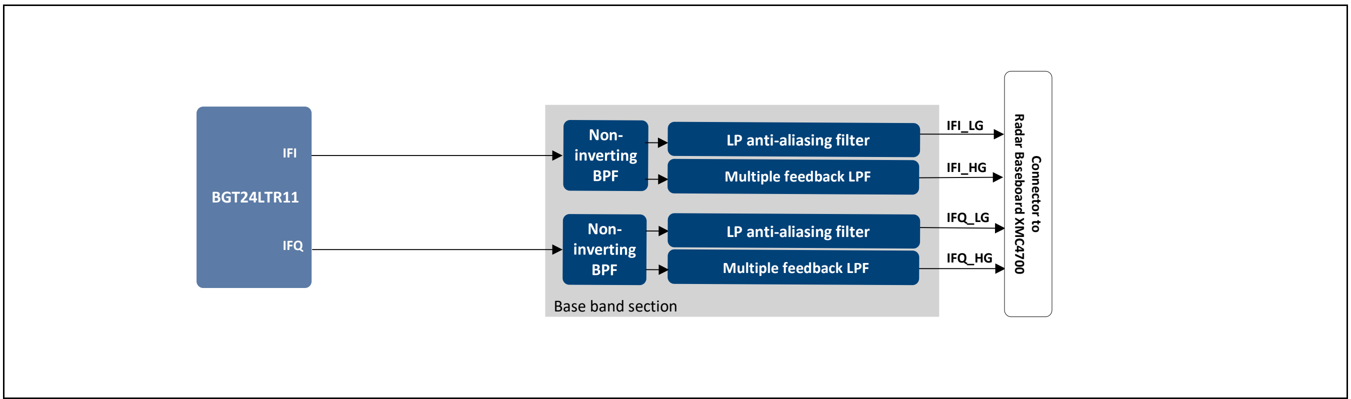

Figure 9 **Baseband amplifier chain – block diagram**

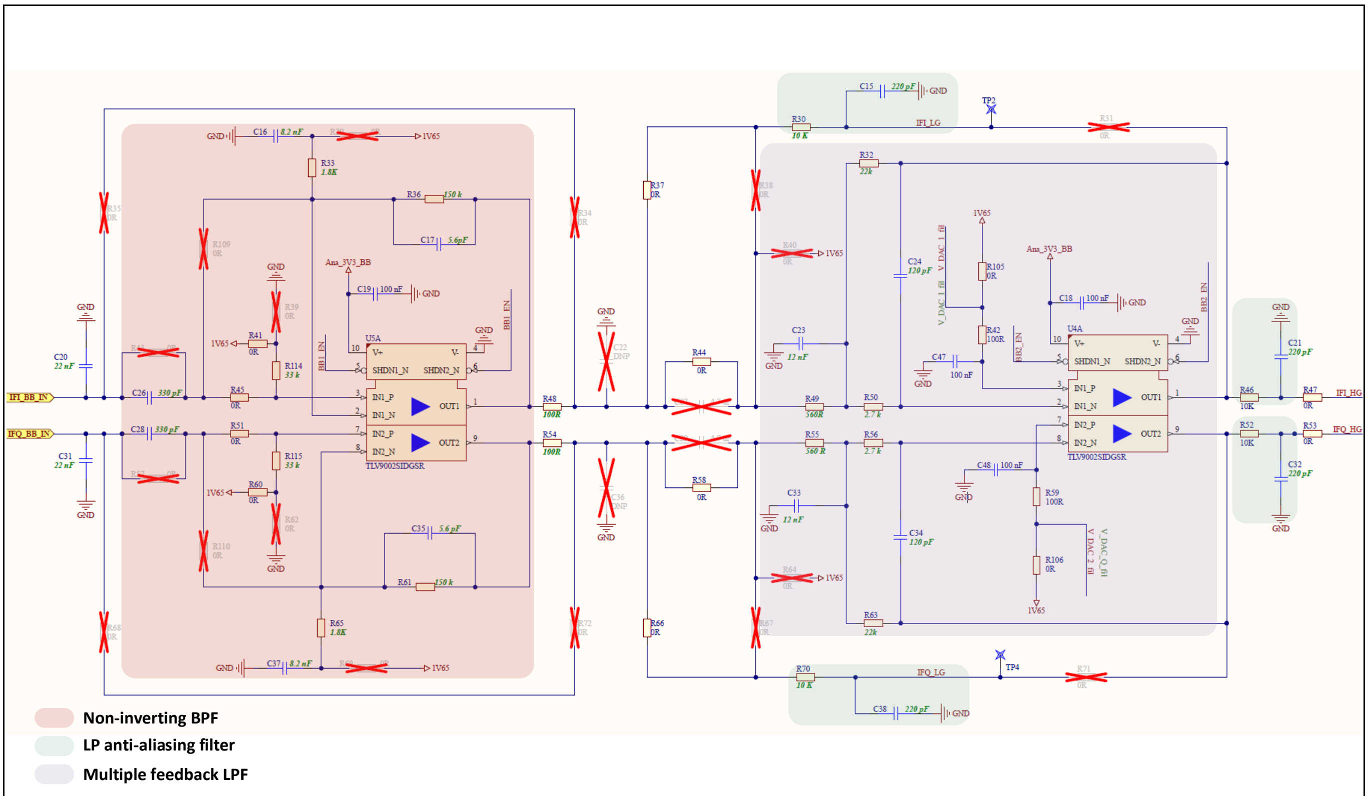

Figure 10 **Baseband amplifier chain – schematic**

The offset of the low-gain signal equals the static offset of the BGT output signals. Due to the DC block at the beginning of the second stage, the offset of the high-gain signal matches the reference voltage of 1.65 V. As shown in Figure 11, the first gain stage provides a gain of up to 30 dB (low-gain stage) and both the stages together provide a gain of up to 57 dB (high-gain stage).

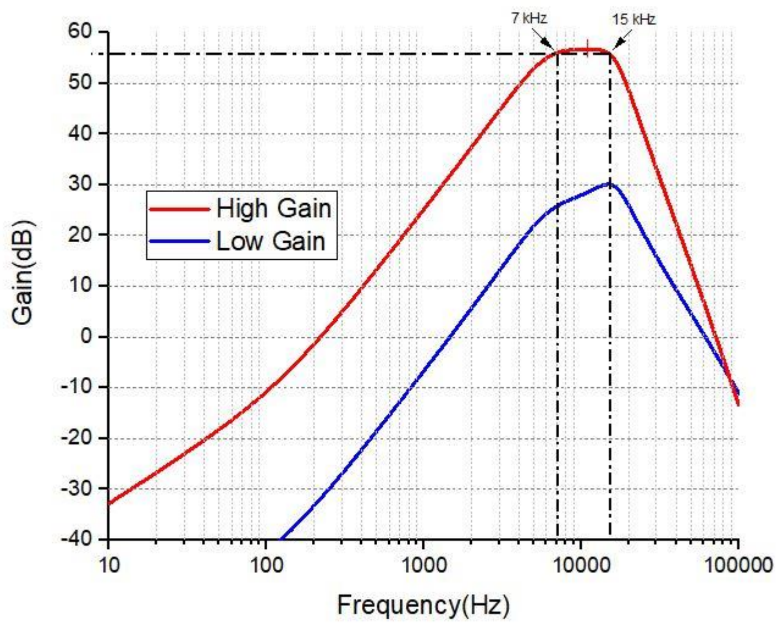

Figure 11 Baseband frequency response for low-gain and high-gain stages

Figure 11 shows the frequency response of the low- and high-gain stages. The BGT24LTR11 shield allows the user to select either the low-gain (first stage only) or high-gain (first stage + second stage) mode depending on the target RCS and distance to be detected. The low-gain output is referenced to the individual mixer output bias voltage (1.6 to 2.0 V), and the high-gain stage is AC coupled and referenced to $V_{CC}/2$ = 1.65 V.

Table 2 lists the MCU pins (on the Radar Baseboard MCU4) associated with each of the gain stages. Use the graphical pin select tool in the DAVE™ software to select the appropriate pins for signal processing.

Table 2 Baseband amplifier to MCU pin connections

XMC4700 – port pin	Pin label	Pin function
P14.6 (VADC.G0CH6)	IF.I1	IFI – high gain
P14.7 (VADC.G0CH7) / P14.3 (VADC.G1CH3)	IF.Q1	IFQ – high gain
P14.14 (VADC.G1CH6) / P15.3 (VADC.G2CH3)	IF.I2	IFI – low gain
P14.15 (VADC.G1CH7) / P15.9 (VADC.G3CH1)	IF.Q2	IFQ – low gain

The gain and bandwidth of the IF stages can be manually configured by the user by changing the resistor and capacitor values specified in Table 3.

Table 3 Baseband amplifier components and settings

IF stage	Designator	Gain	Configurable components – I section	Configurable components – Q section
Stage 1 (low-gain)	U5A	30 dB	C16, R33, C17, R36	C37, R65, C35, R61

IF stage	Designator	Gain	Configurable components – I section	Configurable components – Q section
Stage 1 + Stage 2 (high-gain)	U5A + U4A	57 dB	All components as mentioned for Stage 1 + R49, R50, R32, C23, C24	All components as mentioned for Stage 1 + R55, R56, C34, R63, C33

The bandpass characteristics of the IF section are also determined from the FMCW ramp parameter settings. Different ramp settings result in different IFs for targets at different distances. The baseband section is designed to meet the required IF cut-offs. Table 4 gives an example of IFs produced by stationary targets at particular distances corresponding to different sawtooth-type ramp parameters. These IFs are also called “beat frequencies”. The beat frequencies calculated in the table do not include the Doppler shift.

The $Beat\ Frequency\ (Fb)$ is calculated from the following formula:

$$\boxed{Beat\ Frequency\ (Fb) = \frac{2 * \mathrm{R} * \Delta\mathrm{f}}{\mathrm{c} * T_r}}$$

Where R = target distance in meters (m)

Δf = ramp bandwidth in Hertz (Hz)

T_r= ramp time in seconds (s)

c = speed of light in meters/second (m/s)

Table 4 IF vs. FMCW ramp parameters vs. target distance

Ramp duration (T_r) [µs]	Ramp bandwidth (Δf) [MHz]	Beat frequency (Fb) [kHz]		
		Target at 50 cm (R)	Target at 10 m (R)	Target at 30 m (R)
1000	180	0.60	12.00	36.00
1000	200	0.67	13.33	40.00
1500	180	0.40	8.00	24.00
1500 (default)	200	0.44	9.00	26.70
2000	180	0.30	6.00	18.00
2000	220	0.33	6.70	20.00

4 Power consumption analysis

The BGT24LTR11 shield is designed for low-power consumption.

- The MMIC is turned on with TX enabled for all N_C chirps per frame and with TX disabled during frequency check and recalibration, while the influence of the TX status on the power consumption is neglectable. In order to avoid out-of-band spurs, MMIC and TX are enabled and disabled for chirping only at center frequency, for which reason the on-time per chirp t_{on} is larger than the pure up-chirp time t_{up} If the pulse repetition time (PRT) is smaller than or equal to 3 ms, the fast chirp mode is enabled and t_{on} is equal to the PRT. If the PRT is larger than 3 ms, the power-saving mode is applied and t_{on} is 2.5 ms.
- The PTAT and the divider are used for frequency checks and recalibration (with MMIC enabled). Each frame a frequency check is performed, which requires around 1 ms. The recalibration is only performed if the frequency fails takes around 2 ms. Thus, the mean total recalibration time per frame t_{calib} is 3 ms at maximum.
- The baseband section consists of the two stages of op-amps and the voltage divider. It is turned on simultaneously with the MMIC and TX for chirping and is turned off shortly after the end of the up-chirp.

As shown in Table 5, the major contributors to the power consumption are the MMIC and the divider.

Table 5 Power consumption overview

Component	Current consumption (mA)	On-time per frame (ms)
MMIC (BGT24LTR11)	45	$N_C \times t_{on}$
MMIC+ Divider + PTAT	65.5 (45 + 19 + 1.5)	t_{calib} (~ 3)
Baseband section (Op-amps and voltage divider)	0.335	$t_{up} + 0.6$

The Distance2GoL power consumption can be computed after calculating the current consumption of the BGT24LTR11 for chirping, the frequency check and recalibration, and the duty-cycling of the baseband section. Some exemplary power consumption calculations are shown in the table below:

Table 6 Power consumption calculation

Frame period [ms]	Pulse repetition time [ms]	Chirps per frame	Calibration time [ms]	Current consumption [mA]	Power consumption [mW]
100 (default)	5	10	3	13.3	43.8
100	5	12	3	15.5	51.3
150	5	10	3	8.9	29.3
150	10	12	3	10.4	34.2
200	5	10	3	6.64	21.9
200	10	12	3	7.8	25.6

5 External pin header connectors

The BGT24LTR11 shield has the provision to connect multiple headers on the edge of the board. Figure 12 shows the pin headers on the PCB, and Table 7,Table 8, Table 9, Table 10, Table 11 and Table 12 describe the pins.

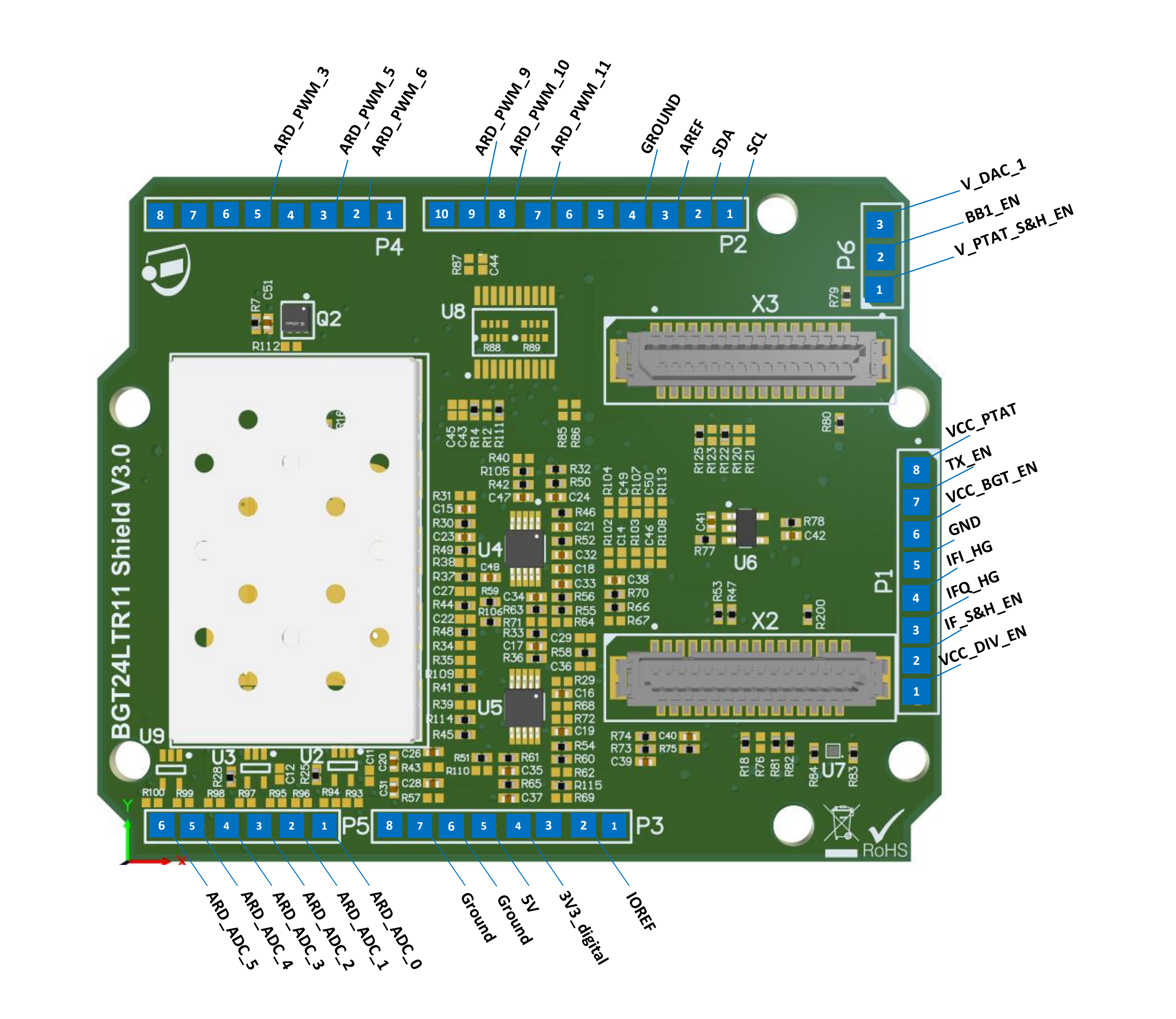

Figure 12 External headers – P1, P2, P3, P4, P5 and P6

Table 7 External headers (P1) – pin description

Pin no.	Signal name	Pin description
1	VCC_PTAT	Control signal for VCC_PTAT pin (pin 16) of MMIC
2	TX_EN	Control signal for TX_EN pin (pin 5) of MMIC
3	VCC_BGT_EN	Control signal for PMOS switch (Q1) to turn MMIC on/off
4	GND	Ground
5	IFI.I1 (IFI_HG)	Second baseband amplifier stage output for IFI signal

Pin no.	Signal name	Pin description
6	IFI.Q1 (IFQ_HG)	Second baseband amplifier stage output for IFQ signal
7	IF_S&H_EN	Control signal for IF S&H switches (U2 and U3)
8	VCC_DIV_EN	Control signal for PMOS switch (Q2) to turn MMIC's divider on/off

Table 8 External headers (P2) – pin description

Pin no.	Signal name	Pin description
1	SCL	(I2C_EEPROM.SCL) serial clock input of the EEPROM
2	SDA	(I2C_EEPROM.SDA) serial data pin of the EEPROM
3	AREF	3.3 V power supply to Arduino
4	Ground	Ground
7	ARD_PWM_	ARD_BB1_EN: control signal to turn on/off the first stage of baseband amplification
8	ARD_PWM_	ARD_V_PTAT_S&H_EN: control signal for V_PTAT
9	ARD_PWM_	ARD_IF_S&H_EN: control signal for S&H switches for IFI and IFQ

Table 9 External headers (P3) – pin description

Pin no.	Signal name	Pin description
2	IOREF	Reference signal
4	3V3	3.3 V power supply to Arduino
5	5V	5 V power supply to Arduino
6	Ground	Ground
7	Ground	Ground

Table 10 External headers (P4) – pin description

Pin no.	Signal name	Pin description
2	ARD_PWM_	ARD_VCC_PTAT: control signal to turn PTAT on/off
3	ARD_PWM	ARD_TX_EN: control signal for turning the TX of BGT24LTR11 on/off
5	ARD_PWM_	ARD_VCC_BGT_EN: control signal for turning the BGT24LTR11 on/off (via Q1 PMOS)

Table 11 External headers (P5) – pin description

Pin no.	Signal name	Pin description
1	ARD_ADC_0	IFI_HG signal from the second baseband stage. Place R94 (0 Ω) and remove R93 to see IFI_LG signal from the first baseband stage.
2	ARD_ADC_1	IFQ_HG signal from the second baseband stage. Place R96 (0 Ω) and remove R95 to see IFQ_LG signal from the first baseband stage.
3	ARD_ADC_2	IFI_LG signal from first baseband stage
4	ARD_ADC_3	IFQ_LG signal from first baseband stage

Pin no.	Signal name	Pin description
5	ARD_ADC_4	V_PTAT_OUT: V_PTAT signal
6	ARD_ADC_5	DIV_OUT: Divider output signal

Table 12 External headers (P6) – pin description

Pin no.	Signal name	Pin description
1	V_PTAT_S&H_EN	Control signal for V_PTAT S&H switch (U9)
2	BB1_EN	Control signal for turning first baseband stage on/off
3	V_DAC_1	Control signal for V_DAC

Notes:

1. *Pins 5, 6 of header P2 are not connected to any signal.*
2. *Pins 1, 3, 8 of header P3 are not connected to any signal.*
3. *Pins 1, 4, 6, 7, 8 of header P4 are not connected to any signal.*
4. *Pin 6 of header P5 is not connected to any signal.*

The pin headers enhance the functionality of the module significantly. They enable probing the analog outputs of the sensor module and also probing various other signals provided to the MMIC. In principle, the accessibility of several pins on the radar MMIC and the IF signals available via the external pin headers enable interfacing the module with an external signal processor.

6 Measurement results

6.1 Human range detection and tracking

The system is designed for use cases such as presence detection, motion detection, proximity sensing and direction of movement detection for a single human target in 1D. It enables detection and tracking of a human walking within a linear distance of over 20 m in an indoor or outdoor environment. The detection range decreases if the human is walking at an angle with respect to radar. Figure 13 shows the detection range for a human target with respect to the detection area.

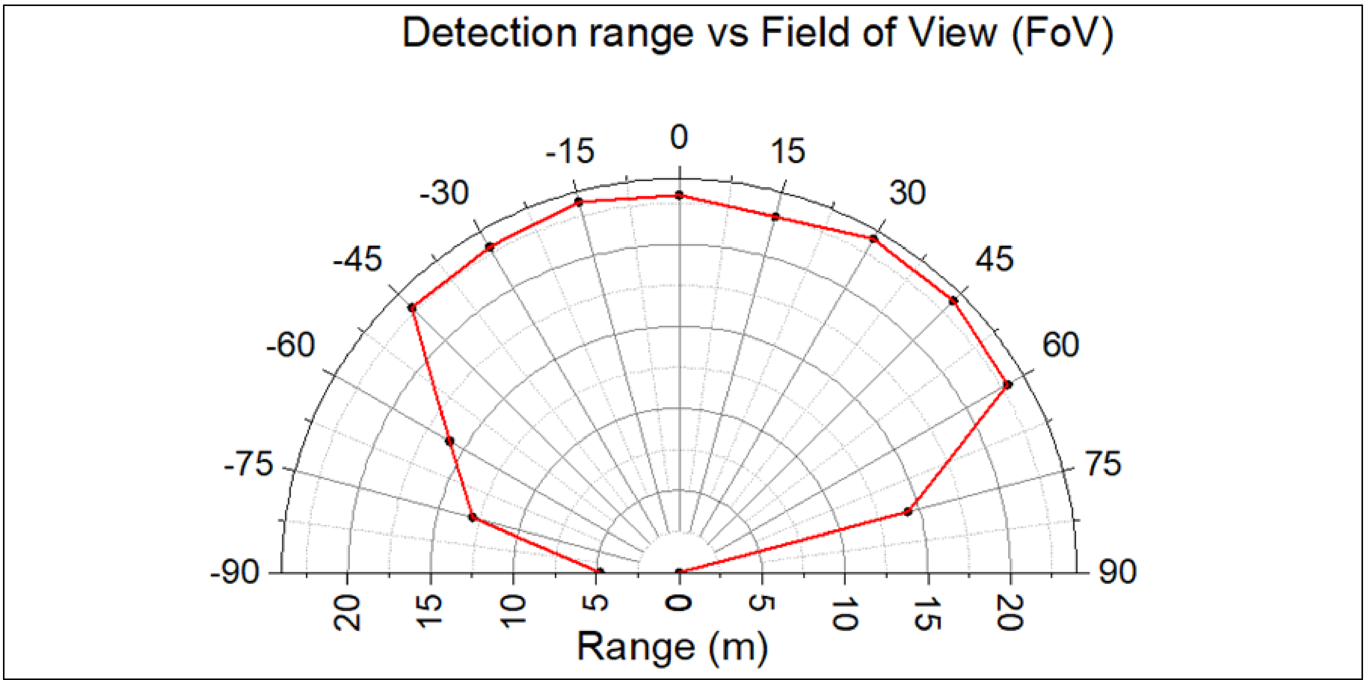

Figure 13 Human target detection range with respect to detection area

6.2 Temperature check for out-of-band emissions

The Distance2GoL demo board is also evaluated inside a temperature chamber for the bandwidth and out of band emissions at the temperature limits of -40°, 25° and 85°C. Markers 1 and 2 are set to 24.000 GHz and 24.250 GHz (ISM band) on the spectrum analyzer. As seen in Figure 14, Figure 15 and Figure 16, the frequencies are always inside the ISM band.

Figure 14 Bandwidth check at +25° inside temperature chamber

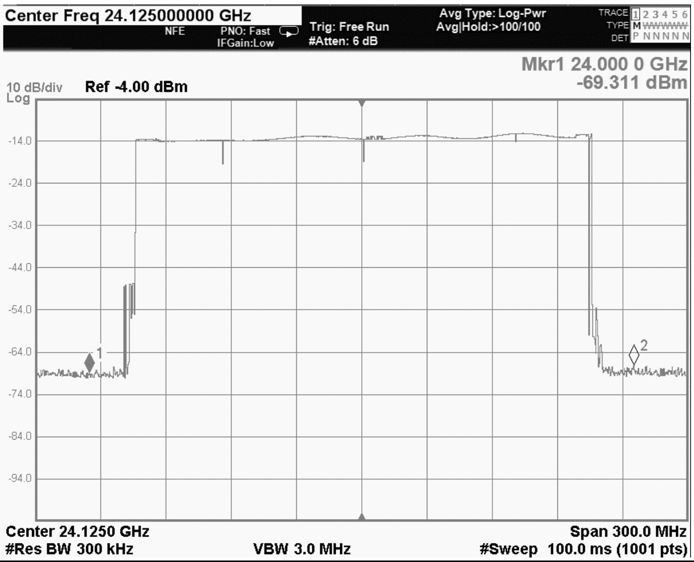

Figure 15 Bandwidth check at +85° inside temperature chamber

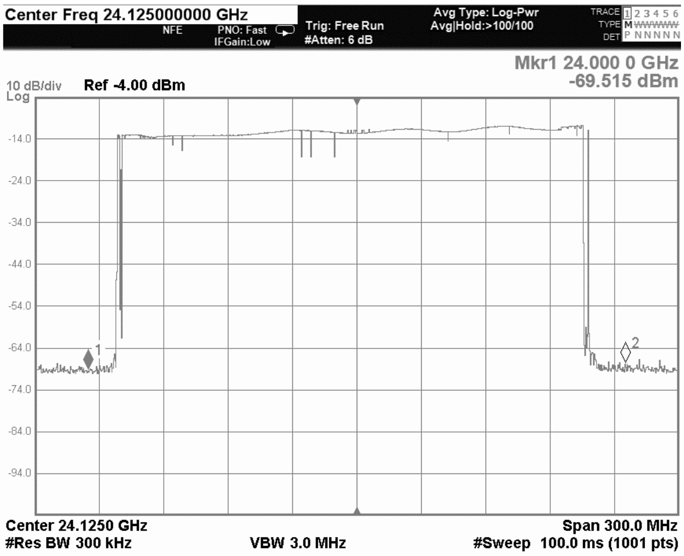

Figure 16 **Bandwidth check at -40° inside temperature chamber**

7 Frequency band and regulations

7.1 24 GHz regulations

Infineon's BGT24LTR11 radar sensor operates in the globally available 24 GHz bands. There is an ISM band from 24 to 24.25 GHz. However, each country may have different regulations in terms of occupied bandwidth, maximum allowed radiated power, conducted power, spurious emissions, etc. Therefore, it is highly recommended checking the local regulations before designing an end product.

7.2 Regulations in Europe

In Europe, the European Telecommunications Standards Institute (ETSI) defines the regulations. For more details on the ETSI standards, please refer to the document EN 300 440 V2.2.1. Please note that some countries do not follow harmonized European standards. Thus, it is recommended to check national regulations for operation within specific regions and monitor regulatory changes.

7.3 Regulations in the United States of America

In the USA, the Federal Communications Commission (FCC) defines standards and regulations. The ISM band covers 24 to 24.25 GHz, and one can operate field disturbance sensors anywhere within this band within allowed power limits for certain applications. For details, please refer to FCC section number 15.245 or 15.249.

8 References

[1] Infineon Technologies AG. BGT24LTR11N16 MMIC Datasheet

[2] Infineon Technologies AG. XMC4700 32-bit Arm® Cortex®-M4 microcontroller Datasheet

[3] Infineon Technologies AG. BGT24LTR11N16 Product brief

[4] Infineon Technologies AG. AN472: User's guide to BGT24LTR11N16

[5] Infineon Technologies AG. AN602: Radar Baseboard MCU4

[6] ETSI regulations – EN 300 440 V2.2.1

[7] FCC regulations – 15.245, 15.249

Revision history

Document revision	Date	Description of changes
1.00	2021-03-31	Initial version
1.10	2023-02-14	Miscellaneous document cleanup updates

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