24 GHz transceiver - BGT24MTR12

Position2Go – XENSIV™ 24 GHz radar demo kit with BGT24MTR12 and XMC4700 32-bit ARM® Cortex™-M4 MCU for ranging, movement and target position estimation

Board version V1.2

About this document

Scope and purpose

This application note describes the key features of Infineon's Position2Go module equipped with the 24 GHz transceiver chip BGT24MTR12 and the 32-bit ARM® Cortex™-M4 based XMC4700 microcontroller and helps the user to quickly get started with the demo board.

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

Intended audience

This document serves as a primer for users who want to get started with hardware design for target position estimation using the Frequency Modulated Continuous Wave (FMCW) radar technique at 24 GHz.

Related documents

Additional information can be found in the supplementary documentation provided with the Position2Go Kit in the Infineon Toolbox or from **www.infineon.com/24GHz**:

- 24 GHz Radar Tools and Development Environment User Manual
- P2G Software User Manual

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1 Introduction

The Position2Go Kit is a demonstration platform for Infineon's silicon-germanium (SiGe) based 24 GHz BGT24MTR12 radar chipset. The board is capable of measuring distance, speed, direction of movement and Angle of Arrival (AoA). These features of the board make it suitable for various applications such as tracking humans, presence detection, collision avoidance, etc.

The Position2Go board consists of the following key components:

- BGT24MTR12 – highly integrated 24 GHz transceiver IC with one transmitter (TX) and two receivers (RX)
- XMC4700 – 32-bit ARM® Cortex™-M4 based microcontroller for signal processing
- IRLHS2242 – 20 V single P-channel HEXFET power MOSFET for duty-cycle operation
- XMC4200 onboard debugger – licensed firmware for Serial Wire Debug (SWD) and UART to USB communication

The main radar technique used on the board is FMCW. In this technique, the time delay between the transmitted and received chirp is used for measuring distance to the target(s). The transmitted and received signals are mixed and then quantized for further processing. Multiple chirps (up to 16) are processed in order to create a 2D range-Doppler map to estimate the distance and the velocity of the target(s). Since the MMIC has two receivers, a phase monopulse comparison technique is used to determine the AoA.

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

This application note describes the key features and hardware configuration of the Position2Go module in detail.

1.1 Key features

The primary features of the Position2Go board are:

- Detect and track position of multiple targets in outdoor environments
- Measure distance of multiple targets in a user-configurable range (1 to 50 m)
- Detect motion, presence, speed and direction of movement (approaching or retreating) for human targets
- Small form factor: 5 x 4.5 cm
- Operational in different weather conditions such as rain, fog, etc.
- Can be hidden in the end application as it detects through non-metallic materials
- Dual analog amplifier stages for each RX channel with user-configurable gain settings
- Micro-strip patch antennas with 12 dBi gain and 19 x 76 degrees Field of View (FoV)
- Onboard PMOS switch for duty-cycle operation and low power consumption

Note: The platform serves as a demonstrator platform with the software to perform simple motion sensing, ranging and tracking. 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 they may impose and components they may use.

2 Getting started

This section provides a step-by-step quick process to get started with the Position2Go board. Some of the steps are optional for going deeper into the analysis of the board, the firmware and the extracted signals.

STEP 1

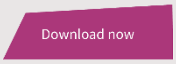
Box contents

- Programmed Position2Go board
- Micro-USB cable
- Foldable corner reflector

STEP 2

Infineon Toolbox

- Go to: www.infineon.com/Toolbox
- Click on "**Download now**" button.



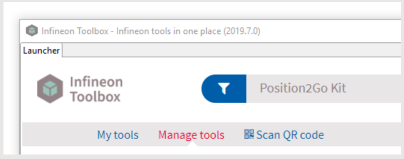
- Run "infineon-toolbox-launcher-web-installer-win-x86-latest.exe" file.

- "**Accept**" the license agreement.
- Finish installation. Create a desktop shortcut.

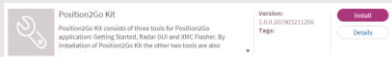
STEP 3

Install Position2Go Kit

- Open "**Infineon Toolbox**".
- Click on "**Manage tools**" tab.
- Search for "**Position2Go Kit**".



- Click on "**Install**".



- "**Accept**" the license agreement.
- Finish installation.

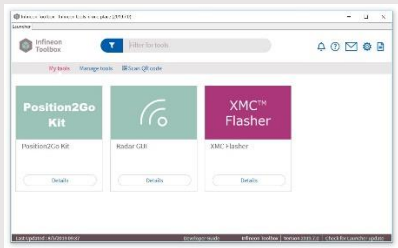
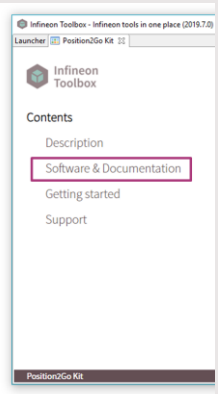


Figure 1 Steps 1 to 3 to get started with Position2Go demo board

STEP 4 Optional

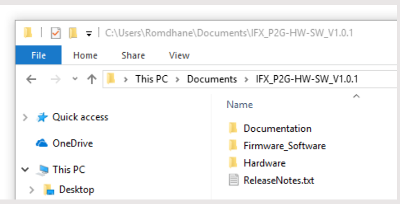
Download SW/HW package

- Open "**Infineon Toolbox**".
- Click on "**Position2Go Kit**".
- Download the package from "**Software & Documentation**" left tab.
- Save the set-up file and run it.



P2G-HW-SW.exe

- Browse to preferred location to store the files.



STEP 5

Connect board

- Insert micro USB cable into Position2Go (main board).

- Insert the USB connector into PC USB port.

✪ ***If the device driver is not recognized***:
Right click on "My Computer" ▶ Manage ▶ Device Manager ▶ Other devices ▶ Right click on "Unknown device" ▶ Update Driver Software ▶ Browse ▶ Firmware_Software ▶ XMC_Serial_Driver.

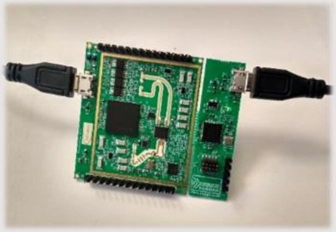
STEP 6 Optional

Firmware (FW) update

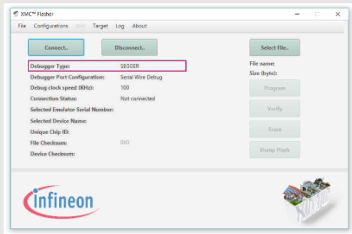
- Download and install SEGGER J-Link USB drivers for Windows:

  www.segger.com/downloads/jlink/#J-LinkSoftwareAndDocumentationPack

- Connect USB cables on both sides (main board and debugger).



- Open **Infineon Toolbox** ▶ **XMC Flasher**.



- Check that debugger type is "**SEGGER**", otherwise go to: "**Configurations**" ▶ "**Setup**", then set it to "**SEGGER**".
- Click on "**Connect**" ▶ **XMC4700-2048**.
- Click on "**Select file**" ▶ Browse to **Firmware_Software** ▶ **Binary** ▶ **.hex** file ▶ **Program**.

Figure 2 Steps 4 to 6 to get started with Position2Go demo board

STEP 7 Optional

View and edit source code

- Download and install DAVE™ IDE tool:

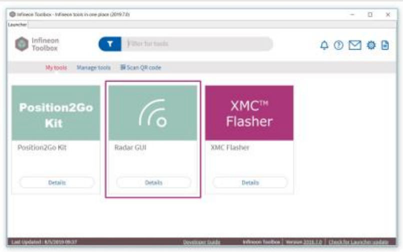
  https://infineoncommunity.com/dave-download_ID645

- Go to **Firmware_Software ▶ DAVE project**.
- Run DAVE™ IDE.
- Import DAVE™ projects and debug.

STEP 8

Radar GUI

- Connect board as **STEP 5**.
- Open **Infineon Toolbox ▶ Radar GUI**.



- Real-time data is now visible on your screen.

STEP 9 Optional

MATLAB interface

- Go to: **Firmware_Software ▶ Communication Library ▶ ComLib_Matlab_Interface ▶ RadarSystemExamples ▶ GettingStarted**. Copy the path.
- Open MATLAB. Paste the path in the top tab. "**extract_raw_data.m**" file will show up on the left tab.
- Connect board as **STEP 5**.
- Click on "**Run**" to see raw data.

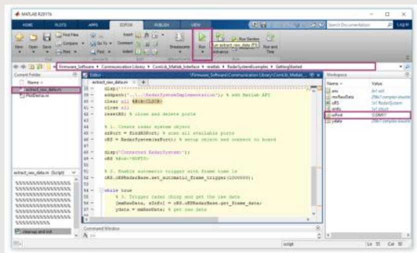


Figure 3 Steps 7 to 9 to get started with Position2Go demo board

2.1 Additional material

The board comes with additional documentation for customer support. These documents can be found in the folders downloaded through Step 4 in Figure 2. They are:

- Altium project
- DAVE™ project and binary files
- Software user manual
- ComLib documentation
- Schematics
- Bill of Materials (BOM)
- Production data

3 System specifications

Table 1 gives the specifications of the Position2Go module.

Table 1 Position2Go module performance specifications

Parameter	Unit	Min.	Typ.	Max.	Comments
System performance					
Minimum speed	km/h		0.7		Based on the formula: Min speed (m/s) = $\lambda/(2 \times N_{FFT,D} \times PRT)$ in P2G_FMCW firmware λ = wavelength (m) $N_{FFT,D}$ = DOPPLER_FFT_SIZE PRT = Pulse Repetition Time
Maximum speed	km/h		22.4		Based on the formula: Max speed (m/s) = $\lambda/(4 \times \mathrm{PRT})$ in P2G_FMCW firmware λ = wavelength (m) PRT = Pulse Repetition Time
Minimum distance	cm		60		Radar Cross-Section (RCS) = 1 m^2
Maximum distance	m		15		RCS = 1 m^2 (based on 100 LSB range detection threshold)
Range accuracy (for values beyond 60 cm)	cm		±20		RCS = 1 m^2
Range resolution	cm		90		With Blackman window (BW 200 MHz, 300 µs ramp up, 64 samples/chirp, 256 FFT size)
Angle accuracy	Degrees		≤ 5		FoV +/-30 degrees RCS = 1 m^2 at 3 m range
	Degrees		≤ 10		FoV +/-65 degrees RCS = 1 m^2 at 3 m range
Power supply					
Supply voltage	V	3.3	5	5.5	
Supply current	mA		420		All blocks on (no duty-cycle)
Transmitter characteristics					
Transmitter frequency	GHz	24.0		24.25	
Effective Isotropic Radiated Power (EIRP)	dBm		18		EIRP controllable via SPI for ISM operation
System phase noise with PLL	dBc/Hz		-89		At 100 kHz offset, VCOARSE = VFINE. Measured in CW mode
External oscillator frequency	MHz		40		

Table 1 Position2Go module performance specifications

Parameter	Unit	Min.	Typ.	Max.	Comments
Receiver characteristics					
Receiver frequency	GHz	24.0		24.25	
IF conversion gain (Stage 1)	dB		23.5		
-3dB bandwidth (Stage 1)	kHz		14 to 140		Can be selected by reconfiguring the ADC pins in DAVE™ project
IF conversion gain (Stage 1 + Stage 2)	dB	23.5	47.5	65.5	Configurable by PGA SPI settings of Stage 2
-3dB bandwidth (Stage 1 + Stage 2)	kHz		13 to 105		Default setting of the sensor module when delivered
Antenna characteristics (measured)					
Antenna type (TX/RX)			1 x 6		
Horizontal – 3dB beamwidth	Degrees		76		
Elevation – 3dB beamwidth	Degrees		19		
Horizontal sidelobe level suppression	dB		20		
Vertical sidelobe level suppression	dB		20		

Note: The above specifications are indicative values based on typical datasheet parameters of BGT24MTR12 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.

4 Hardware description

4.1 Overview

The Position2Go module contains a radar main board and a breakable debugger board as shown in Figure 4. The radar main board contains four important sections:

- RF part – consists of the Infineon 24 GHz radar MMIC – BGT24MTR12 and the tapered micro-strip patch antennas for the TX and RX sections;
- Analog amplifier part – provides the interface between the RF and digital parts of the board. It has programmable gain amplifiers (PGAs), which can be programmed over the SPI to provide variable gains for different use cases;
- Frequency control part – contains a low-noise fractional-N PLL;
- Digital part – consists of a XMC4700, 32-bit ARM® Cortex™-M4 microcontroller from Infineon to sample and process the analog data from the radar front end and also to configure the BGT24MTR12, PLL and PGAs via an SPI.

The board demonstrates the features of the BGT24MTR12 RF front-end chip and gives the user a complete "plug and play" radar solution. It 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™.

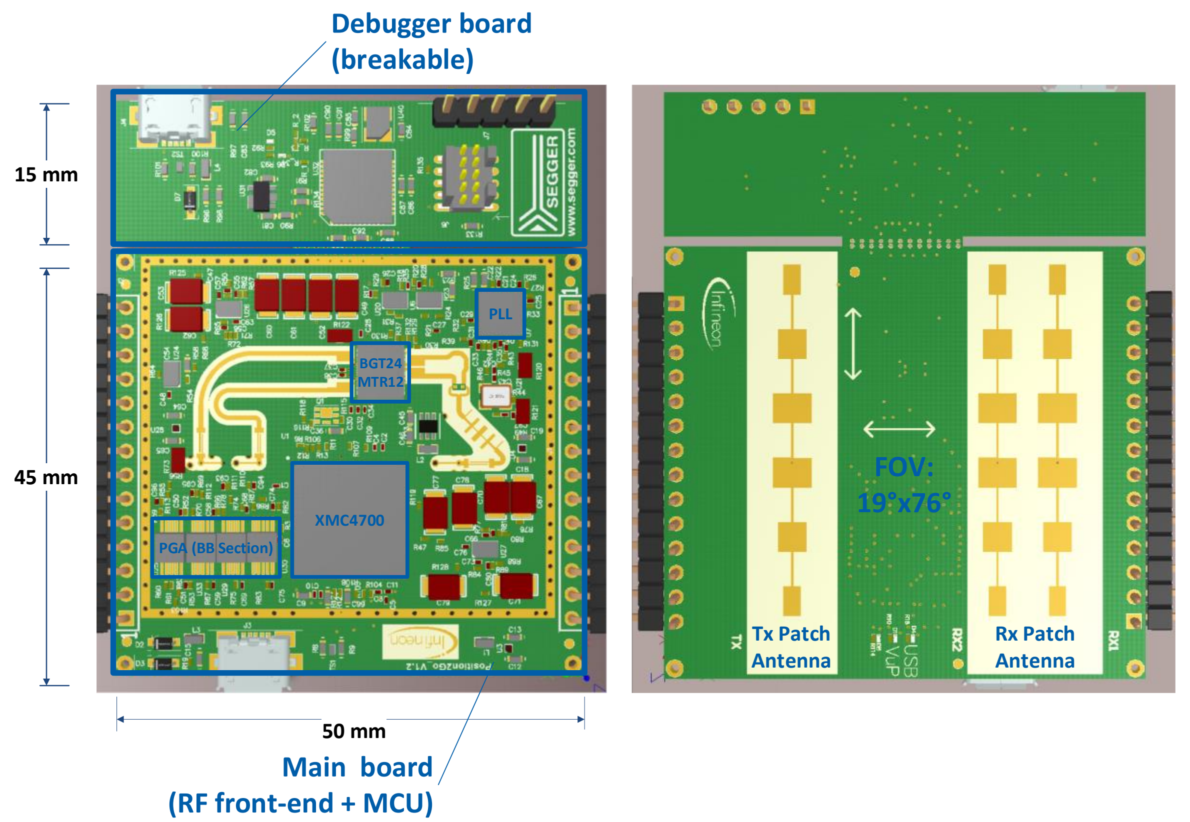


Figure 4 Position2Go board with main components and dimensions

4.2 Hardware features

The Position2Go demo board has the following features:

- BGT24MTR12 24 GHz RF front-end chip with 1 TX and 2 RX with the following specification:
    - Low Noise Figure (NF_{SSB}): 12 dB
    - High conversion gain: 26 dB
    - High 1 dB input compression point: -12 dBm
    - Switchable prescaler with 1.5 GHz and 23 kHz output
    - On-chip power and temperature sensors
- XMC4700 Cortex-M4 microcontroller for sampling and signal processing of the analog signals with the following features:
    - 144 MHz CPU frequency, 2048 kB Flash and 352 kB RAM size
    - Four Capture and Compare Units (CCU4) for use as general-purpose timers
    - Four 12-bit ADCs, 26 channels each with input out-of-range comparators, and a 12-bit DAC with two channels
    - USB 2.0 device, with integrated PHY, Controller Area Network interface (MultiCAN), Full-CAN/Basic-CAN with six nodes, 256 message objects (MOs), data rate up to 1 MBaud
    - Six Universal Serial Interface Channels (USICs), providing six serial channels, usable as UART, double-SPI, quad-SPI, I^2C, I^2S and LIN interfaces
- Onboard breakable debugger with UART communication
- Onboard low-noise fractional-N PLL with chirp generation
- Dual analog amplifier stage for each RX channel with programmable gain settings
- Micro-strip patch antennas with 12 dBi gain(simulated) and 19 x 76 degrees FoV
- Onboard PMOS switch for duty-cycle operation of BGT24MTR12
- Power supply:
    - Via micro-USB connector
    - Via external power supply (5 V maximum)

4.3 Block diagram

Figure 5 shows the block diagram of the demo board. The board is split into a main RF unit and a breakable debugger unit for programming. The RF unit consists of the highly integrated 24 GHz transceiver IC BGT24MTR12 with 1 TX and 2 RX. The MMIC features an integrated Voltage Controlled Oscillator (VCO), Power Amplifier (PA), integrated temperature and power sensors, prescalers and IQ receivers.

The board also has integrated micro-strip patch antennas, and a Wilkinson combiner is used to combine the differential transmitter output power from the radar IC before feeding it to the antennas. Each receiver channel is connected to a dual analog amplifier stage at its IF outputs. A 32-bit ARM® Cortex™-M4 XMC4700 microcontroller is used to sample and process the analog down-converted signals from the baseband amplifiers using the integrated 12-bit ADC, and also control the radar chip via the SPI interface. The output power of the radar chip and the gain of its receive section can be controlled via the SPI settings. There are also SPI commands to read out the different sensor outputs.

A low-noise fractional-N Phase Locked Loop (PLL) IC is used to perform the frequency control and ramp generation. The output of the /16 prescaler on the radar IC is connected to the PLL's RF input pins and the output voltage from the PLL's charge pump is connected via a loop filter to the tuning ports of the BGT24MTR12, thereby forming a closed-loop system. This procedure is used to lock the transmitted signal of the module to an output frequency inside the ISM band. The /65536 prescaler produces a low-frequency output signal (23 kHz), which is connected to a CCU4 of the XMC4700 for monitoring purposes.

The module is powered over the micro-USB plug, and several low-noise voltage regulators are used to provide a regulated power supply to the different building blocks .The BGT24MTR12 MMIC is supplied over a PMOS switch, which enables operation of the sensor in a duty-cycle mode. The Position2Go features a breakable onboard debugger, which comes preloaded with licensed firmware for debugging and communicating with the main radar MCU via the UART pins. Pin headers on the PCB enable the sensor module to interface with an external processor.

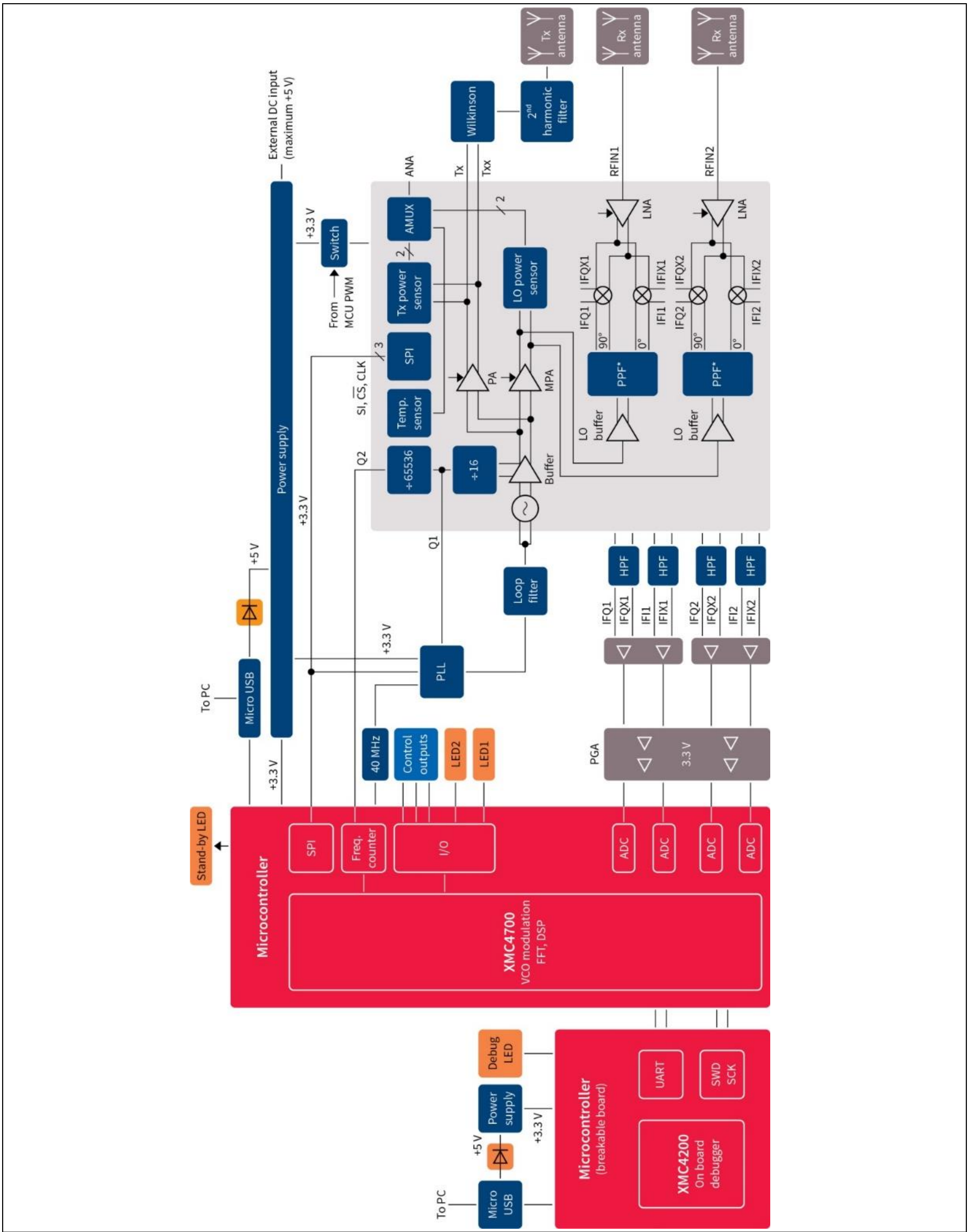


Figure 5 **Block diagram – Position2Go demo board**

4.4 Power supply

Figure 6 shows the power supply concept used on the module. The board is powered via micro-USB connector when used with a PC. The power supply is via an external DC input pin (5 V maximum). The USB plugs on the main board as well as the breakable debugger board can be used to supply the module.

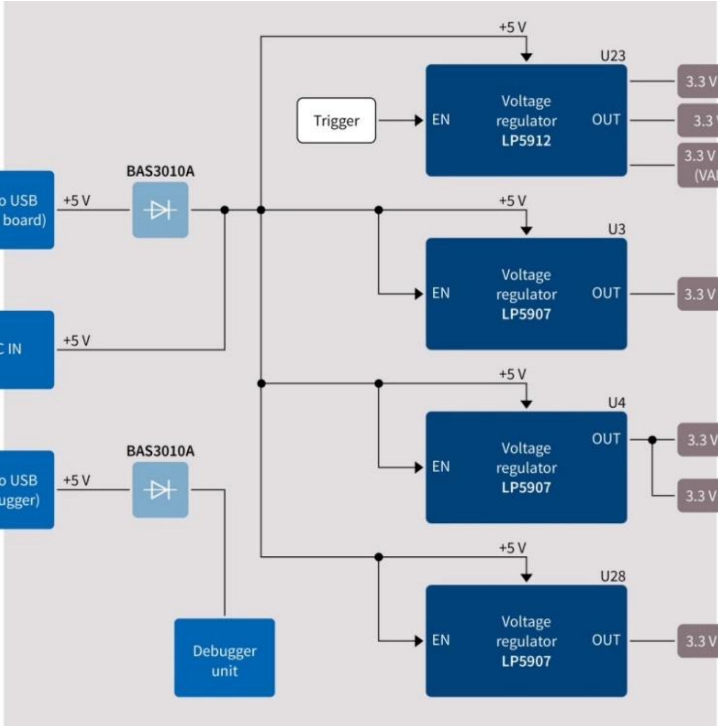


Figure 6 Block diagram – power supply concept

The power supply via the USB or external input is provided to four different voltage regulators. The 24 GHz transceiver IC is powered by a low-noise voltage regulator U23. U23 has an enable pin that must be triggered via the pin P1.4 of the MCU to enable the LDO. Regulator U20 is also used to supply the analog domain of the XMC4700 MCU and the first baseband IF amplifier stage. A second low-noise voltage regulator U3 is used to supply the digital MCU of the board. U4 is used to power up the PLL and the 40 MHz reference oscillator. The enable pins of U3 and U4 are hardwired to their input voltage pins on the PCB and are not available to the user. Additionally, another low-noise regulator U28 is used to supply the PGA.

4.5 RF front end

Figure 7 shows the top view of the RF front end. The RF front end can be shielded with a cover and absorber material to get the best RF performance. The following paragraph describes the various sections of the RF front end in detail.

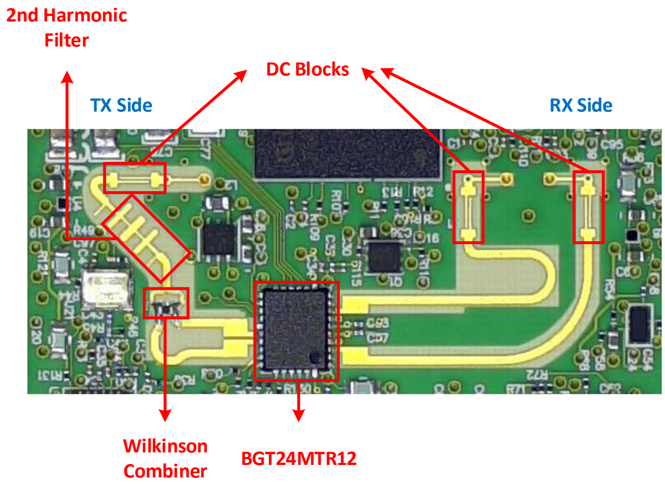


Figure 7 RF front end overview (top)

4.5.1 Board stack-up

It is necessary to use a defined board layer stack-up for proper functioning of the RF part. All the micro-strip RF parts must be calculated according to the stack-up used. The cross-sectional view of the PCB is shown in Figure 8. The module uses six-layer stack-up with a symmetrical RO-4350B core. The matching structures for the transmitter and receiver parts are designed based on this stack-up.

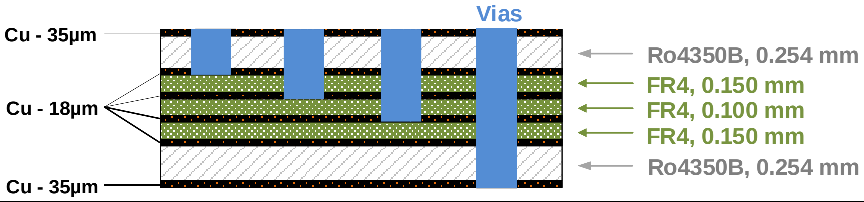


Figure 8 PCB cross-section

The most important part for the RF micro-strip components is the top and bottom RO-4350B, 0.254 mm-thick core. On the top layer (layer 1) are the micro-strip structures, and layer 2 is the RF ground for the micro-strip components used on the top layer. Layer 3 and layer 4 are used for routing various signals. On the bottom layer (layer 6) are the micro-strip patch antennas and layer 5 is the RF ground for the micro-strip patch antennas. The substrate thickness for the other layers have been chosen taking into account the blind-via diameters used on the PCB, and this can vary depending on the PCB manufacturing technology (aspect ratio). From simulations it was observed that such variation of the thickness of these FR4 substrates has a very low impact on the RF performance.

4.5.2 BGT24MTR12 – 24 GHz transceiver MMIC

The heart of the sensor module is the highly integrated BGT24MTR12 24 GHz transceiver IC. Figure 9 shows the detailed block diagram of the MMIC.

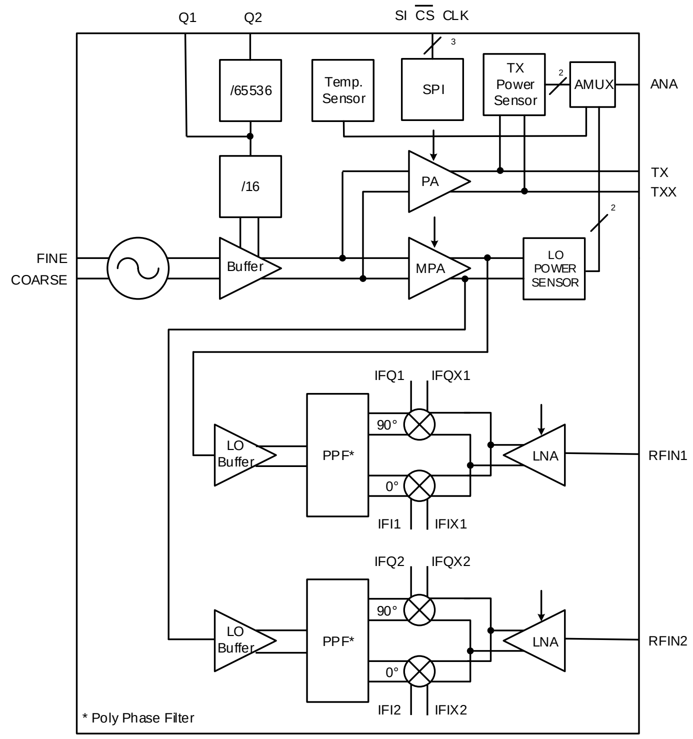


Figure 9 Block diagram – BGT24MTR12

The MMIC features a very high level of integration, which includes a VCO with prescaler outputs for frequency control, transmitter chain including amplifiers for both TX and LO outputs, and dual receiver section with Low-Noise Amplifiers (LNAs) and mixers. The dual receive channels help to determine the AoA of the signal from the radar target.

The VCO is a free-running, fundamental oscillator. It can be controlled by two tuning inputs – one for coarse preadjustment, and one for fine-tuning. There are two prescalers available in the VCO section of the chip. The first prescaler has an output frequency of 1.5 GHz and can be used to feed an RF-PLL for frequency control. The second prescaler has a 23 kHz square-wave output that may be used by a microcontroller-based software loop.

The TX section consists of a power amplifier with a differential output. Its typical output power is +11 dBm and can be reduced in eight steps down to 2 dBm. A part of the TX signal is used as the LO signal for the on-chip mixers. The receiver sections have a single-sideband NF of 12 dB and a voltage conversion gain of 26 dB. The gain of the LNA can be reduced by a typical gain-step of 5 dB. The built-in quadrature down-conversion mixers translate the RF signal directly to zero-IF.

Additionally, the chip features power sensors on both TX outputs and LO outputs, as well as a temperature sensor that supports the implementation of a software-based loop to control the VCO. The settings of the different internal building blocks can be controlled via an SPI.

4.5.3 Module transmitter section

The transmitter output of BGT24MTR12 is differential. The differential outputs are first connected over matching structures followed by a Wilkinson power combiner. The matching structures compensate for the bondwire inductance and other parasitic effects due to the VQFN package. Figure 10 shows the schematic of the transmitter section and the dimensions of the matching structures used at the TX outputs. The Wilkinson power combiner combines the differential signals into single-ended ones. Following the power combiner a second harmonic micro-strip filter is used. The harmonic filter provides an attenuation greater than 20 dB for frequencies around 48 GHz and shows a simulated loss of approximately 0.5 dB. The filter path then goes over a DC block and a feed-through via to the other side of the PCB to the antennas. The simulated loss for the entire RF section connecting the TX output from the MMIC to the antennas on the other side of the board including the vias was approximately 2 dB. There are DC shorts before the feed-through vias for enhanced ESD protection.

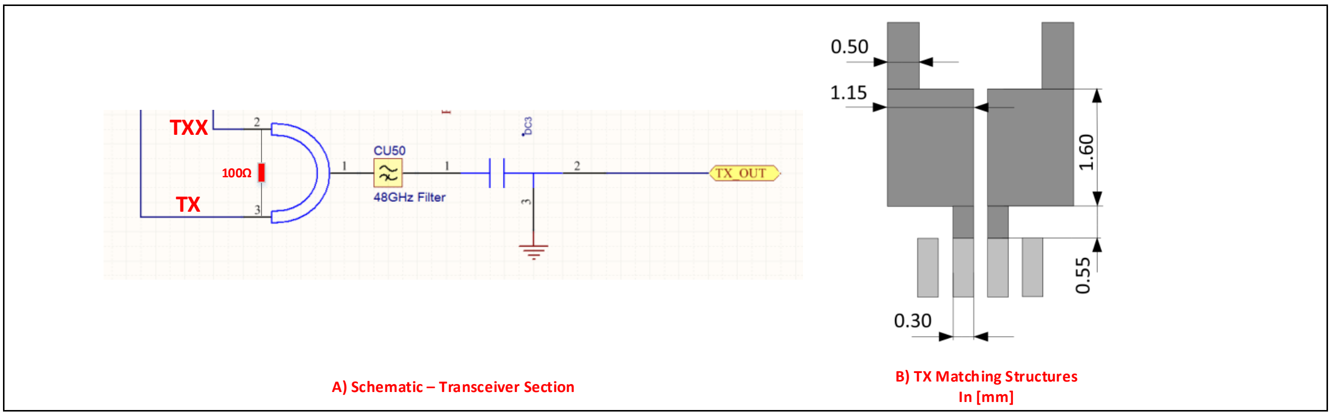


Figure 10 Transmitter section schematic and matching structure dimensions

4.5.4 Module receiver section

The receiver input of the BGT24MTR12 is single-ended. The RX input is connected over a matching structure, a DC block and a feed-through via to the antennas on the other side of the board. Figure 11 shows the schematic of the receiver section and the dimensions of the matching structures used at the RX input. The simulated loss for the entire RF section connecting the RX input at the MMIC to the antennas on the other side of the board including the vias was approximately 1 dB. There are DC shorts before the feed-through vias for enhanced ESD protection.

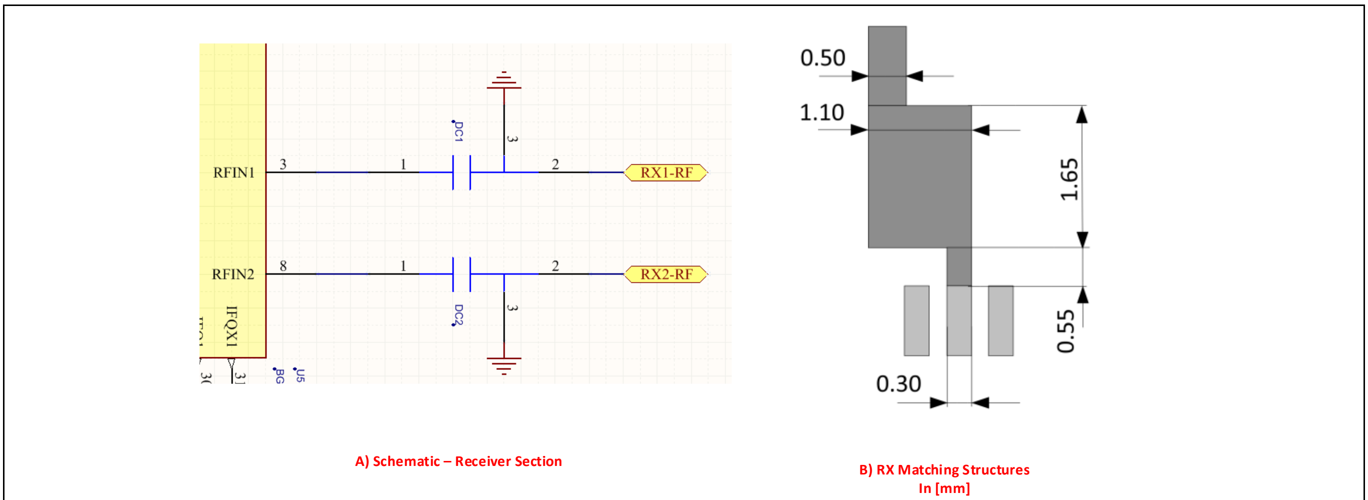


Figure 11 Receiver section schematic and matching structure dimensions

4.5.5 Antennas

Position2Go features a 6 x 1 series-fed tapered array antenna for the transceiver and receiver sections. The antenna has a measured gain of 12 dBi (simulated) and an opening angle of 19 x 76 degrees. Figure 12 shows the measured 2D radiation pattern.

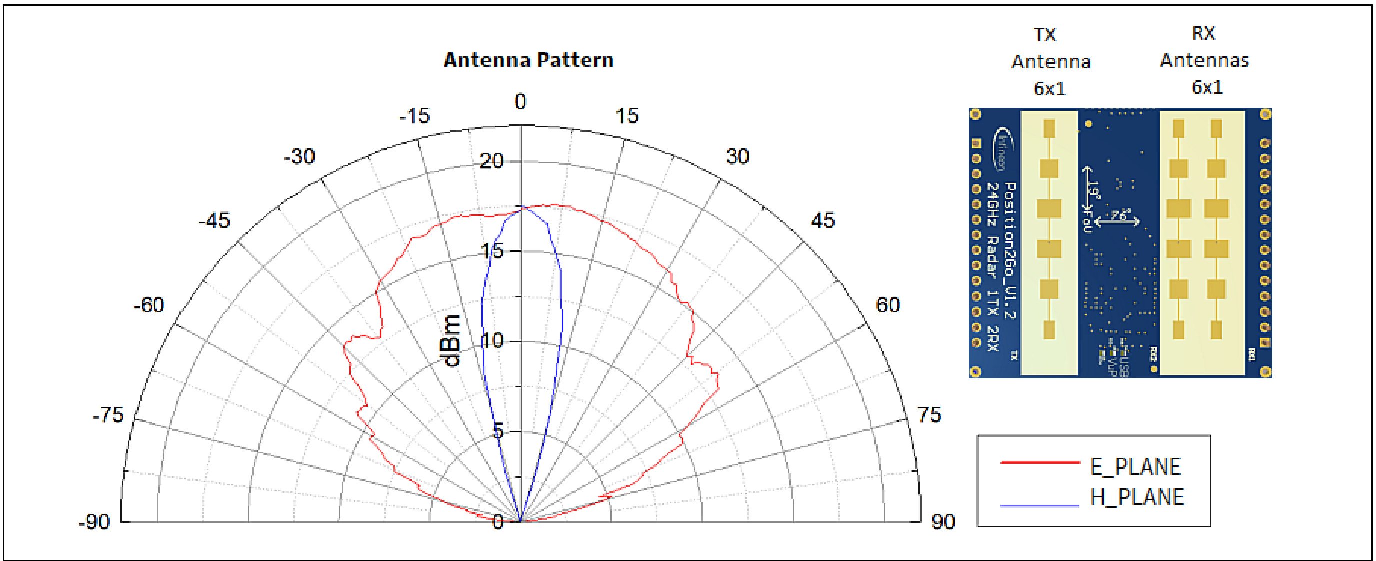


Figure 12 2D radiation pattern for array antennas

It must be noted that the values of 19 x 76 degrees are for 3 dB Half Power Beamwidth (HPBW). This implies that the gain of the antenna beyond these angles is 3 dB lower than the maximum gain at 0 degrees. In practical cases, a target with large RCS can still be detected for this reduced gain. In addition, weaker targets (i.e., low RCS) in close proximity to the radar can also be detected outside the opening angles. Therefore, a careful judgement has to be made regarding the radar detection zone by taking into account both distance of target from radar and also the target RCS.

4.6 Prescaler output and PLL section

BGT24MTR12 has two prescaler outputs: Q1 and Q2. Q1 represents the VCO output divided by a factor of 2^4. Q2 represents the VCO output divided by a factor of 2^{20}. As shown in Figure 13, the Q1 output is connected to the RF input terminal of a low-noise fractional-N PLL LMX2491 with integrated ramp/chirp generation functionality. The prescaler output from the MMIC is DC-coupled via capacitor C27.

The VCO can be controlled by DC inputs on two different pins: VCOARSE (Pin 6) and VFINE (Pin 5) of the BGT24MTR12. The VCOARSE and VFINE pins are tied together and connected to the PLL's charge pump output voltage (CP_{out}) via a loop filter circuit. The loop filter has been optimized for an FMCW ramp of 300 µs. A 40 MHz reference oscillator is used as the clock source for the PLL. Table 2 lists the loop filter components with their values.

Schematics with more detailed information can be downloaded from the Infineon Toolbox (refer to Figure 2).

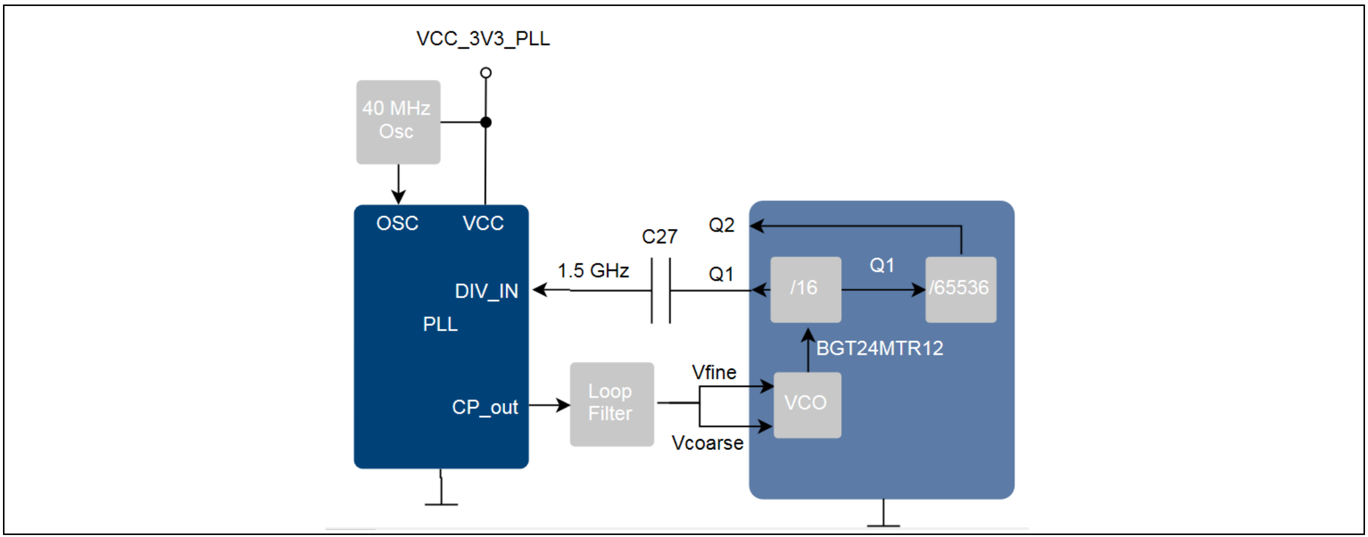


Figure 13 Block diagram for PLL control loop

Table 2 PLL loop filter components and values

Component	Value
C23	33 nF
C22	2.2 nF
C37, C38	150 pF
R23	820 kΩ
R25	120 Ω

The current firmware version provided with the module is optimized and tested with sawtooth ramps of 300 µs. In principle, use of other ramp types (e.g. triangular) and other ramp durations should also be possible. However this is not tested using the hardware/firmware configurations provided and may require reconsidering other system timing settings (e.g. duty-cycle, waiting times, etc.) and baseband section modification.

For the optimized PLL settings, refer to the DAVE™ project delivered with the Infineon Toolbox. Please refer to Step 4 in Figure 2 for further download information. Apart from the SPI pins, Table 3 lists the other PLL pins accessible on the module via the MCU for various configuration settings.

Table 3 PLL pin description

Pin number – PLL	Description	Functionality	MCU pin connection
Pin 12	MOD	Multiplexed input/output pins for ramp triggers, FSK/PSK modulation, FastLock, and diagnostics	P1.2
Pin 13	CE	Chip enable	P2.2
Pin 17	MUXOUT	Multiplexed input/output pins for ramp triggers, FSK/PSK modulation, FastLock, and diagnostics	P1.0
Pin 20	TRIG 1	Multiplexed input/output pins for ramp triggers, FSK/PSK modulation, FastLock, and diagnostics	P1.3
Pin 21	TRIG 2	Multiplexed input/output pins for ramp triggers, FSK/PSK modulation, FastLock, and diagnostics	P1.1

The Q2 prescaler output from the BGT24MTR12 is 23 kHz and this is fed into the CCU4 of the XMC4700 MCU. This can be used to keep the VCO inside the ISM band by controlling the tuning voltage pins via the MCU's DAC. This procedure would eliminate the need for hardware PLL but requires complex ramp generation, linearization

techniques and signal processing algorithms for proper target detection. The Position2Go board is designed to implement this functionality if one desires to do so. However, Infineon currently does not provide firmware, supporting such software-based ramp generation for distance measurements. When using the Q2 output, it is very important to keep the Q1 output terminated with a DC block to obtain a proper Q2 signal at the microcontroller timer input. It is recommended to keep the Q2 divider off during signal processing to prevent unwanted spurs and baseband noise.

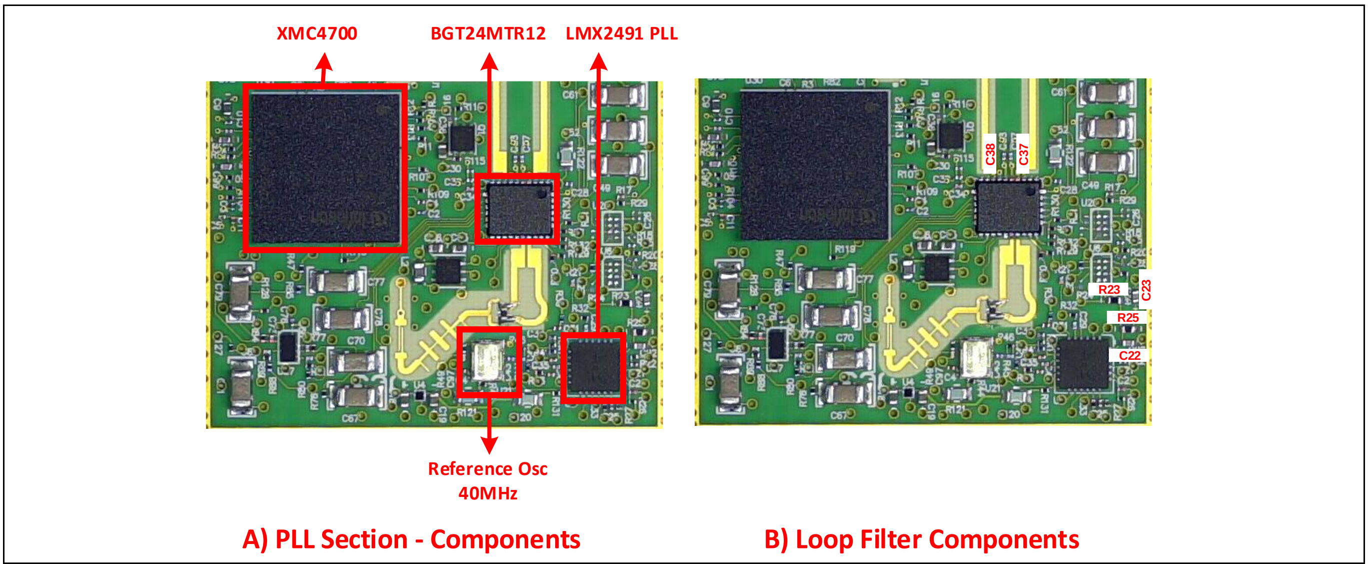


Figure 14 PLL section overview with loop filter components

4.7 Analog baseband section

The BGT24MTR12 provides both in-phase and quadrature-phase Intermediate Frequency (IF) signals from each of its receive channels. The in-phase and quadrature-phase signals are differential in nature, thus making available four different IF output signals from each receive channel (IFI, IFIx, IFQ and IFQx). Depending on the target in front of the radar antennas, the analog output signal from the BGT24MTR12 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 that come out of the RF front end with analog amplifiers.

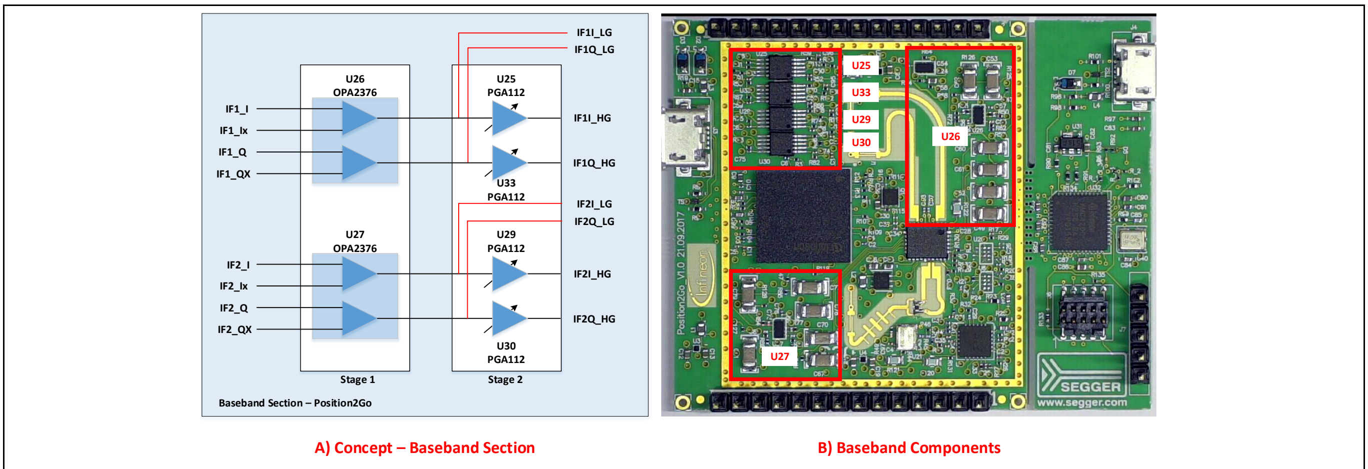


Figure 15 Baseband amplifier chain on PCB

The Position2Go module enables 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 the distance to be detected by simply configuring the MCU pin settings in the software. No hardware changes are needed for this process. Table 4 lists the MCU pins 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 4 Baseband amplifiers to MCU pin connections

XMC4700 – BGA196 – port pin	Pin function
P14.4	IF1I – high gain
P14.14	IF1Q – high gain
P15.3	IF2I – high gain
P15.8	IF2Q – high gain

4.7.1 Gain settings

The Position2Go module has a two-stage baseband amplification process. The first stage is designed with an operational amplifier with fixed gain and cut-off frequency settings. The second stage has PGAs to adjust the gains easily using SPI.

The baseband section of the Position2Go module is designed to have a bandpass characteristic. Due to limited isolation between the TX and RX of the radar system, there is a feed-through of the TX signal into the RX part. Consequently, there is always a dominant low-frequency component at the receiver output of the radar IC. The value of this low-frequency component depends on the value of the FMCW ramp settings. This low-frequency signal will be further amplified by the gain of the baseband section and may completely saturate the radar IF chain (ADCs and further amplifier stages). This effect is inherent to all FMCW radar systems and cannot be eliminated completely in the analog domain. The TX-to-RX cross-talk effect also limits the minimum distance that can be measured by the radar. However, by using appropriate filtering, the effect of this cross-talk can be minimized. This requires the implementation of filtering stages prior to the amplification of the IF signal by the baseband section.

Stage 1 is designed for a gain of 23.5 dB with a 3 dB bandwidth from 14 kHz to 140 kHz. The second IF amplifier stage consists of a programmable gain amplifier, and in combination with the first IF stage provides a total IF gain of maximum 65.5 dB with a 3 dB bandwidth from 13 kHz to 105 kHz.

Table 5 IF BB section gain settings

GUI setting	Binary gain	PGA gain (dB)	Total BB section gain (dB)
Max.	128	42	65.5
L6	64	36	59.5
L5	32	30	53.5
L4	16	24	47.5 (default setting)
L3	8	18	41.5
L2	4	12	35.5
L1	2	6	29.5
Min.	1	0	23.5

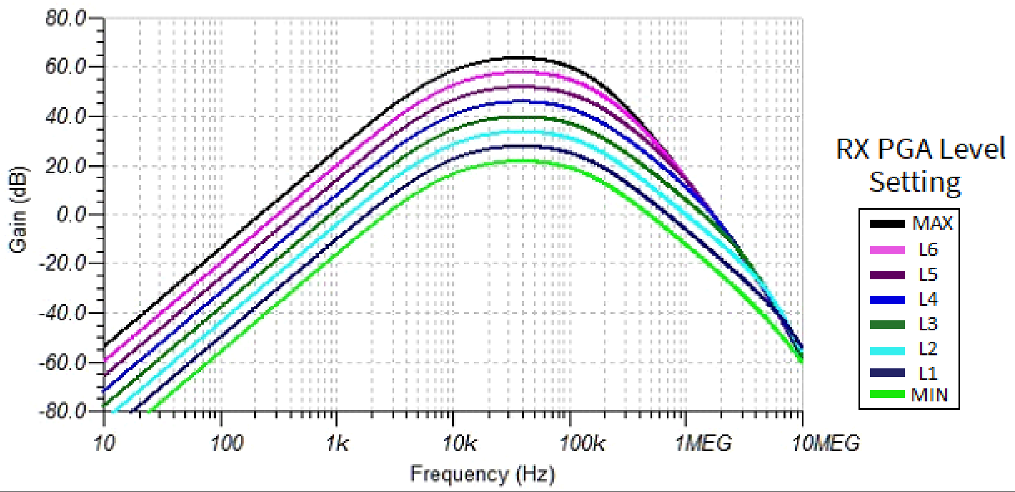


Figure 16 PGA gain plots for different settings

For short-range measurements (less than 10 m) it is sufficient to use only a single IF amplification stage. The PGAs can be removed for this range, thereby reducing the BOM cost. For long-range measurements (more than 10 m), and for targets with very low and varying RCS (e.g. human beings) the radar may not be able to provide a precise detection, depending on the environmental condition.

4.7.2 IF section and FMCW ramp setting

The bandpass characteristics of the IF section are also determined from the FMCW ramp parameter settings. Different ramp settings lead to different IF frequencies for targets at different distances. Table 6 gives an example of IF frequencies produced by stationary targets at particular distances corresponding to different sawtooth-type ramp parameters. These IF frequencies are also called as “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:

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

Where R = target distance in meter (m)

Δf = ramp bandwidth in Hertz (Hz)

T_r = ramp time in second (s)

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

Table 6 IF frequency vs. FMCW ramp parameters vs. target distance

Ramp duration (µs)	Ramp bandwidth (MHz)	Beat frequency (kHz)			
		Target at 0.5 m	Target at 5 m	Target at 10 m	Target at 25 m
300	180	2	20	40	100
300	200	2	22	44	111
400	180	2	15	30	75
400	200	2	17	33	83
500	180	1	12	24	60
500	200	1	13	27	67

4.8 Duty-cycle circuit for low-power operation (default mode)

The Position2Go module offers the possibility of operating the BGT24MTR12 and PLL in a duty-cycle mode. This is done by enabling/disabling the PMOS (Q1) over the pin P2.3 of the MCU, as shown in Figure 17. Toggling this pin enables switching the power supply on/off to the MMIC over the FET. The signal is low-active and has a pull-down resistor in place. The PLL is switched on/off using the CE pin. In its default state, the module is already programmed for the duty-cycle mode of operation.

To enable the operation of BGT24MTR12, the trigger pin of LDO U23 connected to the MCU port pin P4.3 must be configured first. This is already implemented in the default software. Care must be taken when changing anything on the firmware, and it must be ensured that the LDO U23 is enabled via the MCU pin P4.3.

It is recommended to use the module in a duty-cycle mode to keep the overall power consumption and thermal dissipation low. Position2Go was designed to have a compact form factor. Keeping the BGT24MTR12 always turned on will heat up the module significantly and could result in undefined behavior. In such cases it is recommended to turn off all the unused building blocks inside the BGT24 via the SPI, and for short distance measurements reduce the transmit output power to minimum. Also putting the microcontroller in a deep sleep mode when it is not in operation will help to minimize power consumption and thermal dissipation significantly. The current firmware does not include the settings to put the microcontroller in a power-optimized mode.

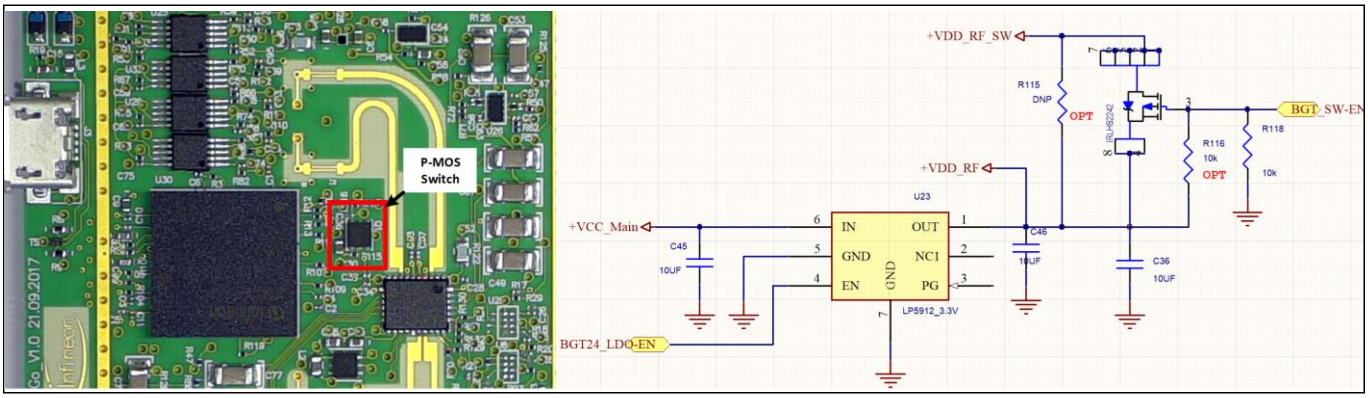


Figure 17 BGT24MTR12 duty-cycle concept

The module also offers a second possibility to turn off the BGT24MTR11 and the IF section by using the LDO trigger pins. The BGT24MTR12 and the baseband stage 1 consisting of U26 and U27 can be turned off by disabling the LDO U23. This will also turn off the reference voltage generator IC U24. The PGAs can be turned OFF by disabling the LDO U28 via pin P7.11 of the MCU. It must be noted that this mode requires detailed timing analysis for proper signal processing, due to slower start-up time of the LDO and baseband amplifiers when compared to the PMOS. The reduction in power consumption is minimal, since the baseband amplifiers consume very low power. The IF section is not duty-cycled in the default board configuration.

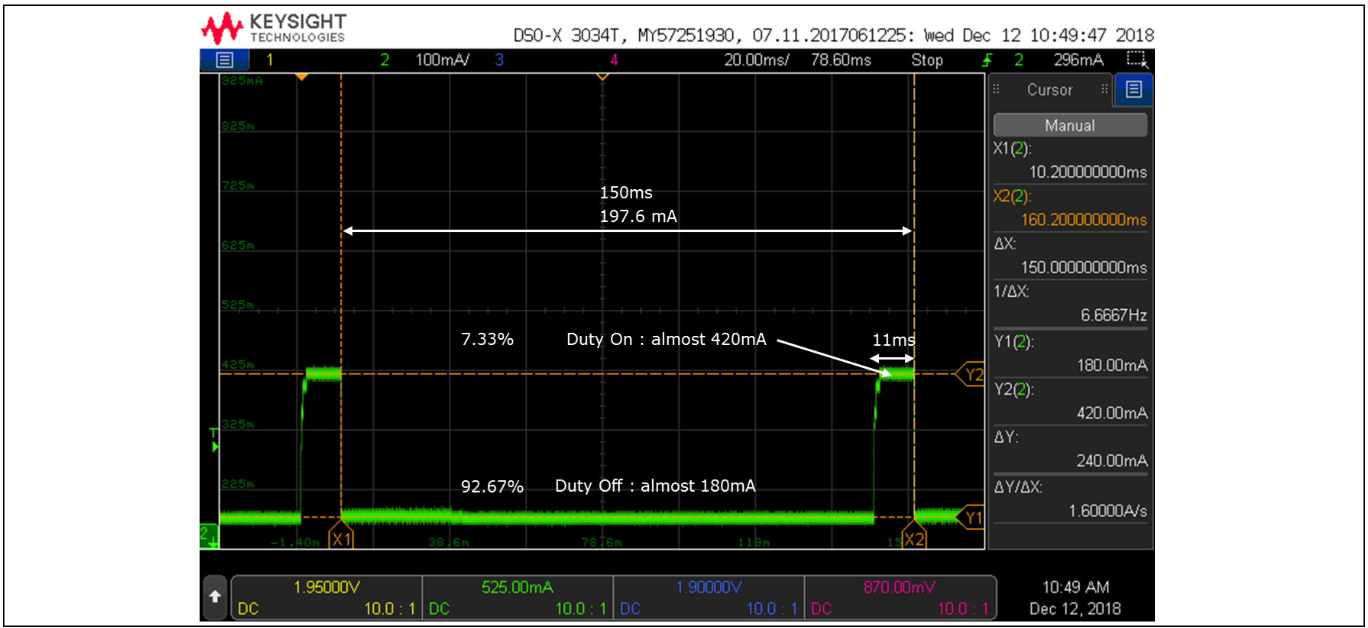


Figure 18 Duty-cycle vs. no duty-cycle current consumption

As shown in Figure 18, during duty-cycle on-time the demo board typically draws 420 mA, while during the duty-cycle off-time with deactivated BGT24MTR12 and PLL, only 180 mA. With the default configuration of 7.3 percent on-time the demo board has a typical average current consumption of 200 mA.

4.9 External pin header connectors

The Position2Go module has the provision to connect two 14-pin headers on the edges of the board as shown in Figure 19. Table 7 describes the pins.

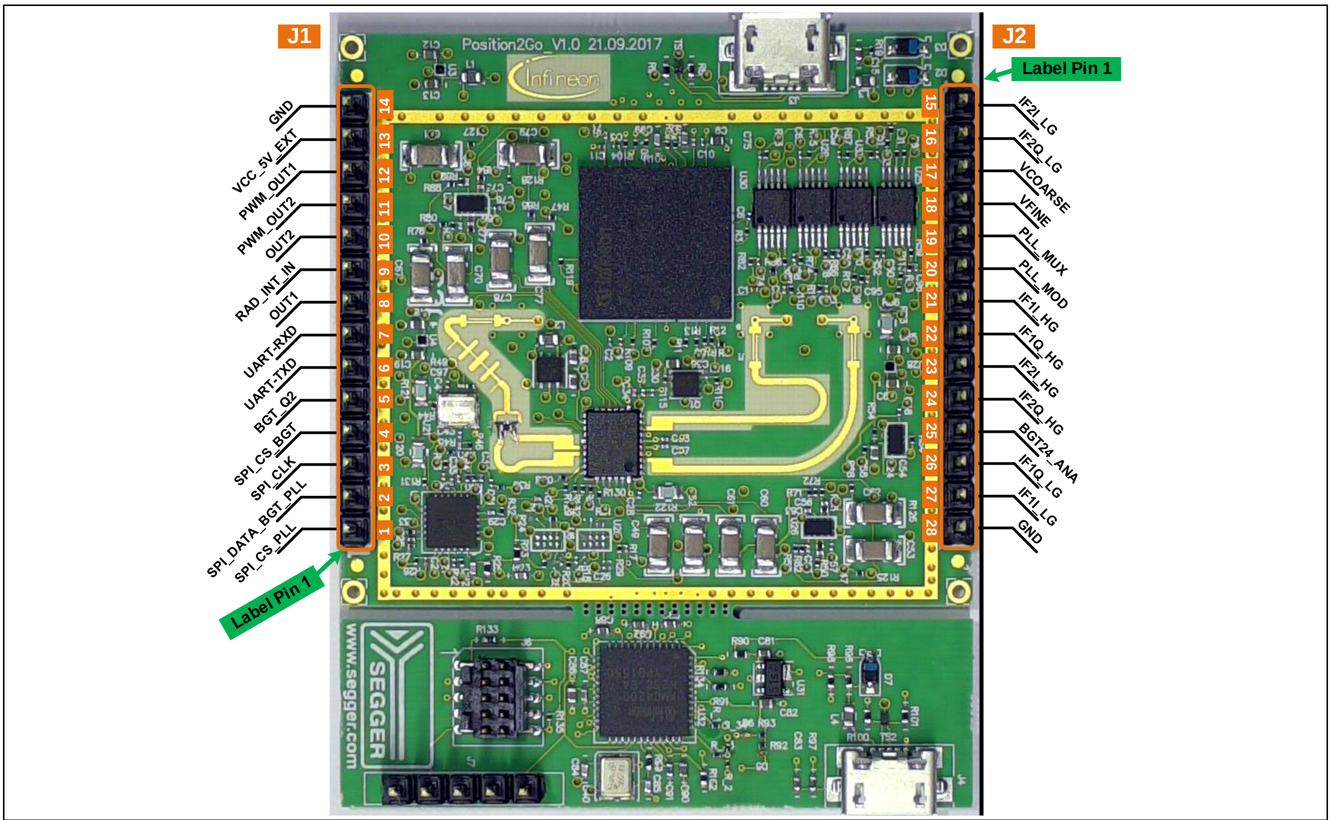


Figure 19 Position2Go external header pin overview

Table 7 External headers – pin description

Pin number	Signal name	Pin description
1	SPI_CS_PLL	SPI chip select input/output – LMX2491 PLL
2	SPI_DATA_BGT_PLL	SPI master out slave input/output (BGT and PLL)
3	SPI_CLK	SPI clock input/output
4	SPI_CS_BGT	SPI chip select input/output – BGT24MTR12
5	BGT_Q2	BGT24MTR12 Q2 prescaler output – 23kHz
6	UART-TXD	Transmit pin for UART communication
7	UART-RXD	Receive pin for UART communication
8	OUT1	External GPIO pin (user configurable)
9	RAD_INT_IN	GPIO pin for interrupt signals (user configurable)
10	OUT2	External GPIO pin (user configurable)
11	PWM_OUT2	External GPIO with CCU4 unit (user configurable)
12	PWM_OUT1	External GPIO with CCU4 unit (user configurable)
13	VCC_5V_EXT	External +5.0 V input power supply pin (maximum = 5.5 V)
14	GND	Ground
15	IF2I_LG	BGT24MTR12 RX-2 I-channel – analog signal output – first gain stage
16	IF2Q_LG	BGT24MTR12 RX-2 Q-channel – analog signal output – first gain stage
17	VCOARSE	BGT24MTR12 – VCO coarse tuning input (0.5 to 3.3 V)
18	VFINE	BGT24MTR12 – VCO fine tuning input (0.5 to 3.3 V)
19	PLL_MUX	Multiplexed input/output pins for ramp triggers, FSK/PSK modulation, FastLock and diagnostics
20	PLL_MOD	Multiplexed input/output pins for ramp triggers, FSK/PSK modulation, FastLock and diagnostics
21	IF1I_HG	BGT24MTR12 RX-1 I-channel – analog signal output – second gain stage
22	IF1Q_HG	BGT24MTR12 RX-1 Q-channel – analog signal output – second gain stage
23	IF2I_HG	BGT24MTR12 RX-2 I-channel – analog signal output – second gain stage
24	IF2Q_HG	BGT24MTR12 RX-2 Q-channel – analog signal output – second gain stage
25	BGT24_ANA	Multiplexed output pins of BGT24MTR12 to read various sensor values
26	IF1Q_LG	BGT24MTR12 RX-1 Q-channel – analog signal output – first gain stage
27	IF1I_LG	BGT24MTR12 RX-1 I-channel – analog signal output – first gain stage
28	GND	Ground

The pin headers enhance the functionality of the module significantly. They allow probing the analog outputs of the sensor module and also probing various other signals provided to the IC. In principle, the accessibility of several pins on the radar IC and the IF signals available via the external pin headers enable interfacing the module with an external signal processor. Apart from the onboard user LEDs, the external headers provide two additional user-configurable GPIO pins from the microcontroller with a number of features, and can be used to drive external shields such as the Infineon RGB LED lighting shield.

4.10 Microcontroller unit – XMC4700

The Position2Go platform uses an XMC4700 32-bit ARM® Cortex™-M4 MCU to perform the radar signal processing. The XMC4700 takes care of communication with all the subsystems on the radar module, enables data acquisition, performs the complete radar signal processing (including sampling and FFT) and communicates the results via its UART or USB interface to an external device.

An XMC4700 in a 194-pin BGA package is used, featuring a 144 MHz CPU frequency, 2048 kB Flash and 352 kB RAM. Four 12-bit ADCs help to implement the radar signal sampling and also acquire the various sensor data from the BGT24MTR12 MMIC. The MCU has also a USB 2.0 device interface which enables communication with a PC directly. Figure 20 shows a system block diagram of the XMC4000 series MCUs.

Please refer to [2] for detailed information on the XMC4700 microcontroller.

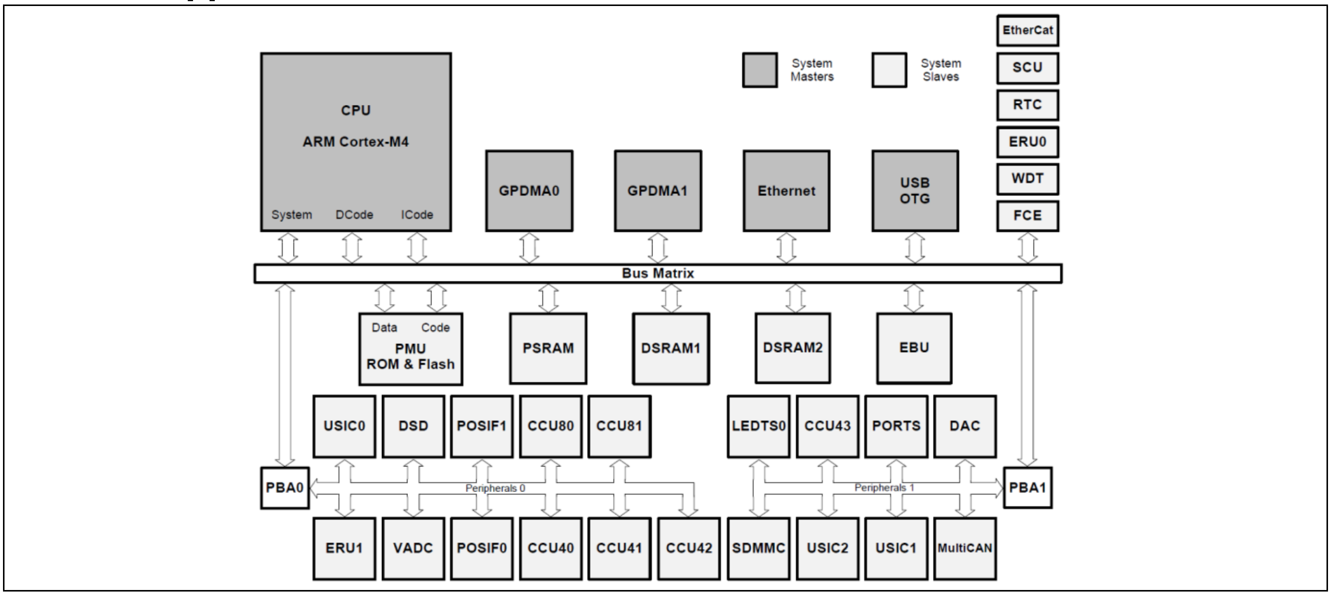


Figure 20 Block diagram – XMC4700

4.11 Onboard debugger and UART connection

The onboard breakable debugger supports two-pin SWD and UART communication. Both require the installation of SEGGER's J-Link driver (refer to STEP 6, in Figure 2) which is part of the DAVE™ installation (refer to STEP 7 in Figure 3).

During installation of the J-Link driver make sure to select the option "**Install USB Driver for J-Link-OB with CDC**" as shown in Figure 21.

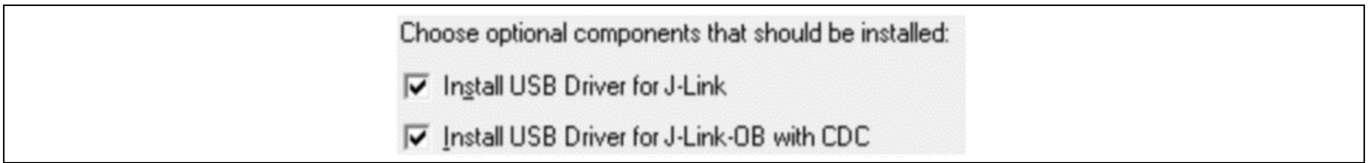


Figure 21 Recommended installation options for the J-Link driver

Table 8 shows the pin assignment of the XMC4200-VQFN48 MCU used for debugging and UART connection.

Table 8 XMC4200 pins used for debugging and UART communication

Port pin	Pin function
TMS (Pin 35)	Data pin for debugging via SWD/SPD
TCK (Pin 39)	Clock pin for debugging via SWD
0.5	Transmit pin for UART communication
0.4	Receive pin for UART communication

The debugger section supports communication between a PC/laptop and target XMC™ device via a UART-to-USB bridge). Therefore, the UART pins of the target XMC4200 on the radar main board are connected to the TX/RX pins of the debug connector. The TX pin of the debugger MCU is connected to the RX pin of the target XMC4200 MCU. The RX pin of the debugger is connected to the TX pin of the XMC™ target device.

The connectors J6 (Cortex-10 pin) and J7 (5-pin header) shown in Figure 22 are used for internal development and testing purposes and are not recommended for customer use.

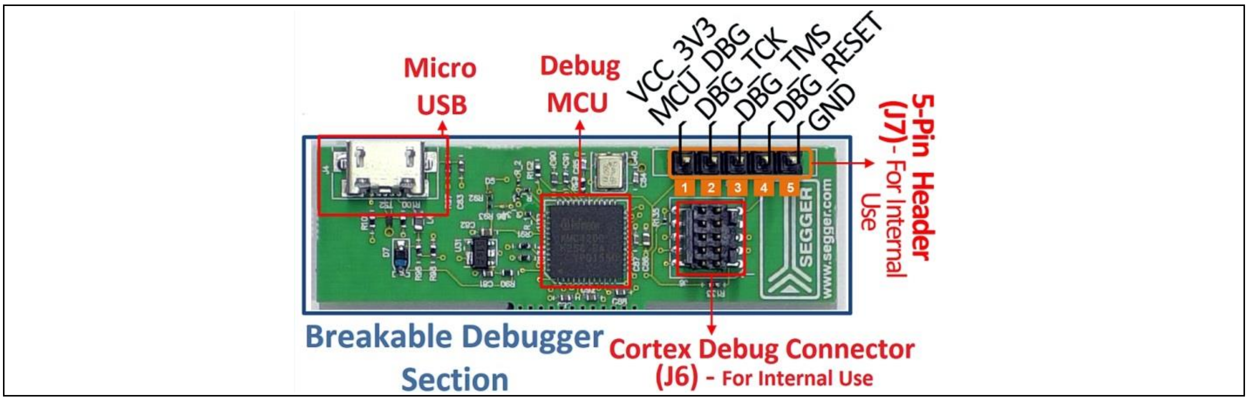


Figure 22 Breakable onboard debugger section

4.12 User LEDs

Some pins of the XMC4700 on the Distance2Go module are connected to external LEDs on the antenna side of the PCB for status indication. Table 9 lists the user LEDs pin assignment.

Table 9 User LEDs pin assignment

LED	MCU port pin
D8 (green LED)	P7.8 (H14)

5 Measurement results

5.1 Measurement default configuration

The Position2Go board was used in the default configuration for distance and angle measurements:

- BW: 200 MHz
- Chirp time: 300 µs
- TX power level: 7
- RX PGA level: L4
- RX BGT LNA gain: enabled
- Duty-cycle status: enabled

5.2 Maximum distance measurement

The maximum distance was measured with a defined detection range threshold of 100 LSB in an outdoor scenario with minimum environmental clutter. Higher detection ranges can be achieved with larger RCS targets and by increasing the RX PGA level.

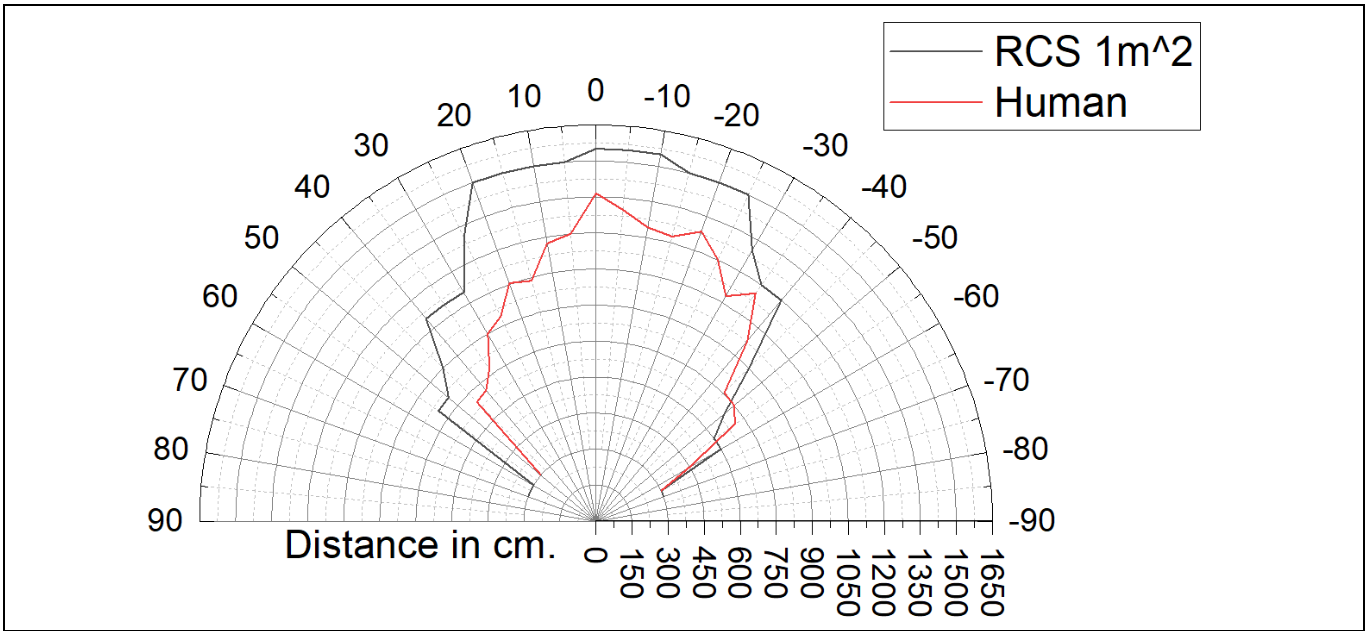


Figure 23 Maximum distance vs. AoA

For indoor measurements, like with all FMCW radar, the maximum detection range of human targets will reduce significantly. It is challenging to quantify the maximum detection range in such indoor measurement cases reliably due to unknown levels of background clutter specific to each environment.

5.3 Range accuracy measurement

Figure 24 shows the set-up of the radar module for range measurements and the range accuracy plots for the measurements.

As can be seen from the measurement plots, the target could be measured up to 18 m away with an accuracy of ±15 cm up to 13 m and accuracy of ±25 cm for the 13 to 18 m range.

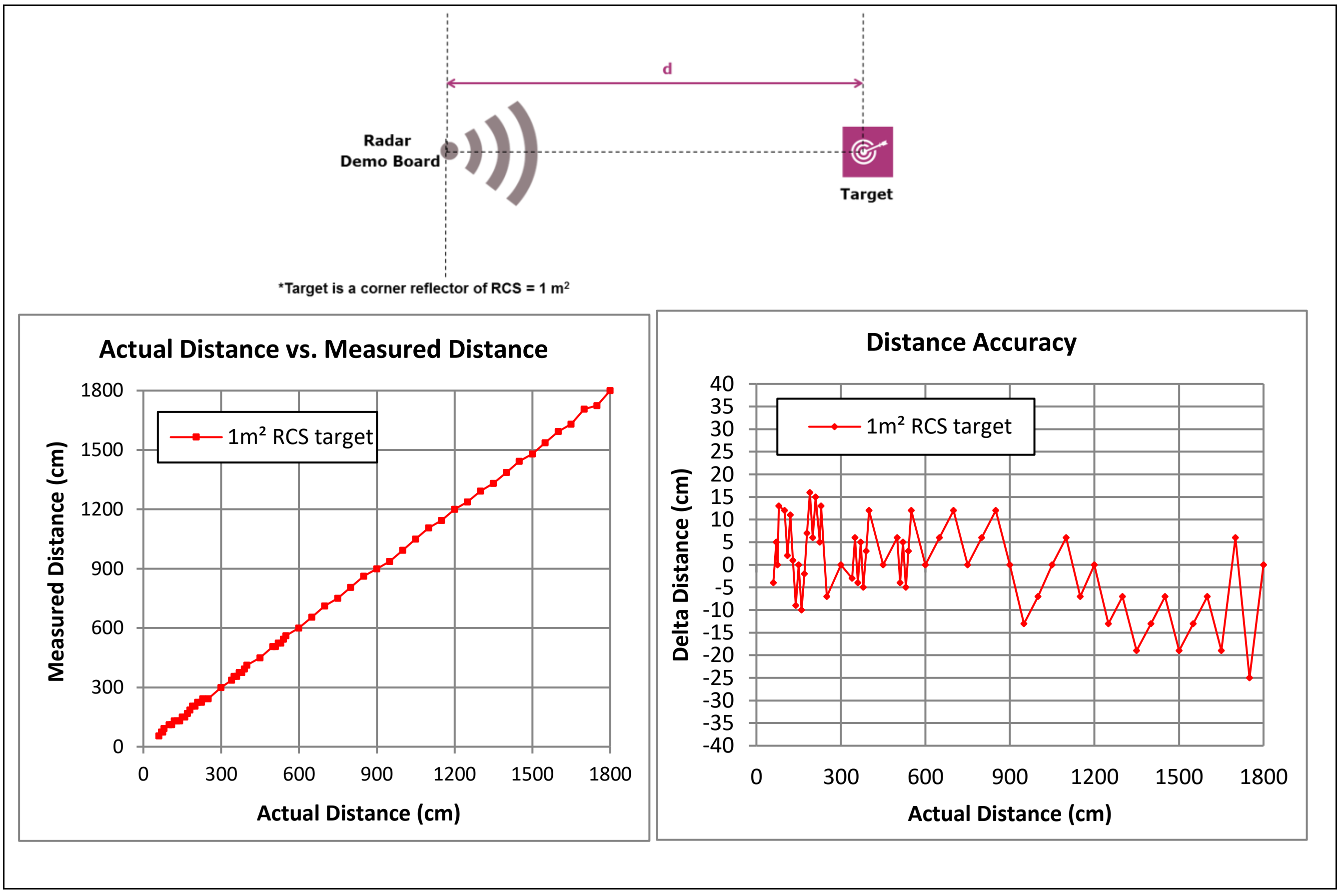


Figure 24 Range accuracy for 1 m² corner reflector target

5.4 Angular accuracy measurement

Figure 25 shows the set-up of the radar module for range measurements and the angular accuracy plots for the measurements. The demo board was used in the default configuration (as mentioned in Section 5.1). For accurate angle measurements it is necessary to avoid signal clipping in the IF baseband section.

The measurement was performed in an outdoor environment at 3 m distance with an RCS target of 1 m^2. As can be seen from the results, the angular accuracy was ±2 degrees in the ±20 degrees angular range and ±8 degrees in the ±65 degrees angular range.

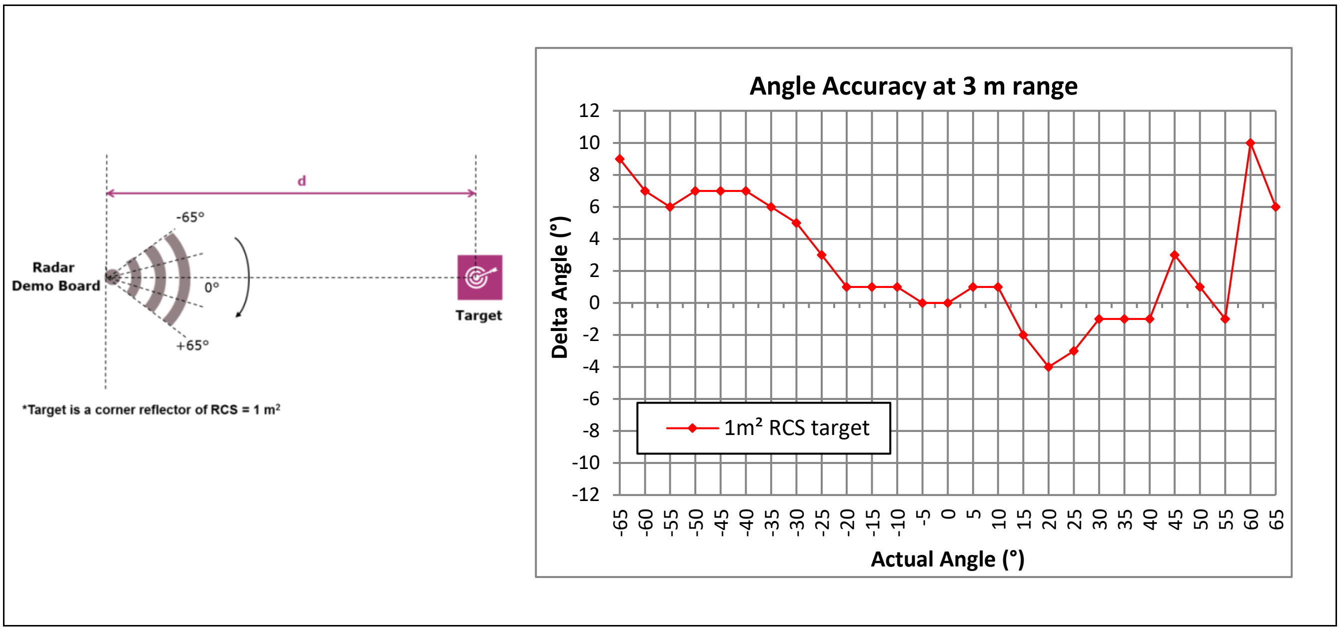


Figure 25 Angular accuracy for 1 m^2 corner reflector target

5.5 Temperature chamber measurement

Three temperature chamber measurements were performed for 25°C, 85°C and -35°C. Figure 26, Figure 27 and Figure 28 show the results and verify that the Position2Go demo board remains within the designated ISM band at these temperatures.

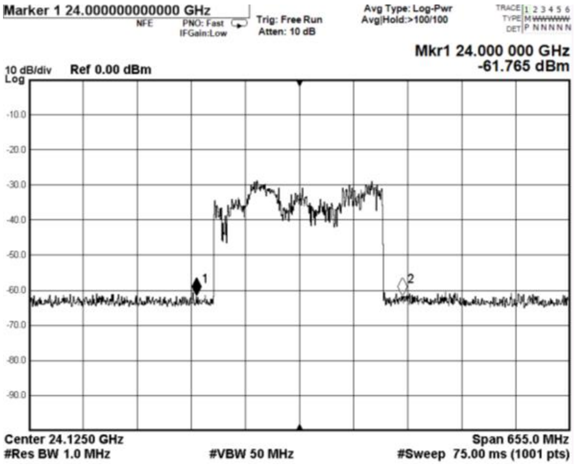


Figure 26 Temperature measurement at 25°C (markers at 24.000 GHz and 24.250 GHz)

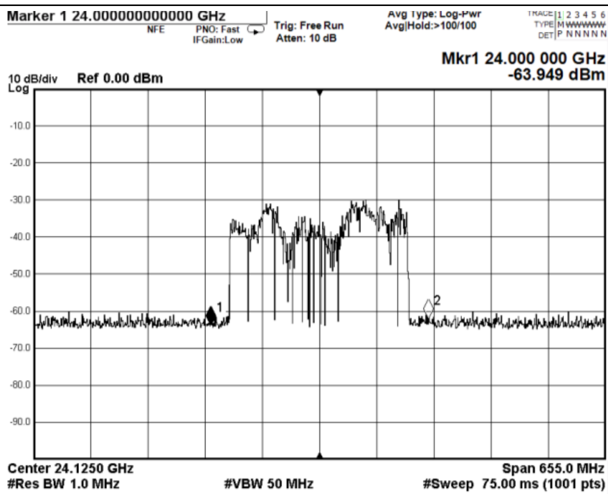


Figure 27 Temperature measurement at 85°C (markers at 24.000 GHz and 24.250 GHz)

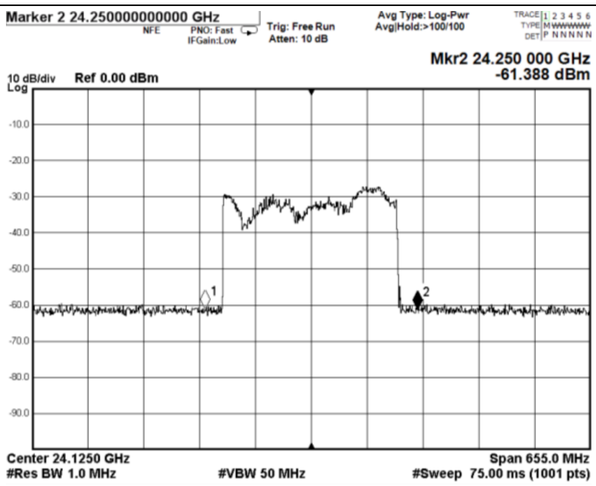


Figure 28 Temperature measurement at -35°C (markers at 24.000 GHz and 24.250 GHz)

6 Frequency band and regulations

6.1 24 GHz regulations

Infineon's BGT24MTR12 radar sensor operates in the globally available 24 GHz bands. There is an industrial, scientific and medical (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 to check the local regulations before designing an end product.

6.2 Regulations in Europe

In Europe, the European Telecommunications Standards Institute (ETSI) defines the regulations. For more details on the ETSI standards, please refer to its 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.

6.3 Regulations in the United States of America

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

7 Authors

Radar Application Engineering Team, Business Line “Radio Frequency and Sensors”

8 References

[1] Infineon BGT24MTR12 – 24 GHz Radar IC – Datasheet

[2] Infineon XMC4700 32-bit ARM Cortex™-M4 Microcontroller – Datasheet

[3] Infineon Application Note – AN305 – "Users Guide to 24 GHz Radar Transceiver"

[4] 24 GHz industrial radar – FAQs

[5] Innosent Application Note – Application Note IV – "Recommendations for the using of radar sensors in general and specifically for low cost devices"

[6] Innosent Application Note – Application Note II – "Detection and Ranging of moving and Stationary Objects by using the FMCW radar principle"

[7] ETSI Regulations – EN 300 440 V2.2.1

[8] FCC Regulations – 15.245, 15.249

Revision history

Document version	Date of release	Description of changes
V1.0	2018-12-14	Initial version
V1.1	2019-06-14	p. 33: Added temperature chamber measurements p. 35: Added frequency regulation information Moved Firmware description, Programming API and GUI overview sections to 24 GHz Radar Tools and Development Environment User Manual Moved Algorithm description section to P2G Software User Manual
V1.2	2019-09-16	p. 10: Added Minimum speed row to the System performance table
V1.3	2020-05-05	p. 10: Correction on minimum and maximum speed values and formula

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Edition 2020-05-05
Published by
Infineon Technologies AG
81726 Munich, Germany

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Email: erratum@infineon.com

Document reference
<AN_1812_PL32_1812_145434>