

24 GHz Transceiver: BGT24LTR11

Sense2GoL Pulse (Pulsed Doppler) – XENSIV™ 24 GHz low power radar shield using BGT24LTR11 for motion, speed and direction of movement detection

Board version V1.0

About this document

Scope and purpose

This application note describes the key features of Infineon's BGT24LTR11 Shield, part of Infineon's 24 GHz Sense2GoL Pulse radar system platform. The shield is the evaluation platform for the 24 GHz low-power transceiver chip BGT24LTR11.

1. The application note describes the hardware configuration and specifications of the sensor module in detail.
2. The document 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 speed and direction of movement detection using Doppler radar techniques at 24 GHz.

Related documents

Additional information can be found in the supplementary documentation provided with the Sense2GoL Pulse Kit in the Infineon Toolbox or from www.infineon.com/24GHz:

- 24 GHz Radar Tools and Development Environment User Manual
- Sense2GoL Pulse Software User Manual
- AN602 – Radar Baseboard XMC4700
- AN605 – Radar Baseboard XMC4700 and BGT24LTR11 Shield with Arduino

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Introduction

1 Introduction

The Sense2GoL Pulse radar system is a demo platform for Infineon's 24 GHz silicon-germanium (SiGe) BGT24LTR11 radar chipset. It consists of two boards – the microcontroller board: Radar Baseboard XMC4700, and a radar front-end board: BGT24LTR11 Shield. This document focuses on the BGT24LTR11 Shield for a pulsed Doppler implementation. Detailed information about the Radar Baseboard XMC4700 can be found in the corresponding application note.

The system is designed to allow customers to carry out prototyping and system integrations as well as initial product feature evaluations. The platform is a low-power solution for detecting speed and direction of movement (approaching or retreating). These features of the board make it suitable for various applications such as motion detection, presence sensing, etc. These use cases target applications such as smart lighting, smart doors, smart devices, etc.

The main radar technique used on the platform is Continuous Wave (CW/Doppler) radar for velocity estimation. The principle of the Doppler effect is used. The radar transmits a constant-frequency signal continuously and receives the echo signal from the moving target. The change in phase between the transmitted and received signal is used to calculate the target's velocity.

Sample and Hold (S&H) circuitry is implemented 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 system is also equipped with current sensors to determine real-time power consumption of the boards individually. 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 domain. 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.

Introduction

1.2 Key features

The primary features of the Sense2GoL Pulse radar system are as follows:

- Detects motion, presence, speed and direction of movement (approaching or retreating) for human targets
- Extremely low power consumption (less than 5 mW)
- Two-board topology for RF section and microcontroller sections
- S&H circuitry for low power consumption
- Two configurable analog amplifier stages for the RX channel
- Micro-strip patch antennas with 10 dBi gain and 29 x 80 degree 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 XMC4700 (for signal processing).

The Sense2GoL Pulse radar system consists of the following key components:

- BGT24LTR11 – highly integrated 24 GHz transceiver IC with one transmitter (TX) and one receiver (RX)
- XMC4700 – 32-bit ARM® Cortex™-M4 based microcontroller for signal processing
- TS5A4596 - SPST S&H switches for low power consumption
- IRLHS2242 – 20 V single P-channel HEXFET power MOSFET for duty-cycle operation
- INA226 – current shunt and power monitors for current consumption estimation
- 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

Introduction

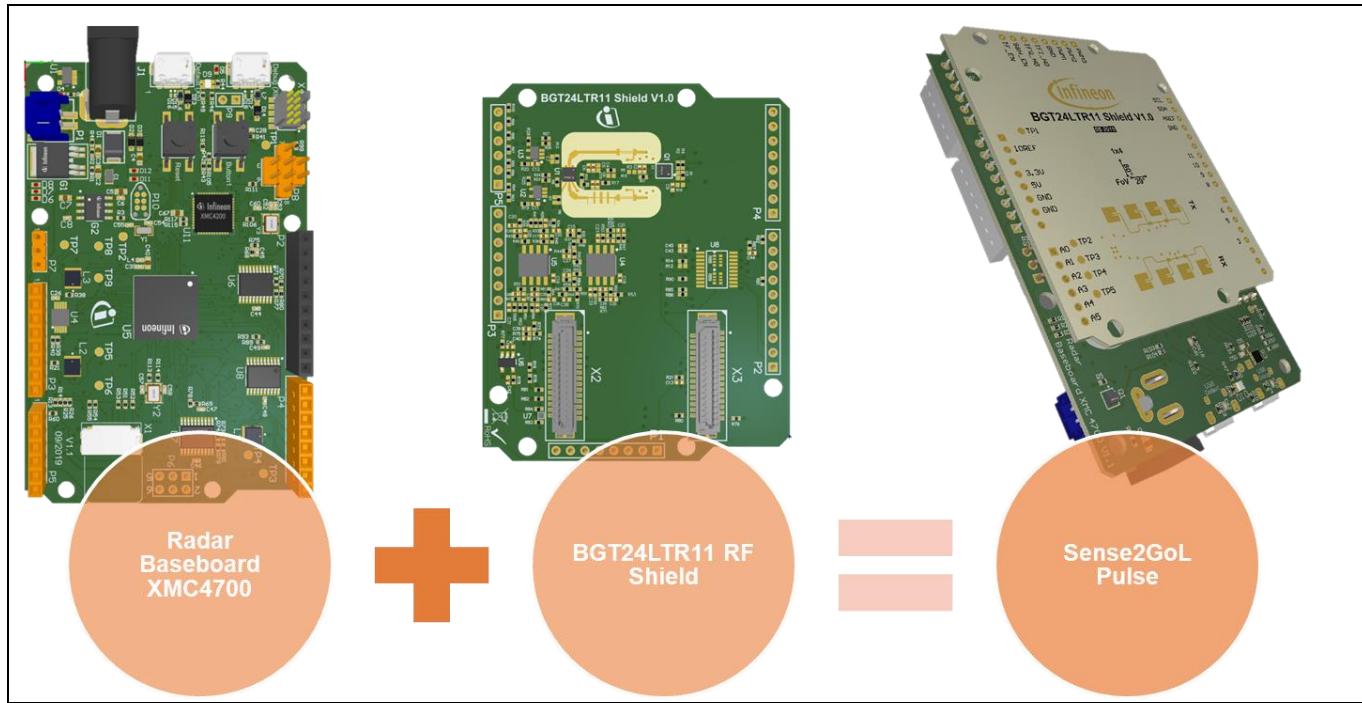


Figure 1 BGT24LTR11 Shield – front and back view with dimensions

The circuitry for the BGT24LTR11 Shield (Pulsed Doppler) is designed to carry out Doppler detection with low power consumption. The analog I/Q signals from the MMIC act as inputs to the S&H circuitry. When the switch is closed (sample mode), the hold capacitor follows the I/Q analog signal of the MMIC and charges to its peak value. When the switch is opened (hold mode), the hold capacitor holds the sampled voltage. This implementation allows us to turn the BGT24LTR11 off during the “hold time” and hence save power. The S&H_EN signal from the Radar Baseboard XMC4700 controls the on/off timing of the switches. The output of the S&H circuitry is amplified and filtered by the baseband section. These amplified I/Q signals are then routed to the Radar Baseboard XMC4700 via connectors for signal processing. It also provides the control signals for the BGT24LTR11 Shield board via connectors.

Getting started

2 Getting started

This section provides a step-by-step quick process to get started with the Sense2GoL Pulse board. Some of the steps are optional for going deeper into the analysis of the board, the firmware and the extracted signals.

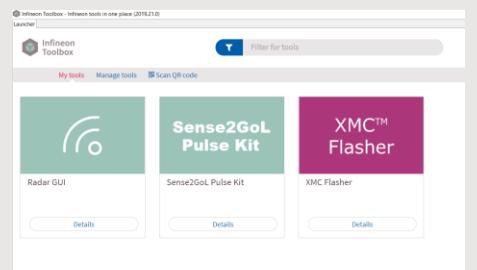
STEP 1	STEP 2	STEP 3
<p>Box contents</p> <ul style="list-style-type: none">• BGT24LTR11 Shield• Radar Baseboard XMC4700• Micro-USB cable• Fold-able corner reflector	<p>Infineon Toolbox</p> <ul style="list-style-type: none">• Go to: www.infineon.com/Infineon-Toolbox/• Click on the “Download now” button.  <ul style="list-style-type: none">• Run the “infineon-toolbox-launcher-web-installer-win-x86-latest.exe” file.  <p>infineon-toolbox-launcher-web-installer-win-x86-latest.exe</p> <ul style="list-style-type: none">• “Accept” the license agreement.• Finish installation. Create a desktop shortcut.  <p>Infineon Toolbox</p>	<p>Install Sense2GoLP kit</p> <ul style="list-style-type: none">• Open “Infineon Toolbox”.• Click on the “Manage tools” tab.• Search for “Sense2GoLPulse Kit”.  <ul style="list-style-type: none">• Click on “Install”.  <ul style="list-style-type: none">• “Accept” the license agreement.• Finish installation. 

Figure 2 Steps 1 to 3 to get started with Sense2GoL Pulse demo board

Getting started

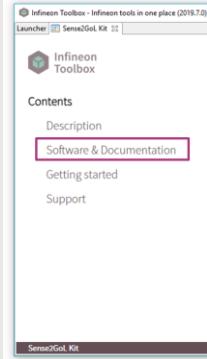
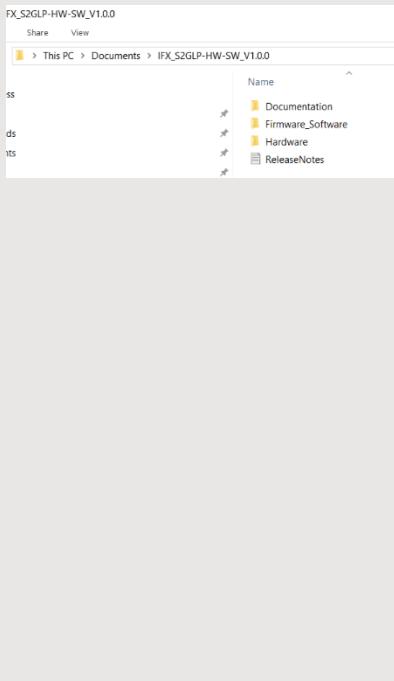
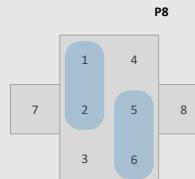
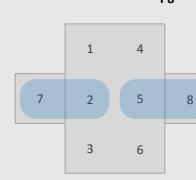
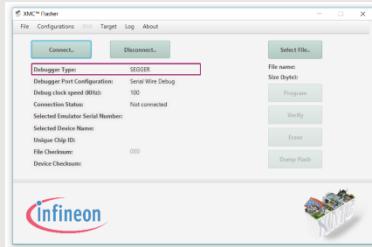
STEP 4	STEP 5	STEP 6
<p>Download SW/HW package</p> <ul style="list-style-type: none"> Open “Infineon Toolbox”. Click on “Sense2GoLPulse Kit”. Follow the instructions mentioned on the left tab (2. Getting Started). Save the set-up file and run it.  <p>S2GLP-HW-SW.exe</p> <ul style="list-style-type: none"> Browse to the preferred location to store the files. 	<p>Connect board</p> <ul style="list-style-type: none"> Insert micro-USB cable(Default) into the Radar Baseboard XMC4700.  <ul style="list-style-type: none"> Insert the USB connector into the PC’s USB port.  <p>★ If the device driver is not recognized:</p> <p>Right-click on “My Computer” ► Manage ► Device Manager ► Other devices ► Right-click on “Unknown device” ► Update Driver Software ► Browse ► Firmware_Software ► XMC_Serial_Driver.</p> <p>★ Make sure Headers P9 is NOT connected and P8 is connected as</p> 	<p>Firmware (FW) update</p> <ul style="list-style-type: none"> Download and install SEGGER J-Link USB driver for Windows: www.segger.com/downloads/jlink/#J-LinkSoftwareAndDocumentationPack Insert micro-USB cable(Debug) into the Radar Baseboard XMC4700. <p>★ Make sure Headers P9 is connected and P8 is connected as</p>  <ul style="list-style-type: none"> Open Infineon Toolbox ► XMC Flasher.  <p>Check the debugger type is “SEGGER”, otherwise go to: “Configurations” ► “Setup”, then set it to “SEGGER”.</p> <ul style="list-style-type: none"> Click on “Connect” ► XMC4700-2048. Click on “Select file” ► Browse to Firmware_Software ► Binary ► .hex file ► Program.

Figure 3 Steps 4 to 6 to get started with Sense2GoL Pulse demo board

Getting started

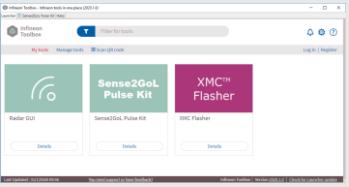
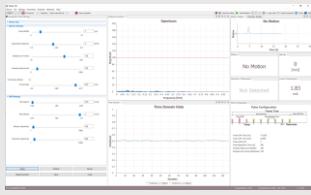
<p>STEP 7</p> <p>Optional</p> <p>View and edit source code</p> <ul style="list-style-type: none">• Connect board as STEP 6• Download and install the https://infineoncommunitiy.com/dave-download_ID645 <p>DAVE™ IDE tool:</p> <ul style="list-style-type: none">• Go to Firmware_Software ► DAVE project. Unzip the DAVE™ project files of your choice.• Run DAVE™ IDE.• Import DAVE™ projects and debug. 	<p>STEP 8</p> <p>Radar GUI</p> <ul style="list-style-type: none">• Connect board as STEP 5.• Open Infineon Toolbox ► Radar GUI  <p>• Real-time data is now on on your screen.</p> 	<p>STEP 9</p> <p>Optional</p> <p>MATLAB interface</p> <ul style="list-style-type: none">• 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. 
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Figure 4 Steps 7 to 9 to get started with the Sense2GoL Pulse 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 3. They are:

- Altium project
- DAVE™ project and binary files
- Schematics
- Bill of Materials (BOM)
- Production data

System specifications

3 System specifications

Table 1 gives the specification of the Sense2GoL Pulse (Pulsed Doppler) radar system.

Table 1 Sense2GoL Pulse (Pulsed Doppler) module performance specifications

Parameter	Unit	Min.	Typ.	Max.	Comments
System performance					
Minimum speed	km/h	0.5	5	10	Configurable by changing baseband section (Table 3)
Maximum distance	m	0.1	15	20	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	24.05	24.125	24.25	
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	24.05	24.125	24.25	
IF conversion gain – (stage 1)	dB		30		Configurable by changing baseband section (Table 3)
IF conversion gain – (stage 1 + stage 2)	dB		59		Configurable by changing baseband section (Table 3)
-3 dB bandwidth – (stage 1 + stage 2)	Hz	16		420	Configurable by changing 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.

Hardware description: BGT24LTR11 Shield

4 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.

4.1 Overview

The radar shield is shown in Figure 5. 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
- S&H part – consists of SPST switches and hold capacitors to sample and hold the analog I/Q signals from the MMIC using the control signal S&H_EN
- Analog amplifier part – smoothes the sampled I/Q signals from the S&H circuitry and amplifies them for the digital part
- EEPROM part – to store data such as board identifier information

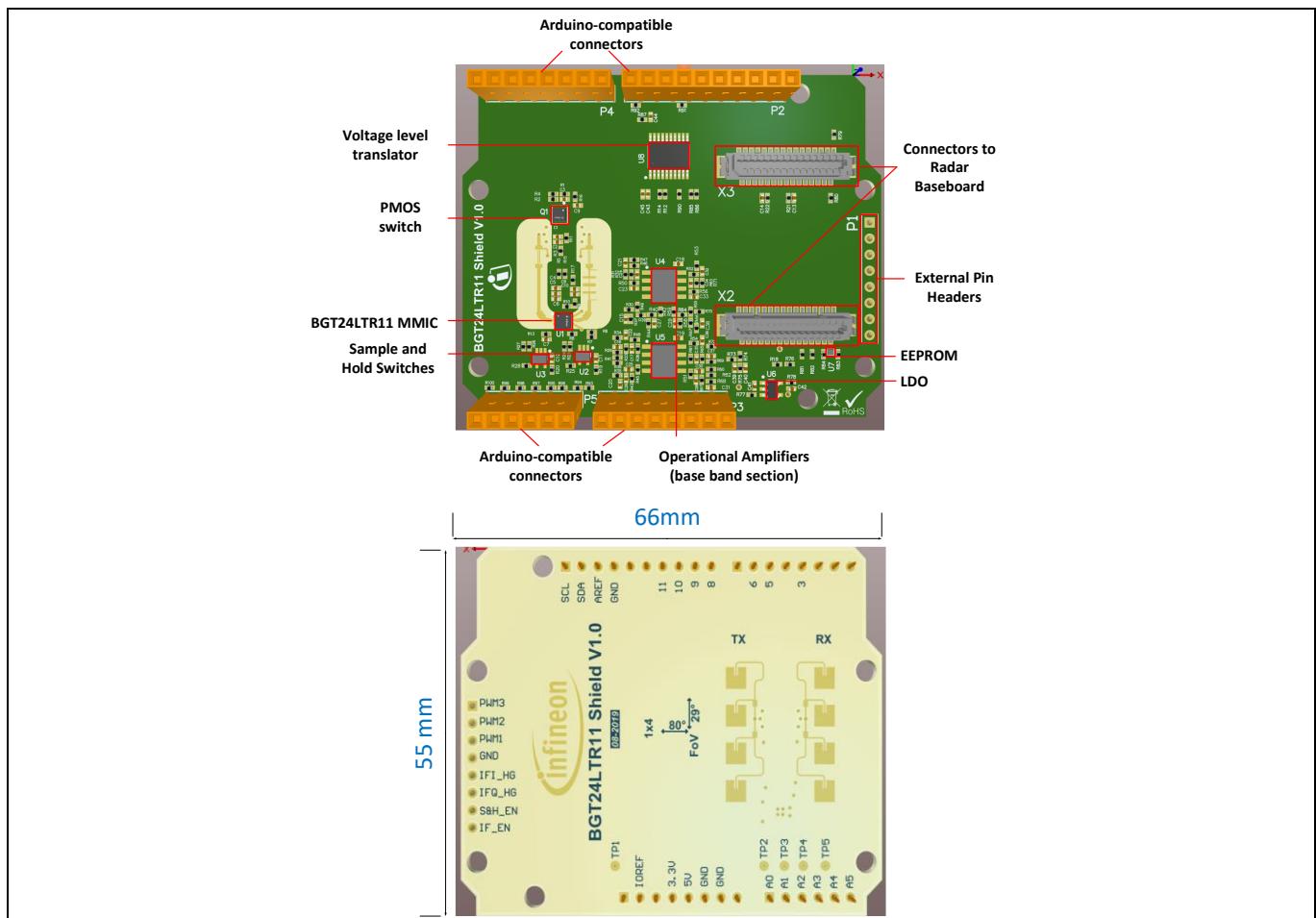


Figure 5 BGT24LTR11 Shield board with main components and dimensions

The radar shield demonstrates the features of the BGT24LTR11 RF front-end chip and gives the user a customizable radar solution. The board gives possibilities to implement 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™.

Hardware description: BGT24LTR11 Shield

4.2 Block diagram

Figure 6 shows the block diagram of the Sense2GoL Pulse system. It consists of the highly integrated 24 GHz transceiver IC BGT24LTR11 with 1 TX and 1 RX. A built-in voltage source, Proportional to Absolute Temperature (PTAT) delivers a VCO tuning voltage. When connected to the VCO tuning pin it compensates for the inherent frequency drift of the VCO over-temperature, thus stabilizing the VCO within the ISM band and eliminating the need for a PLL/microcontroller.

The I/Q outputs from the BGT24LTR11 are connected with the SPST switches to perform a S&H operation. During the sample time, C_{hold} charges to its peak value, following the input analog signal. During the hold time, it holds the value and allows us to turn the BGT24LTR11 off. The S&H_EN control signal is provided by the Radar Baseboard XMC4700 via the connectors.

The output of the S&H circuitry is routed to the baseband section to provide the required gain to the IF signals. The outputs of the baseband section are connected with ADC inputs of the XMC4700 on the radar baseboard.

The system is powered through the radar baseboard via the micro-USB plug. It is also possible to power it via external 7 V power supply or with a LiPo battery. A low-noise voltage regulator (U6) is used to provide a regulated power supply to the different building blocks of the RF shield.

BGT24LTR11 is supplied over a PMOS, which enables turning the MMIC on/off during S&H timings. Pin headers on the PCB allow for interfacing the sensor module with an external processor.

Hardware description: BGT24LTR11 Shield

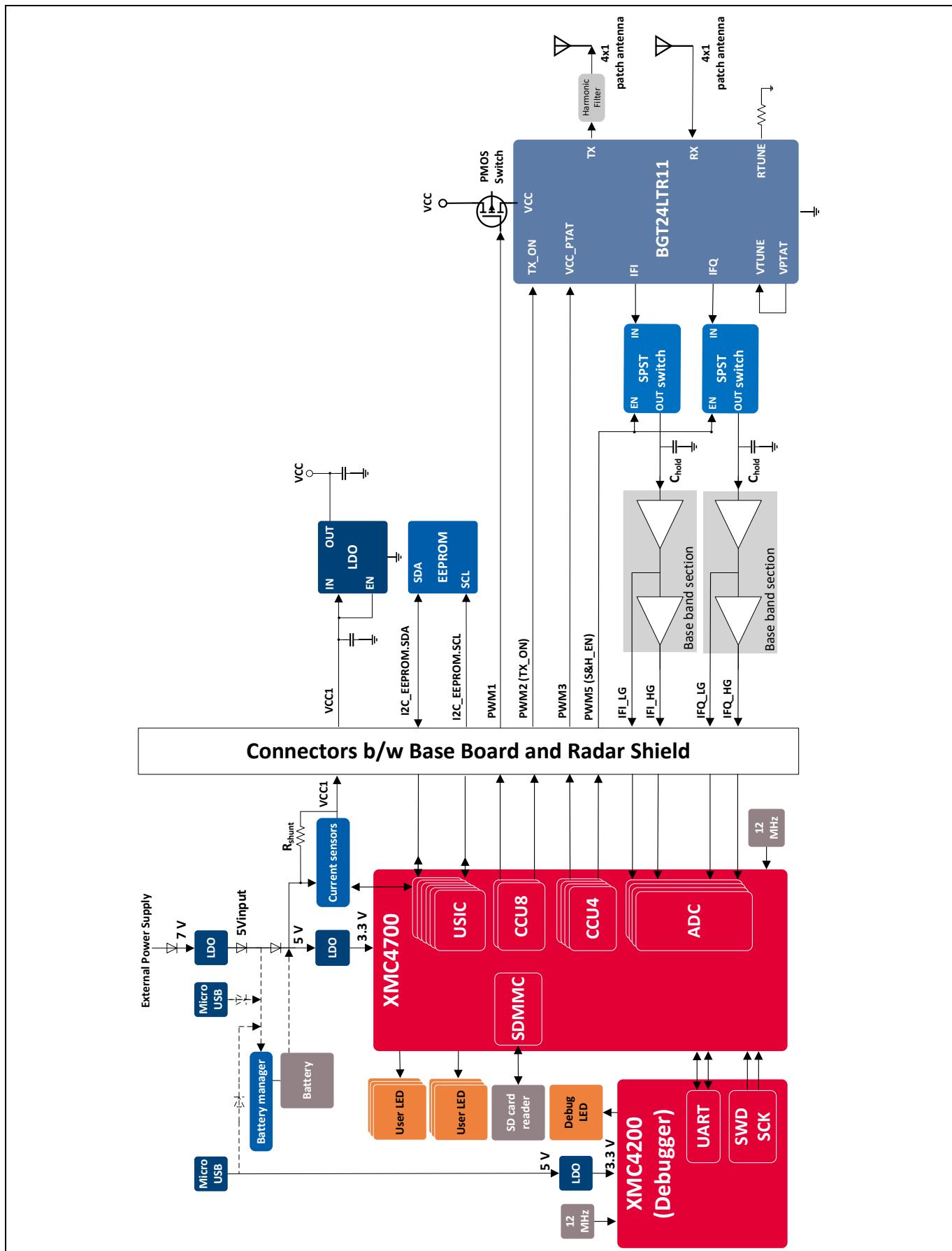


Figure 6 Block diagram – Sense2GoL Pulse

Hardware description: BGT24LTR11 Shield

4.3 Power supply

The Radar Baseboard XMC4700 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. A LDO (U6) is used on the BGT24LTR11 Shield to supply all the components. Figure 7 shows the power supply concept used in the system.

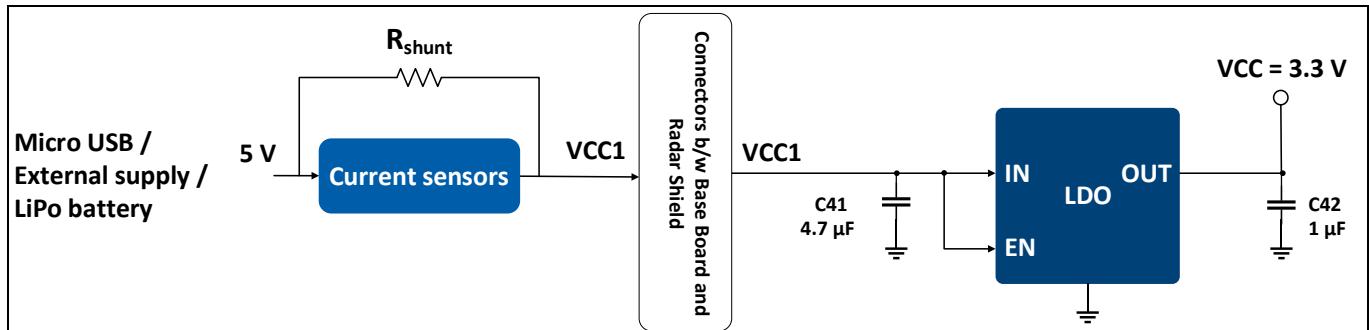


Figure 7 Block diagram - power supply concept

4.4 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 XMC4700, 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.

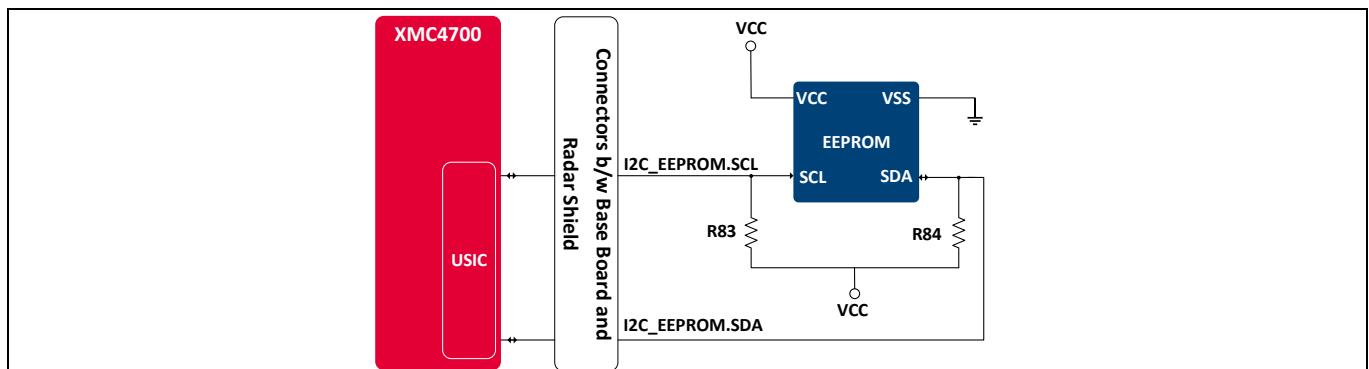


Figure 8 EEPROM block diagram

4.5 RF front end

Figure 9 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 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 9.

Hardware description: BGT24LTR11 Shield

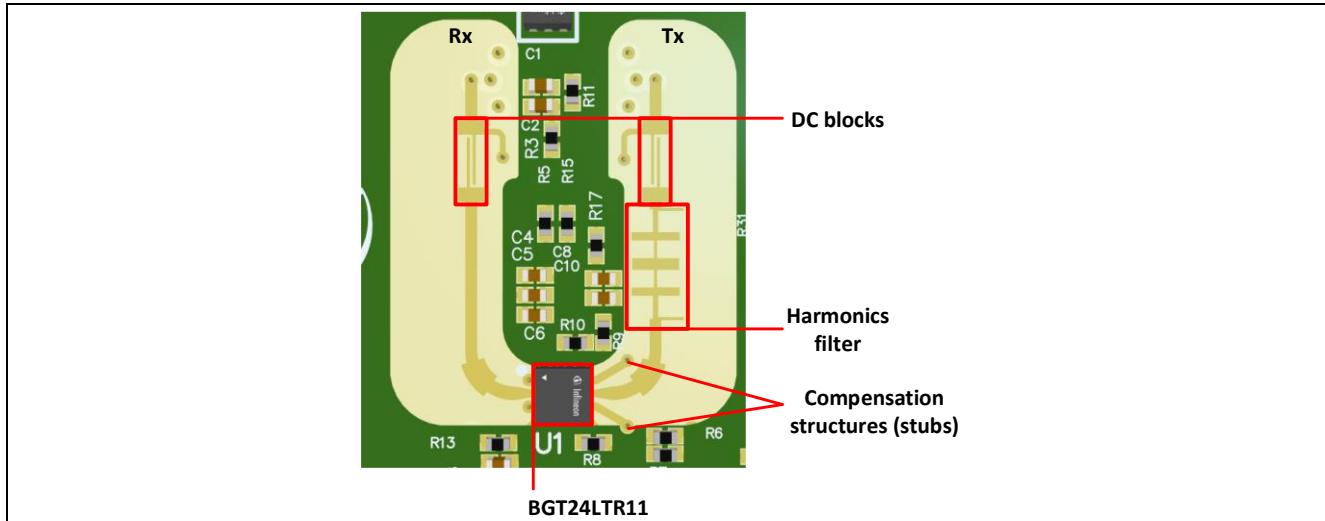


Figure 9 RF front-end overview (top)

4.6 BGT24LTR11 – 24 GHz transceiver 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).

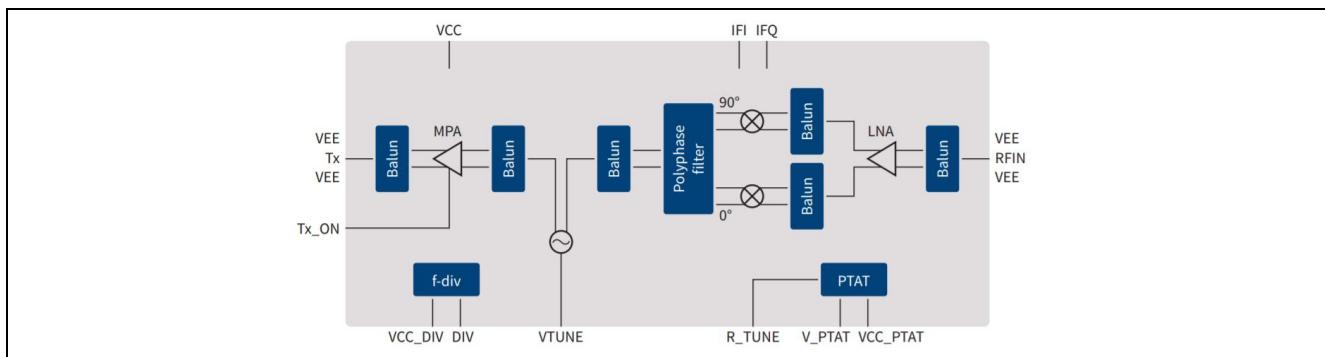


Figure 10 Block diagram - BGT24LTR11

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 over-temperature, 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 in order 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.

Hardware description: BGT24LTR11 Shield

4.7 Antennas

The BGT24LTR11 Shield features a 4×1 array antenna for the transceiver and receiver sections. The antenna has a gain of 10 dBi and an opening angle of 29×80 degrees. Figure 11 shows the simulated 2D and 3D radiation pattern.

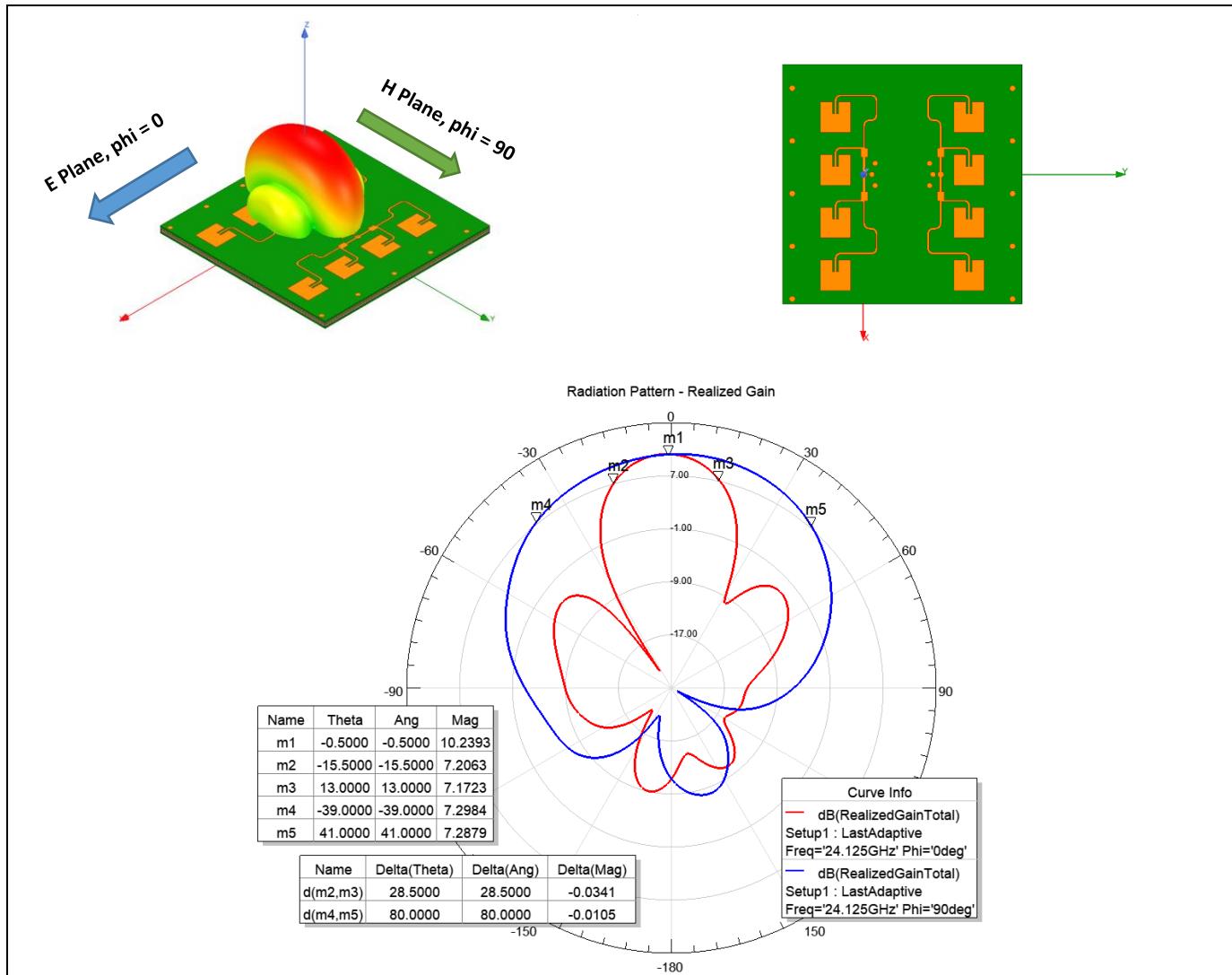


Figure 11 2D radiation pattern for array antennas

Hardware description: BGT24LTR11 Shield

4.8 Sample and Hold (S&H) circuitry

The BGT24LTR11 Shield has S&H circuitry between the MMIC and the baseband section. The I/Q signals from the BGT24LTR11 are connected to the inputs of SPST switches. The control signal S&H_EN is generated by the MCU on the radar baseboard and routed via connectors to the RF shield. When the switch is closed (sample mode), the hold capacitor (C_{hold}) follows the I/Q analog signal of the BGT and charges to its peak value. When the switch is opened (hold mode), the C_{hold} holds the sampled voltage. This implementation allows us to turn the BGT24LTR11 off during the “hold time” and hence save power. The output of the S&H circuitry is amplified and filtered by the baseband section. It is important to follow the Nyquist criteria for the analog input signal (I/Q) and the control signal, S&H_EN. The frequency of the control signal should be at least twice the frequency of the input signal. Figure 12 shows the block diagram of the circuitry and Figure 13 shows the corresponding signals.

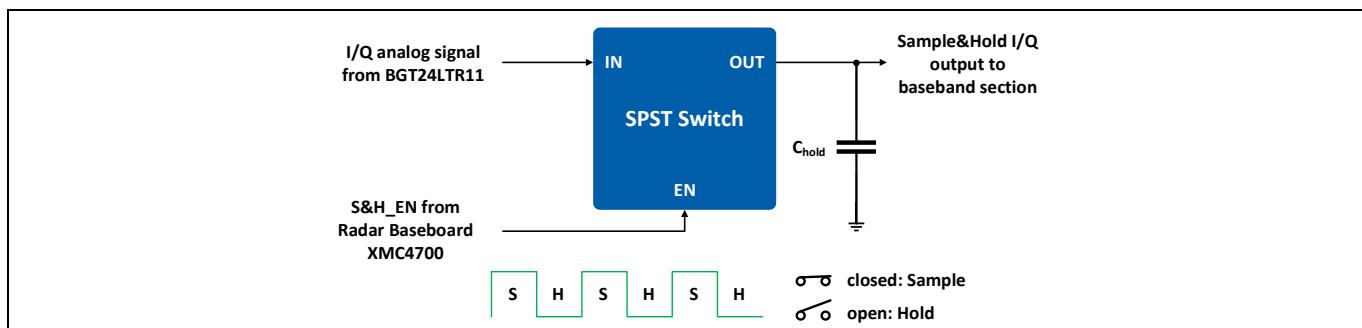


Figure 12 S&H circuitry

The sample time is a portion of the “pulse width”. The pulse width can vary from 1 to 10 μ s. Short pulse widths reduce the sample time of the MMIC’s output signals, saving more power. However, the time might not be enough to charge to the peak value, and so reduce the final signal strength at the output.

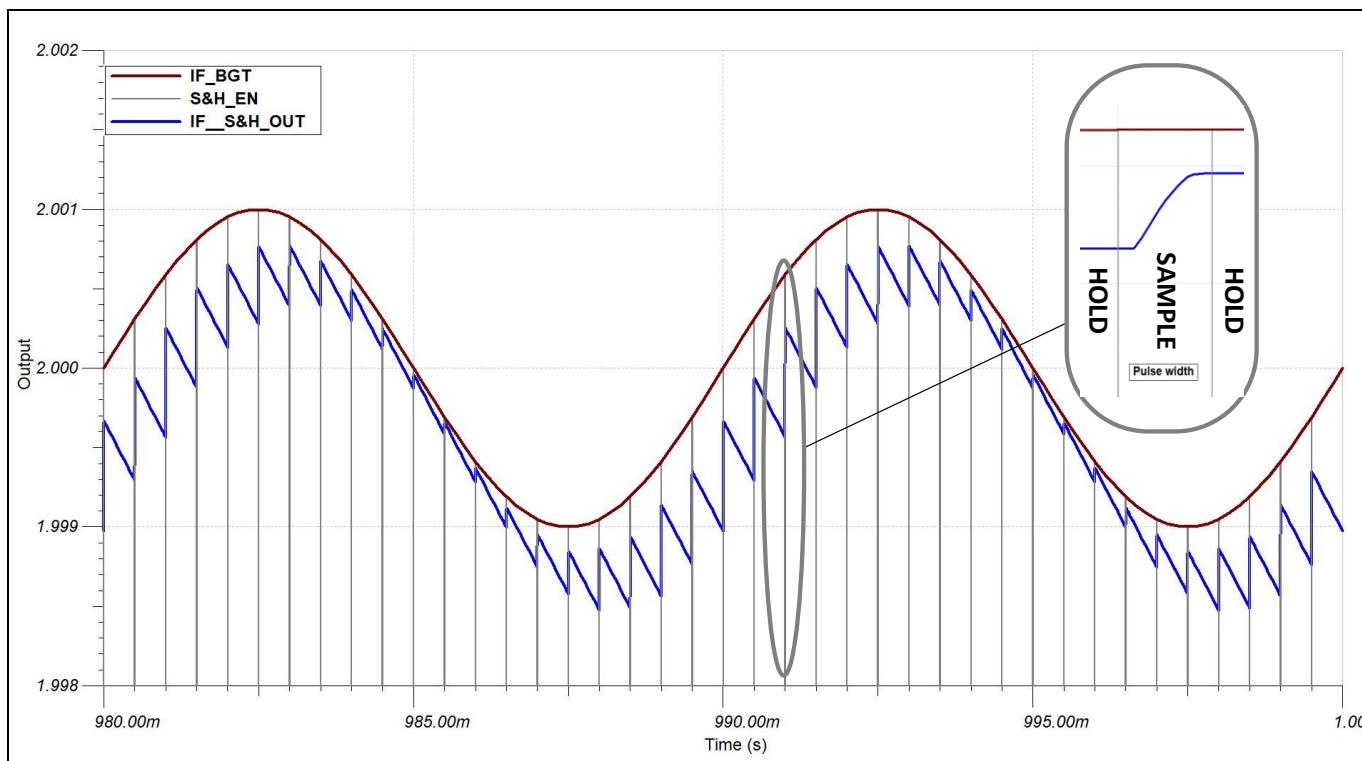


Figure 13 S&H circuit signals (detail): pulse width = 5 μ s, $f_{if} = 100$ Hz

Hardware description: BGT24LTR11 Shield

The hold capacitor value is also a critical point of the circuit. It is a trade-off between current saving capability, preserving the S&H voltage and low-pass filter performance. S&H capacitor leakage must be very low.

For the S&H switch, the leakage current performance is also very important. Leakage in the S&H structure will cause a severe periodic voltage drop of the S&H voltage at sample rate (as shown in Figure 13). This is also visible as an unwanted interferer frequency at sampling frequency at the output of the baseband circuitry. In critical cases, it can block the baseband amplifier. The S&H switch used has a very low leakage current and it is therefore not recommended to change it.

4.8.1 Basic considerations on the S&H circuit

During the S&H process, the entire MMIC (BGT24LTR11) is switched on and off periodically (pulsing). Therefore, the I and Q mixer output from the MMIC will produce short pulses periodically. Each pulse is a discrete, very short sample of the mixer's DC bias voltage superimposed by the actual AC Doppler swing. In BGT off-state, the mixer output becomes zero. The S&H circuit after the mixer output converts a discrete time signal into a continuous time signal by preserving the entire mixer voltage during the pulse off-time.

Switching on the BGT and the S&H switch, the S&H capacitor shows the same DC voltage as the mixer output, because the total voltage (DC + AC) is preserved in the S&H capacitor from the previous pulse. Therefore, only the superimposed AC voltage must be updated without the need to recharge the S&H capacitor for the DC bias voltage.

The required time for updating the AC voltage depends on the mixer output frequency (Doppler frequency) and the time constant of the RC LP1 filter formed by the mixer output impedance and the S&H capacitor. For a given S&H time, the S&H capacitor must be selected to enable an update of the actual S&H voltage.

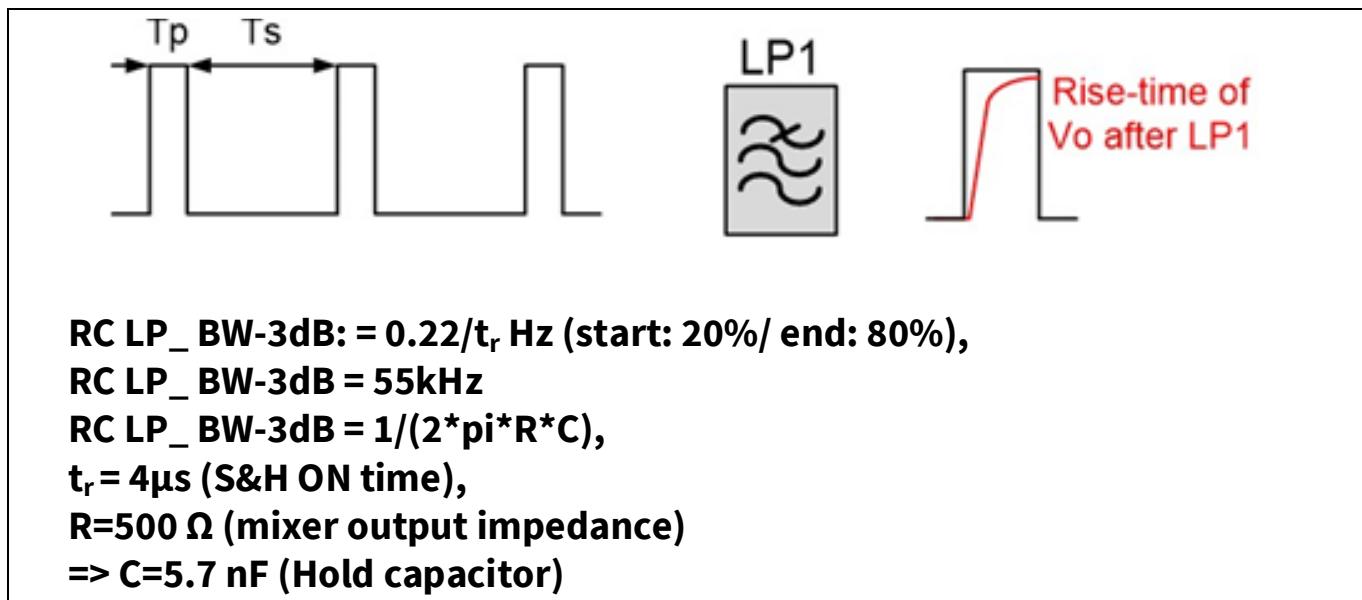


Figure 14 Hold capacitor calculation

The target is to use a RC capacitor with high capacitance although the AC voltage is not fully recharged (20 percent to 80 percent rise-time calc.). A higher capacitor value will reduce noise folding, but leads to a slightly lower magnitude of the baseband Doppler signal.

Hardware description: BGT24LTR11 Shield

4.9 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 operational amplifiers. As shown in Figure 15 and Figure 16, the I/Q outputs of the S&H circuit are filtered and amplified in the first gain stage. The second gain stage consists of a DC block operating as a higass filter and 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 lowpass filtered to avoid aliasing. A voltage divider is used to create the 1.65 V reference voltage.

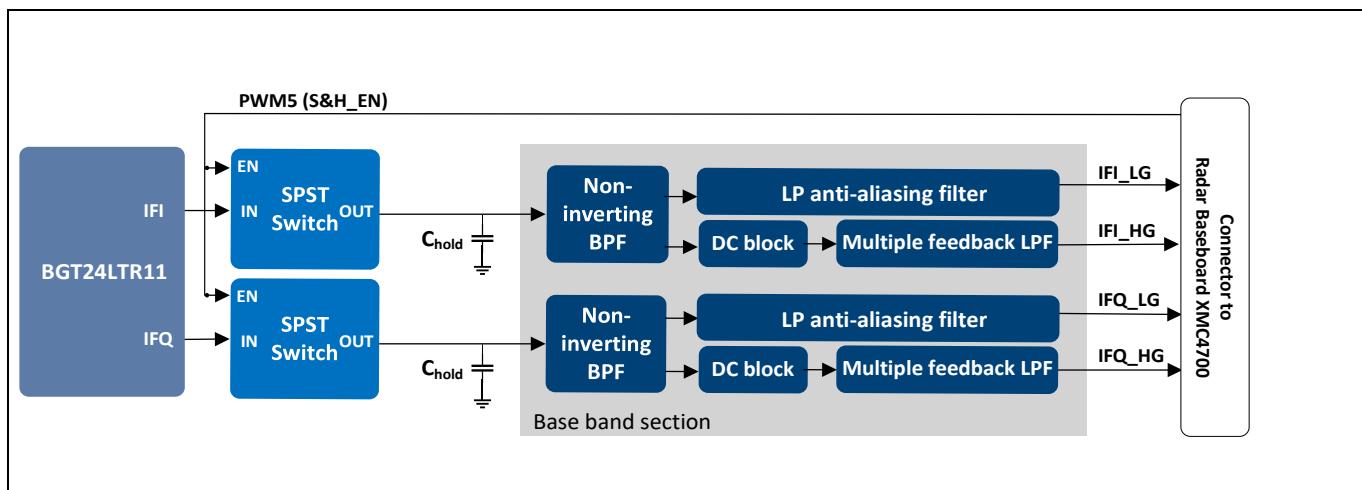


Figure 15 Baseband amplifier chain - block diagram

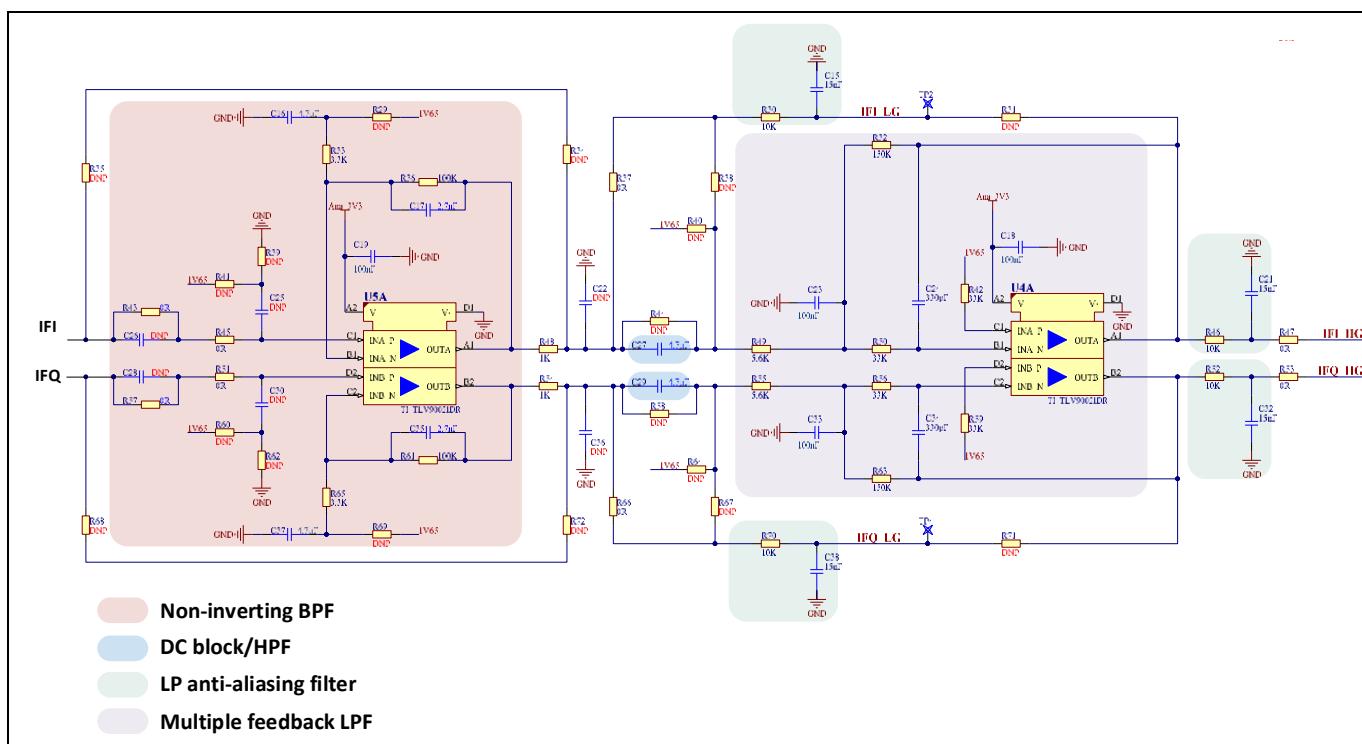


Figure 16 Baseband amplifier chain - schematics

Hardware description: BGT24LTR11 Shield

Figure 17 shows exemplary IF low-gain and high-gain signals. 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.

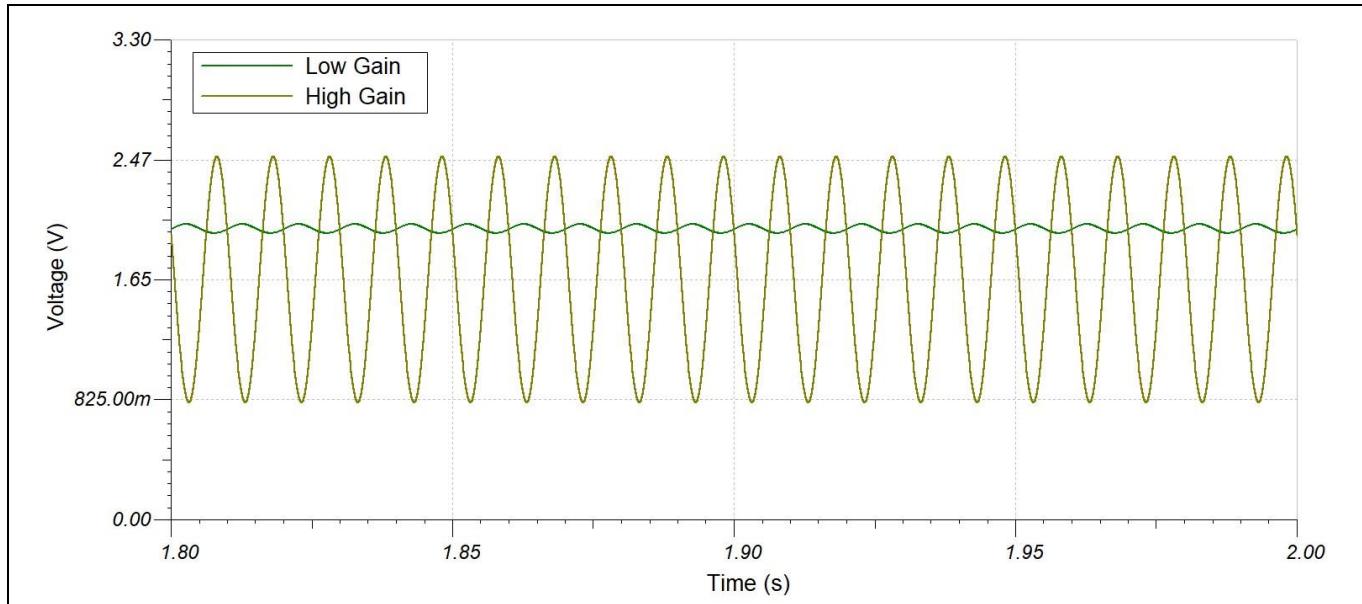


Figure 17 IF low-gain and high-gain signals for an input of 100 Hz, 1 mV input signal

As shown in Figure 18, the first gain stage provides a gain of 29.5 dB (low-gain stage) and both the stages together provide a gain of 59 dB (high-gain stage).

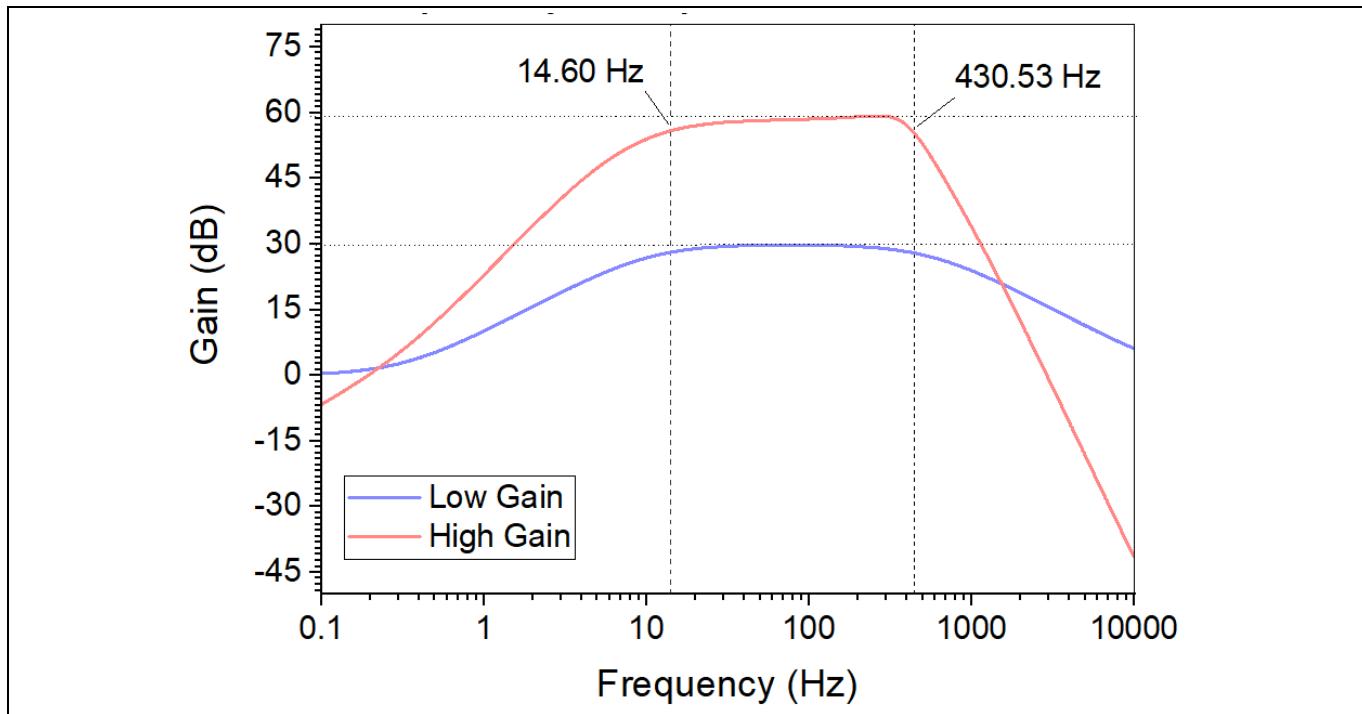


Figure 18 Baseband frequency response for low-gain and high-gain stages

Figure 18 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

Hardware description: BGT24LTR11 Shield

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 XMC4700) 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 amplifiers 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 are fixed and can be manually configured by the user by changing the resistor and capacitor values specified in Table 3. In addition to Table 3, AC coupling by C27 and the input impedance of the I_multiple feedback filter (MFB LP by the second stage) form the second high-pass for the I-channel. For the Q-channel contributors are C29 and the input impedance (Q_MFB low-pass).

Table 3 Baseband amplifier components and settings

IF stage	Designator	Gain	Configurable components – I section	Configurable components – Q section
Stage 1 (low gain)	U5A	29.5 dB	C16, R33, C17, R36	C37, R65, C35, R61
Stage 1 + Stage 2 (high gain)	U5A + U4A	59 dB	All components as mentioned for Stage 1 + R49, R50, R32, C24, C24	All components as mentioned for Stage 1 + R55, R56, C34, R63, C33

4.9.1 Baseband amplifier settings for Doppler radar

The baseband section should be configured accordingly to provide sufficient gain at these frequencies. The cut-off frequencies of the baseband section are 18 to 420 Hz.

The Doppler frequency $f_{Doppler}$ is calculated using the following formula:

$$f_{Doppler}(\text{Hz}) = \frac{2v}{\lambda}$$

Where v = speed of the target (m/s)

λ = wavelength (m)

Table 4 shows the calculated Doppler frequency values for different target speeds for the 24 GHz radar module.

Table 4 Doppler shift frequencies for different speeds using 24 GHz radar

Speed (km/h)	0.5	1	2	4	6	8	10	12
Doppler shift (Hz)	22	44	89	178	268	357	446	536

System configuration and parameters

5 System configuration and parameters

Figure 19 shows the configuration of a frame. Each frame is a series of pulses, followed by a frame off-time.

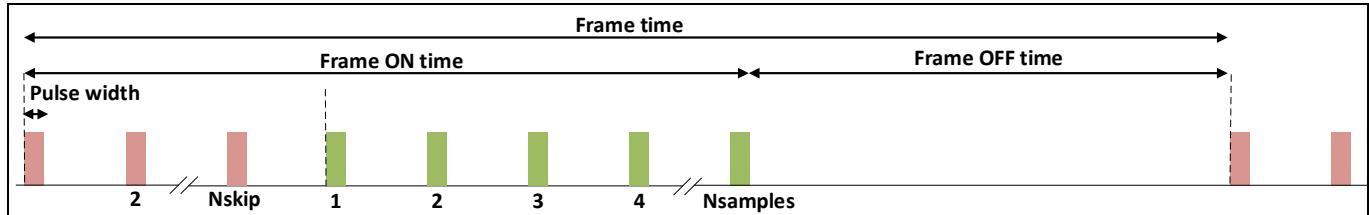


Figure 19 Frame structure and terminology

The steps below explain the design and calculations for the system:

$$f_{Doppler} = 2 * v_{moving\ target} * \cos(\theta) * \frac{f_{Transmitted}}{c}$$

$$\frac{1}{\lambda} = \frac{f_{Transmitted}}{c}$$

1. Select v_{max} (m/s) to determine maximum Doppler frequency:

$$f_{ifmax} = f_{Dopplermax} = \frac{2 \cdot v_{max}}{\lambda}$$

2. Select v_{min} (m/s) to determine minimum Doppler frequency:

$$f_{ifmin} = f_{Dopplermin} = \frac{2 \cdot v_{min}}{\lambda}$$

These f_{ifmin} and f_{ifmax} values are the cut-off frequencies for the baseband section.

3. Determine the minimum sampling frequency and Pulse Repetition Time (PRT).

The required sampling frequency depends on the maximum targeted baseband frequency and on the required over-sampling (minimum factor 2) to get more headroom for the real anti-aliasing filter.

$$f_{sampling} \geq 2f_{ifmax}$$

$$PRT = \frac{1}{f_{sampling}}$$

4. Determine the minimum number of samples per frame (Nsamples):

$$N_{samples} \geq \frac{f_{sampling}}{f_{ifmin}}, \text{ rounded to the next power of 2}$$

5. Determine the minimum frame on-time:

System configuration and parameters

$$\text{Frame ON time} = \frac{N_{\text{skip}} + N_{\text{samples}}}{f_{\text{sampling}}} = (N_{\text{skip}} + N_{\text{samples}}) \cdot \text{PRT}$$

Sample skip count (N_{skip}) is the number of samples to be skipped at the beginning of each frame to get rid of the DC offset in the I/Q signals generated in the pulse interval time. These samples are completely disregarded in the signal processing chain.

6. Select frame time or update rate:

$$\frac{1}{\text{Frame rate}} \geq \text{Frame time} \geq \text{Frame ON time}$$

Table 5 System parameters, symbols and units

Symbol	Parameter	Unit
λ	Wavelength	mm
$f_{\text{transmitted}}$	Transmit frequency	GHz
c	Speed of light	m/s
v_{max}	Maximum speed to be detected	m/s
v_{min}	Minimum speed to be detected	m/s
f_{IFmax}	Max. IF freq. (max. Doppler frequency)	Hz
f_{IFmin}	Min. IF freq. (min. Doppler frequency)	Hz
f_{sampling}	Sampling frequency	Hz
PRT	Pulse repetition time	μs
N_{samples}	No. of samples per frame	-
N_{skip}	No. of samples to be skipped per frame	-
Frame on-time	Duration in which pulses are generated	ms
Frame time	Total frame time	ms
Frame rate	No. of frames per second	Hz
Pulse width	Width of each pulse	μs

System configuration and parameters

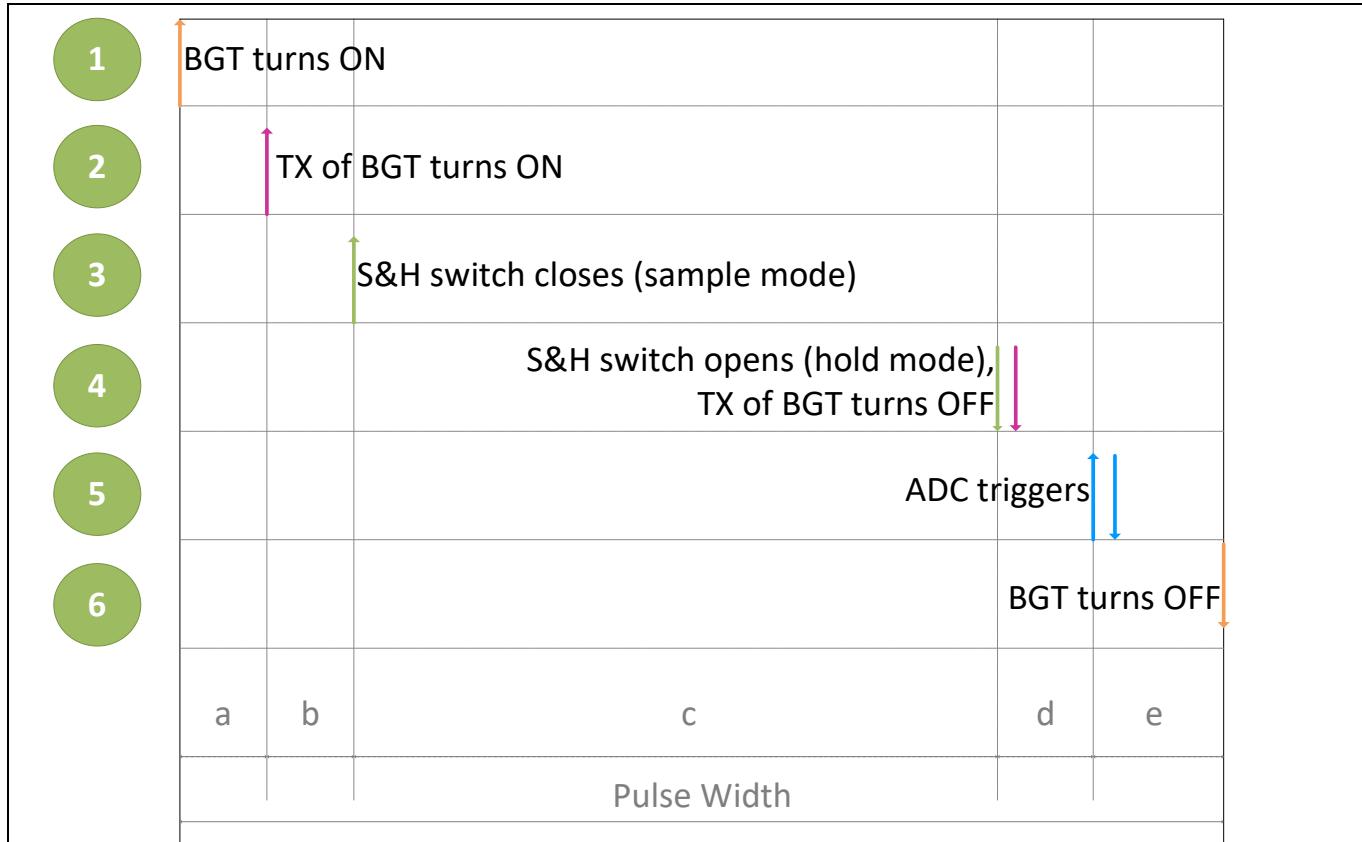


Figure 20 Pulse timing configuration

Figure 20 shows the pulse timing configuration and the steps in which the actions occur. The timings a, b, d and e remain fixed. If the pulse width is increased or decreased, the S&H time (c) is increased or decreased, which in turn affects the on-time of the BGT24LTR11 MMIC. For more timing information, refer to the Software User Manual.

Power consumption analysis

6 Power consumption analysis

The BGT24LTR11 Shield is designed for low power consumption.

- The MMIC is turned on only during the “pulse width” duration and remains off for the remaining time in the frame.
- The PTAT of the MMIC is turned on 1 ms before the start of the first pulse of the frame and then remains on for the frame on-time. This is done to make sure the V_PTAT voltage settles to keep the VCO at the center frequency before the pulses start. It is a key step to avoid out-of-band emissions.
- The baseband section consists of the two stages of operational amplifiers and the voltage divider to generate 1.65 V. This section remains on for the entire frame.

As shown in Table 6, the major contributors to the power consumption are BGT24LTR11 and PTAT. The overall power consumption can be optimized by varying $N_{samples}$, pulse width and frame time.

Table 6 Power consumption overview

Component	Current consumption (mA)	On-time
BGT24LTR11	45	$N_{samples} * \text{pulse width}$
PTAT	1.5	Frame on-time + 1 ms
Baseband section (op-amps and voltage divider)	0.335	Frame time

In default settings (frame time: 150 ms, pulse width: 5 μ s, $N_{samples}$: 128, N_{skip} : 100), the power consumption is 1.8 mA. Figure 22 shows the oscilloscope plot for the default settings.

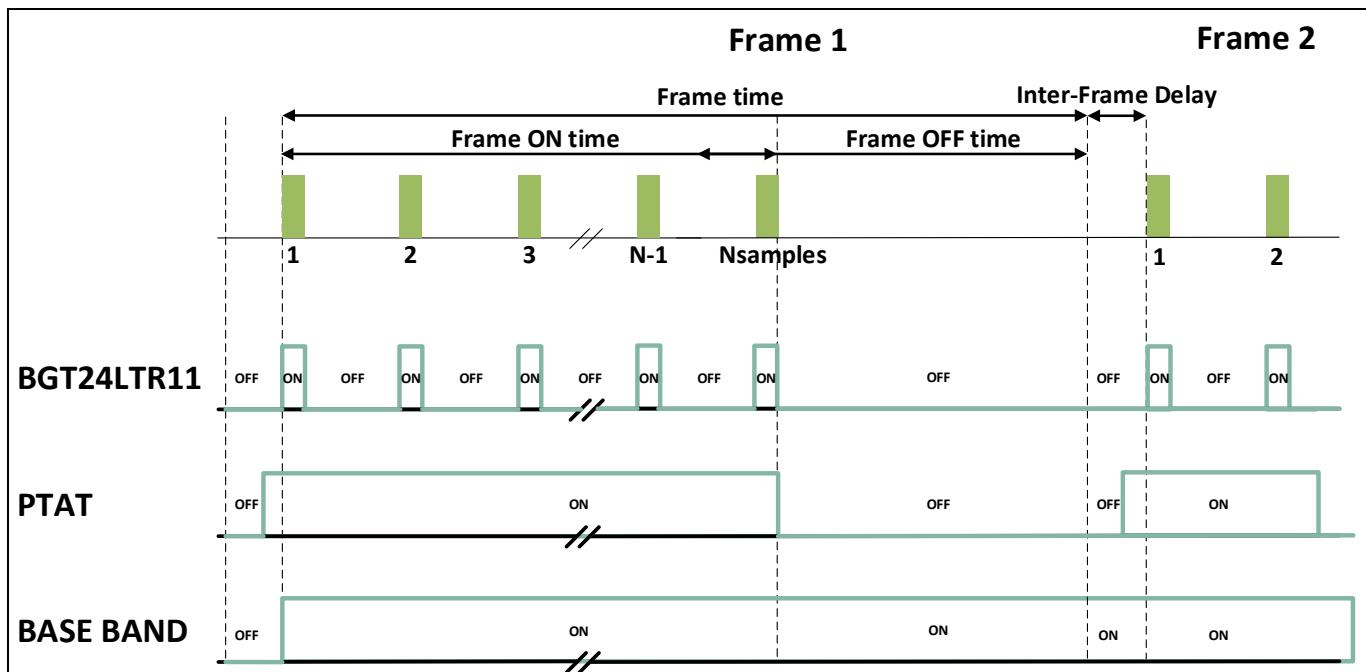


Figure 21 On/off timing diagram for BGT24LTR11, PTAT and baseband section

Power consumption analysis



Figure 22 On/ff timing diagram – Oscilloscope plot

External pin header connectors

7 External pin header connectors

The BGT24LTR11 Shield has the provision to connect multiple headers on the edge of the board. Figure 23 shows the pin headers on the PCB, and Table 7, Table 8, Table 9, Table 10 and Table 11 describe the pins.

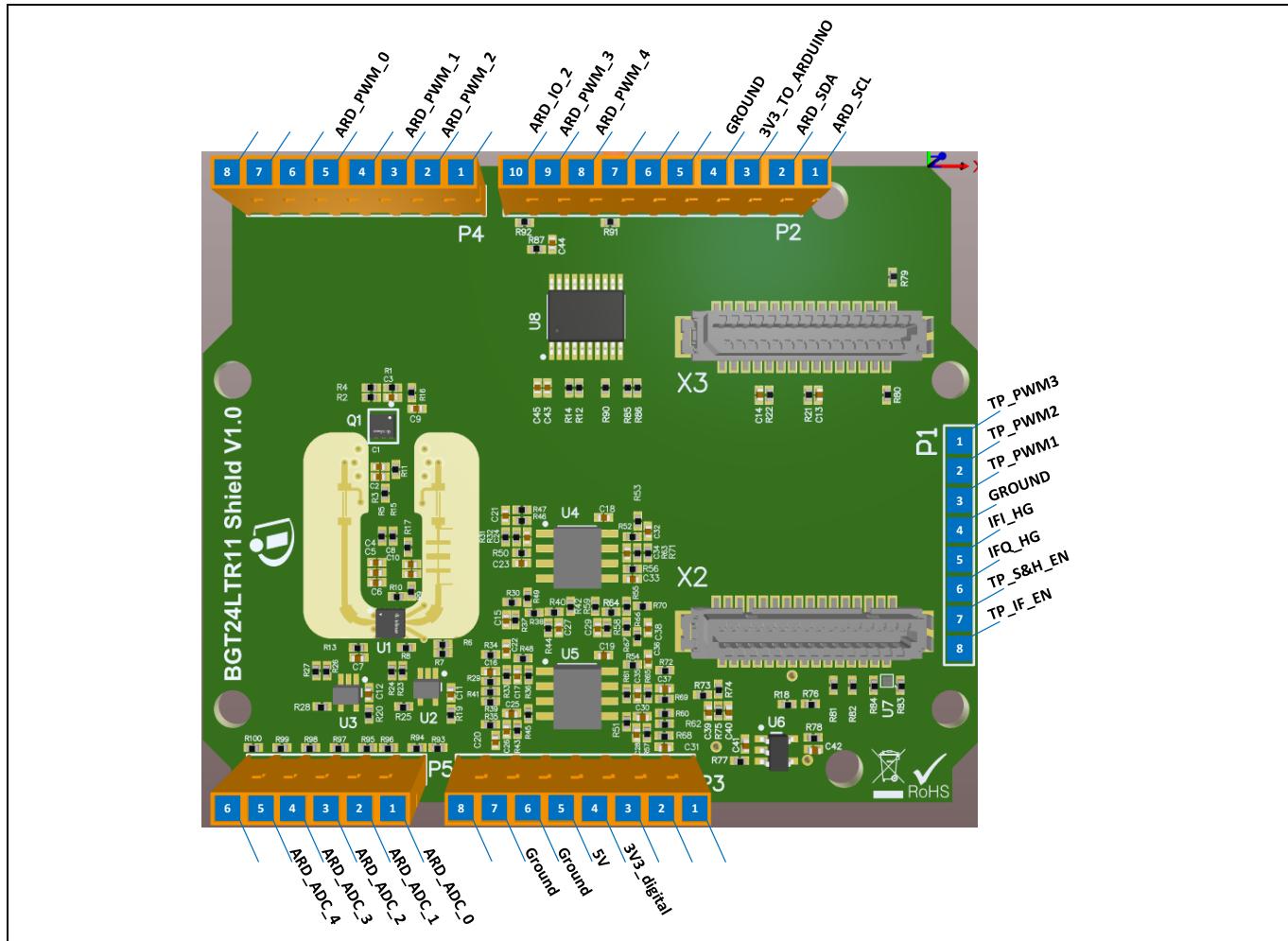


Figure 23 External headers – P1, P2, P3, P4 and P5

Table 7 External headers (P1) – pin description

Pin no.	Signal name	Pin description
1	TP_PWM3	Control signal for VCC_PTAT pin of MMIC
2	TP_PWM2	Control signal for TX_ON pin of MMIC
3	TP_PWM1	Control signal for Q1 PMOS switch to turn MMIC on/off
4	GND	Ground
5	IFI_HG	Second baseband amplifier stage output for IFI signal
6	IFQ_HG	Second baseband amplifier stage output for IFQ signal
7	TP_S&H_EN	Control signal for S&H (SPST) switches

Table 8 External headers (P2) – pin description

Pin no.	Signal name	Pin description
1	ARD_SCL	(I2C_EEPROM.SCL) serial clock input of the EEPROM

External pin header connectors

Pin no.	Signal name	Pin description
2	ARD_SDA	(I2C_EEPROM.SDA) serial data pin of the EEPROM
3	3V3_to_ARDUINO	3.3 V power supply to Arduino
4	Ground	Ground
9	ARD_PWM_3	S&H_EN control signal to turn the SPST switches on/off

Table 9 External headers (P3) – pin description

Pin no.	Signal name	Pin description
4	3V3_digital	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_2	VCC_PTAT_On control signal to turn PTAT on/off
3	ARD_PWM_1	TX_ON control signal for turning the TX of BGT24LTR11 on/off
5	ARD_PWM_0	VCC_ON 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_LG	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_LG	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	VTUNE_St_FMCW signal for stepped FMCW implementation
4	ARD_ADC_3	DIVOUT_St_FMCW signal for stepped FMCW implementation
5	ARD_ADC_4	V_PTAT output from BGT24LTR11

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 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.

Use cases and applications

8 Use cases and applications

8.1 Human walking detection

The system is capable of detecting a single target walking in front of the radar within a distance of 15 m. This can address various indoor and outdoor applications, including:

- smart door openers based on direction of movement (Figure 25)
- security camera activation when a human is approaching
- smart device activation when a human is approaching
- smart toilet automatic flushing when a human is departing.

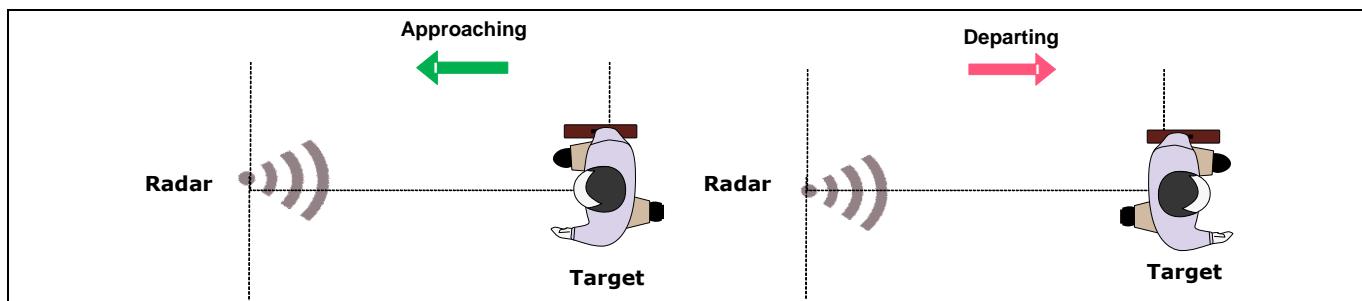


Figure 24 Human walking - use-case visualization

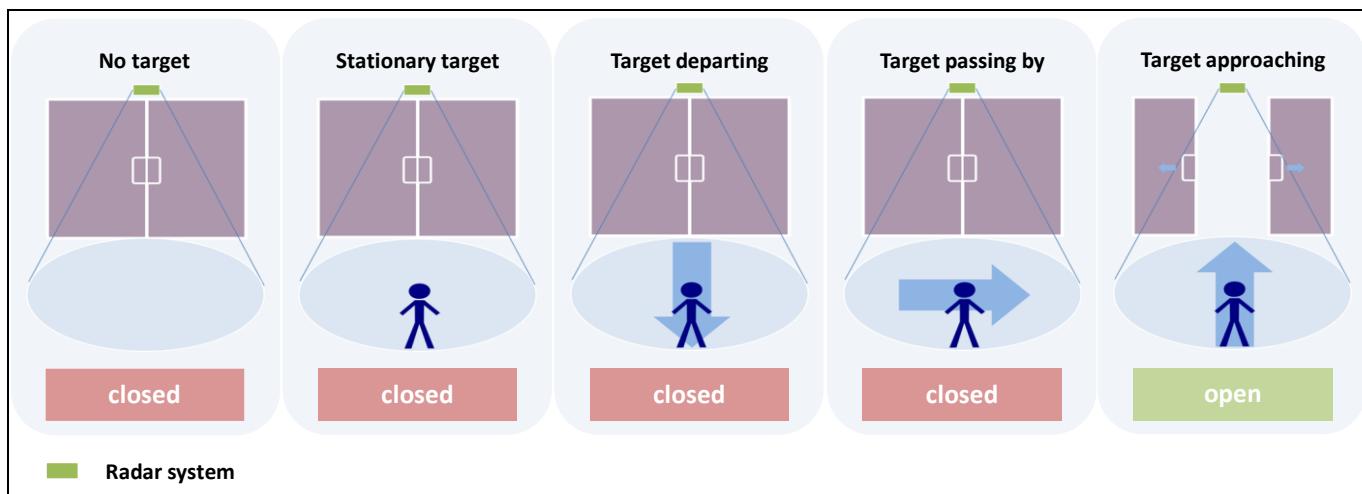


Figure 25 Smart door opener - use-case visualization

Since the sensor can determine the direction of movement, it reduces the false alarms caused by regular motion triggered sensors (like PIR). Moreover, it can be hidden in the end application as it senses through non-metallic materials.

Table 12 Recommended settings for human motion detection

Parameter	Value	Comment
No. of samples per frame	≥ 128	Power of 2
Sampling frequency	≥ 1000 Hz	Based on max speed
Pulse width	Greater than or equal to $4 \mu\text{s}$	-
Frame rate	Greater than or equal to ≥ 2 Hz	i.e., Frame time ≤ 500 ms

Measurement results

9 Measurement results

9.1 Velocity detection

Speed measurements were performed using a Doppler simulator and the Sense2GoL Pulse system for both approaching and departing configurations. The results can be seen in Figure 26.

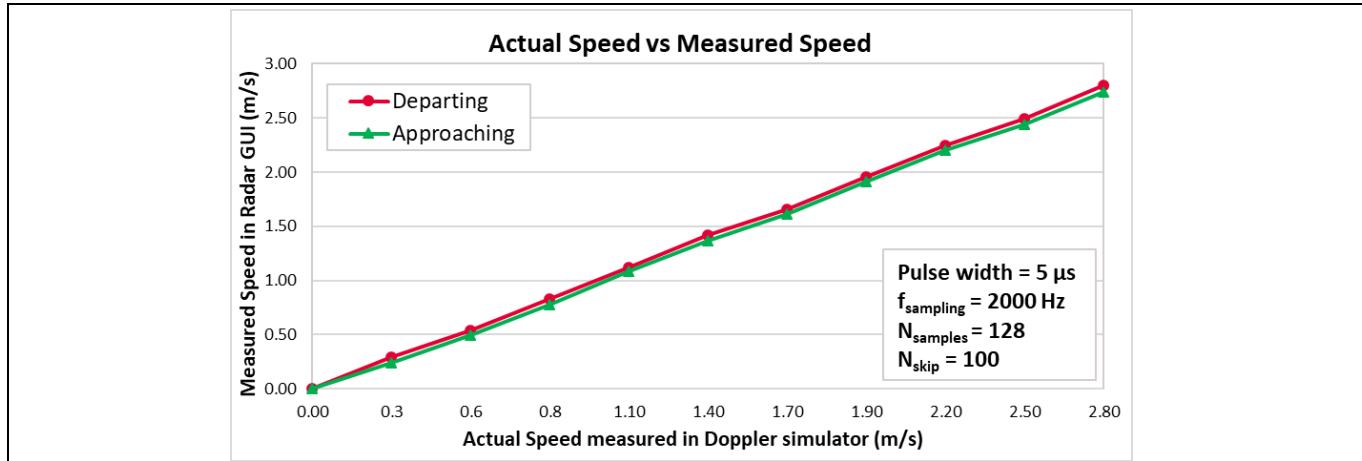


Figure 26 Speed measurements (Doppler simulator vs radar)

The system is able to detect speeds between 0.1 and 3 m/s for the settings mentioned. For human targets, the module is able to detect movement up to 18 m range.

9.2 Human movement detection

The system is designed for use cases like presence detection, motion and direction of movement detection for a single human target. It enables detection of a human walking within a distance of 18 m in an indoor or outdoor environment. Figure 27 shows the detection range for a human target with respect to the field of view.

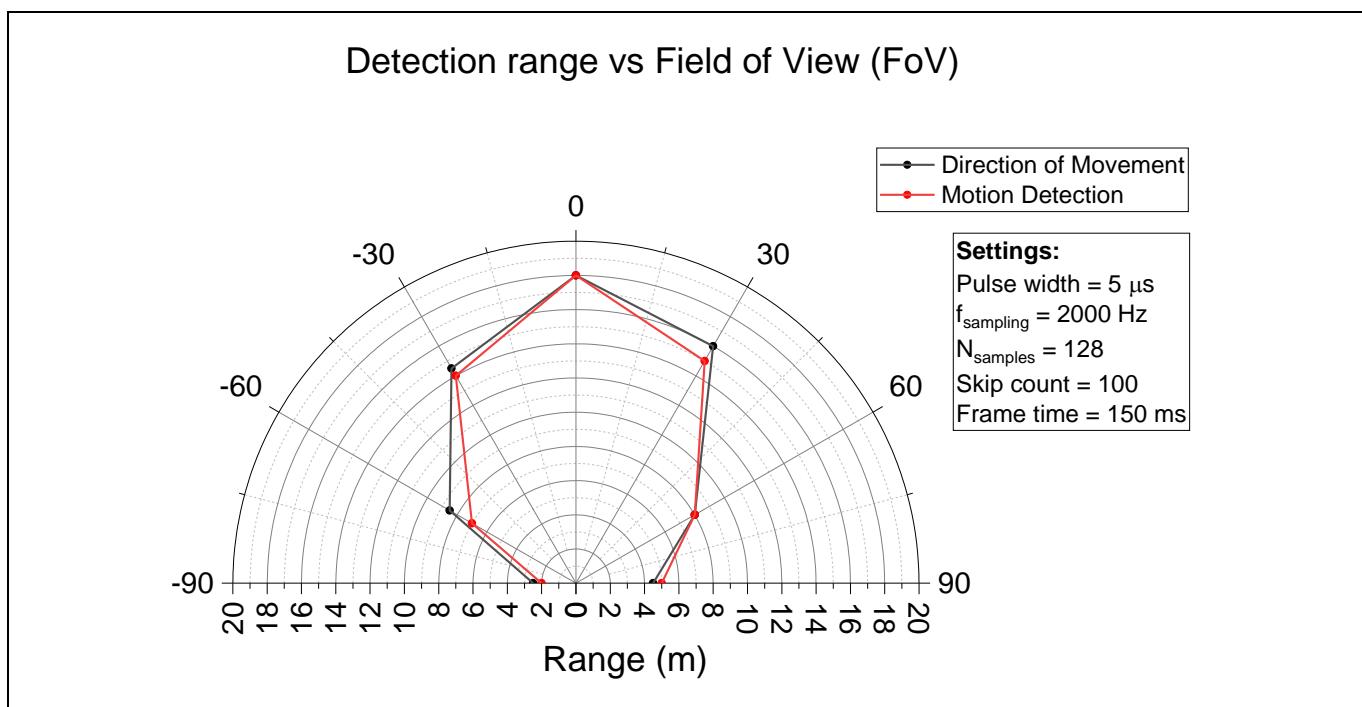


Figure 27 Human target detection range with respect to Field of View (FoV)

Frequency band and regulations

10 Frequency band and regulations

10.1 24 GHz regulations

Infineon's BGT24LTR11 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 deviating regulations in term 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.

10.2 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.

10.3 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](#).

Authors

11 Authors

Arushi Jain, Senior System Application Engineer, Business Line “Radio Frequency and Sensors”

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- [2] Infineon BGT24LTR11 – [product brief](#)
- [3] Infineon application note – [AN472 – “user’s guide to BGT24LTR11N16”](#)
- [4] 24 GHz industrial radar – [FAQs](#)
- [5] ETSI regulations – [EN 300 440 V2.2.1](#)
- [6] FCC regulations – [15.245](#), [15.249](#)

Revision history

Revision history

Document version	Date of release	Description of changes
V1.0	2020-02-17	Initial version

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