

DEMO SENSE2GOL PULSE Software Guide

XENSIV™ 24 GHz radar

Board version V3.0

About this document

Scope and purpose

This user manual describes the firmware, supported algorithms and the development recommendations required to build an application around Infineon's DEMO SENSE2GOL PULSE board.

It describes the demonstration applications of the Sense2GoL Pulse radar demo board based on the XENSIV™ 24 GHz BGT24LTR11 radar MMIC, with details of package architecture and contents.

This document provides guidelines for novice users on how to build and run Sense2GoL Pulse radar applications such as motion detection, presence sensing, speed detection and direction of movement (approaching or departing), and also to support ease-of-use and faster-to-market integration.

Intended audience

This document is intended for users of the Sense2GoL Pulse demo board who want to get started with Infineon's Sense2GoL Pulse firmware solution, test several sensing demonstrations, and implement custom radar applications in the 24 GHz industrial, scientific and medical (ISM) band.

Table of contents

About this document.....	1
Table of contents.....	2
List of figures	3
List of tables	4
1 Introduction	5
2 Basic radar Doppler concepts	6
3 Hardware overview	7
3.1 Sense2GoL Pulse	7
3.2 Radar Baseboard MCU4	7
3.3 BGT24LTR11 shield.....	9
4 Firmware description	11
4.1 Overview	11
4.2 Global architecture.....	11
4.3 Firmware concept	13
4.4 Raw data acquisition.....	14
4.4.1 Doppler pulse generation	14
4.4.2 Data sampling	17
4.5 Radar control layer.....	19
4.5.1 Radar control APIs.....	19
4.5.2 Data store module.....	19
4.5.3 Data store and EEPROM management.....	21
4.6 DAVE™ project overview.....	22
4.7 Firmware package overview	24
4.8 Footprint.....	25
4.9 Firmware timings	26
4.10 Firmware customization and configuration.....	27
5 Algorithm description	29
6 Authors	30
7 References	31
Revision history.....	32

List of figures

Figure 1	Doppler effect.....	6
Figure 2	Sense2GoL Pulse hardware platform	7
Figure 3	Radar Baseboard MCU4	8
Figure 4	XMC4700 block diagram.....	9
Figure 5	BGT24LTR11 shield board.....	10
Figure 6	Firmware architecture.....	11
Figure 7	Firmware flow diagram	13
Figure 8	Raw data acquisition flow diagram	14
Figure 9	All control signals	15
Figure 10	Pulse generation	16
Figure 11	Frame structure and terminology	16
Figure 12	Sense2GoL Pulse data acquisition and sampling flow	17
Figure 13	Data acquisition flow diagram.....	18
Figure 14	Interconnection of the data store module with other firmware modules.....	20
Figure 15	EEPROM block diagram.....	21
Figure 16	EEPROM structure	21
Figure 17	ADC DAVE™ app configuration	23
Figure 18	DMA DAVE™ app configuration	24
Figure 19	Package folder structure.....	24
Figure 20	Raw data acquisition timings	26
Figure 21	Motion and movement detection algorithm flow	29

List of tables

Table 1	Sense2GoL Pulse control and data signals description.....	14
Table 2	Data store hardware device and algorithm settings structures.....	19
Table 3	DAVE™ project apps used.....	22
Table 4	PWM and GPIO pin configurations.....	22
Table 5	Sense2GoL Pulse firmware footprint.....	25
Table 6	Define statements used for radar firmware configuration.....	27

1 Introduction

The Sense2GoL Pulse (S2GLP) radar demo board is a demonstration platform for Infineon's silicon-germanium 24 GHz radar chipset BGT24LTR11. It consists of two boards: the main Radar Baseboard MCU4 and a radar front-end board BGT24LTR11 shield.

This document focuses on the demonstration firmware and the Graphical User Interface (GUI) for a **Pulsed Doppler** radar implementation.

The Sense2GoL Pulse board is designed to evaluate the capabilities of the BGT24LTR11 MMIC, comprising one transmit and one receive channel with the XMC4700 microcontroller utilizing Infineon's powerful, free-of-charge toolchain DAVE™ for microcontroller programming

2 Basic radar Doppler concepts

The main radar technique used for this demonstration is Continuous Wave (CW/Doppler) radar.

Doppler radar operates on the principle of sending a beam of electromagnetic radiation waves, tuned to a precise frequency, toward a moving object. When the electromagnetic radiation wave hits the moving object, it “bounces” back toward the source, which also contains a receiver. However, since the wave is reflected off a moving object, the wave is shifted as outlined by the Doppler effect.

The wave that is coming back toward the radar is treated as an entirely new wave, as if it were emitted by the target it bounced off. The target is acting like a new source for this new wave. When it is received at the radar, this wave has a frequency different from the frequency that was originally sent toward the target.

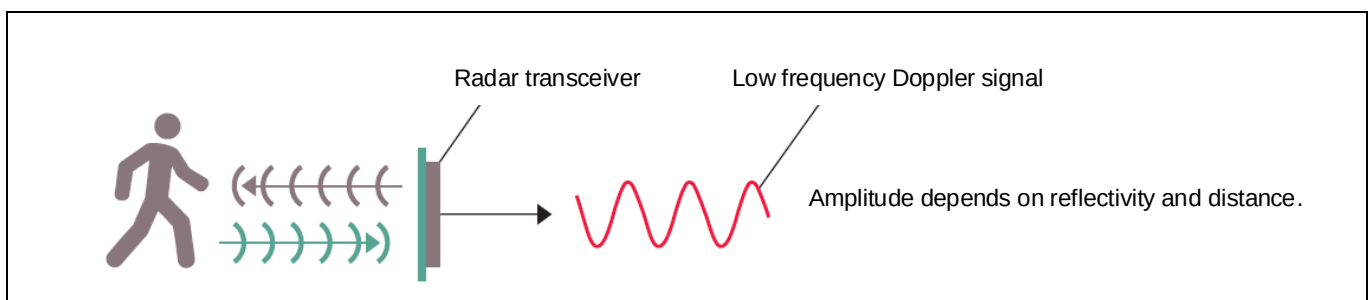


Figure 1 Doppler effect

As the electromagnetic radiation was at a precise frequency when sent out and is at a new frequency on its return, this can be used to calculate the velocity v of the target.

The Doppler effect shifts the received frequency up or down based on the radial velocity of the target (closing or opening) in the beam, allowing for the direct and highly accurate measurement of target velocity.

Doppler shift f_d and velocity v are dependent on each other according to the following equations:

$$f_d = \frac{2 \cdot f_{Tx} \cdot v}{c} \cdot \cos \alpha$$

$$v = \frac{c \cdot f_d}{2 \cdot f_{Tx} \cdot \cos \alpha}$$

f_d : Doppler frequency [Hz]

f_{Tx} : Carrier frequency (24.0 x 10⁹ Hz)

v : Object velocity [m/s]

c : Speed of light in vacuum (3 x 10⁸ m/s)

α : Angle between beam center and target moving direction

3 Hardware overview

The Sense2GoL Pulse radar system is a demonstration platform for Infineon's 24 GHz BGT24LTR11 radar chipset. It consists of two boards: the Radar Baseboard MCU4 and a radar front-end board, BGT24LTR11 shield.

3.1 Sense2GoL Pulse

Figure 2 shows the Sense2GoL Pulse radar system hardware platform. The BGT24LTR11 shield should be plugged into the bottom side of the Radar Baseboard MCU4 using the two connectors X2 and X3.

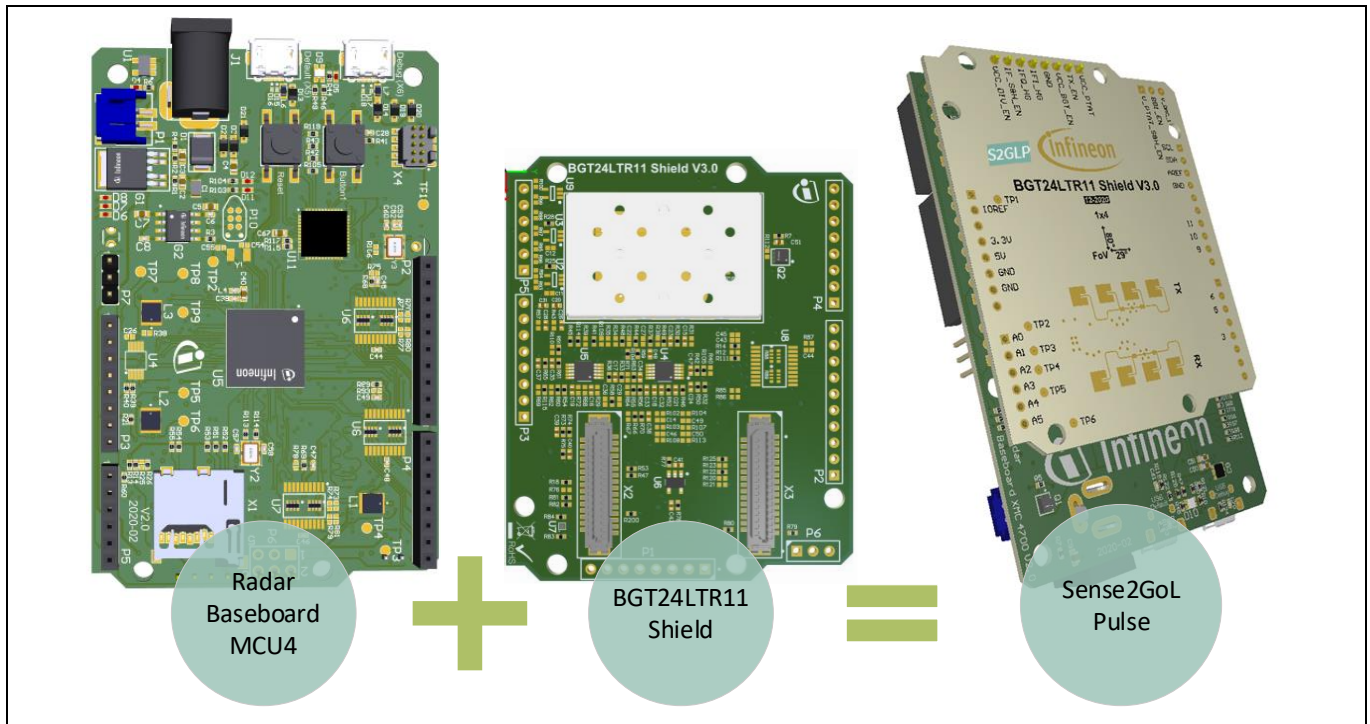


Figure 2 Sense2GoL Pulse hardware platform

Note: The BGT24LTR11 shield in Sense2GoL Pulse platform is assembled for Pulsed Doppler operation.

3.2 Radar Baseboard MCU4

The Radar Baseboard MCU4 is a generic sensor interface for Infineon's 24 GHz radar sensors. The central unit of the XMC4700 32-bit Arm® Cortex®-M4 based microcontroller can perform radar data processing or forward the sensor data to a USB interface, a serial interface or an Arduino interface. The board is designed to enable customers to carry out prototyping and system integrations, as well as initial product feature evaluations.

An onboard debugger with licensed firmware from SEGGER allows easy debugging over USB. Infineon's powerful, free-of-charge toolchain DAVE™ can be used for programming the XMC4700 microcontroller. This user manual describes the key features and hardware configuration of the Radar Baseboard MCU4 in detail. Figure 2 shows the Radar Baseboard MCU4 hardware platform.

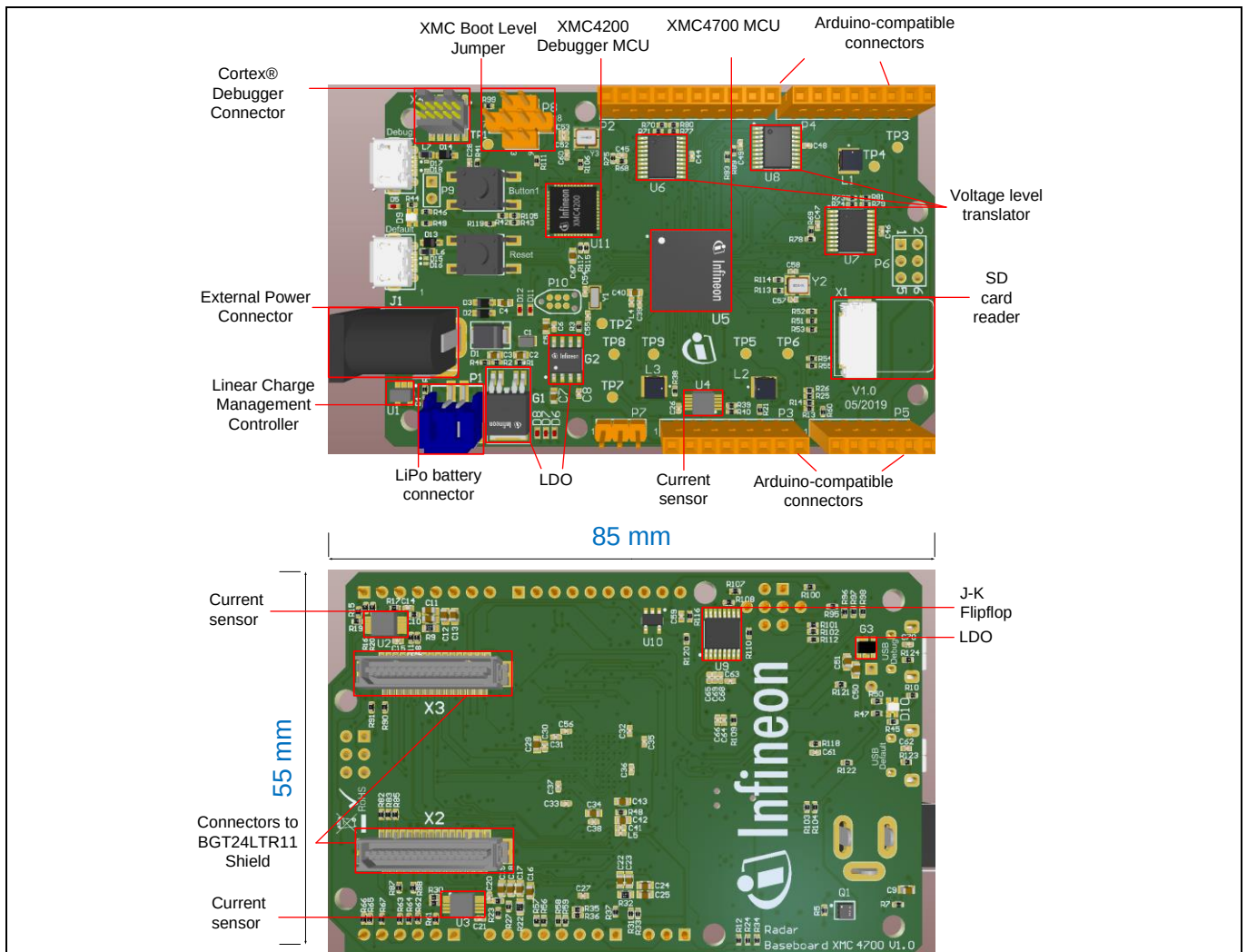


Figure 3 Radar Baseboard MCU4

The Radar Baseboard MCU4 embeds Infineon's XMC4700, 32-bit Arm® Cortex®-M4 based microcontroller. It can be used to perform radar data processing, configure the board's peripherals and RF shield management, and enable radar data communication via a USB or serial interface.

The Sense2GoL Pulse firmware is running in the XMC4700 microcontroller and configures the following peripherals:

- Analog-to-Digital Converter (ADC)
- Direct Memory Access (DMA)
- General-Purpose Input Output (GPIO)
- USIC for I²C serial interface
- CCU8/4 for timer and PWM control signals
- Capture and Compare Unit (CCU)
- Hardware interrupts
- USB interface for host communication

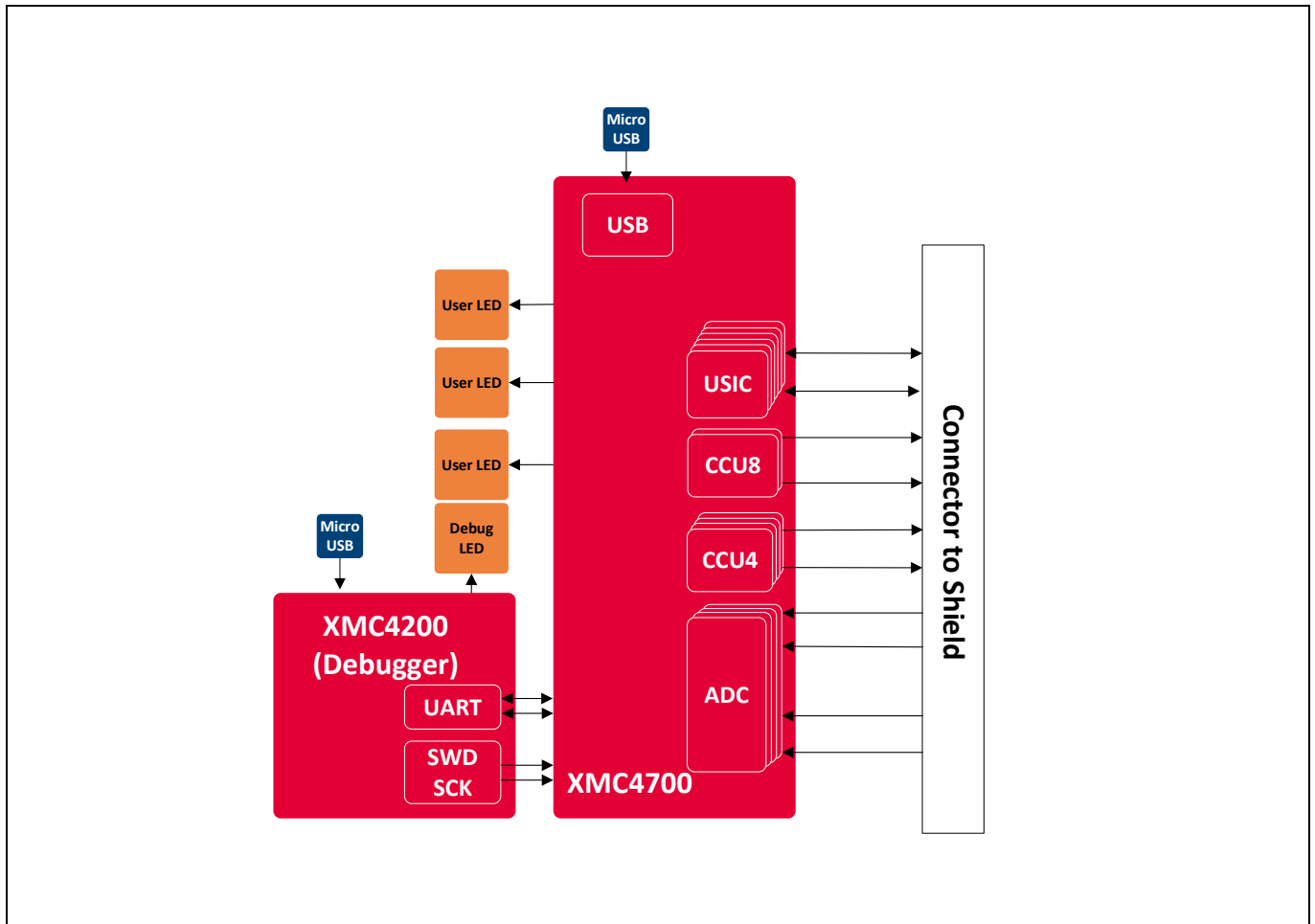


Figure 4 XMC4700 block diagram

3.3 BGT24LTR11 shield

This section gives an overview of the **BGT24LTR11 shield** hardware platform. More detailed information can be found in the corresponding application note.

The radar shield is shown in Figure 5. It contains the following:

- 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 a control signal from the microcontroller.
- Analog amplifier part: consists of two amplifier stages, used to smooth the sampled I/Q signals from S&H circuitry and amplify them for the digital part.
- EEPROM part: can be used to store data such as board identifier information, and RF shield hardware settings.

DEMO SENSE2GOL PULSE Software Guide

XENSIV™ 24 GHz radar

Hardware overview

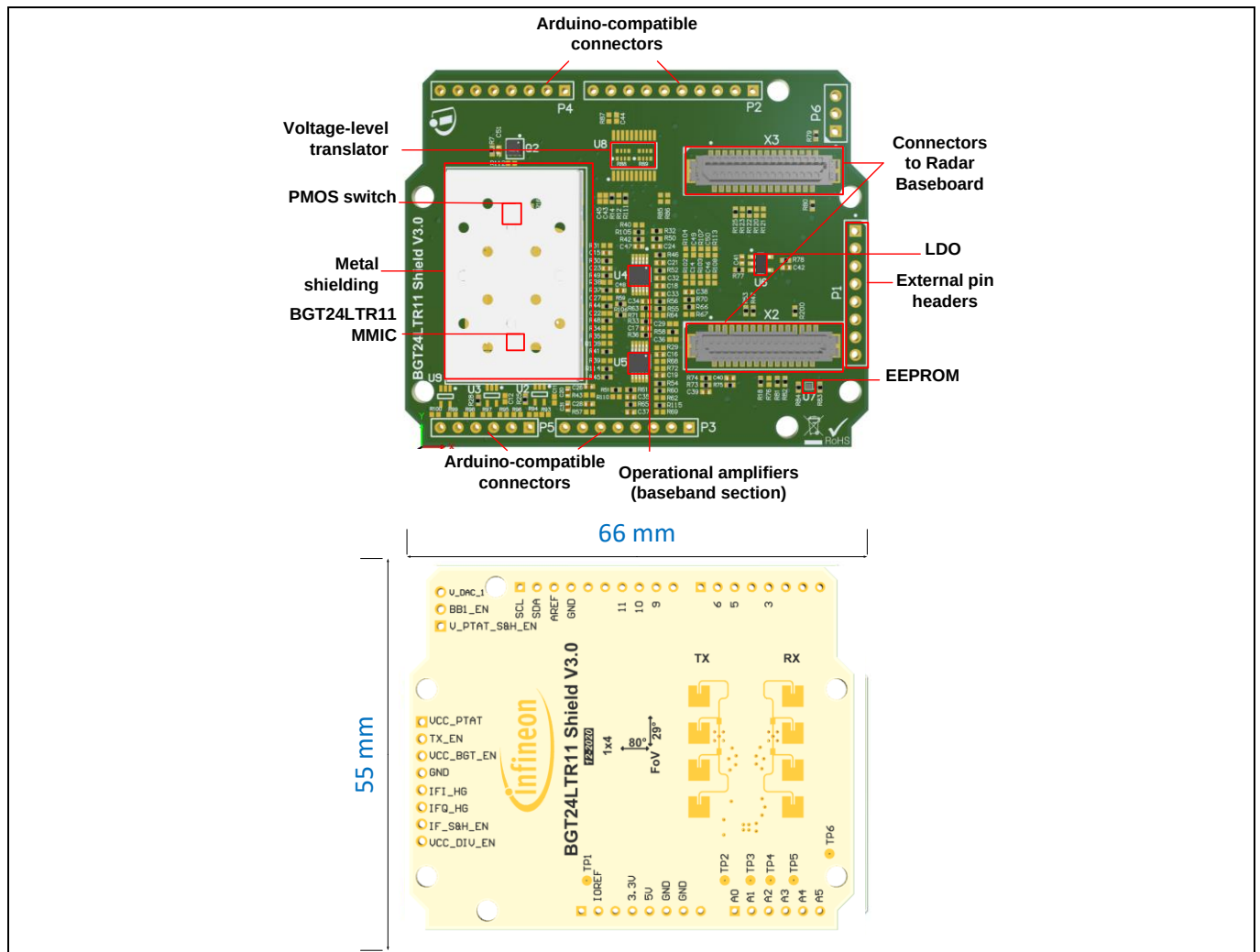


Figure 5 BGT24LTR11 shield board

4 Firmware description

4.1 Overview

The Sense2GoL Pulse firmware is a piece of software written in C language to control different ICs and peripherals via the host processor, which is the XMC4700 32-bit Arm® Cortex®-M4 MCU in the Radar Baseboard MCU4.

The Sense2GoL Pulse firmware is developed with Infineon's DAVE™4 (Digital Application Virtual Engineer), a free development toolchain. It is a C/C++-language software development and code-generation tool for XMC™ microcontroller applications. It is based on graphical user interface (GUI) apps to configure the MCU peripherals (ADC, DMA, CCU4...), which reduces development time and allows for quick porting of the firmware across XMC™-series MCUs.

The Sense2GoL Pulse firmware includes various radar demonstration applications to demonstrate the Sense2GoL Pulse board's capabilities and facilitate the development of user applications, and that can be used for:

- motion detection
- presence sensing
- speed detection and direction of movement, approaching or retreating.

4.2 Global architecture

This section describes the software components of the Sense2GoL Pulse firmware illustrated in Figure 6.

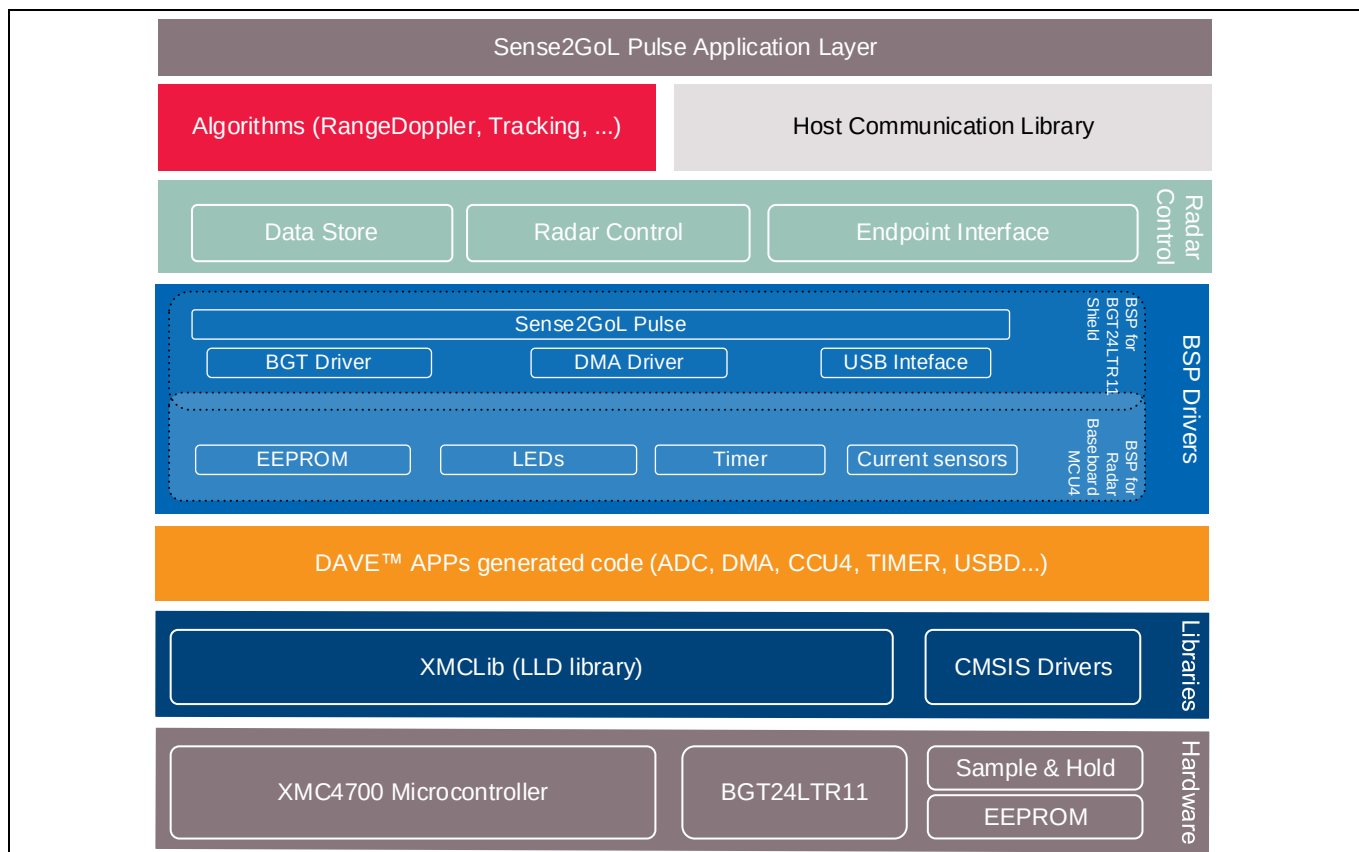


Figure 6 Firmware architecture

- **Sense2GoL Pulse application layer** – a customer-specific layer that defines the entry point of the Sense2GoL Pulse demonstration platform, and contains:
 - the initialization functions for XMC™ peripherals, host communication library and radar control layer
 - the main application state machine
 - a function template for the user to add their own code (data acquisition callbacks, algorithms process...)
- **Algorithms** – contains the supported algorithms by the Sense2GoL Pulse demonstration platform implementations, e.g. range Doppler, presence sensing... used for processing and calculating information out of radar raw data in order to detect stationary and moving objects (refer to the Algorithm description section for more details).
- **Communication library** – contains a set of functions to ensure USB data communication between the Sense2GoL Pulse board and the Radar GUI tool:
 - defines all communication endpoints
 - contains communication endpoint settings and configurations
 - contains a protocol communication layer.
- **Radar control layer** – contains high-level functions that can be used to set the specific mode for the Sense2GoL Pulse board, basically classified into three categories:
 - **radar control** – offers high-level radar services to the user application and host communication library layers, e.g. radar device initialization, radar start, radar stop, set/get calibration...
 - **data store** – contains global structures for hardware settings and algorithms configuration
 - **endpoint interface** – ensures communication between the host communication library and radar control layer.
- **BSP driver** – the Board Support Package (BSP) driver is a set of functions that can be used to control and manage all components embedded in the Sense2GoL Pulse board, and it contains:
 - low-layer functions to initialize and control the specific board features (BGT24LTR11, Sample and Hold (S&H), EEPROM, current sensors...)
 - functions to control power-up and power-down sequences for all hardware components
 - functions to manage the data acquisition process from BGT to XMC™ microcontroller internal RAM memory (DMA, timer, ADC).
- **DAVE™ apps generated code** – contains the generated library sources from DAVE™-configured building-block apps for XMC4700 MCU peripherals. It contains Application Program Interfaces (APIs) and data structures meant to be used in application code.
- **Libraries** – contains the following libraries:
 - **CMSIS** – Cortex® Microcontroller Software Interface Standard (CMSIS) is a vendor-independent hardware abstraction layer for the Cortex®-M processor series and defines generic tool interfaces. The CMSIS enables consistent device support and establishes simple software interfaces to the

processor and the peripherals, simplifying software reuse, reducing the learning curve for microcontroller developers, and reducing the time-to-market for new devices.

- **XMC-Lib** – consists of various low-level drivers for the XMC™ microcontroller's family peripherals. Each driver consists of a set of routines and data structures covering all peripheral functionalities. Built on top of the CMSIS, it provides access to all XMC4000 peripheral features.

4.3 Firmware concept

Sense2GoL Pulse firmware can be divided into repetitive and non-repetitive tasks. After device initialization, control resides in the main loop, where two possible events can trigger further processing:

- frame timer interrupt
- GUI request by the host communication protocol.

A task-level flow diagram of the firmware is shown in Figure 7.

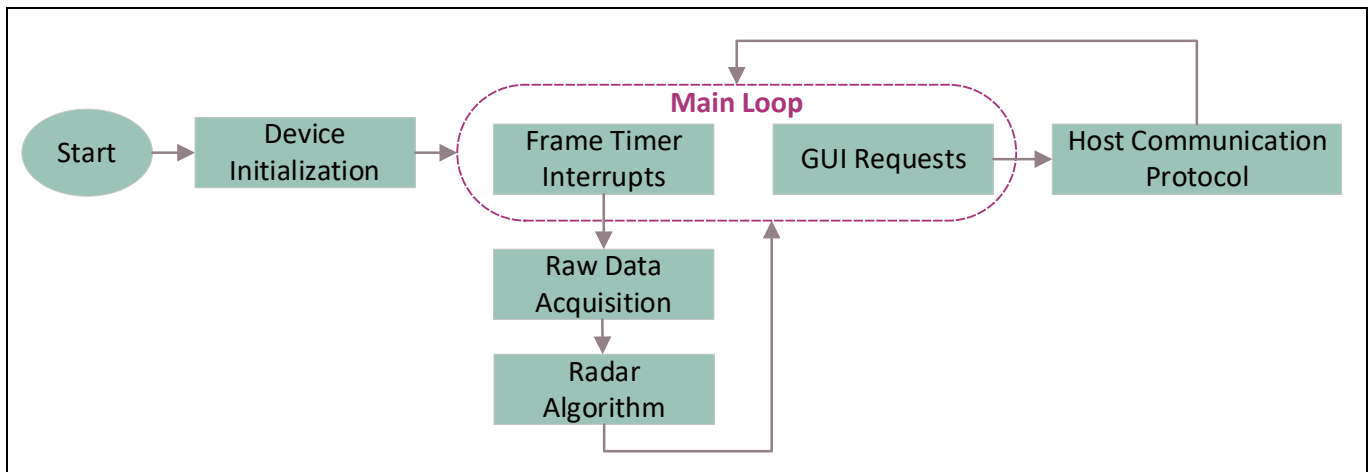


Figure 7 Firmware flow diagram

- **Device initialization** – this is the first task to be executed, only once when the firmware is started. During this task, the firmware initializes XMC™ peripherals and the Sense2GoL Pulse radar device, then registers the endpoints used for the host communication. Program control then goes to the main loop.
- **Frame timer interrupt** – this is a periodic hardware timer interrupt, which triggers the start of the new frame raw data acquisition process.
- **Raw data acquisition** – the BSP layer is configured to start collecting raw data from the radar device.
- **Radar algorithm** – once raw data is collected, run the registered algorithm process in order to compute the parameter of the target's velocity.

4.4 Raw data acquisition

Figure 8 shows the main blocks of the Sense2GoL Pulse raw data acquisition phase in detail, before going through the radar algorithm processing phase. There are more details about the pulse generation and data sampling phases in the next sections.

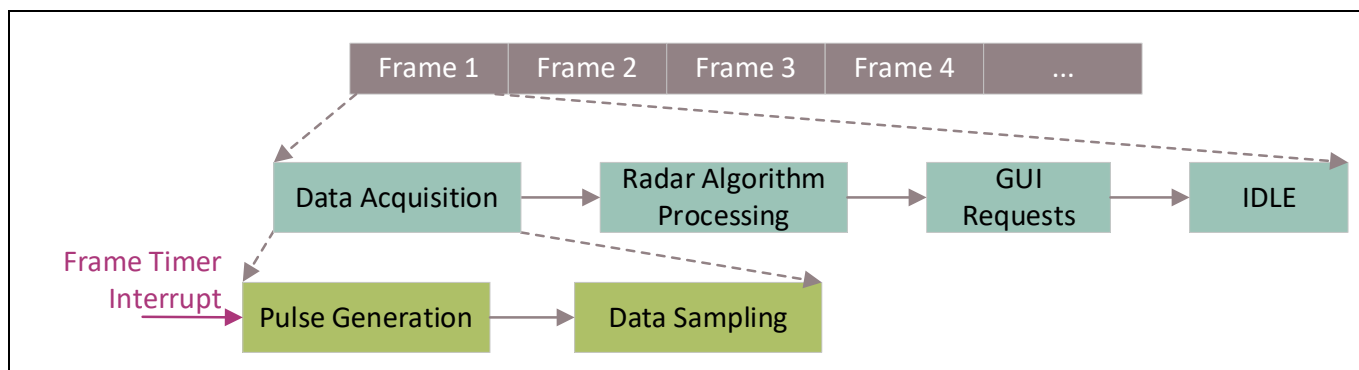


Figure 8 Raw data acquisition flow diagram

4.4.1 Doppler pulse generation

Pulse generation is the first part of the data acquisition process, which is triggered by an internal frame timer. The number of generated pulses per frame consists of the number of desired samples plus the skip count for transient elimination. The Sense2GoL Pulse firmware communicates and controls the BGT and S&H switches via PWM and GPIO signals.

As shown in Figure 9 and Table 1, the BGT24LTR11 shield is controlled through:

- Timer-controlled PWM output signals for VCC_BGT_EN and TX_EN, which are used to turn on the BGT24LTR11 only for the pulse duration and remain off for the remaining time.
- GPIO-based control signals for VCC_PTAT and V_PTAT_S&H_EN, which are used to (re)charge a S&H capacitor with V_PTAT directly before each pulse. The load on this S&H capacitor is then used in the subsequent pulse to feed the tuning voltage of the MMIC. Both control signals are enabled for 1 ms before the first pulse of a frame and for 20 us before all other pulses and remain off for the remaining time, including the pulse duration itself, to reduce noise by decoupling.
- Timer-controlled PWM output signal IF_S&H_EN, which is used to enable the S&H structure for the baseband signals. This signal is only enabled for a few microseconds within each pulse and remains off for the remaining time.
- GPIO-based control signals for BB1_EN and BB2_EN, which are used to enable the OpAmps in the first and second amplification stage, respectively.

Table 1 Sense2GoL Pulse control and data signals description

Header	Pin/Short name	Full signal name in firmware	Signal description
P1	VCC_BGT_EN	PWM_CC08_BGT_VCC_BGT_EN	Control signal to turn on/off V _{CC} for BGT24LTR11 (active low!)
P1	TX_EN	PWM_CC08_TX_EN	Control signal for TX_EN pin of BGT24LTR11
P1	VCC_PTAT	DIGITAL_IO_BGT_VCC_PTAT	Control signal for VCC_PTAT pin of BGT24LTR11

Header	Pin/Short name	Full signal name in firmware	Signal description
P6	V_PTAT_S&H_EN	DIGITAL_IO_V_PTAT_SH_EN	Control signal for S&H switch for VCC_PTAT
P1	IF_S&H_EN	PWM_CCU8_IF_SH_EN	Control signal for S&H switches
P6	BB1_EN	DIGITAL_IO_BB1_EN	Control signal to turn on/off the OpAmps in the first and (due to hard-wiring also) second baseband amplifier stages
N/A	BB2_EN	DIGITAL_IO_BB2_EN	Control signal to turn on/off the OpAmps in the first and (due to hard-wiring also) second baseband amplifier stages
P1	IFI	IFI_HG	Second baseband amplifier stage output for IFI signal
P1	IFQ	IFQ_HG	Second baseband amplifier stage output for IFQ signal

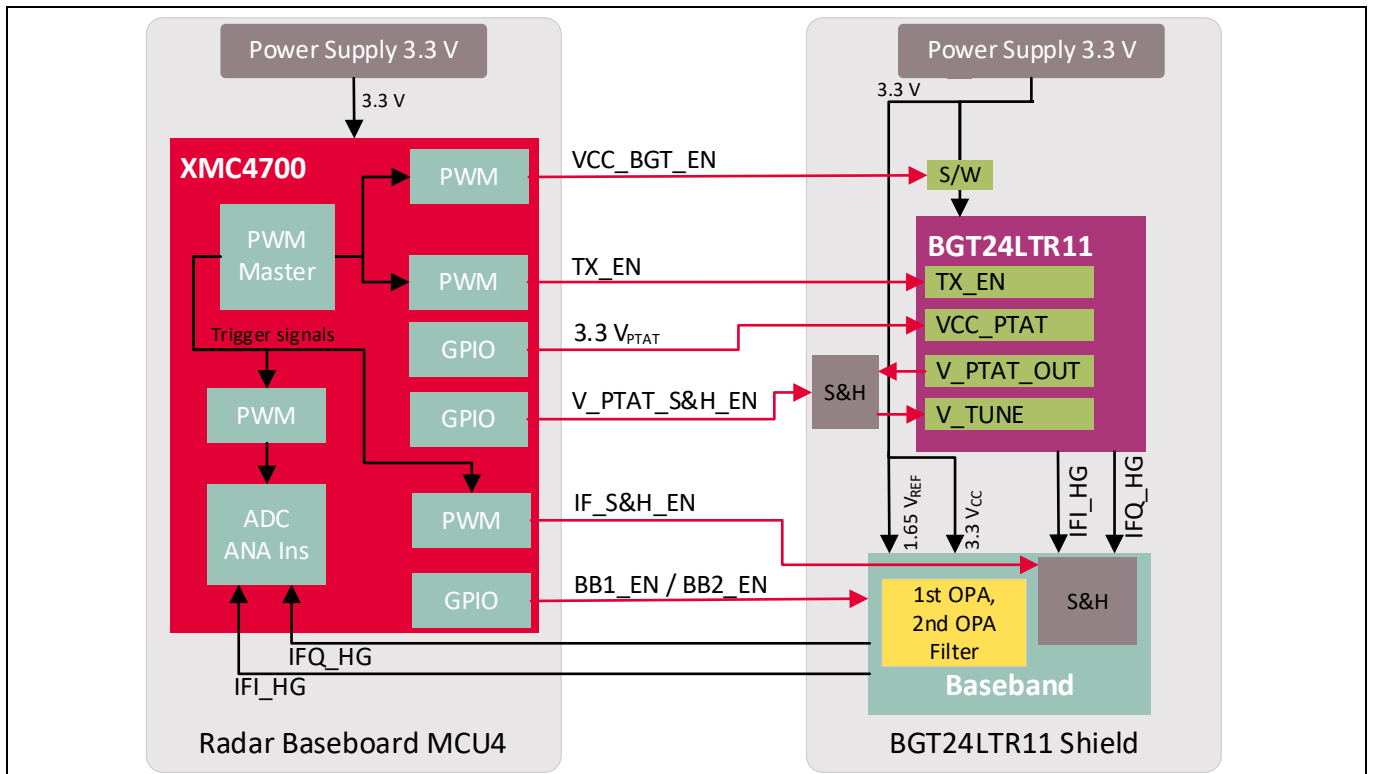


Figure 9 All control signals

The pulse width or BGT V_{CC} on-time can vary between $1\ \mu s$ and $10\ \mu s$, and it represents the time portion to have one data sample. Short pulse width reduces the sample time of the BGT's output signals, hence saving more power. However, the time might not be enough to charge to the S&H, reducing the final signal strength at the output.

Figure 10 shows the control signal timings for one pulse generation. When VCC_BGT_EN signal goes low, we consider $T = 0$. All depending signal delay and advance times are visualized with red arrows. The $VCC\ PTAT$ Advance is $1ms$ for the first generated pulse in a frame, and $20\mu s$ for all other pulses.

DEMO SENSE2GOL PULSE Software Guide

XENSIV™ 24 GHz radar

Firmware description

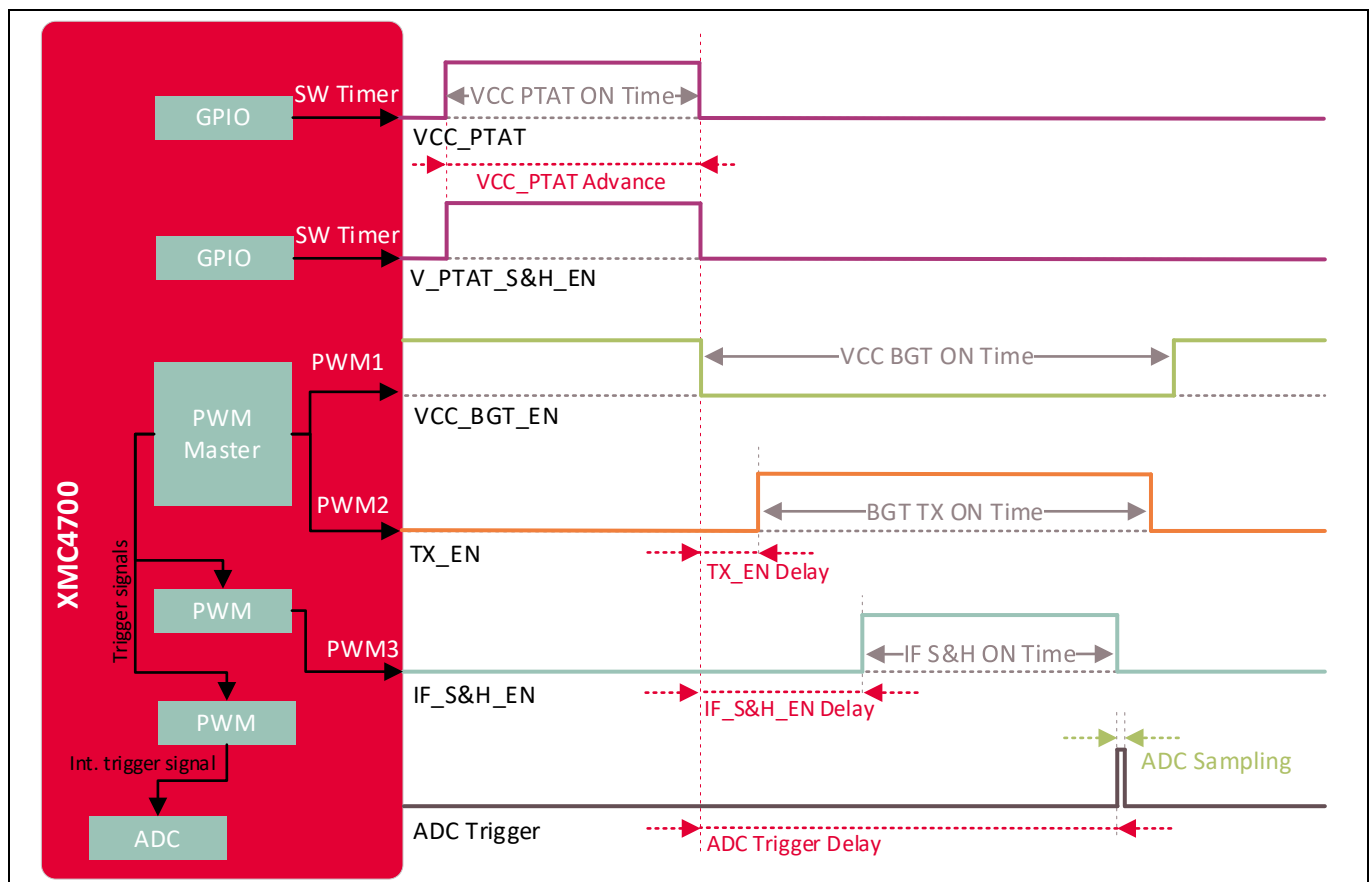


Figure 10 Pulse generation

Figure 11 shows the configuration of a frame. Each frame is a series of pulses, based on the number of samples, followed by a frame off-time.

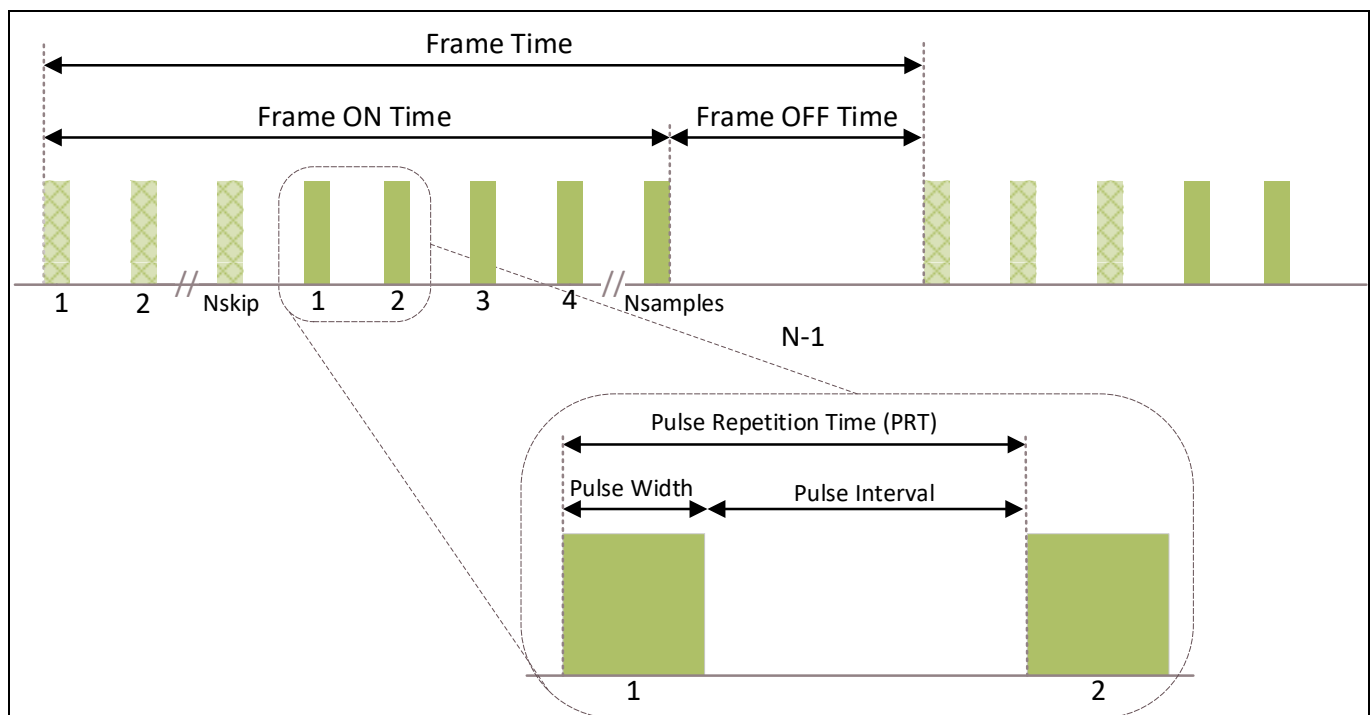


Figure 11 Frame structure and terminology

For more details about BGT24LTR11 shield configuration and power saving, please refer to the BGT24LTR11 shield hardware platform application note.

4.4.2 Data sampling

The data acquisition process for Sense2GoL Pulse application is shown in Figure 13.

The start of the data acquisition process will be triggered by an internal frame timer, which will start pulse generation over PWM signals. The data sampling process is triggered by an internal PWM signal at the same time, which triggers the ADC to start sampling data from the RX antenna.

Once an ADC sample is ready to be moved to the acquisition buffer, the DMA transfer starts. This task is repetitive; it will end once the number of required samples per frame is reached. At that moment, the DMA will stop the transfer process by raising a transfer complete interrupt.

The frame size (or number of samples per frame) depends on the number of samples required by the application or the algorithm and the skip count. The skip count is the number of samples to be skipped at the beginning of each frame to remove the transient in the I and Q signals due to recharging the S&H capacitors. The required skip count value is dependent on the Frame OFF Time; these samples are completely disregarded in the signal processing chain.

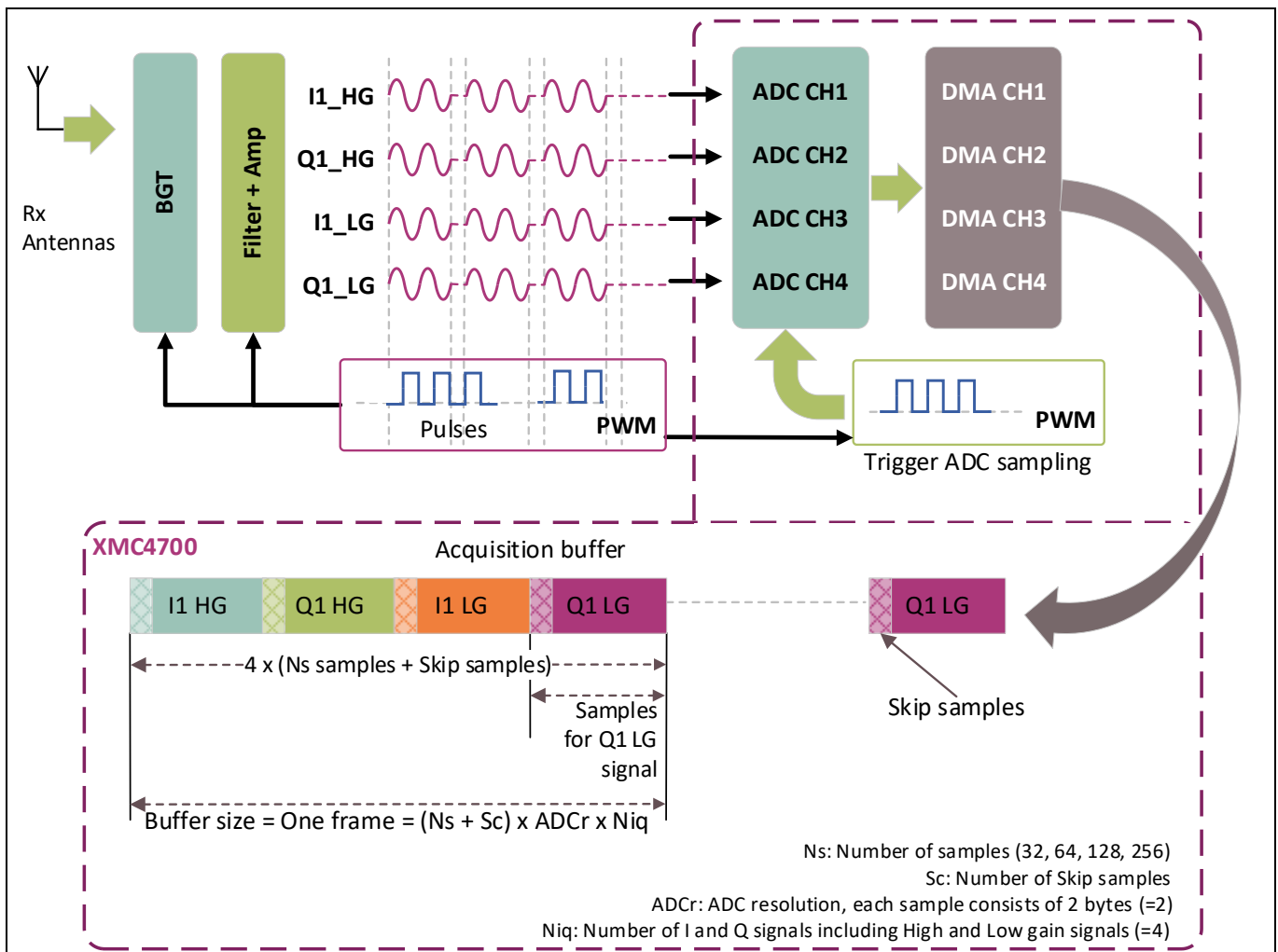


Figure 12 Sense2GoL Pulse data acquisition and sampling flow

Figure 13 gives the detailed flow diagram of the data acquisition phase. Here is a short description of each step of the acquisition process:

- **Step 1 – configure and enable DMA:** DMA source/destination address setup; four DMA channels are configured for the RX complex (I/Q) data samples (Q1 HG, I1 HG, Q1 LG and I1 LG).
- **Step 2 – configure pulse generation:** Configure all PWM control signals for BGT and S&H.
- **Step 3 – trigger pulse generation:** Triggered by an internal frame timer at the beginning of each frame; start PWM pulse generation and ADC data sampling.
- **Step 4 – start ADC sampling:** ADC sampling will start automatically at the same time as pulse generation; it is controlled by an internal PWM signal in order to trigger equidistant ADC samples.
- **Step 5 – stop acquisition process:** Based on the number of samples required, disables the DMA peripheral and stops pulse generation and ADC sampling.

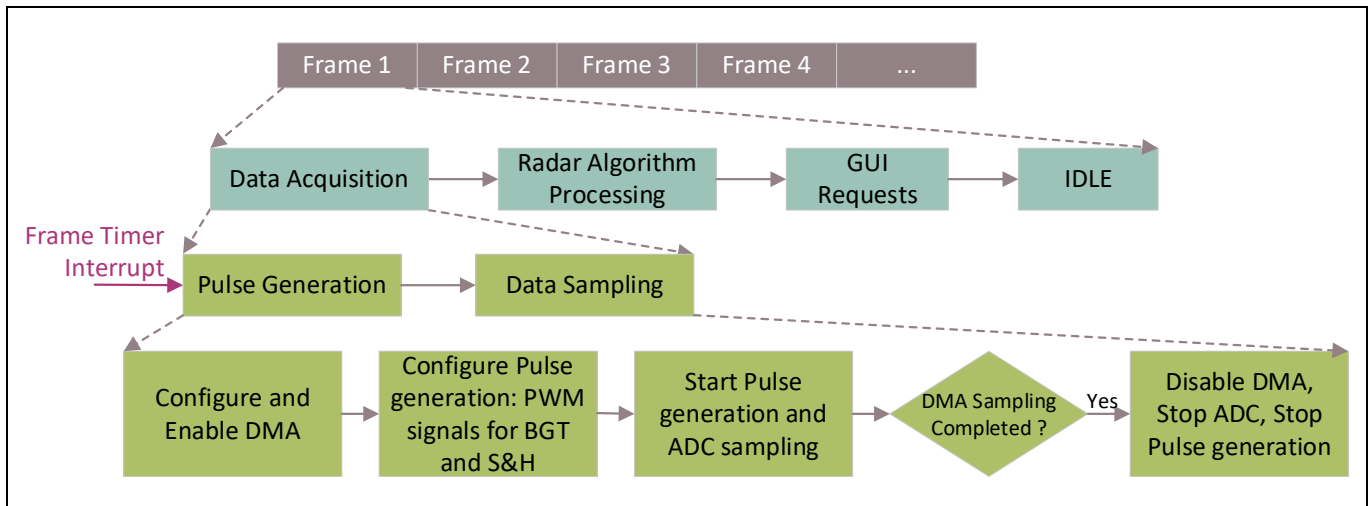


Figure 13 Data acquisition flow diagram

4.5 Radar control layer

The Sense2GoL Pulse software package provides a simple interface to the radar sensor through the radar control layer, which offers full flexibility to configure all radar parameters based on the application end requirements.

4.5.1 Radar control APIs

The APIs define the high-level interface used to configure the radar RF parameters, the behavior and capabilities of the component, and its inputs and outputs, and provide a set of firmware methods to manage radar functionalities. Radar control APIs are called from the application layer and are prefixed by “radar_”.

4.5.2 Data store module

The data store module is apart from the radar control layer; it mainly contains the hardware device settings and the algorithm settings structures, as shown in Table 2.

Table 2 Data store hardware device and algorithm settings structures

Hardware device settings	Algorithm settings
<pre> /* * Hardware configuration structure */ typedef struct device_settings_TAG { uint32_t struct_length; uint32_t struct_version; /* Frequency Settings */ uint32_t pll_chirp_time_usec; float rf_frequency_KHz; uint32_t pll_modulation_mode; /* ADC Settings */ uint32_t adc_sampling_freq_Hz; uint8_t adc_resolution; uint8_t adc_use_post_calibration; /* Frame Settings */ uint32_t num_of_chirps_per_frame; uint32_t frame_period_usec; uint32_t num_samples_per_chirp; uint8_t rx_antenna_mask; uint32_t num_sample_skip_count; /* Pulse mode settings */ uint32_t pulse_width_usec; uint32_t sample_hold_on_time_nsec; uint32_t ptat_is_switched; uint32_t ptat_delay_usec; } device_settings_t; </pre>	<pre> /* * Algorithm settings structure */ typedef struct algo_settings_TAG { uint32_t struct_length; uint32_t struct_version; float speed_detection_threshold; float min_speed_kmph; float max_speed_kmph; uint32_t use_high_gain_doppler; float motion_detection_threshold; } algo_settings_t; /* * Algorithm result structure */ typedef struct { float velocity_kmph; float level; uint8_t target_departing; uint8_t target_approaching; uint8_t motion_detected; float doppler_frequency_hz; float *p_doppler_spectrum; uint32_t doppler_spectrum_elems; uint32_t frame_counter; } algo_result_t; </pre>

These two structures are shared between all firmware modules. If a firmware module, e.g. the host communication library or algorithm, requires one or more parameters from the settings structures, a **fetch operation** is performed to get the up-to-date value from the data store, as shown in Figure 14. The resulting structure holds the results of the last algorithm operation.

On the other hand, if there is an update for one or many parameters in the settings structures, a **push/store operation** is performed to update the data store structures with the new changed value.

A shadow (or a copy) of the hardware settings structure is maintained in the data store, and it always contains the old settings parameters. In case of unsupported parameters (e.g. the value is out of range), the current hardware structure is discarded and overwritten by the shadow copy and the new required change will be discarded.

At the beginning, the shadow and current settings structures parameters are set to the default settings values from the *config.h* file. The user can change these default settings by updating the *config.h* file or through the radar GUI.

In case of a valid hardware change request received from the GUI, the hardware structure will be updated with the new value in the data store. The **radar control** submodule will apply this change to the BSP driver before the start of acquisition of the next new frame.

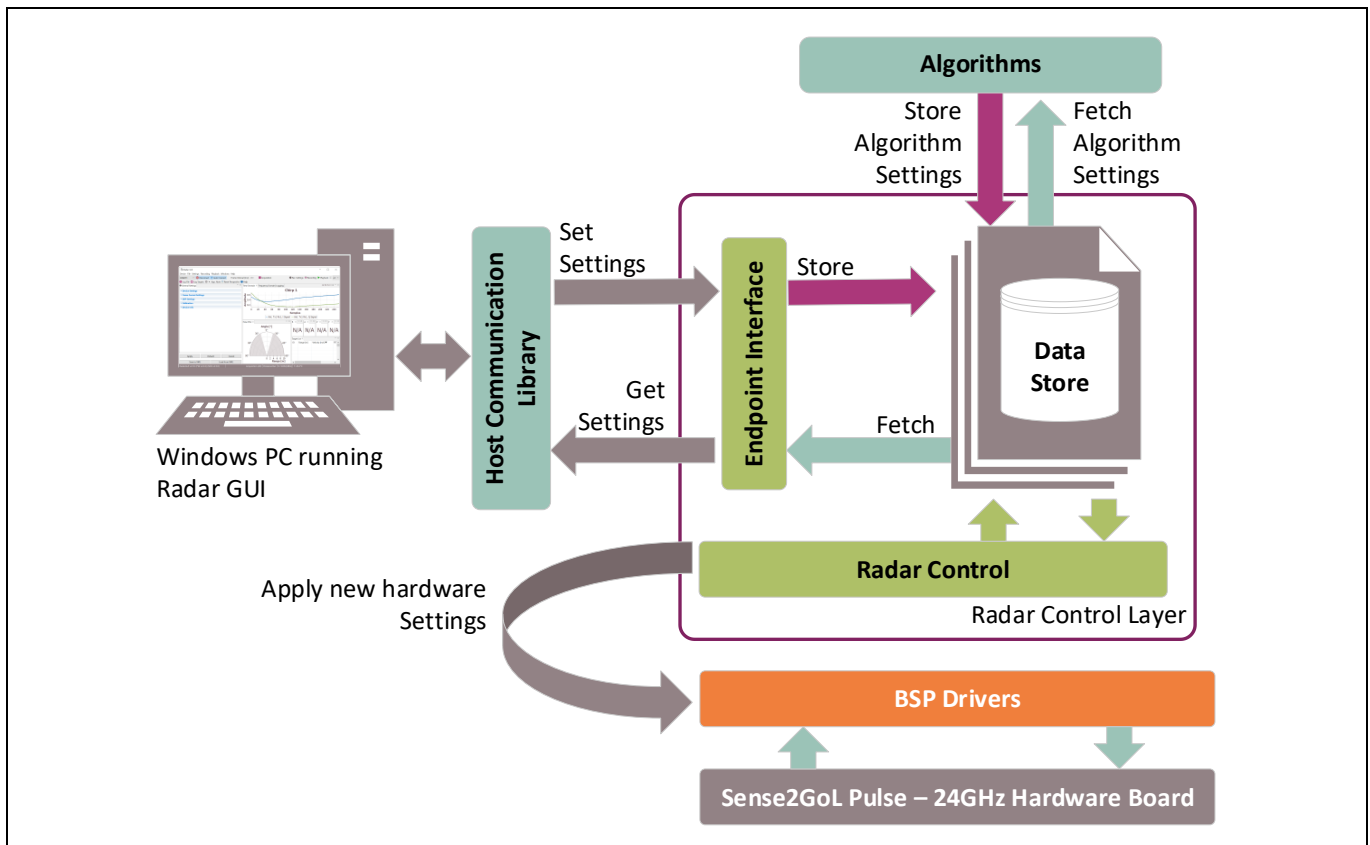


Figure 14 Interconnection of the data store module with other firmware modules

4.5.3 Data store and EEPROM management

The BGT24LTR11 shield contains 16 Kbyte serial EEPROM. The I2C serial data interface is used to transfer addresses and data into and out of the EEPROM.

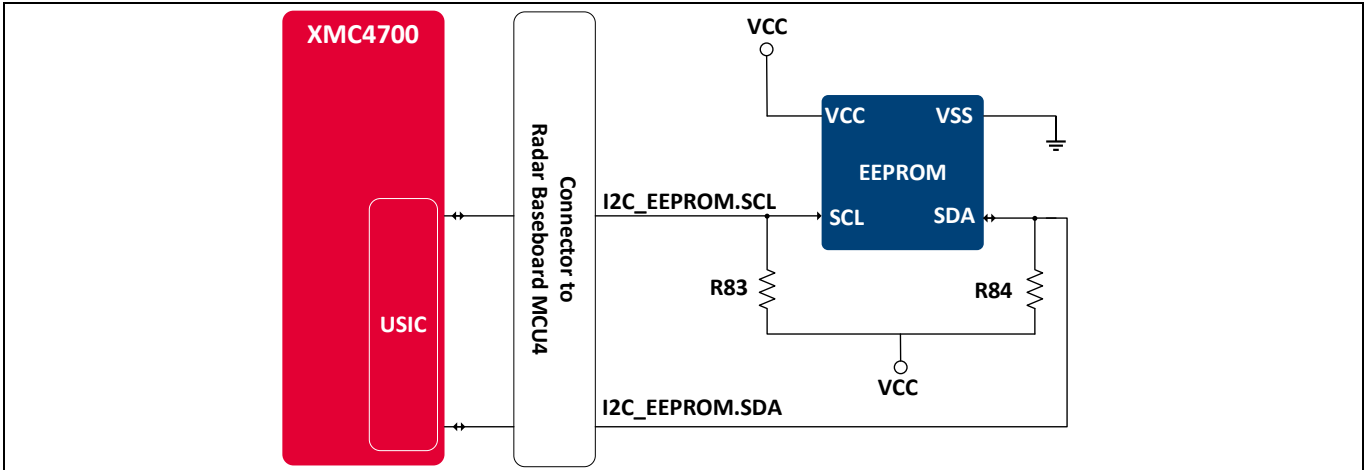


Figure 15 EEPROM block diagram

In Sense2GoL Pulse firmware, the EEPROM is used to store the **hardware settings** and the **algorithm settings** structures, as shown in Table 2. In addition to that, the EEPROM contains a unique, pre-defined and pre-programmed **string ID**, which is used to identify the BGT24LTR11 shield board.

When the Radar Baseboard MCU4 boots up, the firmware detects if a radar shield is plugged into the connectors. If the radar shield is plugged in correctly, it reads the information in the EEPROM's memory to determine what kind of shield is plugged into the interface. The power supply of the radar shield is only enabled when the shield is correctly identified.

After that, the firmware reads the hardware and the algorithm settings from EEPROM. In case of valid settings, the firmware will start based on these new settings; otherwise it will start with the default settings and overwrite the EEPROM settings section with the default settings values.

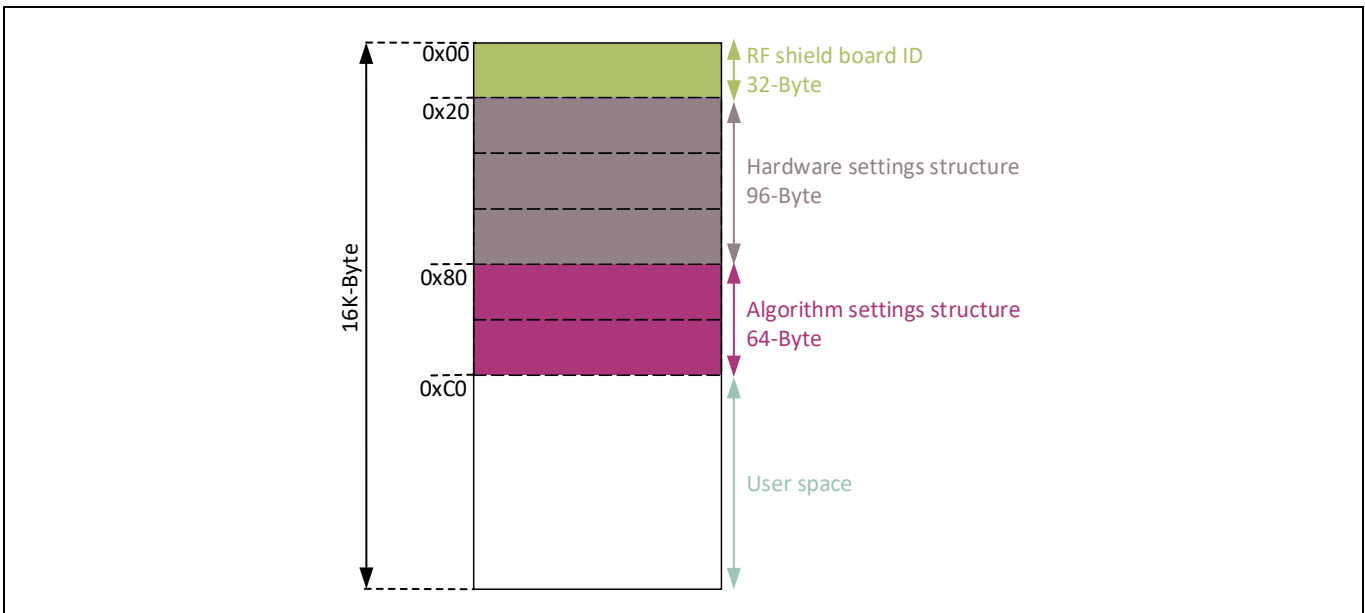


Figure 16 EEPROM structure

4.6 DAVE™ project overview

The Sense2GoL Pulse firmware is released as a ready-to-run DAVE™4 project, where source files are generated based on the DAVE™ apps used, which are graphical-configurable application-oriented software components, used to enable users' quick reuse and customization.

Table 3 lists the DAVE™ apps used, based on the Sense2GoL Pulse board, to generate the appropriate firmware source code.

Table 3 DAVE™ project apps used

DAVE™ app	Number of instances	App description
ADC	4	Allows for digitizing analog signals using ADC via queue and scan request sources with advanced features
CMSIS_DSP	1	Provides the CMSIS DSP software library, a suite of common signal processing functions to apply on Cortex®-M processor-based devices
DIGITAL_IO	4	Used to configure a port pin as digital input/output
DMA_CH	4	Used to perform single- and multi-block data transfer using the General-Purpose Direct Memory Access (GPDMA) module on the XMC4000
I2C_MASTER	1	Used for I²C serial interface communication
INTERRUPT	2	Enables overwriting of the Interrupt Service Routine (ISR) provided in the system file and sets the interrupt priority
SYSTIMER	1	Uses the SysTick interrupt to call user functions periodically at a specified rate after a given time period expires
TIMER	4	Provides an accurate timer by using the hardware CCU timer; this can be used as a trigger input to other peripherals or to create an event
USBD_VCOM	1	USB virtual COM port application. This app implements the VCOM over USB CDC class driver
PWM	4	Used to generate PWM control signals

DAVE™ apps are configured to address the XMC4700 peripherals to ensure communication, data processing and result visualization. The fundamental functionalities are PWM, timer, ADC and DMA.

Table 4 PWM and GPIO pin configurations

Pin name	Pin functionality	Description
PWM control signals		
BGT_VCC	PWM	P5.11 pin: Power Enable/disable V _{CC} 3.3 V power for BGT24LTR11
BGT_TX_EN	PWM	P5.10 pin: Control Control signal to enable/disable output power for BGT24LTR11
BGT_VCC_PTAT	Output	P0.14 pin: Power Provide 3.3 V for PTAT voltage source for BGT24LTR11

Pin name	Pin functionality	Description
Sample_Hold	PWM	P5.9 pin: Control Control signal to enable/disable S&H
LED configuration		
BLUE_LED	Output	P1.13 pin: Control Turn on/off LED
GREEN_LED	Output	P1.14 pin: Control Turn on/off LED
RED_LED	Output	P1.15 pin: Control Turn on/off LED

- ADC configuration** – The XMC4700 integrated 12-bit ADC is used to sample and process the analog down-converted signals in the baseband. The ADC peripheral configuration is set to:
 - conversion mode: 12-bit resolution
 - four channels, two channels for each IF (IF_I_HG, IF_Q_HG, IF_I_LG, IF_Q_LG), with two bytes per sample for each ADC channel
 - sample time [ns]: 75.

The ADC mode has an impact on the maximum possible sample rate. Higher resolution reduces the maximum sample rate. Figure 17 shows the configuration of the ADC DAVE™ app:

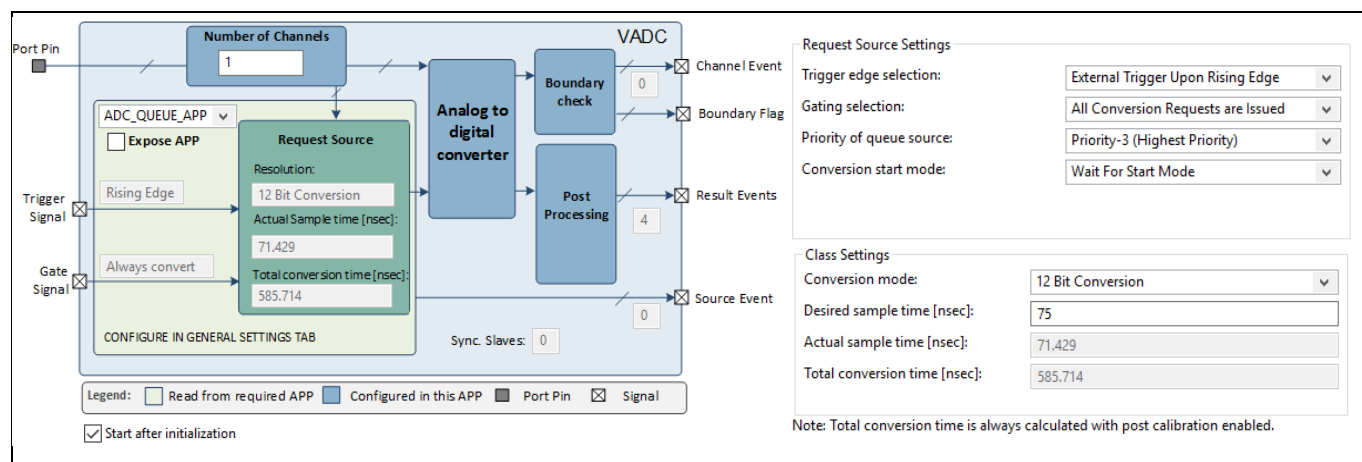


Figure 17 ADC DAVE™ app configuration

- DMA_CH** – The XMC4700 GPDMA peripheral is configured to transfer data from the ADC peripheral to XMC™ memory. Four DMA channels are configured for RX data measurements (Q_HG, I_HG, Q_LG and I_LG), as follows:
 - Transfer type: single block
 - Transfer flow: peripheral to memory (DMA flow controller)
 - Block size: 250
 - Transfer width: 16 bits
 - Burst width: 1 word
 - Handshaking: hardware

Figure 18 shows the configuration of the DMA_CH DAVE™ app.

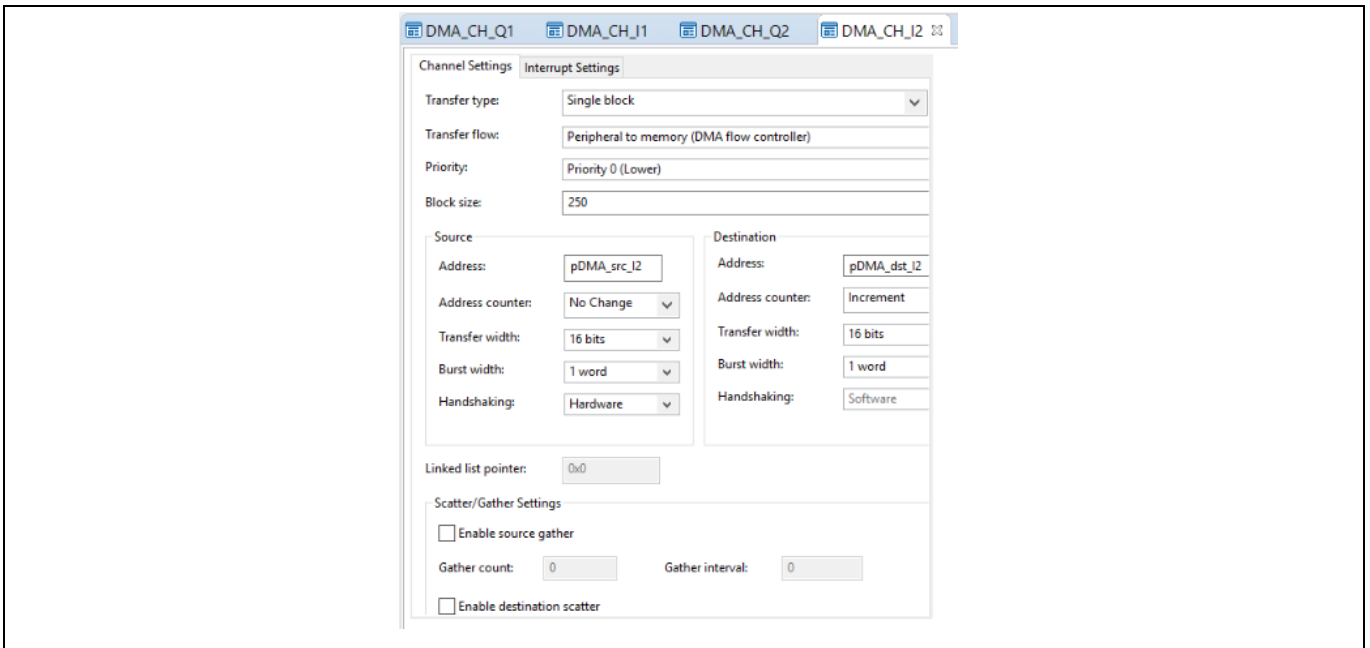


Figure 18 DMA DAVE™ app configuration

4.7 Firmware package overview

Sense2GoL Pulse is a firmware package for XMC™ microcontrollers and BGT24LTR11 radar chips. It provides a complete solution to build radar applications in a single package containing the source code for various exemplary applications, facilitating the development of user applications. Figure 19 shows a top-level view of the Sense2GoL Pulse package file structure.

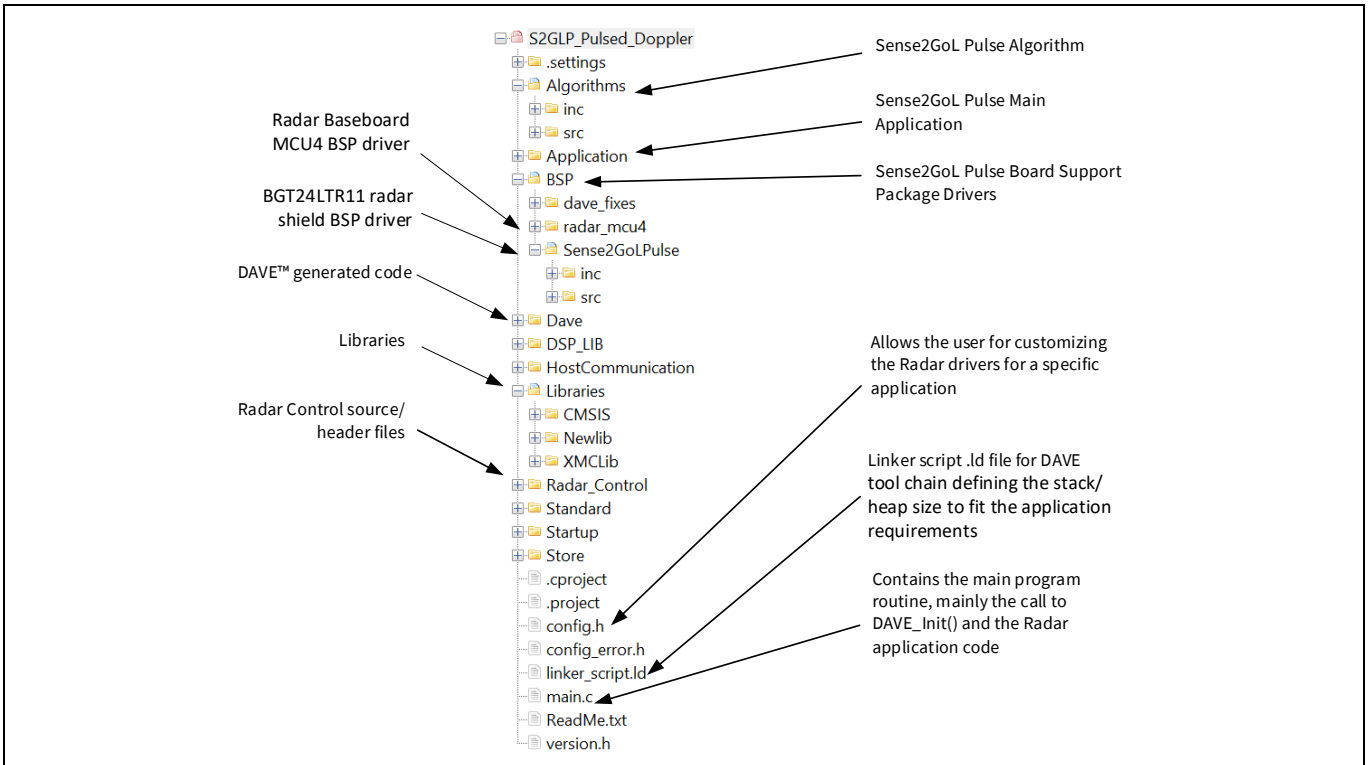


Figure 19 Package folder structure

4.8 Footprint

The purpose of the following sections is to provide the memory requirements for all the Sense2GoL Pulse firmware modules, including devices' drivers, algorithms and main radar applications. The aim is to have an estimation of fixed and customizable memory requirements in case of removal or addition of a module or feature. The footprint data are provided for the following environments:

- **Board** – Sense2GoL Pulse (Radar Baseboard MCU4 V2.0 + BGT24LTR11 RF shield V3.0)
- **Firmware** – S2GLP_Pulsed_Doppler (V2.0.0)
- **Toolchain** – DAVE™ v4.4.2

After building a project, the build result is displayed in the console window, where the code size figures are listed. The values are organized according to memory areas, arranged by the linker file (*.ld) into the text, data and bss sections. Table 5 shows the Sense2GoL Pulse build memory utilization for the radar firmware configurations, main modules and algorithms. The information has been gathered by analyzing the corresponding (*.elf) file.

Table 5 Sense2GoL Pulse firmware footprint

Firmware			Footprint			
Version	DAVE™ project	Optimization	Text ⁽¹⁾ [byte]	Data [byte]	bss ⁽²⁾ [byte]	Total [byte]
V3.0.0	S2GLP_Pulsed_Doppler	None (-O0)	104704	1764	36480	142948 byte (0x22e64)
	S2GLP_Pulsed_Doppler	Optimize most (-O3)	72952	1744	36476	111172 byte (0x1b244)

⁽¹⁾ Text: code.

⁽²⁾ bss: statically allocated variables that are not explicitly initialized to any value.

4.9 Firmware timings

This section presents the typical timings of the Sense2GoL Pulse firmware that should be used to ensure correct execution of the important radar application sequences. Figure 20 shows the raw data acquisition timings, for one frame and one pulse.

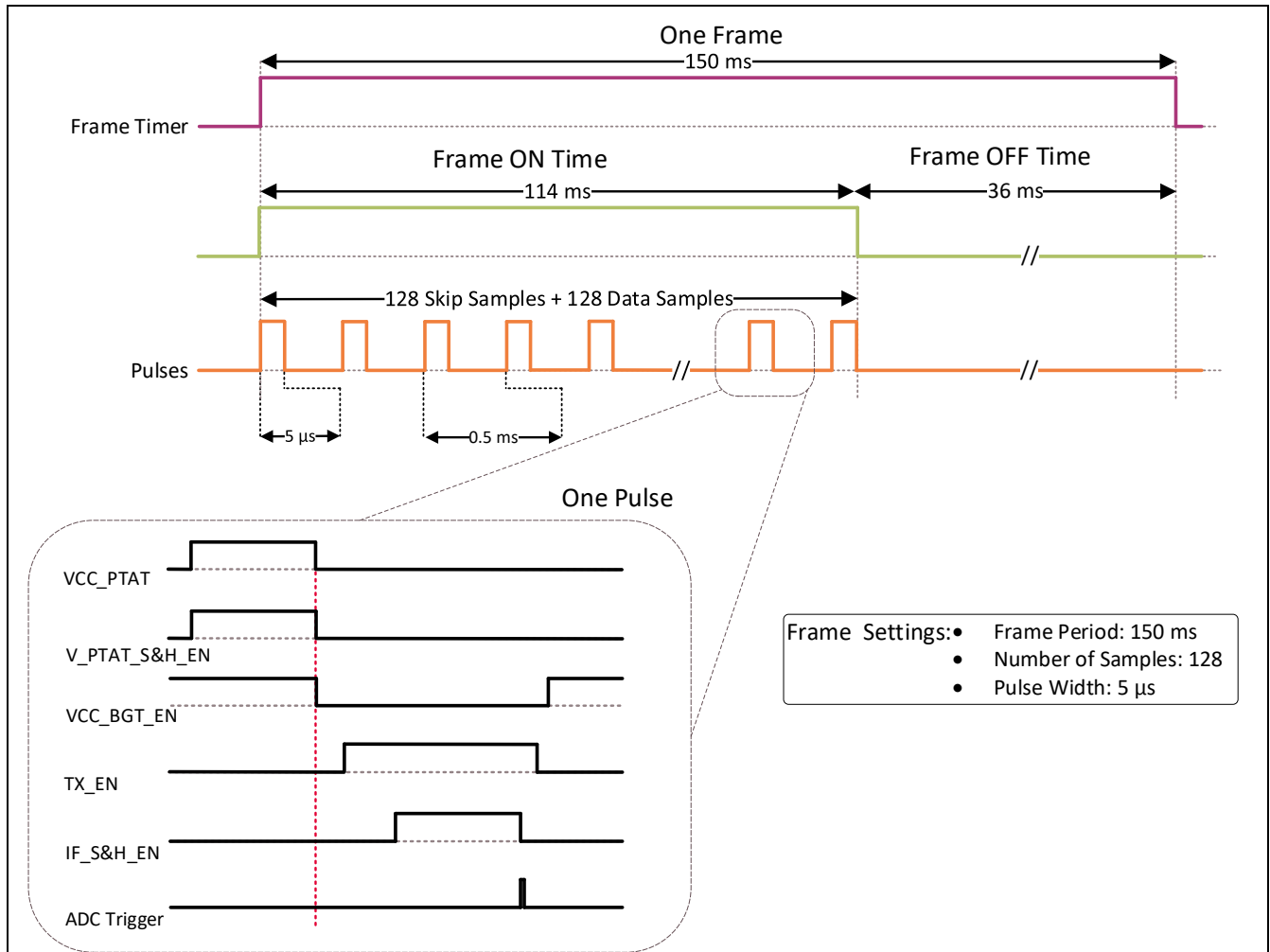


Figure 20 Raw data acquisition timings

4.10 Firmware customization and configuration

The configuration file *config.h* allows for customizing the firmware drivers for the Sense2GoL Pulse radar application. The following parameters can be configured: enable/disable or modify some options by uncommenting/commenting or modifying the values of the related define statements, as described in Table 6.

Table 6 Define statements used for radar firmware configuration

Parameter	Description	Default	Valid range
General configurations			
NUM_OF_CHIRPS	Only one “chirp” (package of samples) per frame is used	1	[1]
SAMPLES_PER_CHIRP	Number of IQ data samples per chirp/frame to be stored and processed	128	[32, 64, 128, 256]
FRAME_PERIOD_MSEC	Time period of one frame to capture and process data (units in ms)	150	[50 to 2000]
SAMPLE_SKIP_COUNT	Default number of samples skipped for signal processing at beginning of frame	40	[0 to 1000]
Doppler configurations			
DOPPLER_SUPPORTED	Comment/uncomment this macro, to enable/disable Doppler support	–	N/A
DOPPLER_SAMPLING_FREQ_HZ	Sampling frequency (units in Hz)	2000	[0 to 10000]
MIN_SPEED_KMPH	Filter out targets below this speed (units in km/h)	72	[0.0 to 9.99]
MAX_SPEED_KMPH	Filter out targets above this speed (units in km/h)	1080	[0.1 to 10.0]
SPEED_DIVIDER	For software implementation purpose, to only keep min. and max. speed within limits of 0 to 10 km/h	100	N/A
SPEED_DETECTION_THRESHOLD	FFT spectrum threshold to detect a target in Doppler FFT	50	[0 to 5000]
MOTION_DETECTION_THRESHOLD	FFT spectrum threshold to detect a target in Doppler	10	[0 to 5000]
GAIN_SELECTOR_DOPPLER	Baseband gain selection for doppler algorithm 1 for high gain, 0 for low gain	1	[0 or 1]
GUARD_FRAME_TIME_USEC	Guard period, until the min. and request frame time must match	500	N/A
Low Level Pulsed Doppler configurations			

Parameter	Description	Default	Valid range
PULSE_WIDTH_USEC	On-time for the Gate of BGT V _{CC} input; 1% of sample period	5	[4 to 10]
SAMPLE_HOLD_ON_TIME_NSEC	Hold time for acquiring raw data (units in ns)	0	[0 to 4520]
SAMPLE_HOLD_ON_DELAY_TIME_NSEC	Delay time for holding signal after turning on BGT V _{CC} signal (units in ns)	480	480
SAMPLE_HOLD_START_DELAY_TIME_NSEC	Slightly shift the start holding signal after turning on BGT V _{CC} signal (units in ns)	400	400
PTAT_DELAY_USEC	The delay between PTAT on-signal and the start of the frame sampling	1000	[1000 to ...]
PTAT_SIGNAL_SWITCHED	Set to 1 if PTAT signal should be switched, 0 avoids switching of PTAT signal	1	[0 or 1]
BGT_TX_ON_DELAY_TIME_NSEC	Delay time for BGT TX signal after turning on BGT V _{CC} signal	400	N/A
BGT_TX_ON_START_DELAY_TIME_NSEC	Delay before to enable the BGT TX	300	N/A
BB_PRE_TRIGGER_ADVANCE_USEC	Pre-trigger advance for Baseband enable	20000	N/A
PTAT_S_H_PULSE_WIDTH_USEC	PTAT S&H Pulse trigger	20	N/A
PTAT_S_H_SWITCHING	PTAT V _{CC} and S&H default behavior	1	[0 or 1]
DSP configurations			
DOPPLER_FFT_SIZE	Doppler FFT length, with zero padding	256	256

5 Algorithm description

This section describes the implemented algorithm for motion and movement detection. If the signal strength of a moving target is above the **Direction Sensitivity**, the algorithm outputs the velocity of the target including the direction of movement. If the signal strength is above the **Motion Sensitivity**, motion is detected. As a larger signal strength is required to determine movement compared to motion, the Direction Sensitivity normally is set higher than the Motion Sensitivity. When the signal strength is above both thresholds, the LED glows green for approaching and red for departing targets. It glows blue for pure motion detection and is disabled if nothing is detected.

A flow chart of the algorithm is depicted in Figure 21. In the first step, a Chebyshev window is applied on all samples of the processed frame to suppress side lobes. For less than 256 samples per frame, the windowed data is zero-padded to improve the received signal characteristics. Next, a complex Fast Fourier Transform (FFT) with a size of 256 is computed and the two-sided amplitude spectrum is calculated.

Here, a peak search is applied within **Minimum Speed** and **Maximum Speed**. The height of the peak determines if motion and/or movement is detected. For detected movement, the corresponding frequency of the peak value is used to calculate the velocity of the target, while the sign of the frequency defines the direction of movement.

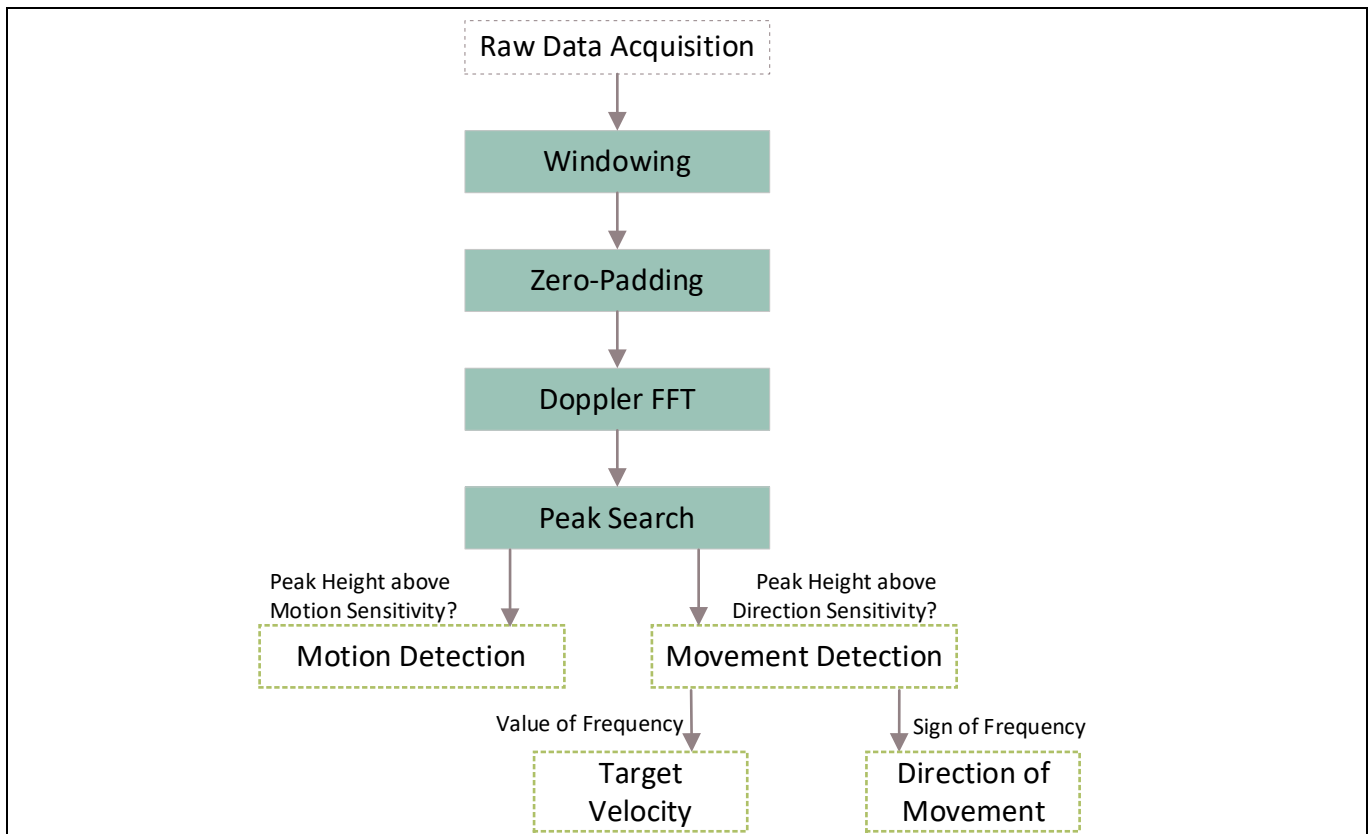


Figure 21 Motion and movement detection algorithm flow

6 Authors

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

7 References

- [1] Infineon BGT24LTR11N16 – 24 GHz Radar MMIC – [datasheet](#)
- [2] Infineon XMC4700 32-bit Arm® Cortex®-M4 microcontroller – [datasheet](#)
- [3] Infineon BGT24LTR11 – [product brief](#)
- [4] 24 GHz industrial radar – [FAQs](#)
- [5] Infineon application note – [AN472 – User's guide to BGT24LTR11N16](#)
- [6] Infineon application note – [AN602 – Radar Baseboard MCU4](#)
- [7] Infineon application note – [AN598 – Demo Sense2GoL Pulse](#)
- [8] Infineon application note – [AN605 – Using Demo Sense2GoL Pulse Board with Arduino](#)

Revision history

Revision history

Document revision	Date	Description of changes
1.00	2020-02-17	Initial version
2.00	2021-08-13	Support BGT24LTR11 shield V3.0
2.10	2023-02-14	Miscellaneous document cleanup updates

Trademarks

All referenced product or service names and trademarks are the property of their respective owners.

Edition 2023-02-14

Published by

Infineon Technologies AG

81726 Munich, Germany

© 2023 Infineon Technologies AG.

All Rights Reserved.

Do you have a question about this document?

Email: erratum@infineon.com

Document reference

UM_1905_PL32_1905_111857

IMPORTANT NOTICE

The information given in this document shall in no event be regarded as a guarantee of conditions or characteristics ("Beschaffenheitsgarantie").

With respect to any examples, hints or any typical values stated herein and/or any information regarding the application of the product, Infineon Technologies hereby disclaims any and all warranties and liabilities of any kind, including without limitation warranties of non-infringement of intellectual property rights of any third party.

In addition, any information given in this document is subject to customer's compliance with its obligations stated in this document and any applicable legal requirements, norms and standards concerning customer's products and any use of the product of Infineon Technologies in customer's applications.

The data contained in this document is exclusively intended for technically trained staff. It is the responsibility of customer's technical departments to evaluate the suitability of the product for the intended application and the completeness of the product information given in this document with respect to such application.

For further information on the product, technology delivery terms and conditions and prices please contact your nearest Infineon Technologies office (www.infineon.com).

WARNINGS

Due to technical requirements products may contain dangerous substances. For information on the types in question please contact your nearest Infineon Technologies office.

Except as otherwise explicitly approved by Infineon Technologies in a written document signed by authorized representatives of Infineon Technologies, Infineon Technologies' products may not be used in any applications where a failure of the product or any consequences of the use thereof can reasonably be expected to result in personal injury.