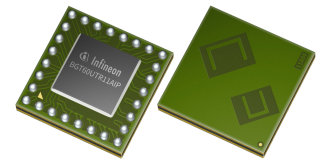


**BGT 60UTR11AIP**  
**60 GHz radar sensor with antennas in package**

**Features**

- Integrated state machine for low-power and real time operation
- Broadcast mode to trigger and configure multiple devices
- Single 50 MHz SPI for chip configuration and data transfer
- 60 GHz radar with 5.6 GHz bandwidth and ramp speed up to 400 MHz/μs
- 4 MSps ADC
- Antenna in package (AIP) with ±60° FoV



**Potential applications**

- Presence detection and range zones segmentation for smart home and doorbell applications
- Vital sign tracking for health care devices, such as sleep trackers and baby monitors
- 1D gesture sensing for smart appliances such as kitchen machines or thermostats
- Distance measurement and level sensing

**Product validation**

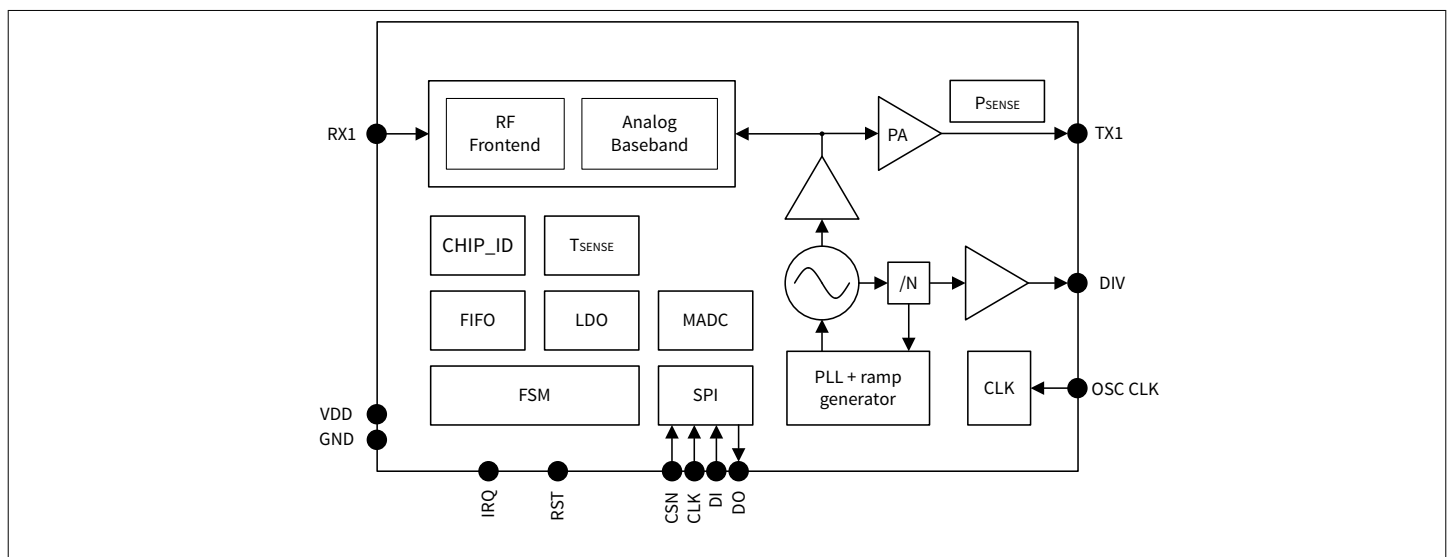
Qualified for applications listed above based on the test conditions in the relevant tests of JEDEC20/22.

**Description**

The BGT60UTR11AIP is a 60 GHz radar sensor with 1 transmitting and 1 receiving U-slotted patch antennas in package. The 5.6 GHz ultra-wide bandwidth allows FMCW operations with extremely high resolution. This enables precise range measurements, 1D gestures and also the measurement of vital signs such as breathing rate or heart rate.

Sensor configuration and data transfer are enabled with a single digital interface. Multiple devices connected to the same bus can be configured and triggered together by using the implemented broadcast mode. Device specific programmable wake-up times allow time domain multiplexed radar frames.

The integrated state machine enables independent and real time data acquisition without interaction to the processor. Three possible power mode options give the user full flexibility between performance and power consumption optimizations.



Product Name	Package	Marking
BGT 60UTR11AIP	PG-VF2BGA-28-1	611A

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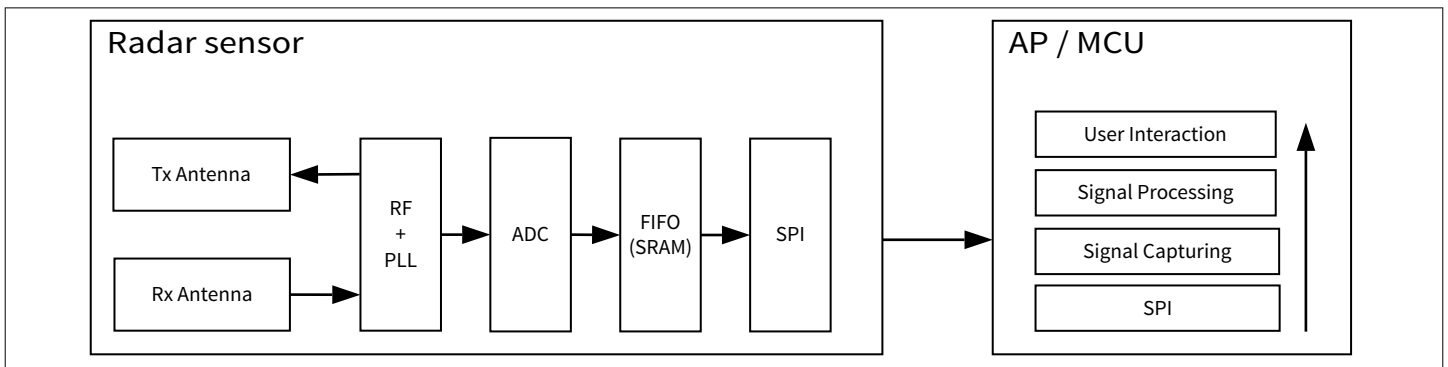
## 1 Introduction

New smart sensors for gesture recognition can be based on radar systems, in special case, *frequency-modulated continuous wave (FMCW)* radars. Those systems can comprise several blocks: *radio frequency (RF)* front-end, *analog base band (ABB)*, *analog-to-digital converter (ADC)*, *phase-locked loop (PLL)*, memory (*first in first out (FIFO)*), *serial peripheral interface (SPI)* and antennas. Smart sensors require a high level of integration, thus, the components listed above should be integrated in a single chip solution. BGT60UTR11AIP offers this level of integration in a single chip.

### 1.1 Product overview

The core functionality of BGT60UTR11AIP is to transmit frequency-modulated continuous wave signal through the *transmitter (TX)* channel and receive the echo signal from the target object on the *receiver (RX)* channel. The receiver path includes a baseband filtering, a *variable gain amplifier (VGA)*, as well as an *ADC*. The digitized output is stored in a *FIFO* based memory. The data are transferred to an external host, *microcontroller unit (MCU)* or *application processor (AP)*, to run radar signal processing. A typical implementation of a sensor system consists of two main blocks:

- Radar sensor (BGT60UTR11AIP) handles the *RF* signals and provides the sampled *intermediate frequency (IF)* signals
- AP or microcontroller unit which captures and processes the digital radar signals

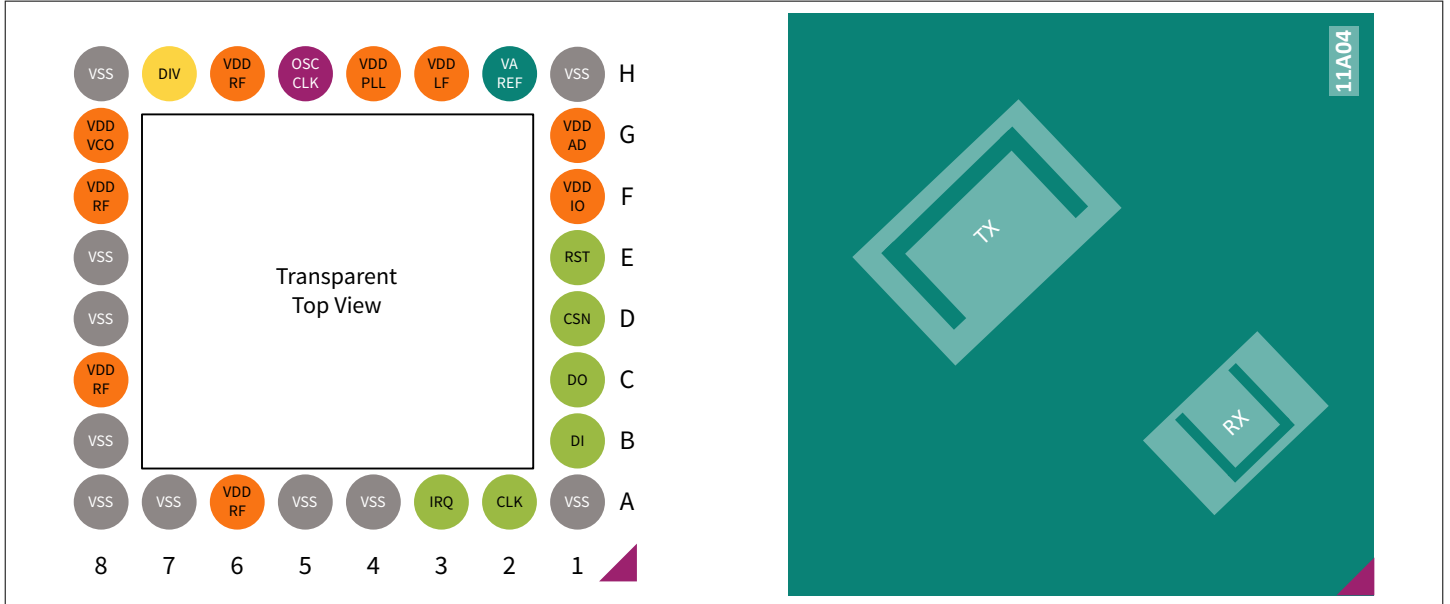


**Figure 2** Data flow in the complete radar sensor system



### 1.3 BGT60UTR11AIP pin definition and function

The following figure shows the transparent top view of BGT60UTR11AIP laminate package with the pin and antenna number assignment.



**Figure 4** BGT60UTR11AIP pin and antenna number assignment

The function of each pin is described in the following tables.

**Table 1** Ball definition

Ball	Function
A1, A4, A5, A7, A8, B8, D8, E8, H1, H8	$VSS_{RF}$ , $VSS_A$ , $VSS_D$
A2	CLK
A3	IRQ
B1	DI
C1	DO
D1	CSN
E1	RST
F1	$VDD_{IO}$
A6, C8, F8, H6	$VDD_{RF}$
G1	$VDD_{AD}$
G8	$VDD_{VCO}$
H2	$V_{AREF}$
H3	$VDD_{LF}$
H4	$VDD_{PLL}$
H5	OSC_CLK
H7	DIV



**Table 2** Antenna definition

Antenna	Function
TX1	Transmitter 1
RX1	Receiver 1

### 1.3.1 IO and supply pins

The following table gives an overview on the input/output pins of BGT60UTR11AIP.

**Abbreviations:**

- $V_{IN}$ : voltage input pin
- $V_{OUT}$ : voltage output pin
- $D_{IN}$ : digital input pin
- $D_{OUT}$ : digital output pin
- $A_{IN}$ : analog input pin
- $A_{OUT}$ : analog output pin
- $GND_D$ : digital ground connection
- $GND_A$ : analog ground connection

**Table 3** BGT60UTR11AIP input/output pins

Symbol	Type	Domain	Description	Type
DIV	$A_{OUT}$	$VDD_{RF}$	VCO divided by 16 output	Analog
OSC_CLK	$A_{IN}$	$VDD_{RF}$	Oscillator input	Analog
CLK	$D_{IN}$	$VDD_{IO}$	SPI clock input	Digital
CSN	$D_{IN}$	$VDD_{IO}$	SPI chip select input, active low	Digital
DI	$D_{IN}$	$VDD_{IO}$	SPI signal from the host output (MOSI)	Digital
DO	$D_{OUT}$	$VDD_{IO}$	SPI signal to the host input (MISO)	Digital
RST	$D_{IN}$	$VDD_{IO}$	Hardware reset pin	Digital
IRQ	$D_{OUT}$	$VDD_{IO}$	Interrupt output	Digital

The power supply pins are described in the following table.

**Table 4** BGT60UTR11AIP supply pins

Domain	Type	Value	Description	Domain
$VDD_{AD}$	$V_{IN}$	1.8 V	Analog and digital supply voltage	Analog-ADC, Digital
$VDD_{IO}$	$V_{IN}$	1.2 V 1.8 V	IO pad supply voltage	IO
$V_{AREF}$	$V_{OUT}$	1.2 V	Positive reference voltage output; for bypass cap	Analog-ADC
$VDD_{VCO}$	$V_{IN}$	1.8 V	Analog supply voltage to the VCO	Analog-RF
$VDD_{RF}$	$V_{IN}$	1.8 V	Analog supply voltage	Analog-RF

**(table continues...)**

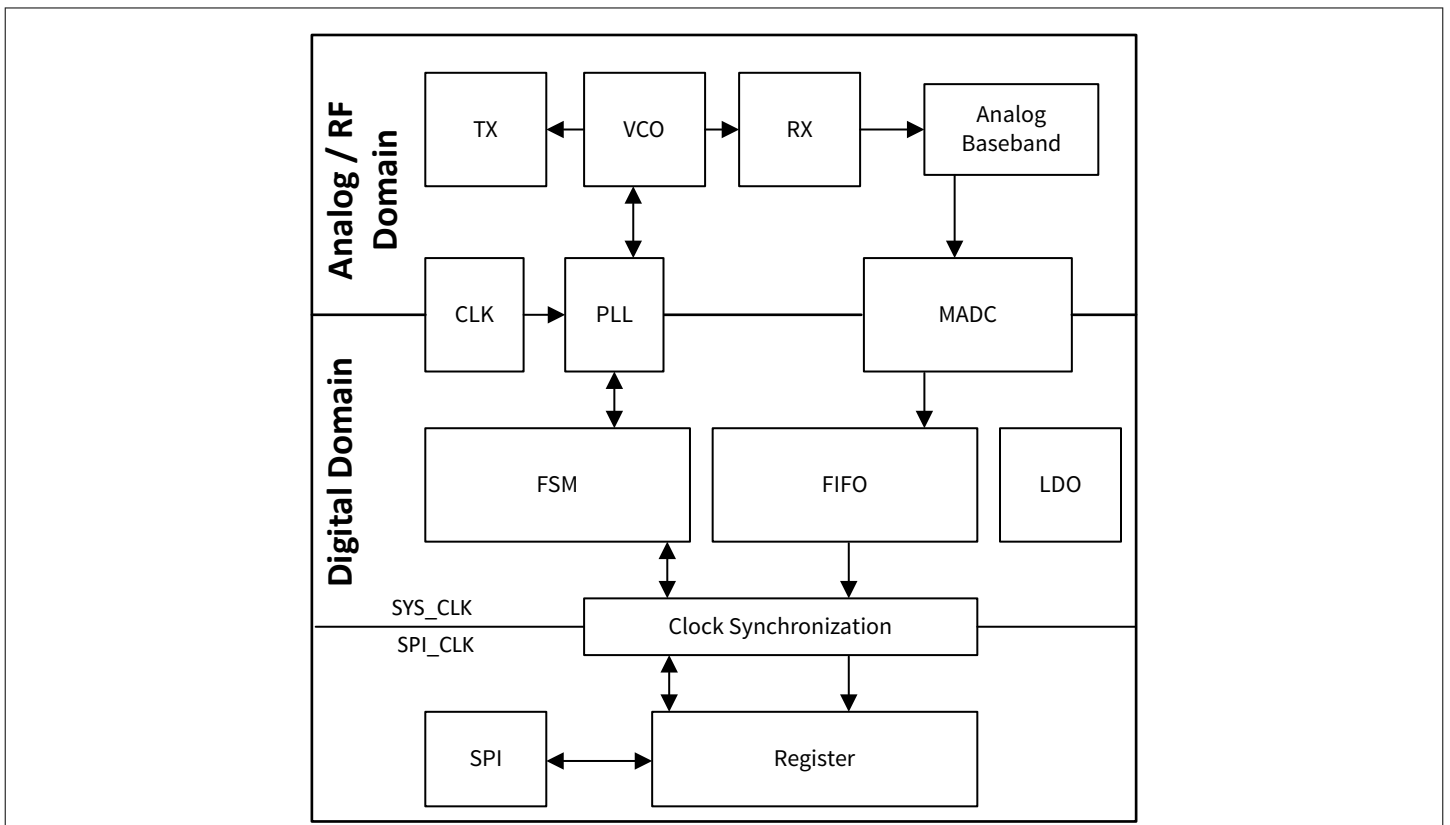
**Table 4** (continued) **BGT60UTR11AIP supply pins**

<b>Domain</b>	<b>Type</b>	<b>Value</b>	<b>Description</b>	<b>Domain</b>
$VDD_{LF}$	$V_{IN}$	3.3 V	Analog supply voltage for the level shifter for the PLL loop filter	Analog-RF
$VDD_{PLL}$	$V_{IN}$	1.8 V	Analog supply voltage to the PLL	Analog-RF
$VSS_{RF}$	$GND_A$	0 V	Analog ground connection	Analog-RF
$VSS_A$	$GND_A$	0 V	Analog ground connection	Analog-ADC
$VSS_D$	$GND_D$	0 V	Digital ground connection	Digital

## 1.4 BGT60UTR11AIP functional block diagram

BGT60UTR11AIP consists of some main functional blocks:

- *FSM* which manage the complete chip
- Register banks, see [Chapter 4](#)
- *FIFO*, 49 kbit = 2048 words x 24 bits
- *SPI*, up to 50 MHz clock
- Two clock domains
  - system clock domain e.g. 38.4/40/76.8/80 MHz for *PLL*, *ADC* and *FIFO*
  - *SPI* clock e.g. 50 MHz
- *PLL*, 3<sup>rd</sup> order sigma-delta based to perform *FMCW* ramp
- *RF* frontend consisting of 1 *RX* channel, 1 *TX* channel, *local oscillator (LO)* generation and divider by 4/5, see [Chapter 7.1](#)
- *ABB* consisting of *HPF*, *VGA* and *AAF*, see [Chapter 7.2](#)
- 1 channel multi ADC, 12 bits differential SAR ADC interfaced to the *ABB* via a driver and to the *FIFO* via a multiplexer, see [Chapter 8](#)
- Antenna built in package, see [Chapter 11](#)



**Figure 5 BGT60UTR11AIP functional overview**

## 2 General product specification

The reference for all specified data is the Infineon application board, available on request.

### 2.1 Absolute maximum ratings

**Table 5 Absolute maximum ratings**

$T_b = -40\text{ °C}$  to  $105\text{ °C}$ , all voltages with respect to ground, positive current flowing into pin (unless otherwise specified). Parameters not subject to production test.

Parameter	Symbol	Value			Unit	Condition
		Min.	Typ.	Max.		
Supply Voltage	$VDD_{AD}$	-0.3	-	+2.0	V	-
Supply Voltage	$VDD_{IO}$	-0.3	-	+2.0	V	-
Supply Voltage	$VDD_{RF}$	-0.3	-	+2.0	V	-
Supply Voltage	$VDD_{VCO}$	-0.3	-	+2.0	V	-
Supply Voltage	$VDD_{PLL}$	-0.3	-	+2.0	V	-
Supply Voltage	$VDD_{LF}$	-0.3	-	+3.7	V	-
RF Input Power Level	$P_{RF}$	-	-	+10	dBm	At the RX input pad (die)
Junction Temperature	$T_j$	-40	-	+125	°C	-
Storage Temperature	$T_{stg}$	-40	-	+150	°C	-

**Warning:** Stresses above the maximum values listed here may cause permanent damage to the device. Maximum ratings are absolute ratings; exceeding only one of these values may cause irreversible damage to the integrated circuit. Exposure to conditions at or below absolute maximum rating but above the specified maximum operation conditions may affect device reliability and lifetime. Functionality of the device might not be given under these conditions.

### 2.2 Range of functionality

**Table 6 Range of functionality**

Parameter	Symbol	Value			Unit	Condition
		Min.	Typ.	Max.		
Supply Voltage	$VDD_{AD}$	1.71	1.8	1.89	V	Noise on each supply domain should not exceed the level of 20 $\mu$ Vpp in the frequency range 20 kHz - 1 MHz <sup>1)</sup>
Supply Voltage	$VDD_{IO}$	1.14	1.2	1.26	V	
		1.71	1.8	1.89		
Supply Voltage	$VDD_{RF}$	1.71	1.8	1.89	V	
Supply Voltage	$VDD_{VCO}$	1.71	1.8	1.89	V	
Supply Voltage	$VDD_{PLL}$	1.71	1.8	1.89	V	
Supply Voltage	$VDD_{LF}$	2.5	3.3	3.63	V	

(table continues...)

**Table 6** (continued) Range of functionality

Parameter	Symbol	Value			Unit	Condition
		Min.	Typ.	Max.		
Chip Backside Temperature	$T_b$	-20	-	70	°C	Measured with the on chip temperature sensor
Frequency Range	$f_{RF}$	57.4	-	63.0	GHz	-
Oscillator Input Clock Frequency	$f_{OSC\_CLK\#1}$	75	80	85	MHz	1.8 V CMOS clock 78 MHz not allowed (frequency doubler disabled)
	$f_{OSC\_CLK\#2}^{2)}$	37.5	40	42.5	MHz	1.8 V CMOS clock 39 MHz not allowed (frequency doubler enabled)
Duty cycle of $f_{OSC\_CLK}$	$f_{DUTOSC}$	45	50	55	%	-
Rise and Fall Time of $f_{OSC\_CLK}$	$t_{RS,FS,SYS}$	-	2	6	ns	-
Phase Jitter of $f_{OSC\_CLK}$	$J_{PHOSC}$	-	1	-	ps	$BW$ : 12 kHz to 20 MHz

1) This value will ensure no artifact/false target in the Range-Doppler map when it is calculated with a minimum of 8 chirps.

2) In case  $f_{OSC\_CLK\#2}$  is used as input clock, an internal doubler will be used to multiply the input frequency by two. The doubler duty-cycle can be calibrated. See [PLL interfaces and clock distribution](#), [Reference clock distribution](#).

## 2.3 Current consumption

**Table 7** Overall current consumption

$VDD_X = 1.71\text{ V to }1.89\text{ V}$ ,  $VDD_{LF} = 2.5\text{ V to }3.3\text{ V}$  and  $T_b = -20\text{ °C to }+70\text{ °C}$ .

Parameter	Symbol	Value			Unit	Condition
		Min.	Typ.	Max.		
Idd Deep Sleep <sup>1)</sup>	$I_{DD_{DS}}$	0.05	0.178	0.555 <sup>2)</sup>	mA	
Idd Idle <sup>3)</sup>	$I_{DD_{Idle}}$	-	1.8	-	mA	-
Idd Init0, 1RX + 1TX	$I_{DD_{Init0}}$	-	3.2	-	mA	-
Idd Init1, 1RX + 1TX <sup>4)</sup>	$I_{DD_{Init1}}$	-	149	-	mA	-
Idd Active, 1RX + 1TX <sup>5)</sup>	$I_{DD_{Active}}$	133	174	220	mA	-

1) All registers in reset mode,  $f_{SYS\_CLK}$  clock path disabled.

2) The value at max refers to the max temperature, +70°C, and the max supply, 1.89 V.

3) MADC band-gap running.

4) Idd for the rest of interchirp similar to Init1.

5) Device set in radar mode, DAC TX set to  $3I_D$ .

**Table 8** **VDD<sub>AD</sub> domain current consumption**

VDD<sub>X</sub> = 1.71 V to 1.89 V, VDD<sub>LF</sub> = 2.5 V to 3.3 V, VDD<sub>IO</sub> = 1.14 V to 1.26 V and T<sub>b</sub> = -20 °C to +70 °C.

Parameter	Symbol	Value			Unit	Condition
		Min.	Typ.	Max.		
I <sub>dd</sub> Deep Sleep <sup>1)</sup>	AD <sub>I</sub> dd <sub>DS</sub>	0.05	0.147	0.490 <sup>2)</sup>	mA	-
I <sub>dd</sub> Idle <sup>3)</sup>	AD <sub>I</sub> dd <sub>Idle</sub>	-	2.0	-	mA	-
I <sub>dd</sub> Init0, 1RX + 1TX	AD <sub>I</sub> dd <sub>Init0</sub>	-	2.5	-	mA	-
I <sub>dd</sub> Init1, 1RX + 1TX <sup>4)</sup>	AD <sub>I</sub> dd <sub>Init1</sub>	-	3.3	-	mA	-
I <sub>dd</sub> Active, 1RX + 1TX <sup>5)</sup>	AD <sub>I</sub> dd <sub>Active</sub>	2.1	3.3	6.2	mA	-

- 1) All registers in reset mode, f<sub>SYS\_CLK</sub> clock path disabled.
- 2) The value at max refers to the max temperature, +70°C, and the max supply, 1.89 V.
- 3) MADC band-gap running.
- 4) I<sub>dd</sub> for the rest of interchirp similar to Init1.
- 5) Device set in radar mode, FIFO in low power mode, DAC TX set to 31<sub>D</sub> for an output power of +5 dBm.

**Table 9** **VDD<sub>PLL</sub> domain current consumption**

VDD<sub>X</sub> = 1.71 V to 1.89 V, VDD<sub>LF</sub> = 2.5 V to 3.3 V and T<sub>b</sub> = -20 °C to +70 °C.

Parameter	Symbol	Value			Unit	Condition
		Min.	Typ.	Max.		
I <sub>dd</sub> Deep Sleep <sup>1)</sup>	PLL <sub>I</sub> dd <sub>DS</sub>	0	0.0002	0.01	mA	-
I <sub>dd</sub> Idle <sup>2)</sup>	PLL <sub>I</sub> dd <sub>Idle</sub>	-	0.0002	-	mA	-
I <sub>dd</sub> Init0, 1RX + 1TX	PLL <sub>I</sub> dd <sub>Init0</sub>	-	0.9	-	mA	-
I <sub>dd</sub> Init1, 1RX + 1TX <sup>3)</sup>	PLL <sub>I</sub> dd <sub>Init1</sub>	-	7.9	-	mA	-
I <sub>dd</sub> Active, 1RX + 1TX <sup>4)</sup>	PLL <sub>I</sub> dd <sub>Active</sub>	5	8	10	mA	-

- 1) All registers in reset mode, f<sub>SYS\_CLK</sub> clock path disabled.
- 2) MADC band-gap running.
- 3) I<sub>dd</sub> for the rest of interchirp similar to Init1.
- 4) Device set in radar mode, DAC TX set to 31<sub>D</sub>.

**Table 10** **VDD<sub>LF</sub> domain current consumption**

VDD<sub>X</sub> = 1.71 V to 1.89 V, VDD<sub>LF</sub> = 2.5 V to 3.3 V and T<sub>b</sub> = -20 °C to +70 °C.

Parameter	Symbol	Value			Unit	Condition
		Min.	Typ.	Max.		
I <sub>dd</sub> Deep Sleep <sup>1)</sup>	LF <sub>I</sub> dd <sub>DS</sub>	0	0.0002	0.01	mA	-
I <sub>dd</sub> Idle <sup>2)</sup>	LF <sub>I</sub> dd <sub>Idle</sub>	-	0.0002	-	mA	-
I <sub>dd</sub> Init0, 1RX + 1TX	LF <sub>I</sub> dd <sub>Init0</sub>	-	0.39	-	mA	-
I <sub>dd</sub> Init1, 1RX + 1TX <sup>3)</sup>	LF <sub>I</sub> dd <sub>Init1</sub>	-	0.39	-	mA	-
I <sub>dd</sub> Active, 1RX + 1TX <sup>4)</sup>	LF <sub>I</sub> dd <sub>Active</sub>	0.2	0.39	0.53	mA	-

- 1) All registers in reset mode, f<sub>SYS\_CLK</sub> clock path disabled.
- 2) MADC band-gap running.
- 3) I<sub>dd</sub> for the rest of interchirp similar to Init1.

**2 General product specification**

4) Device set in radar mode, DAC TX set to 31<sub>D</sub>.

**Table 11** **VDD<sub>RF</sub> + VDD<sub>VCO</sub> domain current consumption**

VDD<sub>X</sub> = 1.71 V to 1.89 V, VDD<sub>LF</sub> = 2.5 V to 3.3 V and T<sub>b</sub> = -20 °C to +70 °C.

Parameter	Symbol	Value			Unit	Condition
		Min.	Typ.	Max.		
I <sub>dd</sub> Deep Sleep <sup>1)</sup>	RFI <sub>ddDS</sub>	0	0.003	0.045	mA	-
I <sub>dd</sub> Idle <sup>2)</sup>	RFI <sub>ddIdle</sub>	-	0.005	-	mA	-
I <sub>dd</sub> Init0, 1RX + 1TX	RFI <sub>ddInit0</sub>	-	0.005	-	mA	-
I <sub>dd</sub> Init1, 1RX + 1TX <sup>3)</sup>	RFI <sub>ddInit1</sub>	-	137	-	mA	-
I <sub>dd</sub> Active, 1RX + 1TX <sup>4)</sup>	RFI <sub>ddActive</sub>	120	162	220	mA	-

- 1) All registers in reset mode, f<sub>SYS\_CLK</sub> clock path disabled.
- 2) MADC band-gap running.
- 3) I<sub>dd</sub> for the rest of interchirp similar to Init1.
- 4) Device set in radar mode, DAC TX set to 31<sub>D</sub>.

**Table 12** **VDD<sub>IO</sub> domain current consumption**

VDD<sub>IO</sub> = 1.71 V to 1.89 V and T<sub>b</sub> = -20 °C to +70 °C.

Parameter	Symbol	Value			Unit	Condition
		Min.	Typ.	Max.		
I <sub>dd</sub> Deep Sleep <sup>1)</sup>	IOI <sub>ddDS</sub>	0	-	0.1 <sup>2)</sup>	mA	Standard SPI
I <sub>dd</sub> Active <sup>3)</sup>	IOI <sub>ddActive</sub>	0	-	0.17	mA	Standard SPI

- 1) All registers in reset mode, f<sub>SYS\_CLK</sub> clock path disabled.
- 2) The value at max refers to the max temperature, +70°C, and the max supply, 1.89 V.
- 3) Activity on SPI MISO and MOSI line.

## 2.4 ESD integrity

**Table 13** **ESD integrity**

VDD<sub>X</sub> = 1.71 V to 1.89 V, VDD<sub>LF</sub> = 2.5 V to 3.3 V, VDD<sub>IO</sub> = 1.08 V to 1.32 V and T<sub>b</sub> = -20 °C to +70 °C.

Parameter	Symbol	Value			Unit	Condition
		Min.	Typ.	Max.		
ESD robustness, <i>human body model (HBM)</i>	V <sub>ESD-HBM</sub>	-2000	-	+2000	V	According to JS-001. All pins.
ESD robustness, <i>charge device model (CDM)</i>	V <sub>ESD-CDM</sub>	-500	-	+500	V	According to JS-002.

charge device model: Field-Induced Charged-Device Model ANSI/ESDA/JEDEC JS-002. Simulates charging/discharging events that occur in production equipment and processes. Potential for CDM ESD events occurs whenever there is metal-to-metal contact in manufacturing.

human body model: Human Body Model ANSI/ESDA/JEDEC JS-001 (R = 1.5 kΩ, C = 100 pF).

## 2.5 Thermal resistance

**Table 14 Thermal resistance**

$VDD_X = 1.71\text{ V to }1.89\text{ V}$ ,  $VDD_{LF} = 2.5\text{ V to }3.3\text{ V}$ ,  $VDD_{IO} = 1.08\text{ V to }1.32\text{ V}$  and  $T_b = -20\text{ °C to }+70\text{ °C}$ .

Parameter	Symbol	Value			Unit	Condition
		Min.	Typ.	Max.		
Package thermal resistance	$R_{th}$	-	35	-	K/W	Chip backside to ambient temperature



### 3 Shapes, frames and channel set definition

This section is intended to provide the user with an overview on the overall modulation and power modes capabilities of BGT60UTR11AIP. Specifically the structure of timers, counters, shapes, channel set and frames will be presented. The section gives also a description of how the *FSM* is setting and controlling the *PLL* for the expected modulation shapes and sequences programmed by the host.

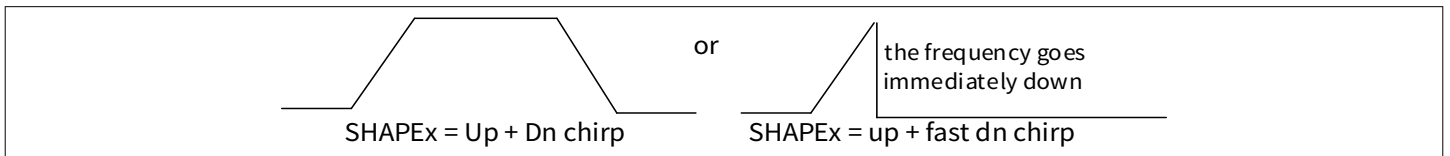
#### 3.1 Shapes and frames

The shape is the modulation chirp that should be performed by the PLL. Two basic shapes are allowed (see [Shape definition](#)):

- Triangular shape: consisting of a frequency upchirp and a frequency downchirp
- Saw-tooth shape: consisting of a frequency upchirp followed by a fast downchirp

The shapes are set and enabled in the PLLx[0..7] registers (see [PLL shape x register 0](#) and [PLL shape x register 7](#)) by the bit PLLx7:SH\_EN. Up to four different shapes can be programmed. If more than one shape is used, the lower shapes must be programmed (e.g. if 3 shapes are needed by the application, then x = 1...3).

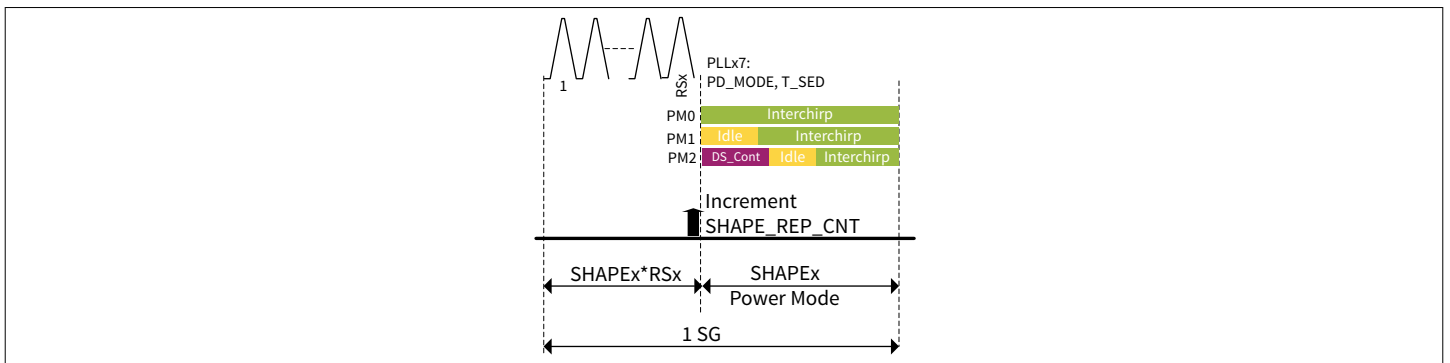
N\_SHAPE\_EN is the number of shapes enabled.



**Figure 6** Shape definition

#### Shape group

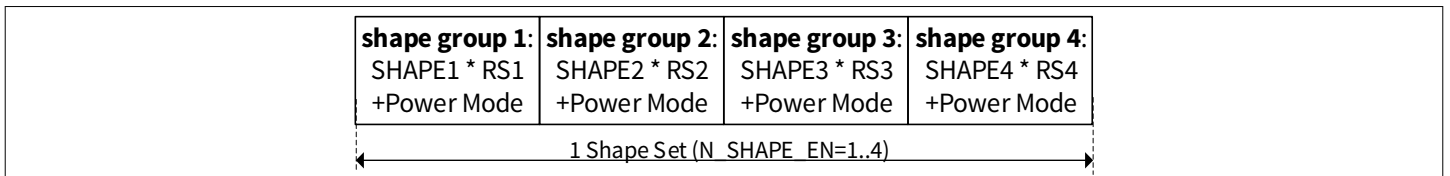
Each shape defined above can be repeated several times (see [Shape group](#)). The same shape repeated several times represents a shape group (SG). The repetition factor for the shape x is called REPSx and described in [PLL shape x register 7](#). Each shape is repeated RSx = 2<sup>REPSx</sup> times.



**Figure 7** Shape group

After the last repetitions the FSM will enter, for a period PLLx7:T\_SED (see [PLL shape x register 7](#)), the power mode programmed according to what is specified in PLLx7:PD\_MODE (see [PLL shape x register 7](#)).

After a shape group, the shape groups counter STAT1: SHAPE\_GRP\_CNT is incremented (see [Status register 1](#)). In [Shape set](#) an example of four programmed shape groups is shown. It represents a shape set.



**Figure 8** Shape set

**Frame**

A frame, as shown in [Example of one frame](#), is a sequence of shape sets followed by a specific power mode. Each shape set can be repeated several times. The repetition factor for the shape set x is called REPTx and described in [Chirp control register 0](#). Each shape set is repeated  $RTx = 2^{REPTx}$  times.

The length of a frame is defined through CCR2: FRAME\_LEN (see [Chirp control register 2](#)), which is the number of shape groups to be executed.

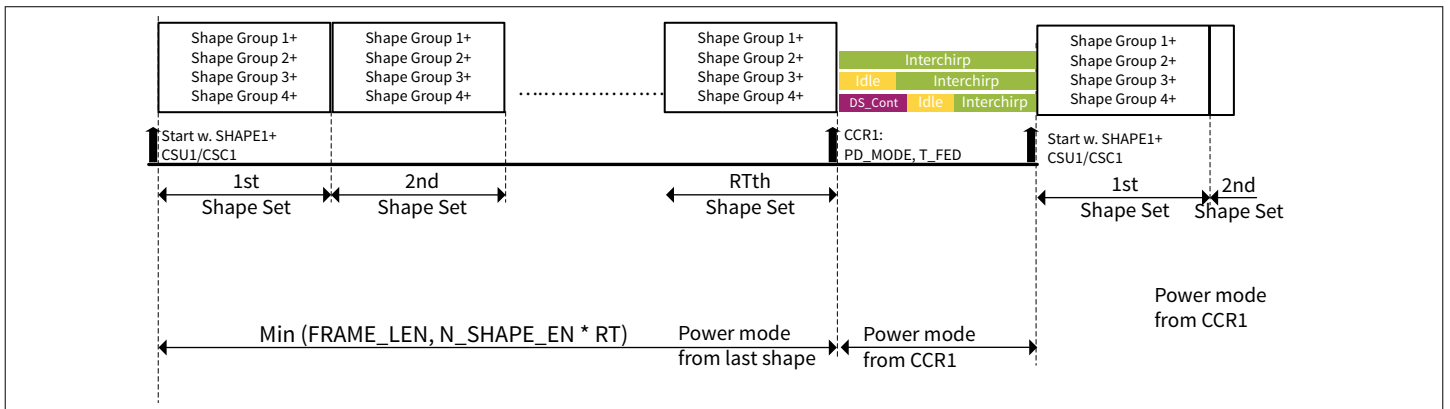
At each start of a frame, the first shape SHAPE1 together with the first channel set, CSU1+CSC1, is loaded.

The number of frame groups the FSM will execute will be:

- $\min(\text{CCR2:FRAME\_LEN}, \text{N\_SHAPE\_EN} * \text{RT})$

With  $RT \leq (4096/\text{shape groups})$  and  $\text{CCR2:FRAME\_LEN} < 4096$ .

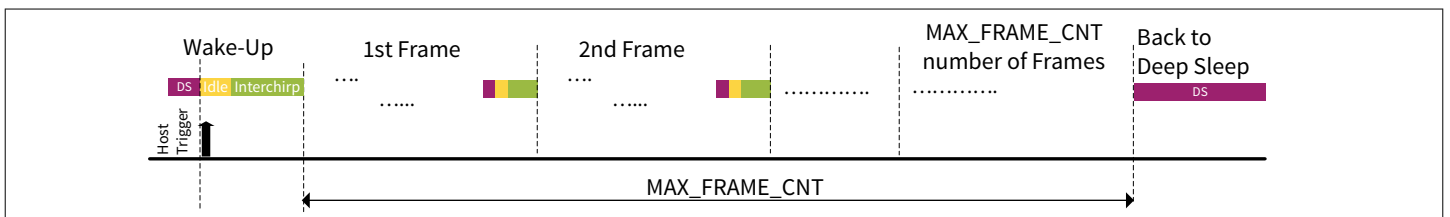
After the last shape group in a frame, the power mode from CCR1:PD\_MODE is used for the period programmed in CCR1:T\_FED instead of PPLx7:MODE for period PLLx7:T\_SED.



**Figure 9 Example of one frame**

**Maximum number of frames**

- The overall frame generation starts after the wake-up period with the first frame
- After the last frame CCR2: MAX\_FRAME\_CNT (see [Chirp control register 2](#)) is reached, the FSM will enter the deep sleep mode instead of the power mode defined at the end of the last but one frame
  - In order to trigger the chip again, a FSM reset is required



**Figure 10 Maximum number of frames**

**3.2 Channel set**

A channel set is a set of registers to control the configurations of the available transmit and receive channels. Each channel set can be repeated several times. The repetition factor for the channel set x is called REPCx and described in [Channel set control x register](#). Each channel set is repeated  $RCx = 2^{REPCx}$  times. There are in total 10 channel sets of 3 different types acting in the specific “modes”. 8 channel sets relate to the shapes (4 shapes x “up” and “down” segment settings) and two to the power modes, idle and deep sleep, respectively:

- Deep sleep power mode is related to channel set CSDS and CSCDS
- Idle mode is related to channel set CSI and CSCSI

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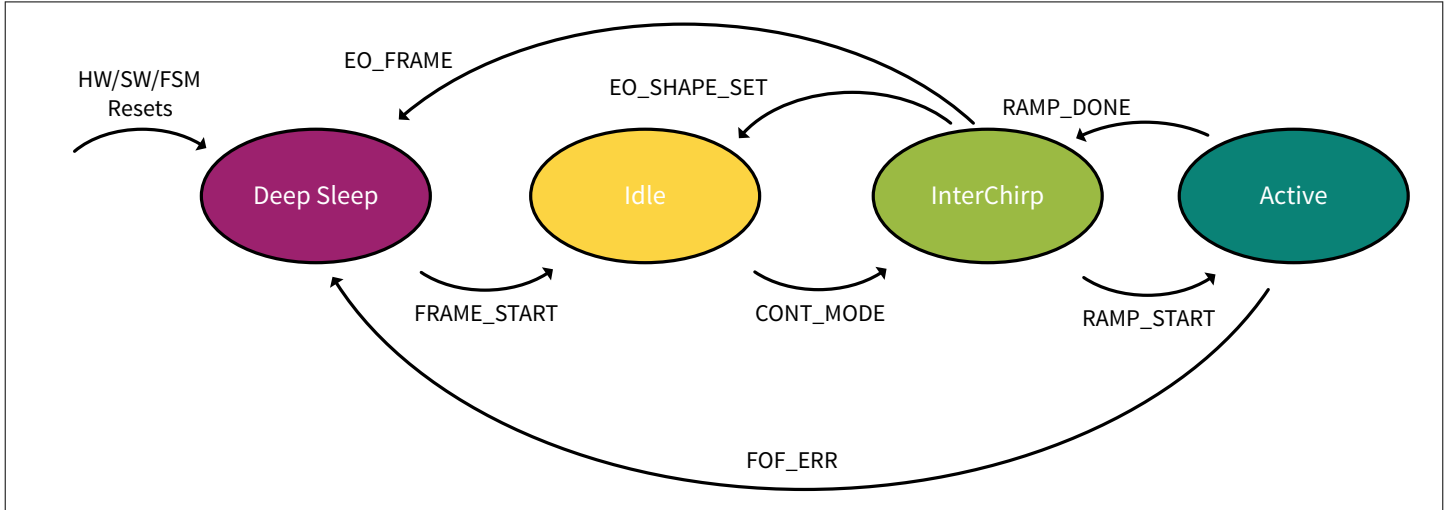
**3 Shapes, frames and channel set definition**

- 8 channel sets are defined for the shapes:
  - CSU1 ... CSU4 registers for upchirp
  - CSD1 ... CSD4 registers for downchirp
  - CSC1 ... CSC4 channel set configuration registers for up- and downchirp
- Each shape from above has up to 2 channel sets CSUx and CSDx
  - In case triangular shape is used, CSUx and CSDx are applied
  - In case sawtooth shape is used, CSDx is skipped
- Channel sets are repeated independent of the shapes
- Channel set repetition factor tells how often a single channel set is repeated until the next channel set is loaded
- On the channel set sequence:
  - The lower channel set number is followed by the next higher channel set number
  - In case the highest channel set number is reached, the next channel set loaded is channel set 1
- On the enabling sequence of channel sets:
  - In case not all channel sets are used, the lower number channel sets have to be used
  - In between the enabled channel sets must not be a disabled channel set
  - Eg: 2 channel sets expected: use only CS1 and CS2. In case 3 channel sets are expected, use only CS1, CS2, and CS3
- Start and end of channel set sequences:
  - After reset, the first channel set loaded is CS1
  - After a frame starts the first channel set loaded will be CS1

*Note: It would be preferable to have REPS = REPC.*

### 3.3 Power modes

The following figure shows the flow chart on all possible power modes for the FSM.



**Figure 11** FSM flow chart

#### Power Management through the power modes

The power modes enable the host to have full flexibility on power consumption during each state of radar frame generation. A set of isolation registers (see [Channel set control x register](#)) enables/disables the different blocks of the chip. The power modes are managed by the FSM.

#### 3.3.1 Mode descriptions

In active, idle, and deep sleep mode the power mode can be defined in the CSCx register, [Channel set control x register](#), for all channel sets: CSC1..4, CSI, CSCDS (CSUx = Channel Set Upchirp, CSDx = Channel Set Downchirp, CSI = Channel Set Idle, CSDS = Channel Set Deep Sleep).

##### Active mode definition:

- During a shape: PLLx7:PD\_MODE = 0<sub>D</sub>
- Power mode defined through registers CSx (CHS1..CHS4), same mode for up-/downchirp
- Default Setting: all expected settings are enabled by the host

##### Interchirp mode definition:

- During a shape: PLLx7:PD\_MODE = 0<sub>D</sub>
- Power mode basically same as active mode, exception: TX1 off (PAOFF)

##### Idle mode definition:

- After a shape: PLLx7:PD\_MODE = 1<sub>D</sub>
- After a frame: CCR1:PD\_MODE = 1<sub>D</sub>
- Idle mode is defined through CSCI
- Wake-up from deep sleep for MAIN:TR\_WKUP

The idle mode can be used as a low-power mode in between interchirp modes or after deep sleep mode to further reduce the overall power consumption while not entering the deep sleep mode. The wake-up times after Idle mode are faster compared to the ones after deep sleep mode.

**Entering deep sleep mode:**

- After a frame: CCR1:PD\_MODE = 2<sub>D</sub> and CCR0:CONT\_MODE = 0<sub>B</sub>
- Deep sleep mode is defined through CSCDS register (see [Channel set control x register](#))
- All blocks can be turned off
- Internal system clock is also turned off - to achieve extra power saving - when CONT\_MODE = 0<sub>B</sub> otherwise (CONT\_MODE = 1<sub>B</sub>) the clock is kept up to count the internal timer T\_FED/T\_SED during the deep sleep
- In order to wake up the FSM from the deep sleep, the host has to program:
  - PACR1:OSCCLKEN = 1<sub>B</sub> to enable the clock gating
  - Then the first trigger can be applied via FRAME\_START

*Note:* No re-configuration need to be performed as the register content is retained in deep sleep mode.

**Entering deep sleep cont mode:**

- After a shape: PLLx7: PD\_MODE = 2<sub>D</sub> and PLLx7:CONT\_MODE = 1<sub>B</sub>
- After a frame: CCR1:PD\_MODE = 2<sub>D</sub> and CCR0:CONT\_MODE = 1<sub>B</sub>

In case CCR0:CONT\_MODE = 1<sub>B</sub> is enabled the wake-up from deep sleep is done automatically. The internal system clock is kept running.

**In case of errors:**

If a FIFO overflow condition occurs, the FSM will bring the radar sensor into the deep sleep power mode even if the internal counters are holding the previous value, i.e., the FSM is not reset and a reset is required. In order to reset the FIFO, the host should send at least a MAIN:FIFO\_RESET command (see [Main register](#)).

If the FIFO overflow occurs, the event is reported in FSTAT:FOF\_ERR (see [FIFO status register](#)) or in GSR0:FOF\_ERR (see [Chapter 4.49](#)).

In this case the data inside a FIFO can be read from the host as long as no reset occurs.

The flags FSTAT:FOF\_ERR and GSR0:FOF\_ERR are cleared after a reset.

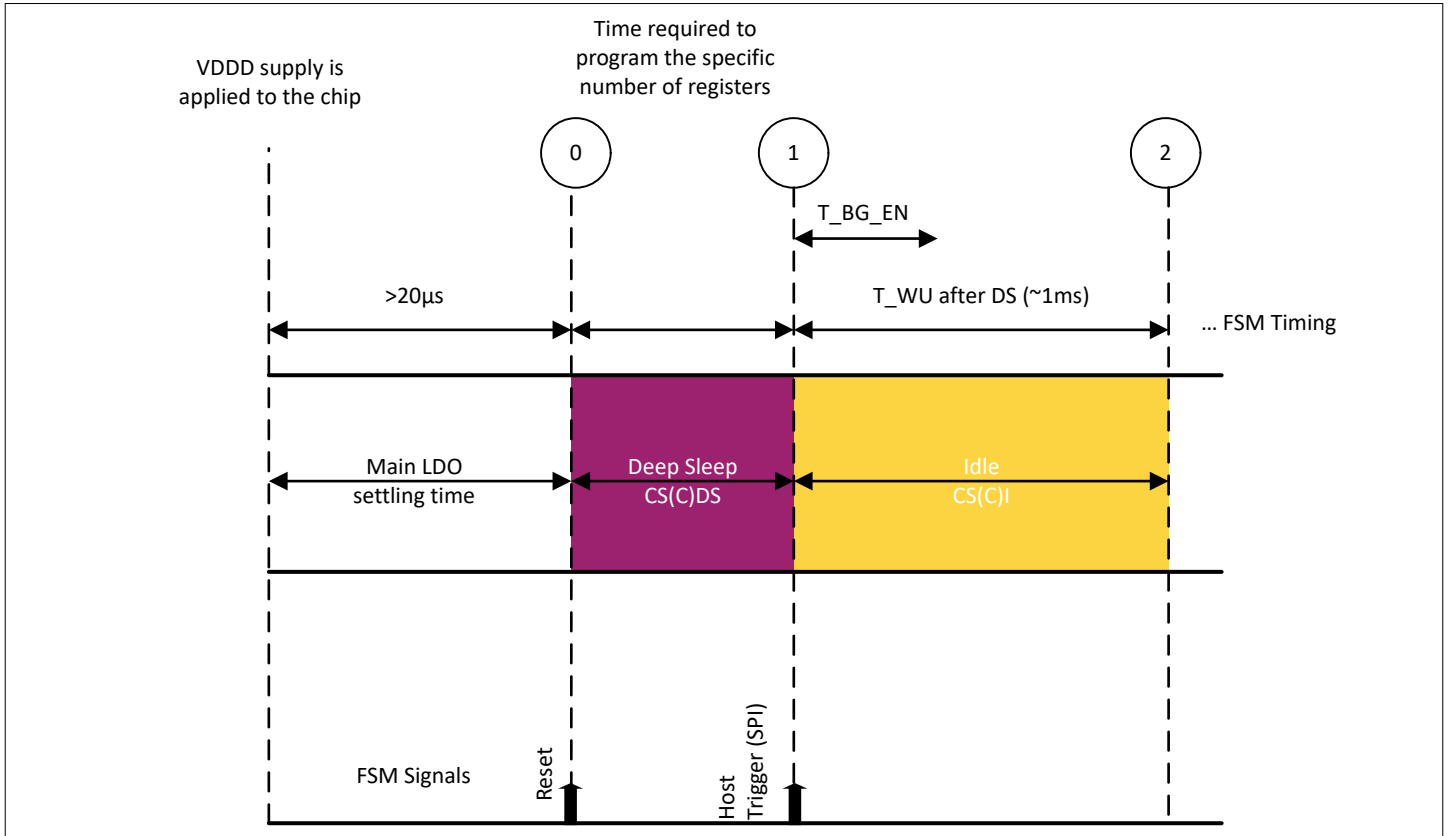
*Note:* Each time the SPI will access the chip, the system clock will be enabled internally for synchronization reasons.

### 3.3.2 Power modes and timings

This section presents the power modes and states that can be entered by the BGT60UTR11AIP FSM.

### 3.3.3 Wake-up phase from “deep sleep” to “idle”

After  $VDD_D$  power up the main LDO will require  $20\ \mu\text{s}$  to settle  $VDD_C$ . After the reset, the chip will move to a deep sleep state. The following figure describes the timing for waking up the chip.

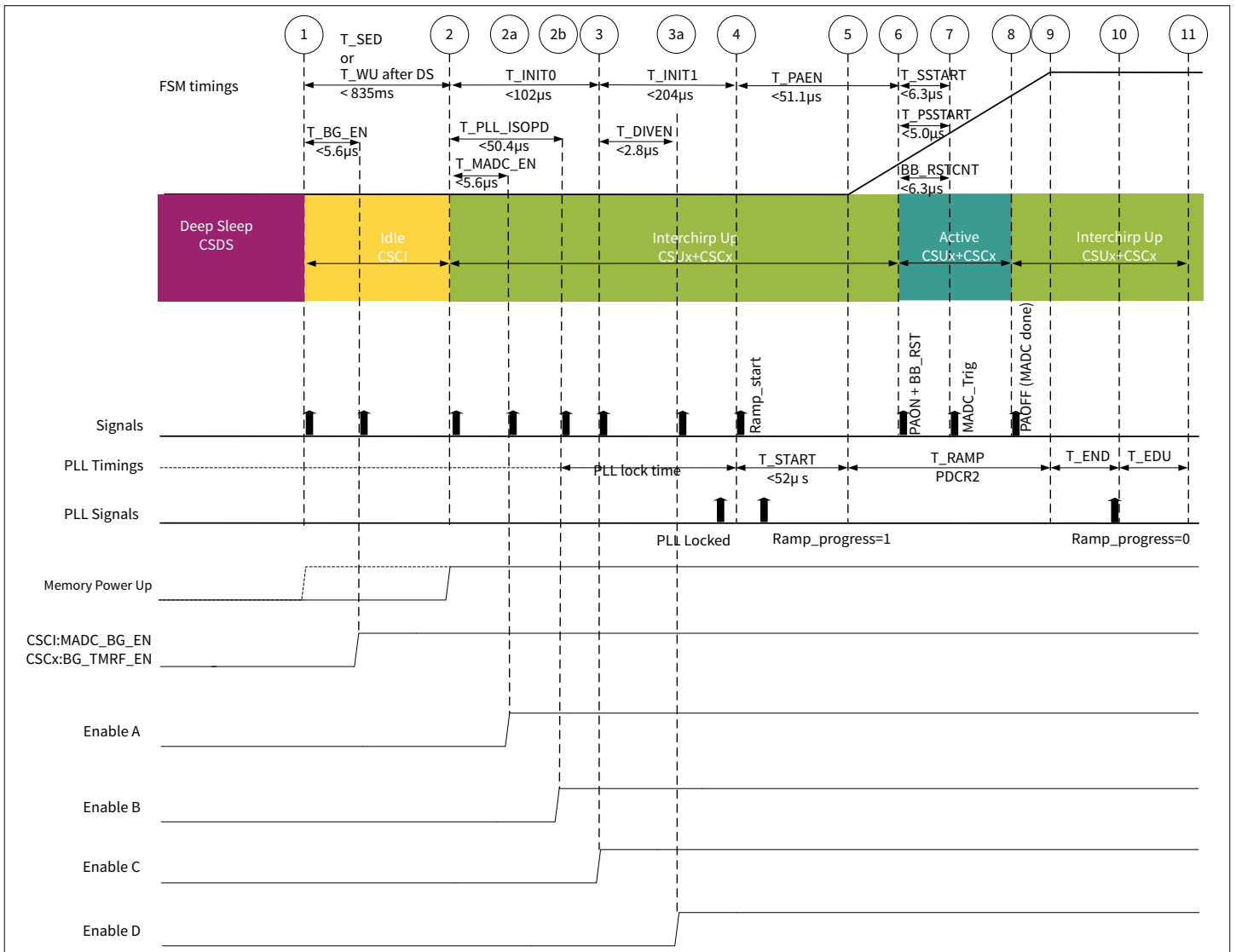


**Figure 12** Deep sleep to idle transition

**Table 15** Transitions from deep sleep into idle

From #	To #	Description	Signals	Related time
#0		Chip is reset by host (see <a href="#">Hardware reset sequence</a> )		
#0	#1	Host programs all registers needed for expected functionality		
#1		Host enables the oscillator: PACR1:OSCCLKEN= $1_B$ to enable the clock gating		
#1		Host starts the first trigger; it can be applied through MAIN:FRAME_START		
#1		Activate bandgap for MADC		
#1	#2	Time required to settle the ADC BG (charge of external cap)		$T_{WU}$
#2		Enable PLL, MADC, and SADC		
#2		MADC sends ready signal to FSM	madc_rdy	

### 3.3.4 Idle to interchirp then active



**Figure 13** Transition from idle to interchirp to active to interchirp again

**Table 16** Transition from idle to interchirp to active to interchirp

From #	To #	Description	Signals	Related time
#1		Idle mode is activated		
#1		The user has to enable the bandgap (CSCI:BG_EN= 1 <sub>B</sub> in <a href="#">Channel set control x register</a> )		
#1		In the case the memory is powered up after DS (SFCTL:FIFO_PD_MODE = 1 <sub>D</sub> ) the bandgap should be enabled delayed. This can be done by the user by programming CSCI:TR_BG_EN		T_BG_EN
#1	#2	If Idle mode comes after a deep sleep (see transition from deep sleep to idle). Wake up time can be used as offset for chirps in case multiple devices are triggered together by <i>SPI</i> broadcast for example		T_WU

(table continues...)

**Table 16 (continued) Transition from idle to interchirp to active to interchirp**

From #	To #	Description	Signals	Related time
#1	#2	If Idle mode comes after an interchirp mode, the bandgap is already running		T_SED
#2		Interchirp Up mode is activated by selecting CSUx + CSCx register depending on the actual channel set (see <a href="#">Channel set up x register 0</a> )		
#2		Host already enabled the blocks required by the PLL: CSx:VCO_EN = 1 <sub>B</sub> CSx:FDIV_EN = 1 <sub>B</sub>		
#2		FSM sets power mode from CSUx + CSCx		
#2		FSM sets PACR1.RFILTSEL = 0 <sub>B</sub>		
#2	#2a	In the case the memory is powered up after Idle (SFCTL:FIFO_PD_MODE = 2 <sub>D</sub> ) the MADC should be enabled delayed. This can be done by the user by programming CSCI:TR_MADC_EN		T_MADC_EN
#2a		After T_MADC_EN is over, enable A gets active which gates CSxx_1:MADC_BBCHx_EN		
#2	#2b	To save power there is the option to keep the PLL in reset state and enable the PLL delayed		T_PLL_ISOPD
#2b		After T_PLL_ISOPD is over, enable B gets active which gates CSCx:PLL_ISOPD		
#2	#3	The PLL needs some time to initialize the filter settings (see <a href="#">Chirp control register 3</a> )		T_INIT0
#3		Enable C gets active which gates following signals: PACR1.RFILTSEL, CSxx_0:VCO_EN, CSxx_0:FDIV_EN, CSCx:ABB_ISOPD, CSCx:RF_ISOPD		
#3	#3a	To save power there is the option to close the feedback loop within the PLL delayed		T_DIVEN
#3a		After T_DIVEN is over, enable D gets active which gates PACR2:TR_DIVEN		
#3	#4	The PLL needs again some time to settle the mode (see Chirp control register 0)		T_INIT1
#4		PLL sends lock signal to FSM	PLL_lock	
#4		FSM give ramp_start signal to PLL	RAMP_START	
#4	#5	PLL needs some settling time before chirp can start. The PLL timer is running in parallel to the FSM timer. T_START will be evaluated during system testing		T_START (PLL)
#5	#9	PLL will run the frequency chirp		T_RAMP (PLL)
#4	#6	Delay PA enable		T_PAEN
#6		Active mode starts here		

**(table continues...)**

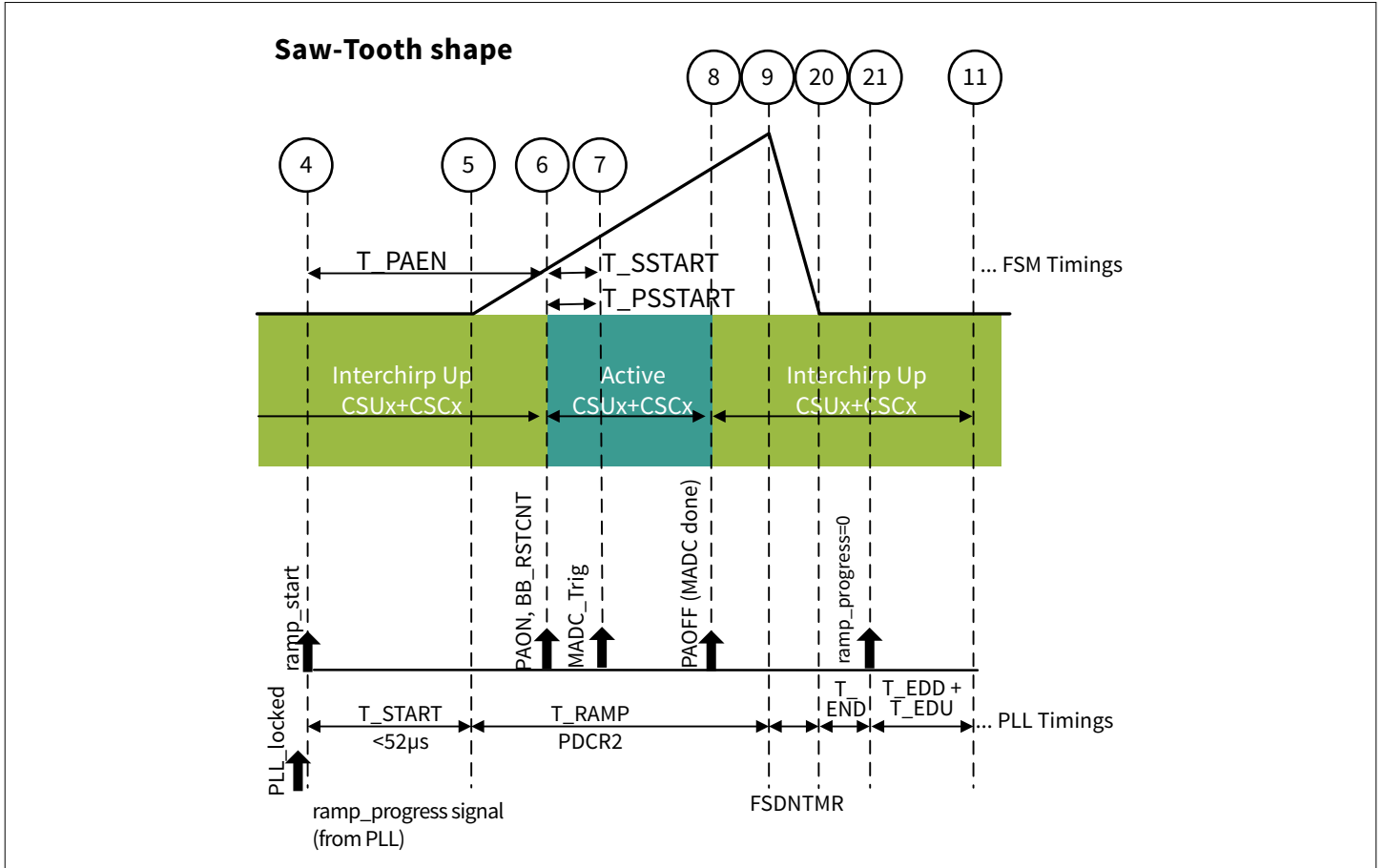


**Table 16** (continued) Transition from idle to interchirp to active to interchirp

From #	To #	Description	Signals	Related time
#6		PA is enabled (PAON). Host makes sure that PA is not ON before the chirp starts (>#5)	PAON	
#6		Baseband reset timer is enabled here based on the CSx:BB_RSTCNT value		
#6	#7	Delay after PA is enabled before the power measurement is started (if activated in CSx)		T_PSSTART
#6	#7	During this phase the baseband can settle		T_SSTART
#7		MADC is triggered for the active segment (Up)	MADC_TRIG	
#7	#8	MADC starts acquiring the given number of samples (PLLx:APU in <a href="#">PLL shape x register 3</a> ).		T_ACQUx
#8		MADC has completed the acquisition of the expected number of samples	MADC_DONE	
#8		PA is disabled (PAOFF) This condition must be reached before #9 The condition is: $T_{PAEN} + T_{SSTART} + T_{ACQUx} > T_{START} + T_{RAMPx}$	PAOFF	
#8		Interchirp up mode is activated again here (CSUx + CSCx)		
#9		PLL has completed the upchirp		
#9	#10	Programmable delay time (eg. 3 $\mu$ s)		T_END
#10		Ramp completed	RAMP_DONE	
#10	#11	Programmable delay time (eg. 1 $\mu$ s)		T_EDU
#11		Interchirp up mode ends here		
#11		Interchirp down mode is programmed here		

### 3.3.5 Saw-tooth shape timing

In the saw-tooth mode, after a normal upchirp segment there will be a fast ramp down segment. The saw-tooth shape should be enabled in the bitfield PACR2:FSTDNEN (see [PLL analog control register 2](#)). For the sawtooth only CSU (Upchirp) is used (see [Channel set up x register 0](#)). The time T\_EDU (see [PLL shape x register 2](#), PLLx2#) is applied after the segment is completed. See following figure.



**Figure 14** Saw-tooth shape timing

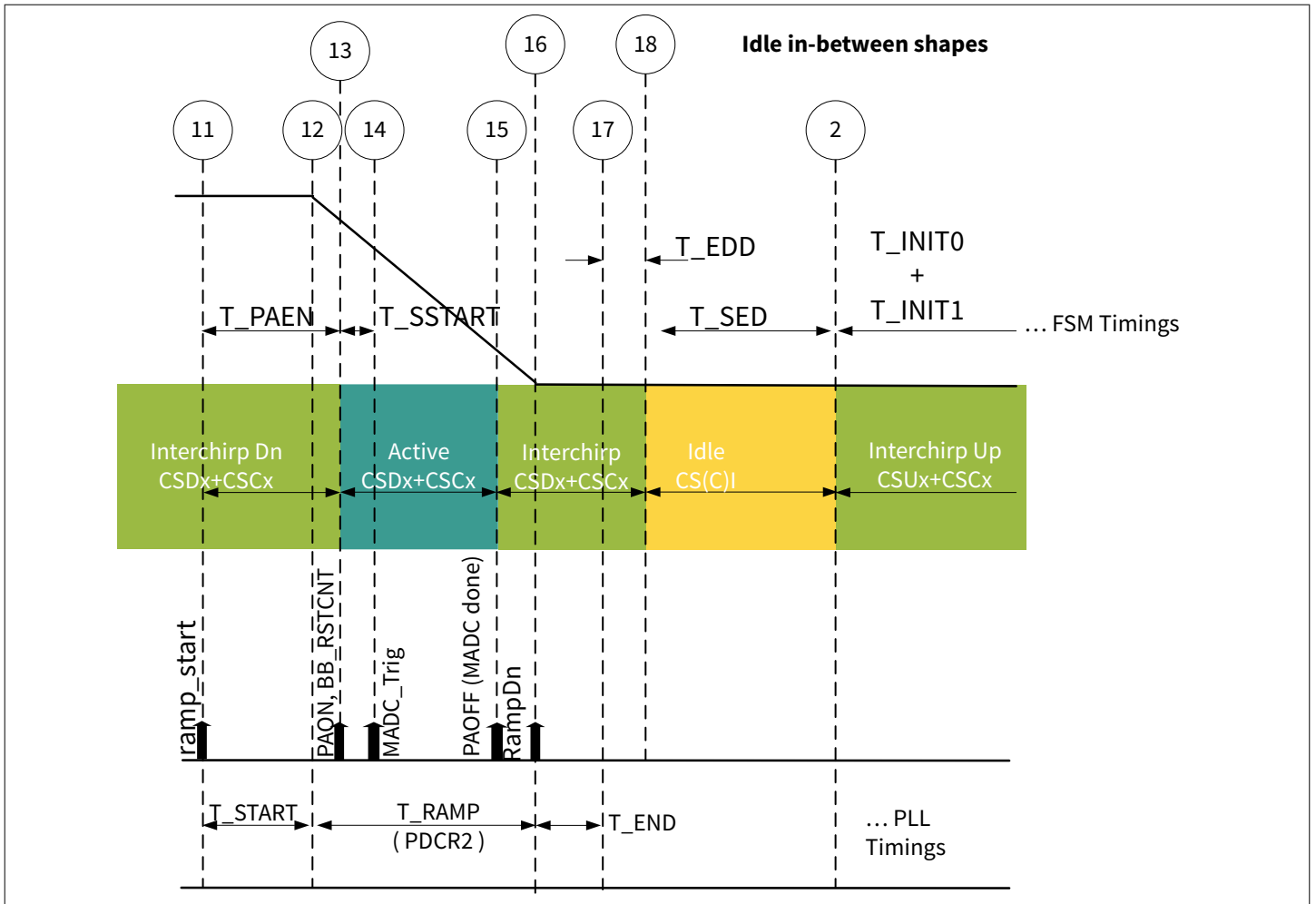
### 3.3.6 Different power modes after shapes and shape groups

After the downchirp shape, the chip can enter different power modes based on the settings (PLLx, CSx, CSCx):

- Interchirp mode in-between shapes – for fast chirp repetitions
- Idle mode after shape groups – in case of longer delay between shape groups and max power saving is required
- Deep sleep + idle mode after shape groups in case if very long delays are expected

#### 3.3.6.1 Idle after shape or shape groups

The idle mode after a shape or shape groups can be set when a long time in low power mode between shapes is required. The following figure represents a time behavior continuation of what presented in [Figure 13](#).



**Figure 15** Idle mode after shape groups

**Table 17** End of shape and interchirp in-between shapes

From #	To #	Description	Signals	Related time
#11		Interchirp Dn mode is programmed here (CSDx + CSCx)		
#11		FSM generates ramp_start signal	Ramp_start	
PLL related:				
#11	#12	Preparation for downchirp		T_START
#12	#16	downchirp time		T_RAMP
#16	#17	Some delay after downchirp is completed		T_END
FSM related:				
#11	#13	Some delay (see above T_PAEN)		T_PAEN
#13		Active mode is entered with settings from previous interchirp Dn mode (CSDx+CSCx)		
#13		PA is enabled (PAON) Host make sure that PA is not on before the chirp starts (>#12)	PAON	

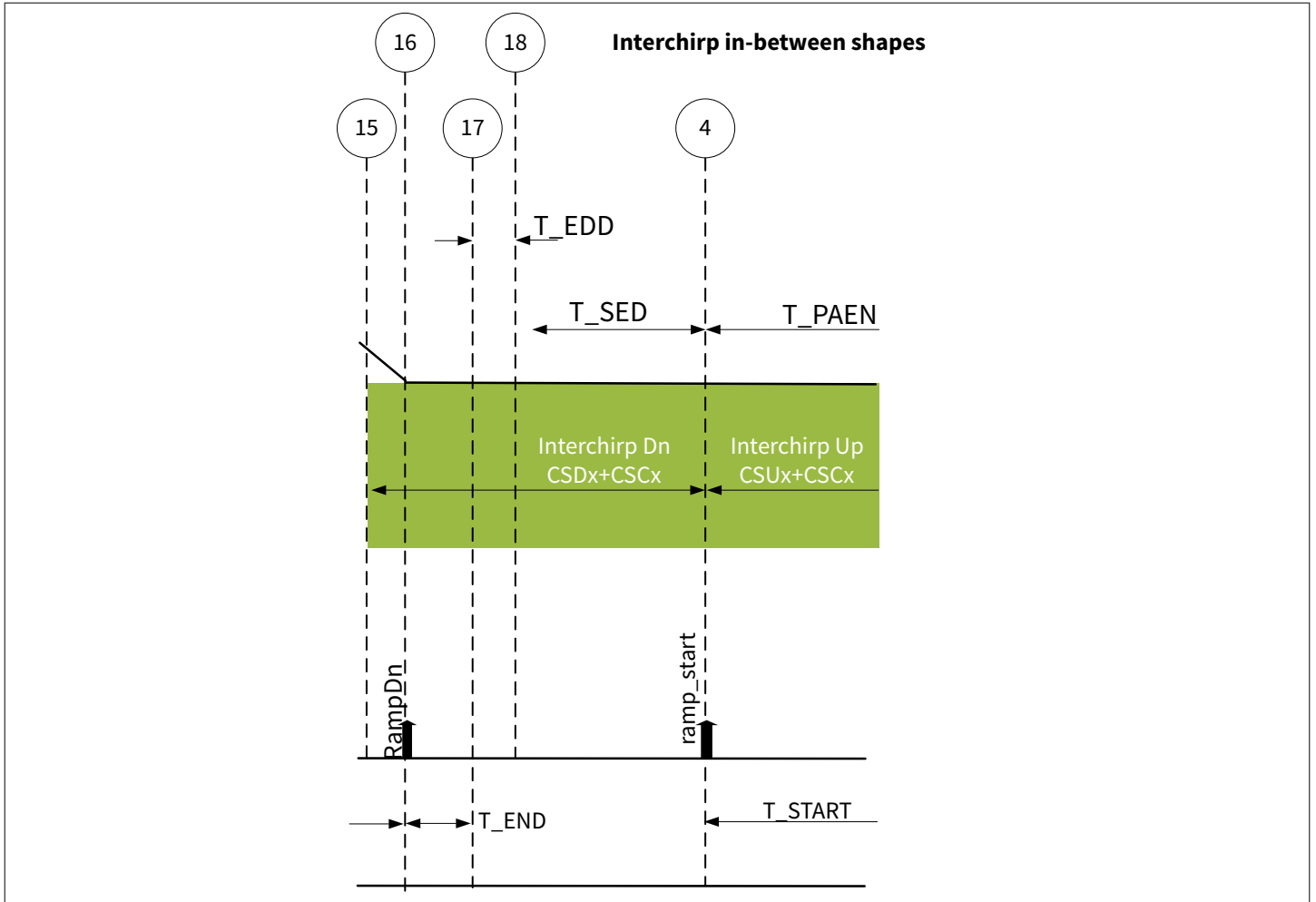
(table continues...)

**Table 17** (continued) **End of shape and interchirp in-between shapes**

From #	To #	Description	Signals	Related time
#13		Baseband reset timer is enabled here based on the CSx:BB_RSTCNT value		
#13	#14	During this phase the baseband can settle		T_SSTART
#14	#15	MADC starts acquiring the given number of samples (PLLx:APD in <a href="#">PLL shape x register 3</a> ).	MADC_TRIG	T_ACQDx
#15		MADC has completed the acquisition of the expected number of samples	MADC_DONE	
#15		PA is disabled (PAOFF) This condition must be reached before #16 The condition is: $T\_PAEN + T\_SSTART + T\_ACQDx > T\_START + T\_RAMPx$ .	PAOFF	
#15		Interchirp Dn mode is activated again here (CSDx + CSCx)		
#14	#16	FSM waits for PLL if ramp down to calculate #17 (TMREND)		
#16		PLL signals the end of the downchirp (ramp progress)	RampDN	
#17		Temperature measurement is started (if activated in CSx).		
#17	#18	Time delay programmed by the host		T_EDD
#18	#2	Time programed by the host to stay in Idle mode		T_SED
#2		Same state #2 as in <a href="#">Figure 13</a> starts here		

### 3.3.6.2 Interchirp in-between shapes

Interchirp between shapes can be set when the required gap between two shapes is relative small (< 25 μs).



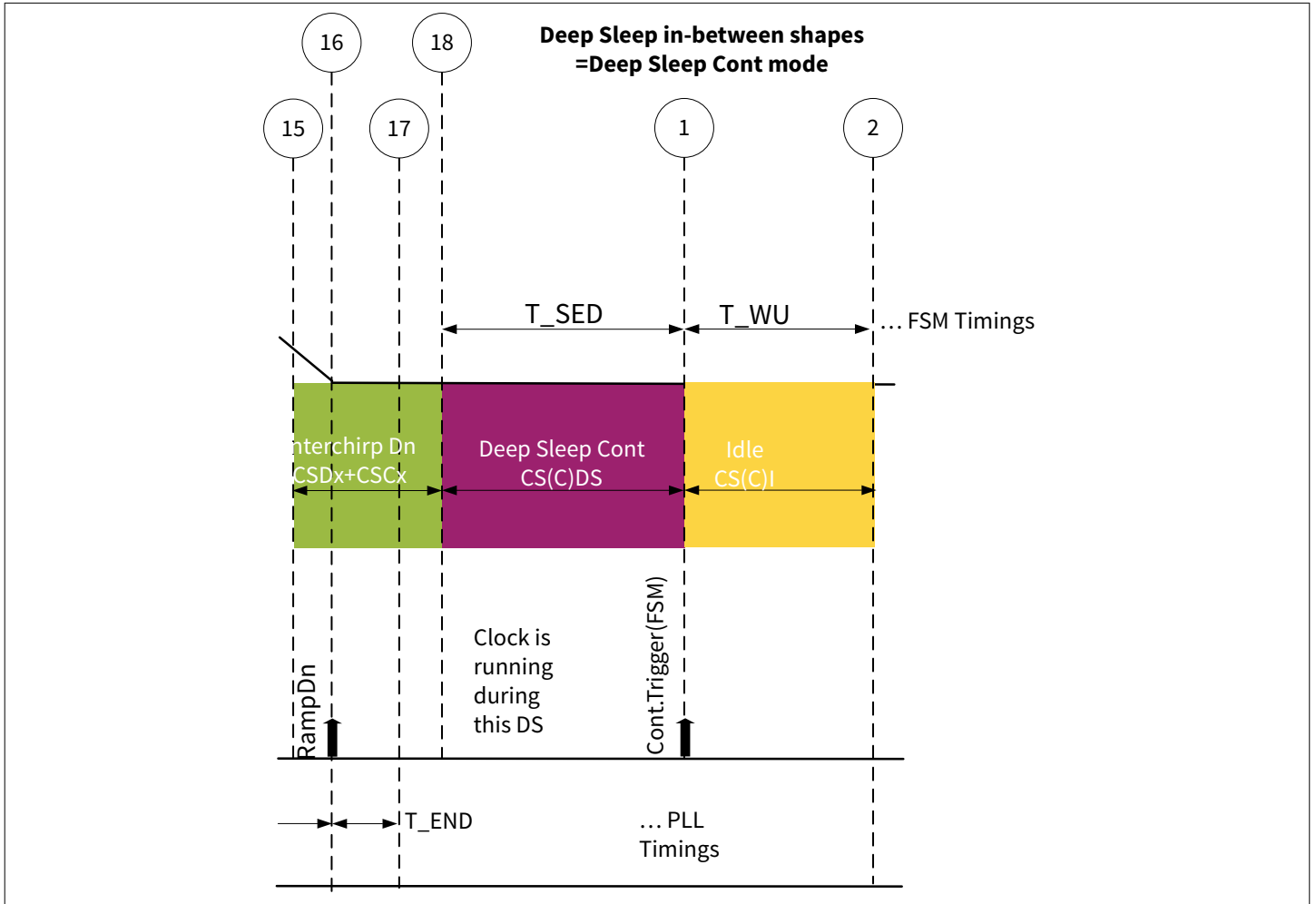
**Figure 16** Interchirp in-between shapes

**Table 18** Interchirp in-between shapes

From #	To #	Description	Signals	Related time
#15		Interchirp Dn (CSDx + CSCx) is activated after active mode		
#16		PLL signals the end of the downchirp (ramp progress)	RampDN	
#16	#17	Some delay after downchirp is completed		T_END
#17		PLL has completed its action		
#17		Temperature measurement is started (if activated in CSx).		
#17	#18	Time delay programmed by the host		T_EDD
#18	#4	The chip will remain in the same interchirp power state for the provided amount of time (T_EDD)		T_SED
#4		Same state #4 as in <a href="#">Figure 13</a> starts here		
#4		Interchirp up mode programmed by FSM here (CSUx + CSCx)		

### 3.3.6.3 Deep sleep continuous + idle wake-up after shape groups

In deep sleep cont(inuous) mode after the shape group is completed, the FSM wakes up automatically after the programmed time  $T_{SED}$ . The internal clock is kept running during this time. Deep sleep cont is the only deep sleep power mode possible between shape groups.



**Figure 17** Deep sleep + idle wake-up after shape groups

**Table 19** Deep sleep cont + idle wake-up after shape groups

From #	To #	Description	Signals	Related time
#16	#17	Some delay after downchirp is completed		$T_{END}$
#17		PLL is completed its action		
#17		Temperature measurement is started (if activated in CSx).		
#17		Deep sleep cont mode is enabled. The difference to the normal deep sleep mode is, the $f_{SYS\_CLK}$ is kept running to count the internal timers		
#17		The internal system clock $f_{SYS\_CLK}$ is kept running		
#17	#18	Time delay programmed by the host		$T_{EDD}$
#18	#1	The chip will be in deep sleep cont mode		$T_{SED}$
#1		Continuous trigger coming from the FSM		

(table continues...)

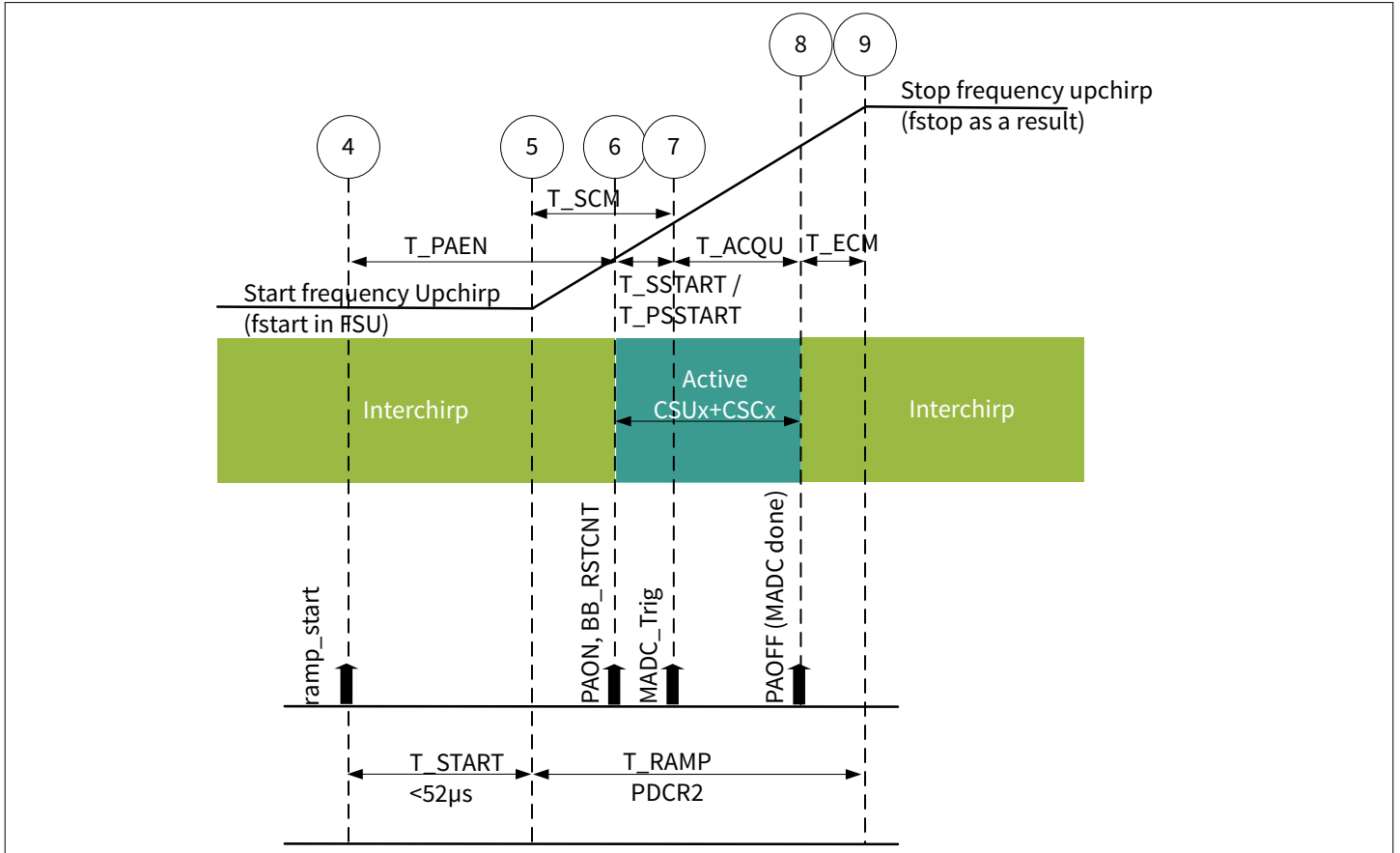
**Table 19** (continued) Deep sleep cont + idle wake-up after shape groups

<b>From #</b>	<b>To #</b>	<b>Description</b>	<b>Signals</b>	<b>Related time</b>
#1		Same start-up procedure as <a href="#">Figure 13</a> starts here		

### 3.4 System constraints

#### 3.4.1 MADC sampling timing conditions and calculations

The number of MADC samples during a frequency chirp (up or down segment of the shape) should fulfill some specific requirements.



**Figure 18** T\_RAMP timing conditions

**Table 20** T\_RAMP timing conditions

From #	To #	Description	Signals	Related time
#4		PLL starts counting		
#4	#5	PLL starts		T_START
#5	#9	PLL performs the frequency upchirp, chirp from fstart (PLLx[1]:FSU) to fstop		T_RAMP
#6	#8	Active phase		
#4	#7	Time to start the MADC		T_PAEN+T_S START
#6	#7	Delay after PA is enabled before the power measurement is started (if activated in CSx)		T_PSSTART
#7	#8	MADC sampling time for upchirp raw data		T_ACQUX

(table continues...)



**Table 20 (continued) T\_RAMP timing conditions**

From #	To #	Description	Signals	Related time
#8	#9	End chirp margin T_ECM is needed to avoid transmission out of band. Empirically derived in system		T_ECM
#5	#7	Start chirp margin T_SCM is needed to avoid transmission out of band. Empirically derived in system		T_SCM

**Summary:**

ADC sampling rate  $f_{ADC\_SAMP}$  (see [Chapter 8.5.5](#)):

- $f_{ADC\_SAMP} = f_{ADC\_CLK}/ADC\_DIV$

ADC acquisition time for Upchirp T\_ACQUx:

- $T\_ACQUx = APUx/f_{ADC\_SAMP}$

Where APU is the number of samples.

End chirp margin T\_ECM is tested in system but assumed to be more than 0  $\mu$ s:

- $T\_ECM > 0 \mu s, T\_SCM > 0 \mu s$

Condition on the data acquisition start time:

- $T\_PAEN + T\_SSTART > T\_START$

Considering the start chirp margin TCM at the beginning:

- $T\_PAEN + T\_SSTART - T\_SCM = T\_START$

Overall timing equation:

- $T\_PAEN + T\_SSTART + T\_ACQUx + T\_ECM = T\_START + T\_RAMP$

**Example with fixed number of samples:**

In case the user expects a fixed number of samples, the APU is set and T\_RAMP is calculated.

The time for a frequency ramp T\_RAMP is:

- $T\_RAMP (PLLx2\#:RTU \text{ in } \text{PLL shape x register 2}) = T\_PAEN + T\_SSTART + T\_ACQUx + T\_ECM - T\_START$

**Example with fixed chirp-time (T\_RAMP):**

- $T\_ACQUx = T\_RAMP - (T\_SCM + T\_ECM)$

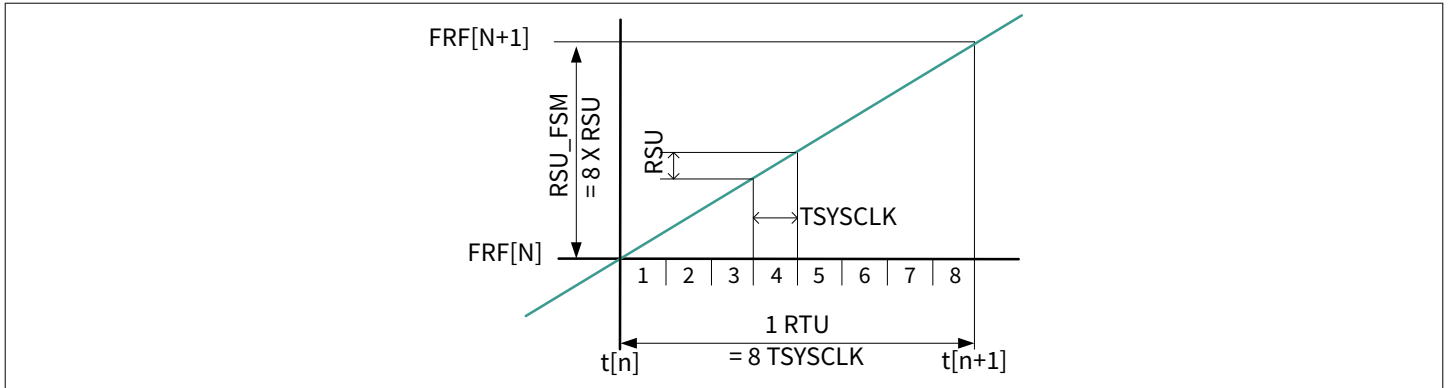
- $APU = (T\_ACQUx * f_{ADC\_SAMP}),$

- $APU (PLLx3\#:APU \text{ in } \text{PLL shape x register 3}) = (T\_RAMP - (T\_SCM + T\_ECM)) * (f_{SYS\_CLK}/ADC\_DIV)$

**3.4.2 PLL frequency ramp setup**

The RF frequency ramps generated by the PLL are controlled through the PLLx registers (see [PLL shape x register 0](#)), where the bit fields FSU, RSU and RTU control the Upchirp of a shape and the registers FSD, RSD and RTD control the down chirp of a shape. The following description refers only to up chirp ramp setup. The given formulas can be adopted to down chirp ramps by replacing FSU by FSD, RSU by RSD and RTU by RTD.

Each RF frequency ramp is defined by the start frequency programmed to FSU, the ramp slope programmed to RSU and the ramp time programmed to RTU. It must be noted that the slope in RSU is specified as frequency increment per clock cycle while the ramp time in RTU is specified as number of steps where a single step means 8 clock cycles. The relation between RSU and RTU is shown in the following figure.



**Figure 19 Relationship between RTU and RSU**

The value NFSU that is programmed to FSU bit field to control the ramp start frequency is a signed 2's complement number in the range of  $-2^{23} \dots (2^{23} - 1)$ . The relation between the RF frequency  $f_{RF}$  and NFSU is given by:

$$f_{RF} = 8f_{SYS\_CLK} \left[ 4(N_{DIVSET} + 2) + 8 + \frac{N_{FSU}}{2^{20}} \right] \quad (1)$$

where  $f_{SYS\_CLK}$  is the frequency of the reference clock oscillator and  $N_{DIVSET}$  is the value programmed to the bit field DIVSET in register PACR2 (default 20, see [PLL analog control register 2](#)). Accordingly the value  $N_{FSU}$  can be calculated by this formula:

$$N_{FSU} = 2^{20} \left[ \frac{f_{RF}}{8f_{SYS\_CLK}} - 4(N_{DIVSET} + 2) - 8 \right] \quad (2)$$

The value  $N_{RSU}$  that is programmed to RSU bit field to control the frequency increment per clock cycle is also a signed 2's complement number in the range of  $-2^{23} \dots (2^{23} - 1)$ . The relation between the RF frequency increment  $\Delta f_{RF}$  and  $N_{RSU}$  is given by:

$$\Delta f_{RF} = 8f_{SYS\_CLK} \frac{N_{RSU}}{2^{20}} \quad (3)$$

or

$$N_{RSU} = 2^{20} \frac{\Delta f_{RF}}{8f_{SYS\_CLK}} \quad (4)$$

**Note:** Both slope bit fields RSU and RSD can hold positive and negative values, so an up chirp can also be programmed with a falling ramp and a down chirp can be programmed with a rising ramp. The naming convention "up chirp" and "down chirp" are based on the assumption that a triangle shape always starts with the rising ramp. Therefore regardless of the actual ramp slope the up chirp registers always refer to the first chirp of a shape and the down chirp registers always refer to the 2nd chirp of a shape in triangle mode.

### PLL setup example 1 ( $f_{SYS\_CLK} = 80$ MHz)

With a reference clock frequency of 40 MHz and activated frequency doubler the recommended value for  $N_{DIVSET}$  is 20, the default values. With these parameters the conversion formulas simplify to:

$$N_{\text{FSU}} = 2^{20} \left[ \frac{f_{\text{RF}}}{640 \text{ MHz}} - 96 \right] \quad (5)$$

and

$$N_{\text{RSU}} = 2^{20} \frac{\Delta f_{\text{RF}}}{640 \text{ MHz}} \quad (6)$$

With the PLL's 24 bit 2's complement frequency registers the total programmable RF frequency range is  $56.32 \text{ GHz} \leq f_{\text{RF}} \leq 66.559 \text{ GHz}$ . This may be a wider range than the effectively achievable frequency range.

To achieve a frequency ramp from 58 GHz to 62 GHz in 36  $\mu\text{s}$ , the FSU register is programmed to:

$$N_{\text{FSU}} = 2^{20} \left[ \frac{58 \text{ GHz}}{640 \text{ MHz}} - 96 \right] = -5636096 \hat{=} AA0000_{\text{hex}} \quad (7)$$

The ramp time bit field RTU is programmed to:

$$N_{\text{RTU}} = \frac{t_{\text{ramp}}}{8 * T_{\text{SYS\_CLK}}} = 36 \mu\text{s} \frac{80 \text{ MHz}}{8} = 360 \quad (8)$$

The frequency increment per clock cycle result to:

$$\Delta f_{\text{RF}} = \frac{f_{\text{RF,end}} - f_{\text{RF,start}}}{8 * N_{\text{RTU}}} = \frac{62 \text{ GHz} - 58 \text{ GHz}}{8 * 360} = \frac{4 \text{ GHz}}{2880} = 1.38 \bar{5} \text{ MHz} \quad (9)$$

Accordingly the bit field RSU is programmed to:

$$N_{\text{RSU}} = 2^{20} \frac{1.38 \bar{5} \text{ MHz}}{640 \text{ MHz}} = 2275.5 \cong 2276 \hat{=} 0008E4_{\text{hex}} \quad (10)$$

Due to rounding errors from the above calculation, the ramp will end at a slightly different end frequency:

$$f_{\text{RF,end}} = f_{\text{RF,start}} + 8 * N_{\text{RTU}} * \frac{640 \text{ MHz}}{2^{20}} N_{\text{RSU}} = 62.000781 \text{ GHz} \quad (11)$$

### PLL setup example 2 ( $f_{\text{SYS\_CLK}} = 76.8 \text{ MHz}$ )

With a reference clock frequency of 38.4 MHz and activated frequency doubler the recommended value for  $N_{\text{DIVSET}}$  is 21. With these parameters the conversion formulas simplify to:

$$N_{\text{FSU}} = 2^{20} \left[ \frac{f_{\text{RF}}}{614.4 \text{ MHz}} - 100 \right] \quad (12)$$

and

$$N_{\text{RSU}} = 2^{20} \frac{\Delta f_{\text{RF}}}{614.4 \text{ MHz}} \quad (13)$$

**3 Shapes, frames and channel set definition**

With the PLL's 24 bit 2's complement frequency registers the total programmable RF frequency range is  $56.5248 \text{ GHz} \leq f_{\text{RF}} \leq 66.3552 \text{ GHz}$ . This may be a wider range than the effectively achievable frequency range.

To achieve a frequency ramp from 58 GHz to 62 GHz in 36  $\mu\text{s}$ , the FSU register is programmed to:

$$N_{\text{FSU}} = 2^{20} \left[ \frac{58 \text{ GHz}}{614.4 \text{ MHz}} - 100 \right] = -5870933.\bar{3} \cong -5870933 \hat{=} A66AAB_{\text{hex}} \quad (14)$$

The ramp time bit field RTU is programmed to:

$$N_{\text{RTU}} = \frac{t_{\text{ramp}}}{8 * T_{\text{SYSCLK}}} = 36 \mu\text{s} \frac{76.8 \text{ MHz}}{8} = 345.6 \cong 346 \quad (15)$$

The frequency increment per clock cycle result to:

$$\Delta f_{\text{RF}} = \frac{f_{\text{RF, end}} - f_{\text{RF, start}}}{8 * N_{\text{RTU}}} = \frac{62 \text{ GHz} - 58 \text{ GHz}}{8 * 346} = \frac{4 \text{ GHz}}{2768} = 1.44509 \text{ MHz} \quad (16)$$

Accordingly the bit field RSU is programmed to:

$$N_{\text{RSU}} = 2^{20} \frac{1.44509 \text{ MHz}}{614.4 \text{ MHz}} = 2466.28 \cong 2466 \hat{=} 0009A2_{\text{hex}} \quad (17)$$

Due to rounding errors from the above calculation, the ramp will end at a slightly different end frequency:

$$f_{\text{RF, start}} = 614.4 \text{ MHz} \left[ 100 + \frac{N_{\text{FSU}}}{2^{20}} \right] = 58.0000002 \text{ GHz} \quad (18)$$

$$f_{\text{RF, end}} = f_{\text{RF, start}} + 8 * N_{\text{RTU}} * \frac{614.4 \text{ MHz}}{2^{20}} N_{\text{RSU}} = 61.99954 \text{ GHz} \quad (19)$$

## 4 BGT60UTR11AIP registers

An array of registers accessible via the SPI is used to control and program the states of the different blocks inside the chip.

The registers are arranged in blocks of 24 bits each. Each block is identified by its unique address. The registers are accessed from the SPI module. The bit fields from each register are arranged in MSB first order.

The following table gives an overview on the BGT60UTR11AIP registers.

### 4.1 Abbreviations

Access modes on the registers:

- r: readable register or bit field
- w: writeable register or bit field
- h: hardware writeable register or bit field

*Note: The reserved (RSVD) bits in the registers should not be modified. They should be kept in the reset state unless otherwise specified. This is also valid for the RSVD states of multi bit fields.*

### 4.2 Register overview - BGT60UTRxxAiP (ascending offset address)

**Table 21** Register overview - BGT60UTRxxAiP (ascending offset address)

Short name	Long name	Offset address	Page number
MAIN	Main register	000 <sub>H</sub>	38
ADC0	ADC control register	001 <sub>H</sub>	40
CHIP_Version	Digital and RF version register	002 <sub>H</sub>	42
STAT1	Status register 1	003 <sub>H</sub>	42
PACR1	PLL analog control register 1	004 <sub>H</sub>	43
PACR2	PLL analog control register 2	005 <sub>H</sub>	45
SFCTL	SPI and FIFO control register	006 <sub>H</sub>	46
CSI_0	Channel set idle register 0	008 <sub>H</sub>	48
CSI_1	Channel set idle register 1	009 <sub>H</sub>	49
CSI_2	Channel set idle register 2	00A <sub>H</sub>	50
CSCI	Channel set control idle register	00B <sub>H</sub>	51
CSDS_0	Channel set deep sleep register 0	00C <sub>H</sub>	52
CSDS_1	Channel set deep sleep register 1	00D <sub>H</sub>	53
CSDS_2	Channel set deep sleep register 2	00E <sub>H</sub>	54
CSCDS	Channel set control deep sleep register	00F <sub>H</sub>	55
CSUx_0	Channel set up x register 0	010 <sub>H</sub> +(x-1)*7	56
CSUx_1	Channel set up x register 1	011 <sub>H</sub> +(x-1)*7	57
CSUx_2	Channel set up x register 2	012 <sub>H</sub> +(x-1)*7	58
CSDx_0	Channel set down x register 0	013 <sub>H</sub> +(x-1)*7	59
CSDx_1	Channel set down x register 1	014 <sub>H</sub> +(x-1)*7	60

(table continues...)

**Table 21** (continued) Register overview - BGT60UTRxxAiP (ascending offset address)

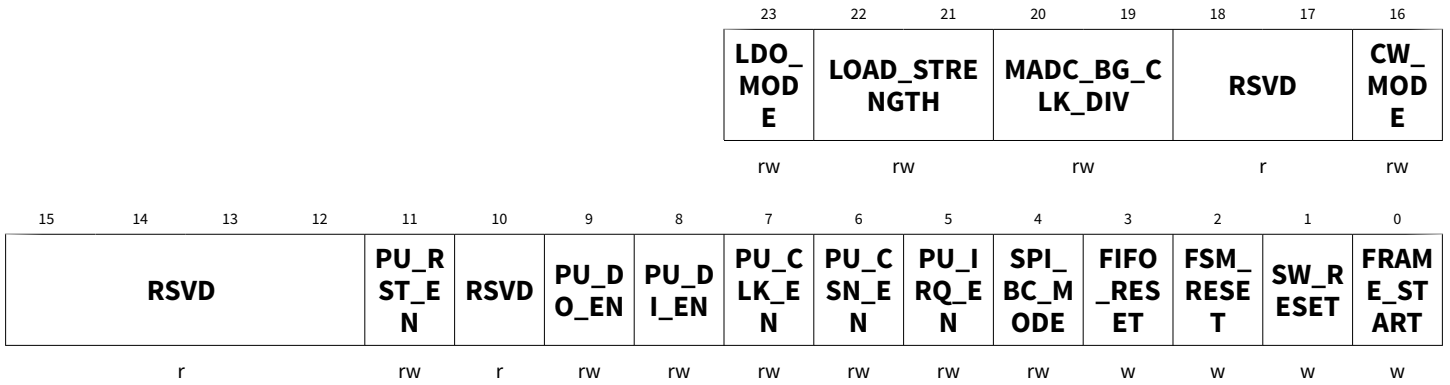
Short name	Long name	Offset address	Page number
CSDx_2	Channel set down x register 2	015 <sub>H</sub> +(x-1)*7	61
CSCx	Channel set control x register	016 <sub>H</sub> +(x-1)*7	62
CCR0	Chirp control register 0	02C <sub>H</sub>	63
CCR1	Chirp control register 1	02D <sub>H</sub>	64
CCR2	Chirp control register 2	02E <sub>H</sub>	65
CCR3	Chirp control register 3	02F <sub>H</sub>	66
PLLx_0	PLL shape x register 0	030 <sub>H</sub> +(x-1)*8	67
PLLx_1	PLL shape x register 1	031 <sub>H</sub> +(x-1)*8	67
PLLx_2	PLL shape x register 2	032 <sub>H</sub> +(x-1)*8	68
PLLx_3	PLL shape x register 3	033 <sub>H</sub> +(x-1)*8	68
PLLx_4	PLL shape x register 4	034 <sub>H</sub> +(x-1)*8	69
PLLx_5	PLL shape x register 5	035 <sub>H</sub> +(x-1)*8	69
PLLx_6	PLL shape x register 6	036 <sub>H</sub> +(x-1)*8	70
PLLx_7	PLL shape x register 7	037 <sub>H</sub> +(x-1)*8	71
ADC1	Sensor ADC register	050 <sub>H</sub>	72
RFT0	RF test register 0	055 <sub>H</sub>	72
EFUSE0	EFUSE register 0	057 <sub>H</sub>	74
EFUSE1	EFUSE register 1	058 <sub>H</sub>	74
PDFT0	PLL test register 0	059 <sub>H</sub>	75
CHIP_ID0	Chip ID register 0	05D <sub>H</sub>	75
CHIP_ID1	Chip ID register 1	05E <sub>H</sub>	76
CLK_IN	Clock input register	05F <sub>H</sub>	76
WU	Wake up register	060 <sub>H</sub>	77
STAT0	Status register 0	061 <sub>H</sub>	78
SENSOR_RESULT	Sensor ADC result register	062 <sub>H</sub>	79
FSTAT	FIFO status register	063 <sub>H</sub>	80

### 4.3 Main register

This register controls the top level behavior of the chip.

**MAIN** Offset address: 000<sub>H</sub>  
Main register Reset value: 1C 0B00<sub>H</sub>

**4 BGT60UTR11AIP registers**



Field	Bits	Type	Description
FRAME_START	0	w	<b>Start a frame generation:</b> 0 <sub>B</sub> ... No effect 1 <sub>B</sub> ... Executes a frame start and clears this bit Note: Can be stopped by executing a HW_RESET, SW_RESET or FSM_RESET.
SW_RESET	1	w	<b>Reset the complete chip:</b> 0 <sub>B</sub> ... No effect 1 <sub>B</sub> ... Executes a software reset and clears this bit
FSM_RESET	2	w	<b>Reset the Finite State Machine:</b> 0 <sub>B</sub> ... No effect 1 <sub>B</sub> ... Executes a FSM reset and clears this bit
FIFO_RESET	3	w	<b>Reset the FIFO:</b> 0 <sub>B</sub> ... No effect 1 <sub>B</sub> ... Executes a FIFO reset and clears this bit
SPI_BC_MODE	4	rw	<b>Enables SPI broadcast mode:</b> 0 <sub>B</sub> ... Disabled 1 <sub>B</sub> ... Enabled Note: When enabled the output drivers of SPI pins are disabled to avoid conflicts on shared MISO line. Can be used to program/trigger multiple devices at the same time.
PU_IRQ_EN	5	rw	<b>Enables pull-up of IRQ pin:</b> 0 <sub>B</sub> ... Disabled 1 <sub>B</sub> ... Enabled
PU_CSN_EN	6	rw	<b>Enables pull-up of CSN pin:</b> 0 <sub>B</sub> ... Disabled 1 <sub>B</sub> ... Enabled
PU_CLK_EN	7	rw	<b>Enables pull-up of CLK pin:</b> 0 <sub>B</sub> ... Disabled 1 <sub>B</sub> ... Enabled
PU_DI_EN	8	rw	<b>Enables pull-up of DI pin:</b> 0 <sub>B</sub> ... Disabled 1 <sub>B</sub> ... Enabled

**(table continues...)**

(continued)

Field	Bits	Type	Description
PU_DO_EN	9	rw	<b>Enables pull-up of DO pin:</b> 0 <sub>B</sub> ... Disabled 1 <sub>B</sub> ... Enabled
RSVD	10, 15:12, 18:17	r	<b>Reserved</b>
PU_RST_EN	11	rw	<b>Enables pull-up of RST pin:</b> 0 <sub>B</sub> ... Disabled 1 <sub>B</sub> ... Enabled
CW_MODE	16	rw	<b>Continuous wave mode:</b> 0 <sub>B</sub> ... Normal mode 1 <sub>B</sub> ... Continuous wave mode Note: When active no shapes are executed but PLL, RF, ADC run with values programmed in PDFT0, PDFT1 and channel set 1 registers.
MADC_BG_CLK_DIV	20:19	rw	<b>MADC bandgap clock frequency divider value:</b> 0 <sub>D</sub> ... Bandgap clock off 1 <sub>D</sub> ... Divider value is 1 2 <sub>D</sub> ... Divider value is 2 3 <sub>D</sub> ... Divider value is 4 Note: not clock tree balanced
LOAD_STRENGTH	22:21	rw	<b>LDO dummy load to smooth current peaks (over and under shoots of VDD<sub>C</sub> caused by toggling of digital logic):</b> 0 <sub>D</sub> ... Disabled 1 <sub>D</sub> ... 100 μA (current in the dummy load) 2 <sub>D</sub> ... 200 μA (current in the dummy load) 3 <sub>D</sub> ... 400 μA (current in the dummy load)
LDO_MODE	23	rw	<b>The LDO settling time is defined by:</b> 0 <sub>B</sub> ... Low power (50 μA), slow settling time 1 <sub>B</sub> ... High power (100 μA), fast settling time

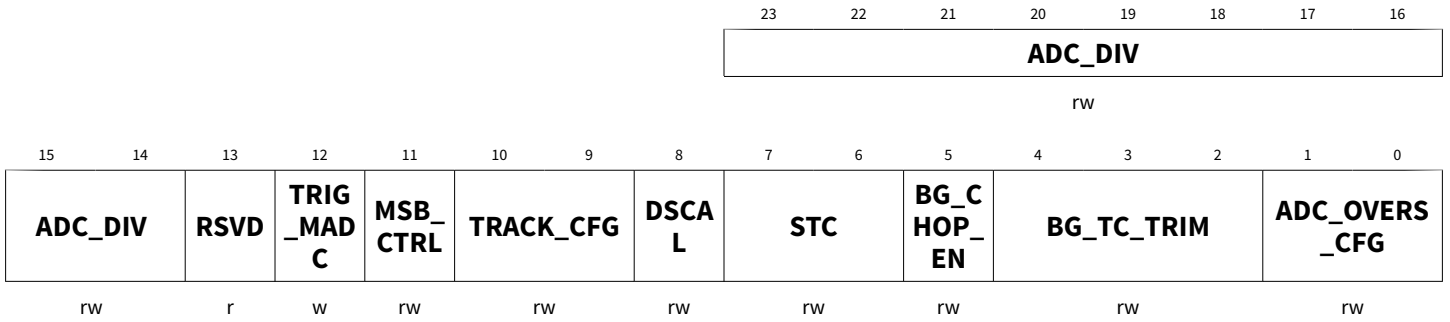
#### 4.4 ADC control register

The bits in this register are used to set properly the ADC in the RX chain.

<b>ADC0</b>	Offset address:	001 <sub>H</sub>
ADC control register	Reset value:	0A 0240 <sub>H</sub>



4 BGT60UTR11AIP registers



Field	Bits	Type	Description
ADC_OVERS_CFG	1:0	rw	<b>ADC oversampling configuration:</b> 0 <sub>D</sub> ... No oversampling (standard 11 bits conversion) 1 <sub>D</sub> ... Reserved 2 <sub>D</sub> ... Reserved 3 <sub>D</sub> ... Reserved
BG_TC_TRIM	4:2	rw	<b>Temperature coefficient trimming (static):</b> 0 <sub>D</sub> ... Minimum value 7 <sub>D</sub> ... Maximum value
BG_CHOP_EN	5	rw	<b>Enables chopping within the bandgap:</b> 0 <sub>B</sub> ... Disabled 1 <sub>B</sub> ... Enabled
STC	7:6	rw	<b>Sample time control:</b> 0 <sub>D</sub> ... 50 ns 1 <sub>D</sub> ... 100 ns 2 <sub>D</sub> ... 200 ns 3 <sub>D</sub> ... 400 ns
DSCAL	8	rw	<b>Disables startup calibration:</b> 0 <sub>B</sub> ... Enabled 1 <sub>B</sub> ... Disabled
TRACK_CFG	10:9	rw	<b>Tracking conversion configuration bits:</b> 0 <sub>D</sub> ... No sub conversion 1 <sub>D</sub> ... 1 sub conversion 2 <sub>D</sub> ... 3 sub conversions 3 <sub>D</sub> ... 7 sub conversions Note: Sub conversions are executed and averaged.
MSB_CTRL	11	rw	<b>MSB decision time selection during calibration and conversion:</b> 0 <sub>B</sub> ... Single MSB decision time 1 <sub>B</sub> ... Double MSB decision time
TRIG_MADC	12	w	<b>Trigger for manual ADC conversion:</b> 0 <sub>B</sub> ... No effect 1 <sub>B</sub> ... Executes a single ADC conversion and clears this bit
RSVD	13	r	<b>Reserved</b>

(table continues...)

(continued)

Field	Bits	Type	Description
ADC_DIV	23:14	rw	<b>ADC sampling frequency divider value. The actual sampling frequency will be <math>f_{ADC\_SAMP} = f_{ADC\_CLK} / ADC\_DIV</math>:</b> 0 <sub>D</sub> ..19 <sub>D</sub> ... Reserved 20 <sub>D</sub> ... Minimum divider value 1023 <sub>D</sub> ... Maximum divider value Note: A typical value is 33 <sub>D</sub> resulting in $f_{ADC\_SAMP} = 2.42$ MS/s (@ $f_{SYS\_CLK} = 80$ MHz)

## 4.5 Digital and RF version register

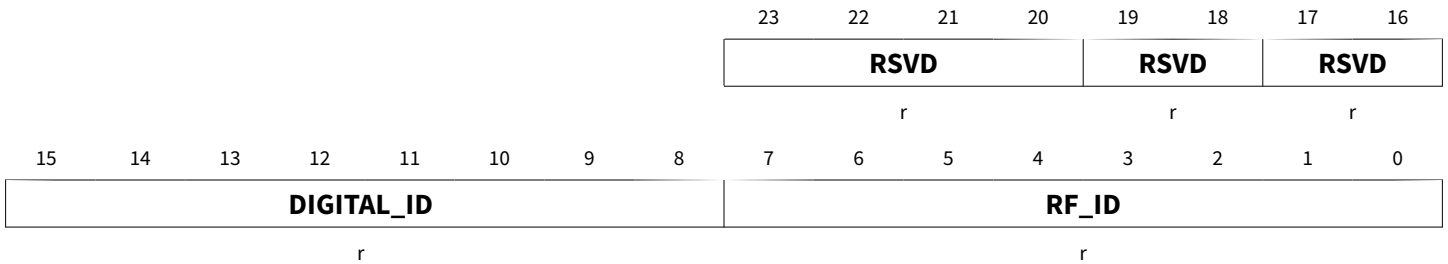
The register CHIP\_Version provides information regarding the digital code version, the RF block version, and the antenna configuration (number of channels, position of the antennas e.g.). It is used by the driver to configure the device properly according to the information below.

### CHIP\_Version

Digital and RF version register

Offset address: 002<sub>H</sub>

Reset value: 00 070C<sub>H</sub>



Field	Bits	Type	Description
RF_ID	7:0	r	<b>Revision of analog logic:</b> 12 <sub>D</sub> ... BGT60UTR11AiP Note: EES sample: 7 <sub>D</sub>
DIGITAL_ID	15:8	r	<b>Revision of digital control logic:</b> 7 <sub>D</sub> ... BGT60UTR11AiP
RSVD	23:16,	r	<b>Reserved</b>

## 4.6 Status register 1

The status register provides internal counter values for the actual number of frames and shapes. They are also provided to the data header. However, it should be mentioned that for all status registers, STAT0, STAT1, and FSTAT, with the exception of the FIFO status and error flags, updates to each status register field can happen on different timing events relative to FSM states and the field content should be treated independently from one-another. In CW mode the status bits can be read properly after eg. 100µs.

### STAT1

Status register 1

Offset address: 003<sub>H</sub>

Reset value: 00 0000<sub>H</sub>



(continued)

Field	Bits	Type	Description
DIGPON	3	rw	<b>Enables the power of the digital regulator:</b> 0 <sub>B</sub> ... Disabled 1 <sub>B</sub> ... Enabled
VDIGREG	5:4	rw	<b>Selects the output voltage of digital regulator:</b> 0 <sub>D</sub> ... 1.44 V 1 <sub>D</sub> ... 1.50 V 2 <sub>D</sub> ... 1.55 V 3 <sub>D</sub> ... 1.60 V (@V <sub>bg</sub> = 1.2 V)
BGAPEN	6	rw	<b>Enables bandgap reference:</b> 0 <sub>B</sub> ... Disabled 1 <sub>B</sub> ... Enabled
U2IEN	7	rw	<b>Enables voltage-to-current converter:</b> 0 <sub>B</sub> ... Disabled 1 <sub>B</sub> ... Enabled
VREFSEL	9:8	rw	<b>Selects the reference voltage/common mode level of loop filter:</b> 0 <sub>D</sub> ... 433 mV 1 <sub>D</sub> ... 506 mV 2 <sub>D</sub> ... 578 mV 3 <sub>D</sub> ... 650 mV
RFILTSEL	10	rw	<b>Selects the resistance R<sub>filt</sub> of the reference filter:</b> 0 <sub>B</sub> ... R <sub>filt</sub> = 100 kΩ 1 <sub>B</sub> ... R <sub>filt</sub> = 1 MΩ Note: Switch together with CPEN from 0 <sub>B</sub> to 1 <sub>B</sub> to improve start-up time!
RLFSEL	11	rw	<b>Selects the resistance R<sub>f</sub> inside the loop filter:</b> 0 <sub>B</sub> ... R <sub>f</sub> = 5 kΩ 1 <sub>B</sub> ... R <sub>f</sub> = 7 kΩ
RSVD	12	r	<b>Reserved</b>
LOCKSEL	15:13	rw	<b>Selects the lock detection window:</b> 0 <sub>D</sub> ... 0.265 ns 1 <sub>D</sub> ... 0.5 ns 2 <sub>D</sub> ... 1.0 ns 3 <sub>D</sub> ... 1.5 ns 4 <sub>D</sub> ... 2.0 ns 5 <sub>D</sub> ... 2.8 ns 6 <sub>D</sub> ... 3.8 ns 7 <sub>D</sub> ... 4.6 ns
LOCKFORC	16	rw	<b>Forces the lock signal:</b> 0 <sub>B</sub> ... Lock not forced 1 <sub>B</sub> ... Lock forced (to high)

(table continues...)

(continued)

Field	Bits	Type	Description
ICPSEL	19:17	rw	<b>Selects the charge pump current:</b> 0 <sub>B</sub> ... 40 μA 1 <sub>B</sub> ... 80 μA 2 <sub>B</sub> ... 120 μA 3 <sub>B</sub> ... 160 μA 4 <sub>B</sub> ... 200 μA 5 <sub>B</sub> ... 240 μA 6 <sub>B</sub> ... 280 μA 7 <sub>B</sub> ... 280 μA
BIASFORC	20	rw	<b>Enables fixed biasing inside charge pump:</b> 0 <sub>B</sub> ... Disabled (Bias regulation loop active) 1 <sub>B</sub> ... Enabled (Bias regulation loop deactivated)
CPEN	21	rw	<b>Enables charge pump:</b> 0 <sub>B</sub> ... Disabled 1 <sub>B</sub> ... Enabled
LFEN	22	rw	<b>Enables loop filter:</b> 0 <sub>B</sub> ... Disabled 1 <sub>B</sub> ... Enabled
OSCCLKEN	23	rw	<b>Enables system clock (SYS_CLK):</b> 0 <sub>B</sub> ... Disabled 1 <sub>B</sub> ... Enabled Note: This bit is controlled by FSM during operation. After deep sleep this bit should be enabled by the host. Before the MAIN:FRAME_START is raised the OSCCLKEN must be enabled!

## 4.8 PLL analog control register 2

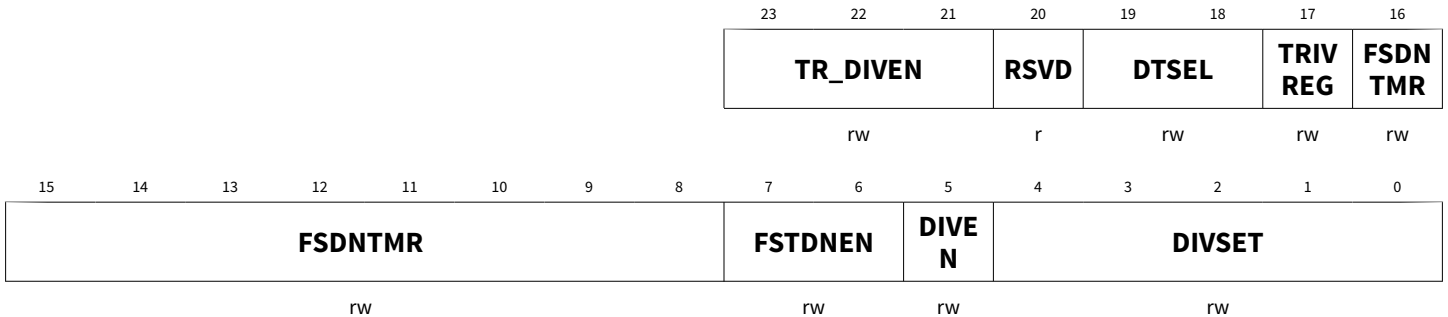
The bits in this register are used to properly set the PLL.

### PACR2

PLL analog control register 2

Offset address: 005<sub>H</sub>

Reset value: 04 0014<sub>H</sub>



Field	Bits	Type	Description
DIVSET	4:0	rw	<b>Set fixed part of integer division factor:</b> $0_D..19_D$ ... Reserved $20_D$ ... valid for 80 MHz system clock $21_D$ ... valid for 76.8 MHz or 38.4 MHz system clock $22_D..31_D$ ... Reserved Note: Consider offset of  2
DIVEN	5	rw	<b>Enables divider:</b> $0_B$ ... Disabled (input clock of divider gated) $1_B$ ... Enabled
FSTDNEN	7:6	rw	<b>Enables fast down chirp</b> $0_D$ ... Disabled $1_D$ ... Reserved $2_D$ ... Enabled fast down chirp $3_D$ ... Reserved
FSDNTMR	16:8	rw	<b>Defines the time for the PLL loop filter discharge during fast down chirp operation. When FSDNTMR = <math>0_D</math> and FSTDNEN <math>\neq 0_D</math>, the fast down chirp length is internally assigned to a default value (@typ <math>f_{SYS\_CLK}</math>):</b> $T\_FSTDN = (FSDNTMR + 1) * T_{SYS\_CLK}$ $0_D..4_D$ ... Reserved $5_D$ ... 75 ns $6_D..511_D$ ... Reserved
TRIVREG	17	rw	<b>Set regulator off state to tristate (for both analog and digital regulator):</b> $0_B$ ... Off state is 0.0 V $1_B$ ... Off state is tristate Note: Setting active for digital regulator if DIGPON = $0_B$ or ANAPON = $0_B$ .
DTSEL	19:18	rw	<b>Select PFD dead time / dead zone:</b> $0_D$ ... 180 ps to 350 ps $1_D$ ... 270 ps to 510 ps $2_D$ ... 360 ps to 680 ps $3_D$ ... 450 ps to 840 ps
RSVD	20	r	<b>Reserved</b>
TR_DIVEN	23:21	rw	<b>Time for T_DIVEN. Defines the delay after PACR2:DIVEN is handed over to PLL and pll_rst_n is released. Running in parallel to T_INIT1.</b> $T\_DIVEN = (TR\_DIVEN * 32 + 1) * T_{SYS\_CLK}$ $0_D$ ... Minimum value $7_D$ ... Maximum value

## 4.9 SPI and FIFO control register

This register is used to configure the SPI and FIFO.

<b>SFCTL</b>	Offset address:	006 <sub>H</sub>
SPI and FIFO control register	Reset value:	79 6000 <sub>H</sub>







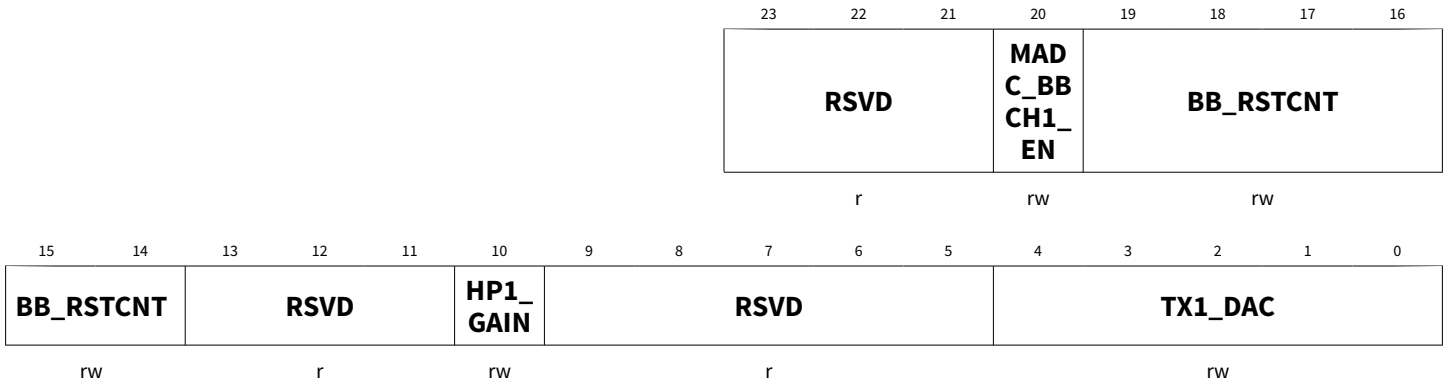
(continued)

Field	Bits	Type	Description
RX1LOBUF_EN	12	rw	<b>Enables the local oscillator buffer to the mixer on channel 1:</b> 0 <sub>B</sub> ... Disabled 1 <sub>B</sub> ... Enabled
RX1MIX_EN	13	rw	<b>Enables the mixer on channel 1:</b> 0 <sub>B</sub> ... Disabled 1 <sub>B</sub> ... Enabled
ABB1_AAF_CTR L	20	rw	<b>Selection of analog base band anti-aliasing filter frequency on channel 1:</b> 0 <sub>B</sub> ... 600 kHz 1 <sub>B</sub> ... 1 MHz

### 4.11 Channel set idle register 1

The channel set registers together with the channel set control registers defines the RF and baseband behavior during the shapes.

**CSI\_1** Offset address: 009<sub>H</sub>  
Channel set idle register 1 Reset value: 00 0000<sub>H</sub>



Field	Bits	Type	Description
TX1_DAC	4:0	rw	<b>TX1 output power setting:</b> 0 <sub>D</sub> ... Minimum output power 31 <sub>D</sub> ... Maximum output power
RSVD	9:5, 13:11, 23:21	r	<b>Reserved</b>
HP1_GAIN	10	rw	<b>Gain setting of the first stage of the high pass filter of channel 1:</b> 0 <sub>B</sub> ... 30 dB 1 <sub>B</sub> ... 18 dB

(table continues...)

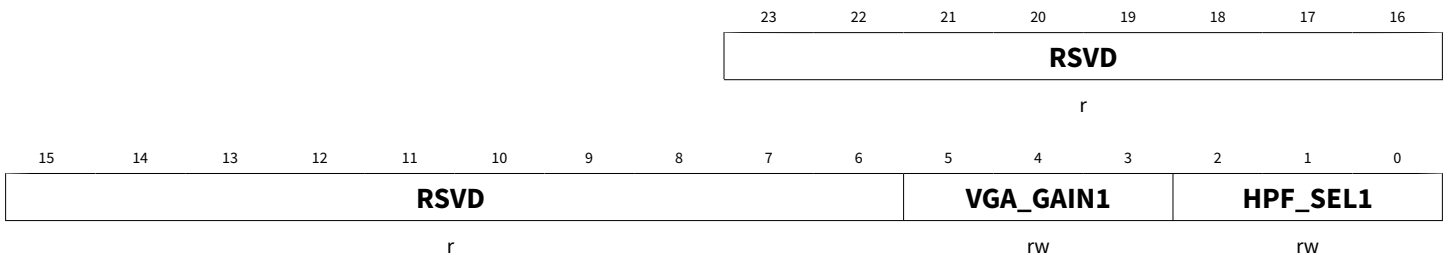
(continued)

Field	Bits	Type	Description
BB_RSTCNT	19:14	rw	<b>Baseband reset timer counter value for the analog baseband amplifiers. The reset counter will start together with the PAON signal after the T_PAEN timer. <math>T_{BBRST} = BB\_RSTCNT * 8 * T_{SYS\_CLK}</math>:</b> 0 <sub>D</sub> ... No analog baseband reset 1 <sub>D</sub> ... Minimum value 127 <sub>D</sub> ... Maximum value
MADC_BBCH1_EN	20	rw	<b>Enables the baseband filters, baseband amplifiers and ADC on channel 1:</b> 0 <sub>B</sub> ... Disabled 1 <sub>B</sub> ... Enabled

## 4.12 Channel set idle register 2

The channel set registers together with the channel set control registers defines the RF and baseband behavior during the shapes.

**CSI\_2** Offset address: 00A<sub>H</sub>  
 Channel set idle register 2 Reset value: 00 0000<sub>H</sub>



Field	Bits	Type	Description
HPF_SEL1	2:0	rw	<b>High pass filter cutoff frequency setting of channel 1:</b> 0 <sub>D</sub> ... 20 kHz 1 <sub>D</sub> ... 40 kHz 2 <sub>D</sub> ... 80 kHz 3 <sub>D</sub> ... 140 kHz 4 <sub>D</sub> ... 160 kHz 5 <sub>D</sub> ... Reserved 6 <sub>D</sub> ... Reserved 7 <sub>D</sub> ... Reserved
VGA_GAIN1	5:3	rw	<b>VGA gain setting of channel 1:</b> 0 <sub>D</sub> ... 0 dB 1 <sub>D</sub> ... 5 dB 2 <sub>D</sub> ... 10 dB 3 <sub>D</sub> ... 15 dB 4 <sub>D</sub> ... 20 dB 5 <sub>D</sub> ... 25 dB 6 <sub>D</sub> ... 30 dB 7 <sub>D</sub> ... Reserved

(table continues...)

(continued)

Field	Bits	Type	Description
RSVD	23:6	r	Reserved

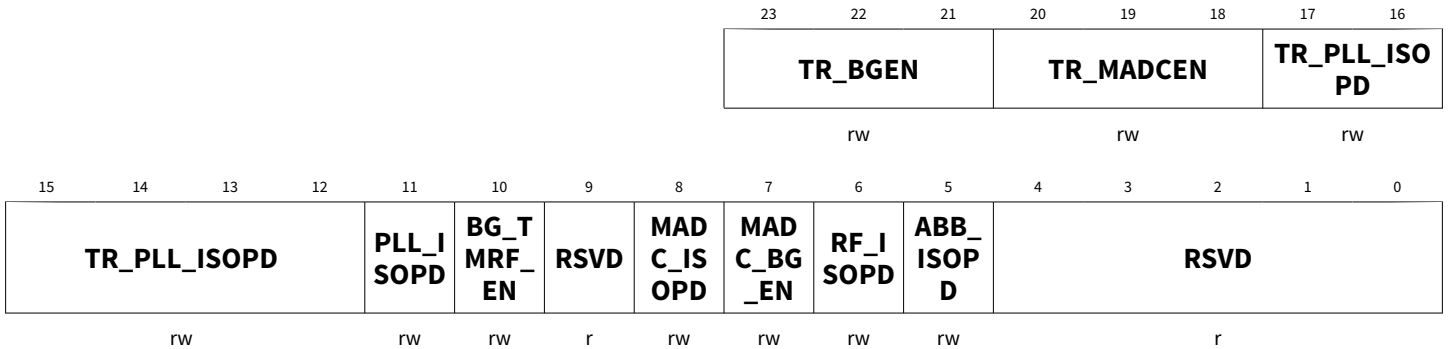
### 4.13 Channel set control idle register

The channel set control register CSCI is related to the channel set register CSI.

All bits are used to define a specific power mode.

ISOPD represent a logical isolation layer and is used to disable complete modules (e.g. MADC) while preserving its configuration (no change in the ADC0 register configuration).

**CSCI** Offset address: 00B<sub>H</sub>  
 Channel set control idle register Reset value: 24 0960<sub>H</sub>



Field	Bits	Type	Description
RSVD	4:0, 9	r	Reserved
ABB_ISOPD	5	rw	<b>Enables the isolation of all control signals to the ABB:</b> 0 <sub>B</sub> ... Disabled 1 <sub>B</sub> ... Enabled Note: In case the isolation is enabled all control signals are connected to 0 <sub>B</sub> .
RF_ISOPD	6	rw	<b>Enables the isolation of all control signals to the RF:</b> 0 <sub>B</sub> ... Disabled 1 <sub>B</sub> ... Enabled Note: In case the isolation is enabled all control signals are connected to 0 <sub>B</sub> .
MADC_BG_EN	7	rw	<b>Enables the bandgap of the MADC:</b> 0 <sub>B</sub> ... Disabled 1 <sub>B</sub> ... Enabled
MADC_ISOPD	8	rw	<b>Enables the isolation of all control signals to the MADC:</b> 0 <sub>B</sub> ... Disabled 1 <sub>B</sub> ... Enabled Note: In case the isolation is enabled all control signals are connected to 0 <sub>B</sub> .

(table continues...)



Field	Bits	Type	Description
TX1_EN	0	rw	<b>Enables the DAC and power amplifier of TX1:</b> 0 <sub>B</sub> ... Disabled 1 <sub>B</sub> ... Enabled
PD1_EN	1	rw	<b>Enables the power detector of TX1:</b> 0 <sub>B</sub> ... Disabled 1 <sub>B</sub> ... Enabled
RSVD	3:2, 9:7, 19:14, 23:21	r	<b>Reserved</b>
VCO_EN	4	rw	<b>Enables the VCO:</b> 0 <sub>B</sub> ... Disabled 1 <sub>B</sub> ... Enabled
TEMP_MEAS_EN	5	rw	<b>Enables the temperature sensor:</b> 0 <sub>B</sub> ... Disabled 1 <sub>B</sub> ... Enabled
FDIV_EN	6	rw	<b>Enables the VCO frequency divider:</b> 0 <sub>B</sub> ... Disabled 1 <sub>B</sub> ... Enabled Note: DIV output
LO_DIST2_EN	10	rw	<b>Enables the local oscillator distribution buffer to RX1 channel:</b> 0 <sub>B</sub> ... Disabled 1 <sub>B</sub> ... Enabled
LO_DIST1_EN	11	rw	<b>Enables the local oscillator distribution buffer to TX1 channel:</b> 0 <sub>B</sub> ... Disabled 1 <sub>B</sub> ... Enabled
RX1LOBUF_EN	12	rw	<b>Enables the local oscillator buffer to the mixer on channel 1:</b> 0 <sub>B</sub> ... Disabled 1 <sub>B</sub> ... Enabled
RX1MIX_EN	13	rw	<b>Enables the mixer on channel 1:</b> 0 <sub>B</sub> ... Disabled 1 <sub>B</sub> ... Enabled
ABB1_AAF_CTRL	20	rw	<b>Selection of analog base band anti-aliasing filter frequency on channel 1:</b> 0 <sub>B</sub> ... 600 kHz 1 <sub>B</sub> ... 1 MHz

## 4.15 Channel set deep sleep register 1

The channel set registers together with the channel set control registers defines the RF and baseband behavior during the shapes.

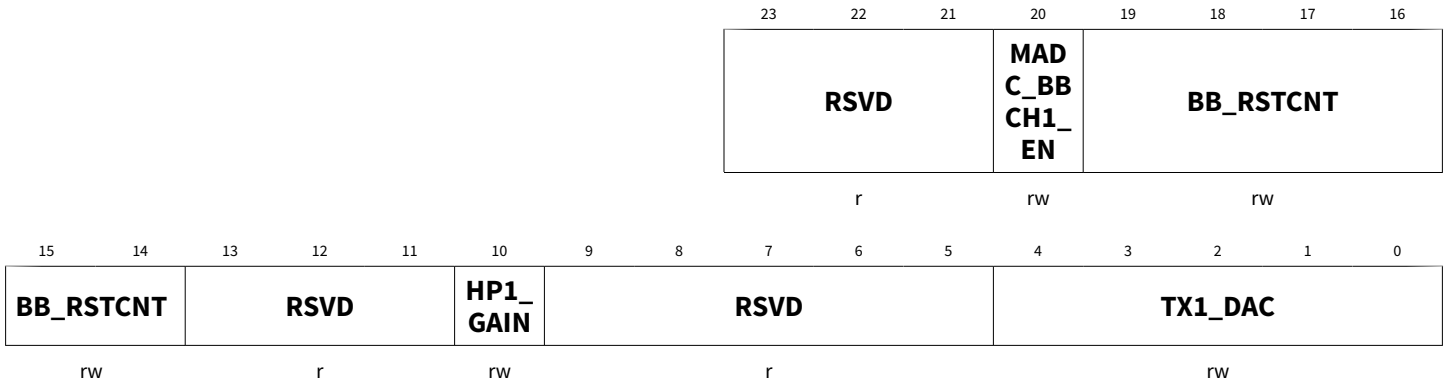
### CSDS\_1

Channel set deep sleep register 1

Offset address: 00D<sub>H</sub>

Reset value: 00 0000<sub>H</sub>

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Field	Bits	Type	Description
TX1_DAC	4:0	rw	<b>TX1 output power setting:</b> 0 <sub>D</sub> ... Minimum output power 31 <sub>D</sub> ... Maximum output power
RSVD	9:5, 13:11, 23:21	r	<b>Reserved</b>
HP1_GAIN	10	rw	<b>Gain setting of the first stage of the high pass filter of channel 1:</b> 0 <sub>B</sub> ... 30 dB 1 <sub>B</sub> ... 18 dB
BB_RSTCNT	19:14	rw	<b>Baseband reset timer counter value for the analog baseband amplifiers. The reset counter will start together with the PAON signal after the T_PAEN timer. <math>T_{BBRST} = BB\_RSTCNT * 8 * T_{SYS\_CLK}</math>:</b> 0 <sub>D</sub> ... No analog baseband reset 1 <sub>D</sub> ... Minimum value 127 <sub>D</sub> ... Maximum value
MADC_BBCH1_EN	20	rw	<b>Enables the baseband filters, baseband amplifiers and ADC on channel 1:</b> 0 <sub>B</sub> ... Disabled 1 <sub>B</sub> ... Enabled

**4.16 Channel set deep sleep register 2**

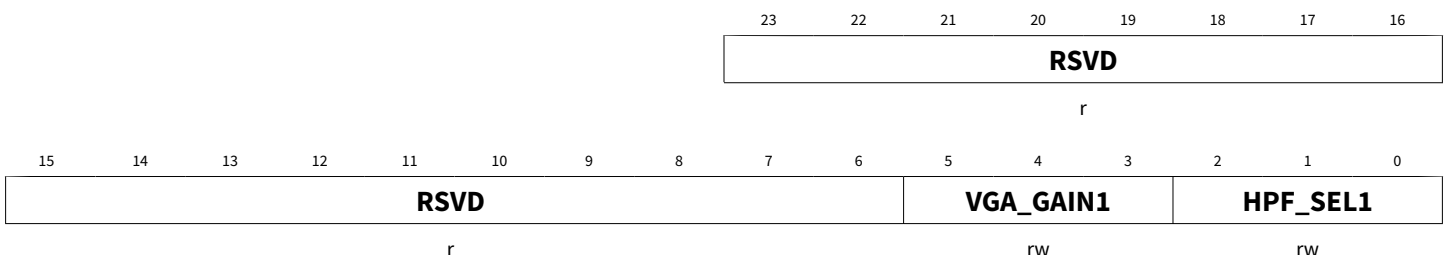
The channel set registers together with the channel set control registers defines the RF and baseband behavior during the shapes.

**CSDS\_2**

Channel set deep sleep register 2

Offset address: 00E<sub>H</sub>

Reset value: 00 0000<sub>H</sub>



Field	Bits	Type	Description
HPF_SEL1	2:0	rw	<b>High pass filter cutoff frequency setting of channel 1:</b> 0 <sub>D</sub> ... 20 kHz 1 <sub>D</sub> ... 40 kHz 2 <sub>D</sub> ... 80 kHz 3 <sub>D</sub> ... 140 kHz 4 <sub>D</sub> ... 160 kHz 5 <sub>D</sub> ... Reserved 6 <sub>D</sub> ... Reserved 7 <sub>D</sub> ... Reserved
VGA_GAIN1	5:3	rw	<b>VGA gain setting of channel 1:</b> 0 <sub>D</sub> ... 0 dB 1 <sub>D</sub> ... 5 dB 2 <sub>D</sub> ... 10 dB 3 <sub>D</sub> ... 15 dB 4 <sub>D</sub> ... 20 dB 5 <sub>D</sub> ... 25 dB 6 <sub>D</sub> ... 30 dB 7 <sub>D</sub> ... Reserved
RSVD	23:6	r	<b>Reserved</b>

### 4.17 Channel set control deep sleep register

The channel set control register CSCDS is related to the channel set register CSDS.

All bits are used to define a specific power mode.

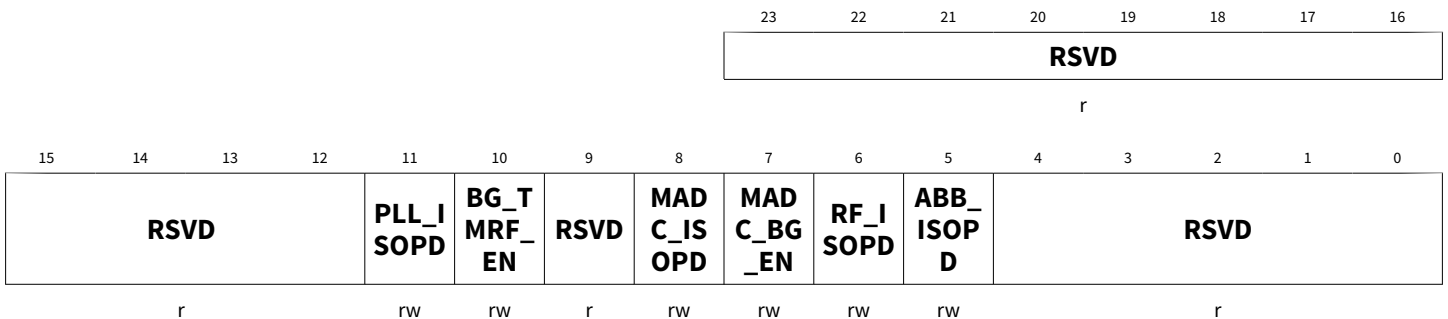
ISOPD represent a logical isolation layer and is used to disable complete modules (e.g. MADC) while preserving its configuration (no change in the ADC0 register configuration).

#### CSCDS

Offset address: 00F<sub>H</sub>

Channel set control deep sleep register

Reset value: 00 0960<sub>H</sub>



Field	Bits	Type	Description
RSVD	4:0, 9, 23:12	r	<b>Reserved</b>

(table continues...)

(continued)

Field	Bits	Type	Description
ABB_ISOPD	5	rw	<b>Enables the isolation of all control signals to the ABB:</b> 0 <sub>B</sub> ... Disabled 1 <sub>B</sub> ... Enabled Note: In case the isolation is enabled all control signals are connected to 0 <sub>B</sub> .
RF_ISOPD	6	rw	<b>Enables the isolation of all control signals to the RF:</b> 0 <sub>B</sub> ... Disabled 1 <sub>B</sub> ... Enabled Note: In case the isolation is enabled all control signals are connected to 0 <sub>B</sub> .
MADC_BG_EN	7	rw	<b>Enables the bandgap of the MADC:</b> 0 <sub>B</sub> ... Disabled 1 <sub>B</sub> ... Enabled
MADC_ISOPD	8	rw	<b>Enables the isolation of all control signals to the MADC:</b> 0 <sub>B</sub> ... Disabled 1 <sub>B</sub> ... Enabled Note: In case the isolation is enabled all control signals are connected to 0 <sub>B</sub> .
BG_TMRF_EN	10	rw	<b>Enables the temperature sensor:</b> 0 <sub>B</sub> ... Disabled 1 <sub>B</sub> ... Enabled
PLL_ISOPD	11	rw	<b>Enables the isolation of all control signals to the PLL:</b> 0 <sub>B</sub> ... Disabled 1 <sub>B</sub> ... Enabled Note: In case the isolation is enabled all control signals are connected to 0 <sub>B</sub> .

## 4.18 Channel set up x register 0

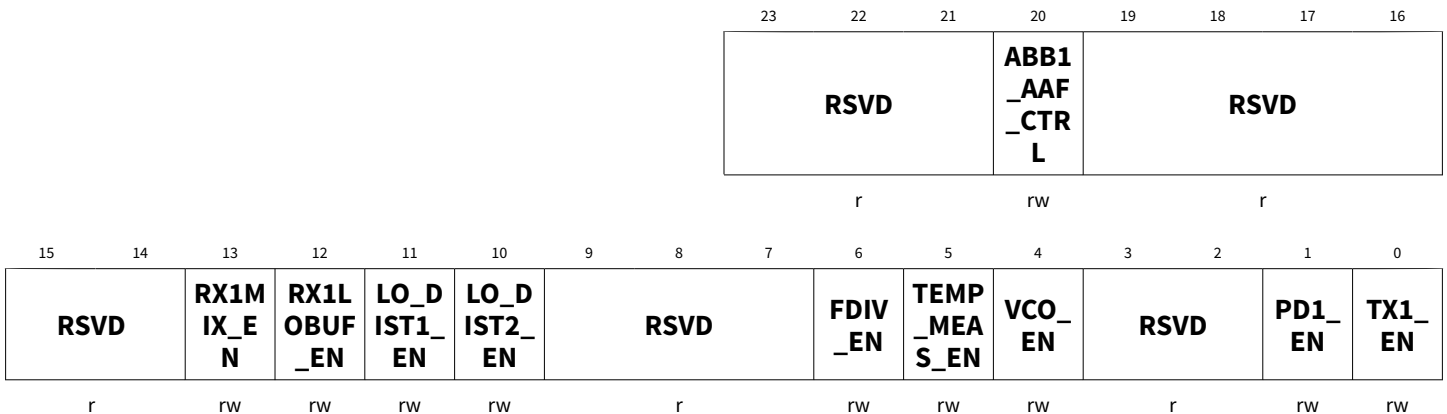
The channel set registers together with the channel set control registers defines the RF and baseband behavior during the shapes.

**CSUx\_0 (x=1-4)**

Offset address: 010<sub>H</sub>+(x-1)\*7

Channel set up x register 0

Reset value: 00 0000<sub>H</sub>





Field	Bits	Type	Description
TX1_EN	0	rw	<b>Enables the DAC and power amplifier of TX1:</b> 0 <sub>B</sub> ... Disabled 1 <sub>B</sub> ... Enabled
PD1_EN	1	rw	<b>Enables the power detector of TX1:</b> 0 <sub>B</sub> ... Disabled 1 <sub>B</sub> ... Enabled
RSVD	3:2, 9:7, 19:14, 23:21	r	<b>Reserved</b>
VCO_EN	4	rw	<b>Enables the VCO:</b> 0 <sub>B</sub> ... Disabled 1 <sub>B</sub> ... Enabled
TEMP_MEAS_EN	5	rw	<b>Enables the temperature sensor:</b> 0 <sub>B</sub> ... Disabled 1 <sub>B</sub> ... Enabled
FDIV_EN	6	rw	<b>Enables the VCO frequency divider:</b> 0 <sub>B</sub> ... Disabled 1 <sub>B</sub> ... Enabled Note: DIV output
LO_DIST2_EN	10	rw	<b>Enables the local oscillator distribution buffer to RX1 channel:</b> 0 <sub>B</sub> ... Disabled 1 <sub>B</sub> ... Enabled
LO_DIST1_EN	11	rw	<b>Enables the local oscillator distribution buffer to TX1 channel:</b> 0 <sub>B</sub> ... Disabled 1 <sub>B</sub> ... Enabled
RX1LOBUF_EN	12	rw	<b>Enables the local oscillator buffer to the mixer on channel 1:</b> 0 <sub>B</sub> ... Disabled 1 <sub>B</sub> ... Enabled
RX1MIX_EN	13	rw	<b>Enables the mixer on channel 1:</b> 0 <sub>B</sub> ... Disabled 1 <sub>B</sub> ... Enabled
ABB1_AAF_CTRL	20	rw	<b>Selection of analog base band anti-aliasing filter frequency on channel 1:</b> 0 <sub>B</sub> ... 600 kHz 1 <sub>B</sub> ... 1 MHz

## 4.19 Channel set up x register 1

The channel set registers together with the channel set control registers defines the RF and baseband behavior during the shapes.

**CSUx\_1 (x=1-4)**

Channel set up x register 1

Offset address: 011<sub>H</sub>+(x-1)\*7

Reset value: 00 0000<sub>H</sub>



Field	Bits	Type	Description
HPF_SEL1	2:0	rw	<b>High pass filter cutoff frequency setting of channel 1:</b> 0 <sub>D</sub> ... 20 kHz 1 <sub>D</sub> ... 40 kHz 2 <sub>D</sub> ... 80 kHz 3 <sub>D</sub> ... 140 kHz 4 <sub>D</sub> ... 160 kHz 5 <sub>D</sub> ... Reserved 6 <sub>D</sub> ... Reserved 7 <sub>D</sub> ... Reserved
VGA_GAIN1	5:3	rw	<b>VGA gain setting of channel 1:</b> 0 <sub>D</sub> ... 0 dB 1 <sub>D</sub> ... 5 dB 2 <sub>D</sub> ... 10 dB 3 <sub>D</sub> ... 15 dB 4 <sub>D</sub> ... 20 dB 5 <sub>D</sub> ... 25 dB 6 <sub>D</sub> ... 30 dB 7 <sub>D</sub> ... Reserved
RSVD	23:6	r	<b>Reserved</b>

### 4.21 Channel set down x register 0

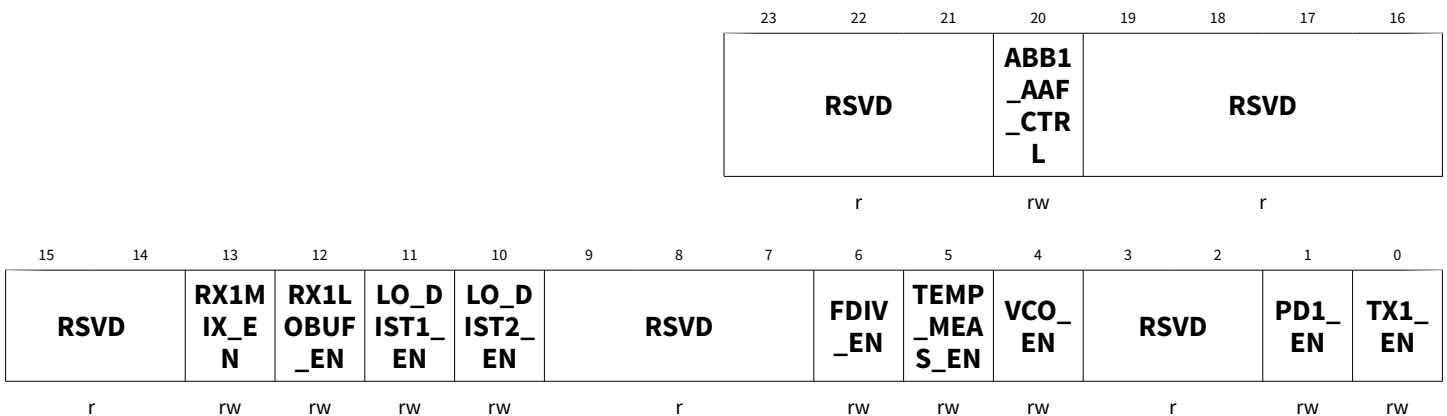
The channel set registers together with the channel set control registers defines the RF and baseband behavior during the shapes.

#### CSDx\_0 (x=1-4)

Offset address: 013<sub>H</sub>+(x-1)\*7

Channel set down x register 0

Reset value: 00 0000<sub>H</sub>



Field	Bits	Type	Description
TX1_EN	0	rw	<b>Enables the DAC and power amplifier of TX1:</b> 0 <sub>B</sub> ... Disabled 1 <sub>B</sub> ... Enabled

(table continues...)

(continued)

Field	Bits	Type	Description
PD1_EN	1	rw	<b>Enables the power detector of TX1:</b> 0 <sub>B</sub> ... Disabled 1 <sub>B</sub> ... Enabled
RSVD	3:2, 9:7, 19:14, 23:21	r	<b>Reserved</b>
VCO_EN	4	rw	<b>Enables the VCO:</b> 0 <sub>B</sub> ... Disabled 1 <sub>B</sub> ... Enabled
TEMP_MEAS_EN	5	rw	<b>Enables the temperature sensor:</b> 0 <sub>B</sub> ... Disabled 1 <sub>B</sub> ... Enabled
FDIV_EN	6	rw	<b>Enables the VCO frequency divider:</b> 0 <sub>B</sub> ... Disabled 1 <sub>B</sub> ... Enabled Note: DIV output
LO_DIST2_EN	10	rw	<b>Enables the local oscillator distribution buffer to RX1 channel:</b> 0 <sub>B</sub> ... Disabled 1 <sub>B</sub> ... Enabled
LO_DIST1_EN	11	rw	<b>Enables the local oscillator distribution buffer to TX1 channel:</b> 0 <sub>B</sub> ... Disabled 1 <sub>B</sub> ... Enabled
RX1LOBUF_EN	12	rw	<b>Enables the local oscillator buffer to the mixer on channel 1:</b> 0 <sub>B</sub> ... Disabled 1 <sub>B</sub> ... Enabled
RX1MIX_EN	13	rw	<b>Enables the mixer on channel 1:</b> 0 <sub>B</sub> ... Disabled 1 <sub>B</sub> ... Enabled
ABB1_AAF_CTRL	20	rw	<b>Selection of analog base band anti-aliasing filter frequency on channel 1:</b> 0 <sub>B</sub> ... 600 kHz 1 <sub>B</sub> ... 1 MHz

## 4.22 Channel set down x register 1

The channel set registers together with the channel set control registers defines the RF and baseband behavior during the shapes.

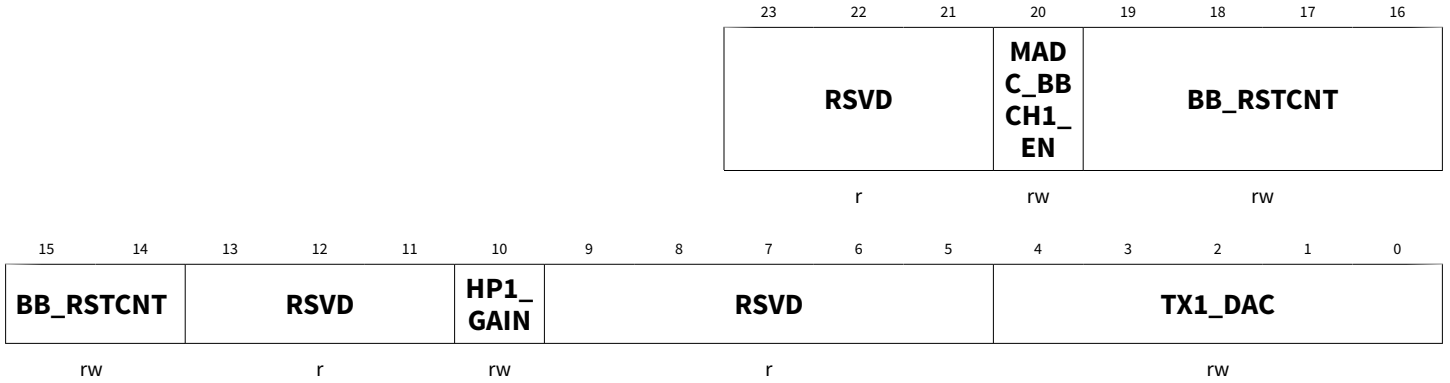
### CSDx\_1 (x=1-4)

Channel set down x register 1

Offset address: 014<sub>H</sub>+(x-1)\*7

Reset value: 00 0000<sub>H</sub>

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Field	Bits	Type	Description
TX1_DAC	4:0	rw	<b>TX1 output power setting:</b> $0_D$ ... Minimum output power $31_D$ ... Maximum output power
RSVD	9:5, 13:11, 23:21	r	<b>Reserved</b>
HP1_GAIN	10	rw	<b>Gain of the first stage of the high pass filter of channel 1:</b> $0_B$ ... 30 dB $1_B$ ... 18 dB
BB_RSTCNT	19:14	rw	<b>Baseband reset timer counter value for the analog baseband amplifiers. The reset counter will start together with the PAON signal after the T_PAEN timer. <math>T_{BBRST} = BB\_RSTCNT * 8 * T_{SYS\_CLK}</math>:</b> $0_D$ ... No analog baseband reset $1_D$ ... Minimum value $127_D$ ... Maximum value
MADC_BBCH1_EN	20	rw	<b>Enables the baseband filters, baseband amplifiers and ADC on channel 1:</b> $0_B$ ... Disabled $1_B$ ... Enabled

**4.23 Channel set down x register 2**

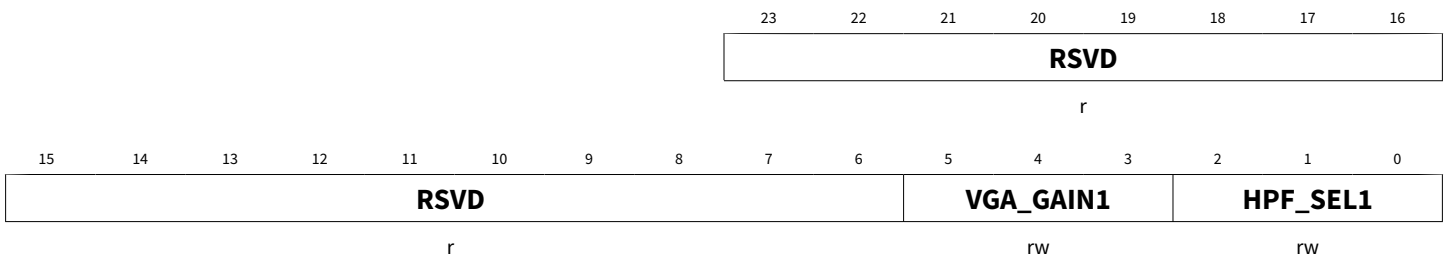
The channel set registers together with the channel set control registers defines the RF and baseband behavior during the shapes.

**CSDx\_2 (x=1-4)**

Offset address:  $015_H + (x-1)*7$

Channel set down x register 2

Reset value:  $00\ 0000_H$



Field	Bits	Type	Description
HPF_SEL1	2:0	rw	<b>High pass filter cutoff frequency setting of channel 1:</b> 0 <sub>D</sub> ... 20 kHz 1 <sub>D</sub> ... 40 kHz 2 <sub>D</sub> ... 80 kHz 3 <sub>D</sub> ... 140 kHz 4 <sub>D</sub> ... 160 kHz 5 <sub>D</sub> ... Reserved 6 <sub>D</sub> ... Reserved 7 <sub>D</sub> ... Reserved
VGA_GAIN1	5:3	rw	<b>VGA gain setting of channel 1:</b> 0 <sub>D</sub> ... 0 dB 1 <sub>D</sub> ... 5 dB 2 <sub>D</sub> ... 10 dB 3 <sub>D</sub> ... 15 dB 4 <sub>D</sub> ... 20 dB 5 <sub>D</sub> ... 25 dB 6 <sub>D</sub> ... 30 dB 7 <sub>D</sub> ... Reserved
RSVD	23:6	r	<b>Reserved</b>

## 4.24 Channel set control x register

The channel set control register CSCx is related to the channel set register CSUx.

Besides REPC, all other bits are used to define a specific power mode.

ISOPD represent a logical isolation layer and is used to disable complete modules (e.g. MADC) while preserving its configuration (no change in the ADC0 register configuration).

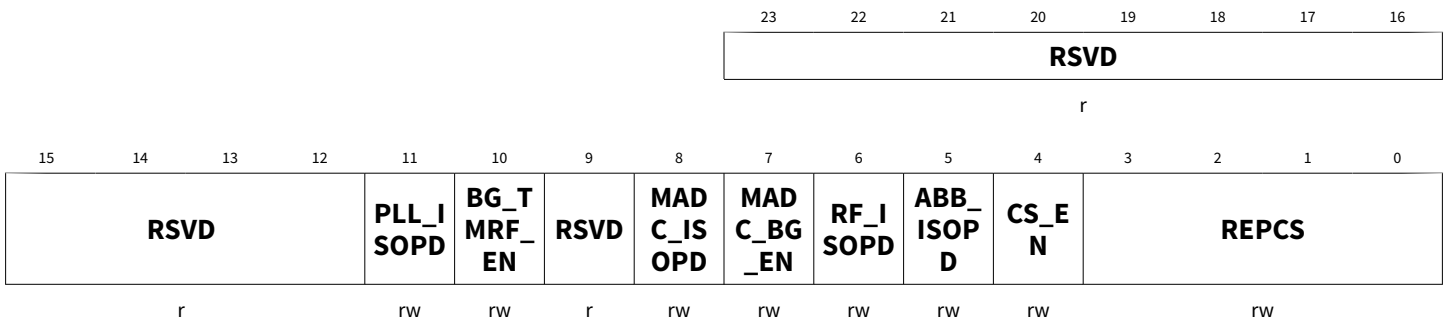
REPC is one parameter used to define the modulation sequence.

### CSCx (x=1-4)

Offset address: 016<sub>H</sub>+(x-1)\*7

Channel set control x register

Reset value: 00 0960<sub>H</sub>



Field	Bits	Type	Description
REPCS	3:0	rw	<b>Repetition factor of channel set:</b> 0 <sub>D</sub> ..15 <sub>D</sub> ... RC = 2 <sup>REPC</sup>

(table continues...)

(continued)

Field	Bits	Type	Description
CS_EN	4	rw	<b>Enables channel set (CS):</b> 0 <sub>B</sub> ... Disabled 1 <sub>B</sub> ... Enabled Note: At least the first channel set should be used (CSC1:CS_EN = 1 <sub>B</sub> ).
ABB_ISOPD	5	rw	<b>Enables the isolation of all control signals to the ABB:</b> 0 <sub>B</sub> ... Disabled 1 <sub>B</sub> ... Enabled Note: In case the isolation is enabled all control signals are connected to 0 <sub>B</sub> .
RF_ISOPD	6	rw	<b>Enables the isolation of all control signals to the RF:</b> 0 <sub>B</sub> ... Disabled 1 <sub>B</sub> ... Enabled Note: In case the isolation is enabled all control signals are connected to 0 <sub>B</sub> .
MADC_BG_EN	7	rw	<b>Enables the bandgap of the MADC:</b> 0 <sub>B</sub> ... Disabled 1 <sub>B</sub> ... Enabled
MADC_ISOPD	8	rw	<b>Enables the isolation of all control signals to the MADC:</b> 0 <sub>B</sub> ... Disabled 1 <sub>B</sub> ... Enabled Note: In case the isolation is enabled all control signals are connected to 0 <sub>B</sub> .
RSVD	9, 23:12	r	<b>Reserved</b>
BG_TMRF_EN	10	rw	<b>Enables the temperature sensor:</b> 0 <sub>B</sub> ... Disabled 1 <sub>B</sub> ... Enabled
PLL_ISOPD	11	rw	<b>Enables the isolation of all control signals to the PLL:</b> 0 <sub>B</sub> ... Disabled 1 <sub>B</sub> ... Enabled Note: In case the isolation is enabled all control signals are connected to 0 <sub>B</sub> .

## 4.25 Chirp control register 0

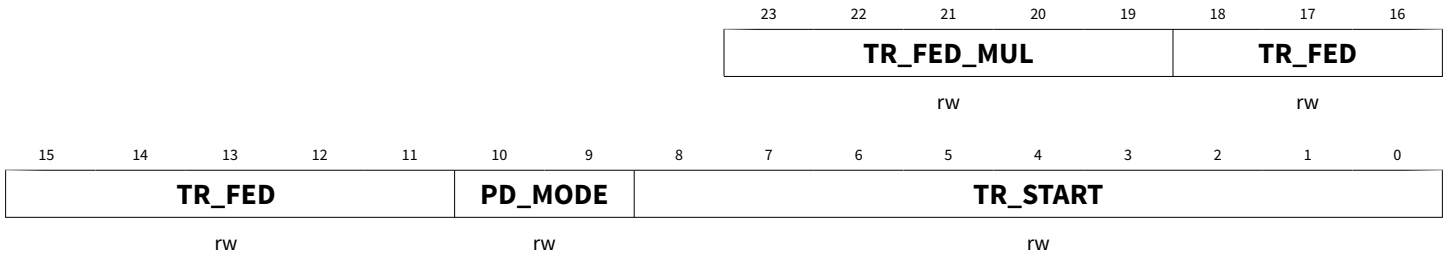
Register CCR0 is used to program the parameters for the modulation sequence. The main FSM will use those parameters to set internal timers and counters to run the expected modulation sequence in standalone mode (no external trigger required except the first one).

**CCR0** Offset address: 02C<sub>H</sub>  
Chirp control register 0 Reset value: 00 0000<sub>H</sub>





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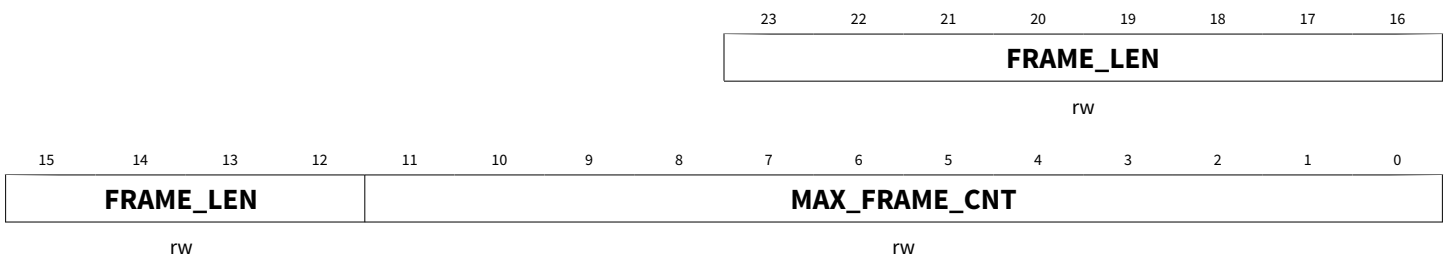


Field	Bits	Type	Description
TR_START	8:0	rw	<b>Timer for T_START. Ramp start delay defines the delay before generating the ramp:</b> $0_D..511_D \dots T\_START = (TR\_START * 8 + 10) * T_{SYS\_CLK}$
PD_MODE	10:9	rw	<b>Power down mode. After the last repetition RT the chip enters the defined power mode (during T_FED):</b> $0_D \dots$ Keep the same power mode (CSx + CSCx) $1_D \dots$ Change to IDLE power mode (CSI + CSCi) $2_D \dots$ Change to DS power mode (CSDS + CSCDS) $3_D \dots$ Reserved
TR_FED	18:11	rw	<b>Timer for T_FED:</b> $0_D \dots T_{SYS\_CLK}$ $1_D..255_D \dots T\_FED = (TR\_FED * 2^{TR\_FED\_MUL} * 8 + TR\_FED\_MUL + 3) * T_{SYS\_CLK}$
TR_FED_MUL	23:19	rw	<b>Timer multiplier factor for T_FED:</b> $0_D..31_D \dots 2^{TR\_FED\_MUL}$

## 4.27 Chirp control register 2

Register CCR2 is used to program the parameters for the modulation sequence. The main FSM will use those parameters to set internal timers and counters to run the expected modulation sequence in standalone mode (no external trigger required except the first one).

**CCR2** Offset address: 02E<sub>H</sub>  
 Chirp control register 2 Reset value: 00 0000<sub>H</sub>

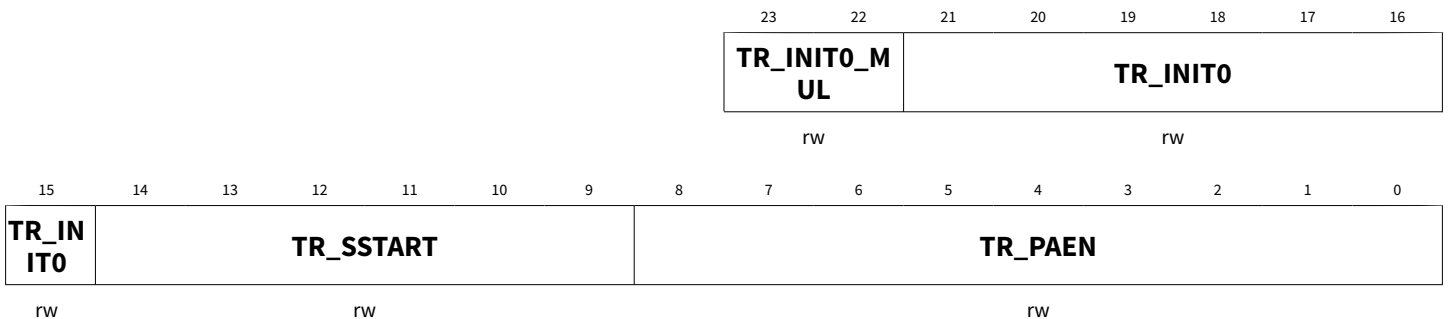


Field	Bits	Type	Description
MAX_FRAME_CNT	11:0	rw	<p><b>Maximum number of frames to be executed. When MAX_FRAME_CNT is reached, the shape generation is stopped and the chip is set to deep sleep power mode. The next frame can be triggered only after a reset (eg. FSM_RESET). The frame generation can be stopped at any time by resetting the FSM (see MAIN:FSM_RESET).</b></p> <p>0<sub>D</sub> ... Endles frame generation            1<sub>D</sub> ... 1 frame is generated            4095<sub>D</sub> ... 4095 frames are generated</p>
FRAME_LEN	23:12	rw	<p><b>Frame Length specifies the number of shape groups in a frame. When specified frame length is reached the frame counter is incremented and the shape group counter is reset:</b></p> <p>0<sub>D</sub> ... Minimum value (1 shape group)            4095<sub>D</sub> ... Maximum value (4096 shape groups)</p>

### 4.28 Chirp control register 3

Register CCR3 is used to program the parameters for the modulation sequence. The main FSM will use those parameters to set internal timers and counters to run the expected modulation sequence in standalone mode (no external trigger required except the first one).

**CCR3** Offset address: 02F<sub>H</sub>  
 Chirp control register 3 Reset value: 00 0000<sub>H</sub>



Field	Bits	Type	Description
TR_PAEN	8:0	rw	<p><b>Timer for T_PAEN. Delay time after PLL start and power amplifier enable:</b></p> <p>0<sub>D</sub> ... Reserved            1<sub>D</sub>..511<sub>D</sub> ... <math>T_{PAEN} = TR\_PAEN * 8 * T_{SYS\_CLK}</math></p>
TR_SSTART	14:9	rw	<p><b>Timer for T_SSTART. Delay time after power amplifier enable and first trigger to ADC:</b></p> <p>0<sub>D</sub>..63<sub>D</sub> ... <math>T_{SSTART} = (TR\_SSTART * 8 + 1) * T_{SYS\_CLK}</math></p>
TR_INIT0	21:15	rw	<p><b>Timer for T_INIT0:</b></p> <p>0<sub>D</sub> ... <math>T_{SYS\_CLK}</math>            1<sub>D</sub>..255<sub>D</sub> ... <math>T_{INIT0} = (TR\_INIT0 * 2^{TR\_INIT0\_MUL} * 8 + TR\_INIT0\_MUL + 3) * T_{SYS\_CLK}</math></p> <p>Note: After the wake-up period the timer for T_INIT0 should be at least 70 μs according to the typical ADC calibration time.</p>

(table continues...)

(continued)

Field	Bits	Type	Description
TR_INIT0_MUL	23:22	rw	<b>Timer multiplier for T_INIT0:</b> $0_D..3_D \dots 2^{TR\_INIT0\_MUL}$

## 4.29 PLL shape x register 0

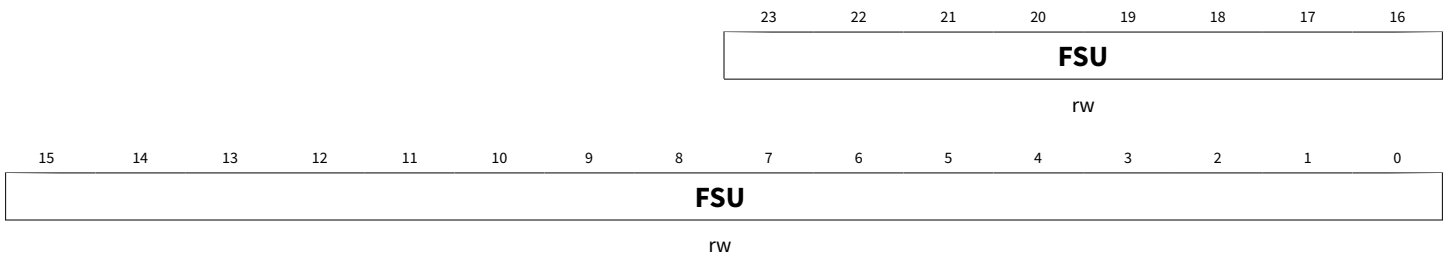
Registers PLLx, they are used to program the parameters for the modulation sequence inside the local PLL FSM. The main FSM will control the local PLL FSM to run the expected modulation sequence in standalone mode (no external trigger required except the first one).

### PLLx\_0 (x=1-4)

Offset address:  $030_H + (x-1) * 8$

PLL shape x register 0

Reset value:  $00\ 0000_H$



Field	Bits	Type	Description
FSU	23:0	rw	<b>Chirp start frequency for up chirp. Sigma delta start frequency for the ramp generator:</b> $0_D \dots$ Sawtooth shape Note: In case $FSD = 0_D$ , $RSD = 0_D$ , and $RTD = 0_D$ , the fast sawtooth shape is enabled. In all other cases the triangular shape is enabled.

## 4.30 PLL shape x register 1

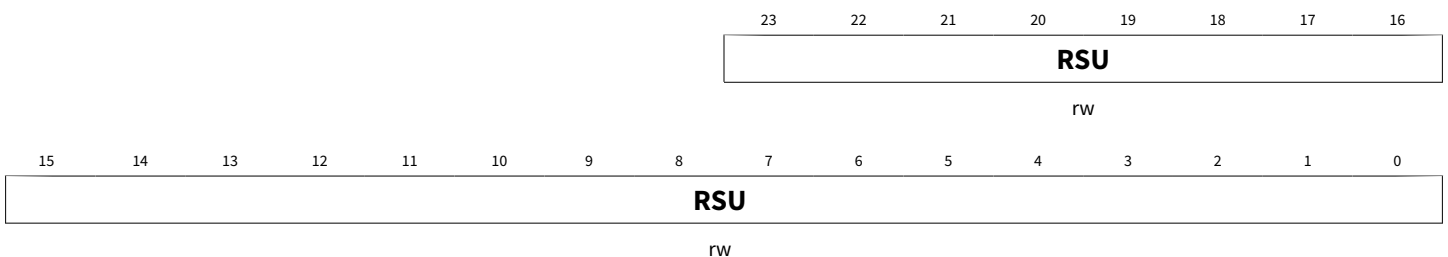
Registers PLLx, they are used to program the parameters for the modulation sequence inside the local PLL FSM. The main FSM will control the local PLL FSM to run the expected modulation sequence in standalone mode (no external trigger required except the first one).

### PLLx\_1 (x=1-4)

Offset address:  $031_H + (x-1) * 8$

PLL shape x register 1

Reset value:  $00\ 0000_H$



Field	Bits	Type	Description
RSU	23:0	rw	<p><b>Ramp step up chirp. A ramp step is the RF frequency difference added to the actual frequency during single clock cycle time of <math>T_{SYS\_CLK}</math>. In case the value is zero the RF frequency will be almost constant during the RTU time.</b></p> <p>Bit(23) represents the sign for the ramp:  <math>0_D</math> ... Up chirp  <math>1_D</math> ... Down chirp</p>

### 4.31 PLL shape x register 2

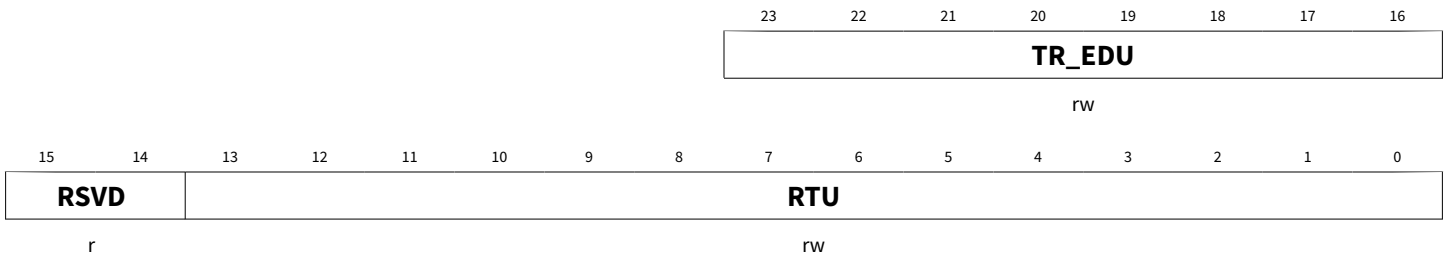
Registers PLLx, they are used to program the parameters for the modulation sequence inside the local PLL FSM. The main FSM will control the local PLL FSM to run the expected modulation sequence in standalone mode (no external trigger required except the first one).

#### PLLx\_2 (x=1-4)

Offset address:  $032_H + (x-1) * 8$

PLL shape x register 2

Reset value:  $00\ 0000_H$



Field	Bits	Type	Description
RTU	13:0	rw	<p><b>Ramp time for up chirp. RTU defines the number of clock cycles for the up chirp. The actual ramp time is:</b></p> <p><math>0_D</math> ... Timer disabled (needed for fast down chirp)  <math>1_D..16383_D</math> ... <math>T\_RAMP = RTU * 8 * T_{SYS\_CLK}</math></p>
RSVD	15:14	r	<b>Reserved</b>
TR_EDU	23:16	rw	<p><b>Timer for T_EDU. End of chirp delay applied after every up chirp:</b></p> <p><math>0_D</math> ... <math>T\_EDU = 2 * T_{SYS\_CLK}</math>  <math>1_D..255_D</math> ... <math>T\_EDU = (TR\_EDU * 8 + 5) * T_{SYS\_CLK}</math></p>

### 4.32 PLL shape x register 3

Registers PLLx, they are used to program the parameters for the modulation sequence inside the local PLL FSM. The main FSM will control the local PLL FSM to run the expected modulation sequence in standalone mode (no external trigger required except the first one).

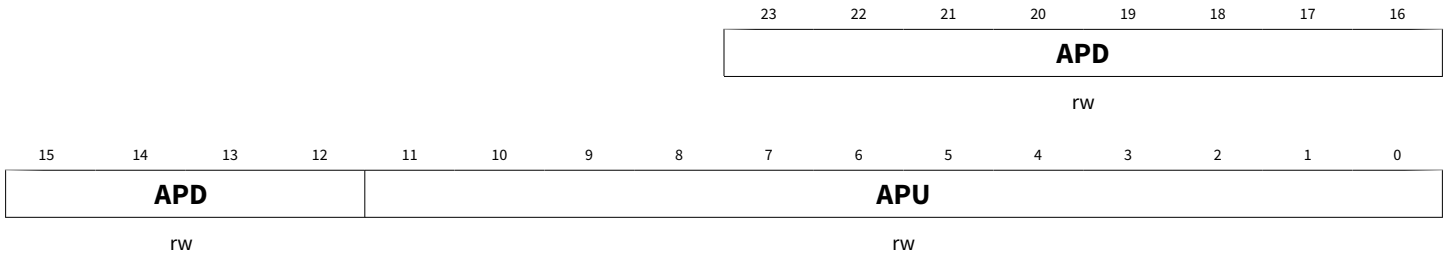
#### PLLx\_3 (x=1-4)

Offset address:  $033_H + (x-1) * 8$

PLL shape x register 3

Reset value:  $00\ 0000_H$

**4 BGT60UTR11AIP registers**



Field	Bits	Type	Description
APU	11:0	rw	<b>Number of samples for an up chirp of a single ADC:</b> 0 <sub>D</sub> ..4095 <sub>D</sub> ... Number of samples
APD	23:12	rw	<b>Number of samples for a down chirp of a single ADC:</b> 0 <sub>D</sub> ..4095 <sub>D</sub> ... Number of samples

**4.33 PLL shape x register 4**

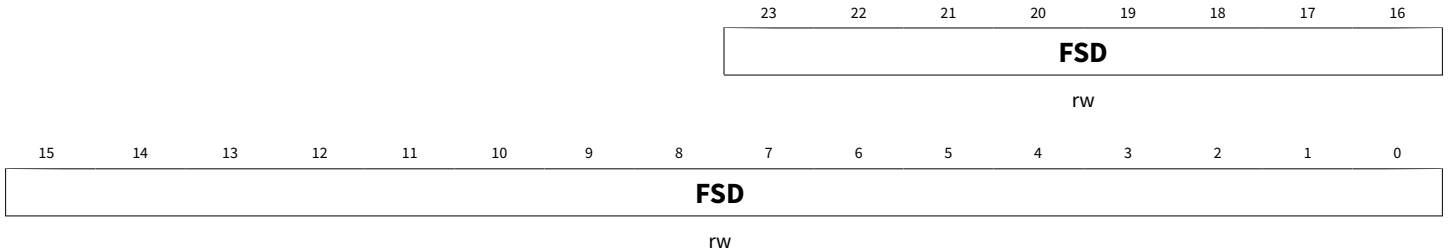
Registers PLLx, they are used to program the parameters for the modulation sequence inside the local PLL FSM. The main FSM will control the local PLL FSM to run the expected modulation sequence in standalone mode (no external trigger required except the first one).

**PLLx\_4 (x=1-4)**

Offset address: 034<sub>H</sub>+(x-1)\*8

PLL shape x register 4

Reset value: 00 0000<sub>H</sub>



Field	Bits	Type	Description
FSD	23:0	rw	<b>Chirp start frequency for down chirp. Sigma delta start frequency for the ramp generator:</b> 0 <sub>D</sub> ... Sawtooth shape Note: In case FSD = 0 <sub>D</sub> , RSD = 0 <sub>D</sub> , and RTD = 0 <sub>D</sub> , the fast sawtooth shape is enabled. In all other cases the triangular shape is enabled.

**4.34 PLL shape x register 5**

Registers PLLx, they are used to program the parameters for the modulation sequence inside the local PLL FSM. The main FSM will control the local PLL FSM to run the expected modulation sequence in standalone mode (no external trigger required except the first one).

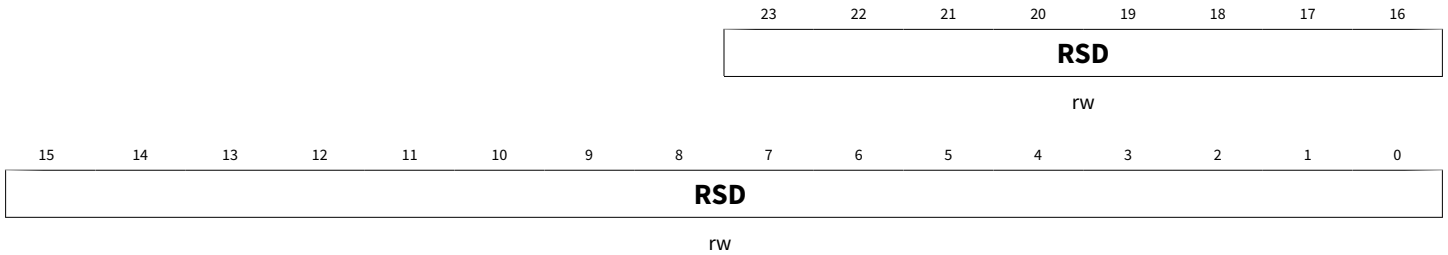
**PLLx\_5 (x=1-4)**

Offset address: 035<sub>H</sub>+(x-1)\*8

PLL shape x register 5

Reset value: 00 0000<sub>H</sub>

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Field	Bits	Type	Description
RSD	23:0	rw	<p><b>Ramp step down chirp. A ramp step is the RF frequency difference added to the actual frequency during single clock cycle time of <math>T_{SYS\_CLK}</math>. In case the value is zero the RF frequency will be almost constant during the RTD time.</b></p> <p>Bit(23) represents the sign for the ramp:  <math>0_D</math> ... Up chirp  <math>1_D</math> ... Down chirp</p>

### 4.35 PLL shape x register 6

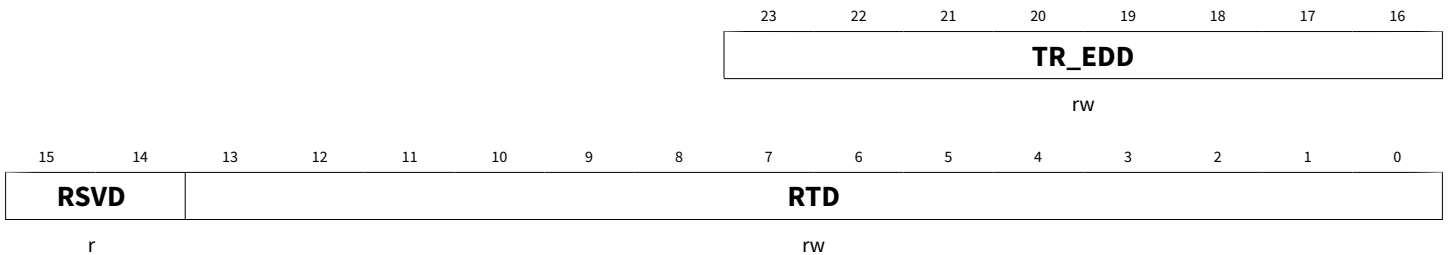
Registers PLLx, they are used to program the parameters for the modulation sequence inside the local PLL FSM. The main FSM will control the local PLL FSM to run the expected modulation sequence in standalone mode (no external trigger required except the first one).

#### PLLx\_6 (x=1-4)

Offset address:  $036_H + (x-1) * 8$

PLL shape x register 6

Reset value:  $00\ 0000_H$



Field	Bits	Type	Description
RTD	13:0	rw	<p><b>Ramp time for down chirp. RTD defines the number of clock cycles for the down chirp. The actual ramp time is:</b></p> <p><math>0_D</math> ... Timer disabled (needed for fast down chirp)  <math>1_D..16383_D</math> ... <math>T\_RAMP = RTD * 8 * T_{SYS\_CLK}</math></p>
RSVD	15:14	r	<b>Reserved</b>
TR_EDD	23:16	rw	<p><b>Timer for T_EDD. End of chirp delay applied after every down chirp:</b></p> <p><math>0_D</math> ... <math>T\_EDD = 2 * T_{SYS\_CLK}</math>  <math>1_D..255_D</math> ... <math>T\_EDD = (TR\_EDD * 8 + 5) * T_{SYS\_CLK}</math></p>

### 4.36 PLL shape x register 7

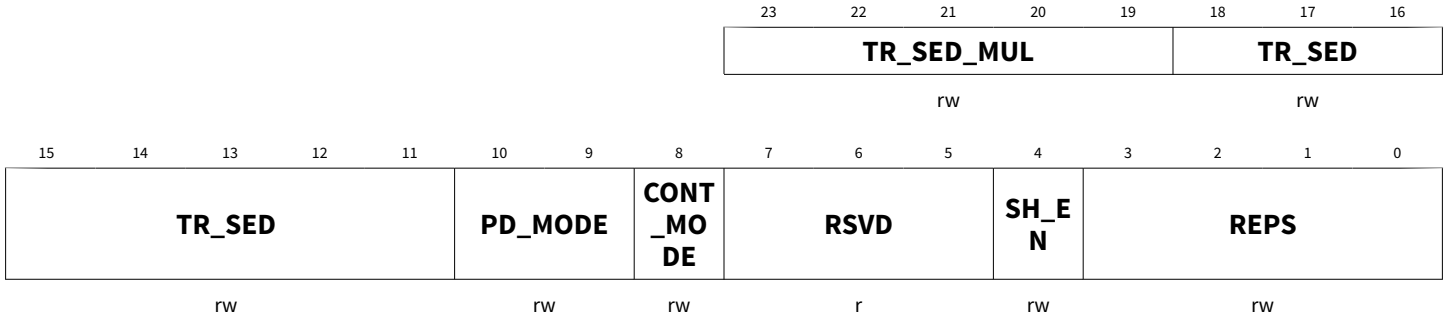
Registers PLLx, they are used to program the parameters for the modulation sequence inside the local PLL FSM. The main FSM will control the local PLL FSM to run the expected modulation sequence in standalone mode (no external trigger required except the first one).

**PLLx\_7 (x=1-4)**

Offset address: 037<sub>H</sub>+(x-1)\*8

PLL shape x register 7

Reset value: 00 0000<sub>H</sub>

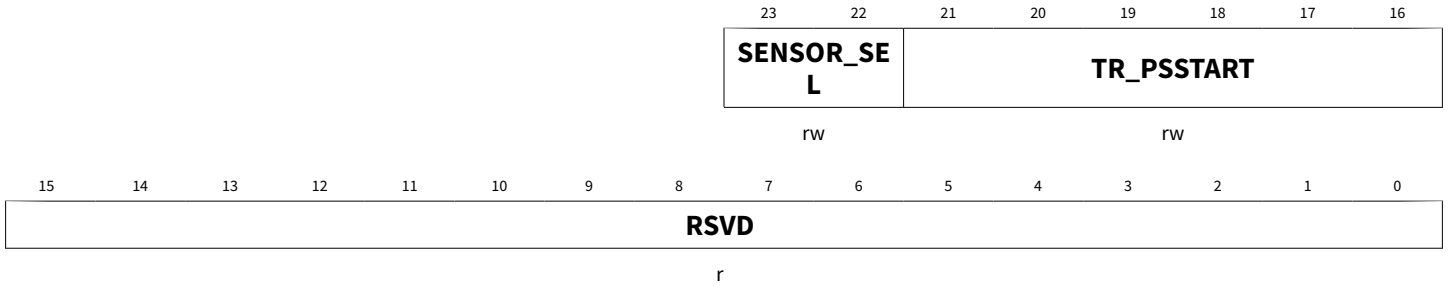


Field	Bits	Type	Description
REPS	3:0	rw	<b>Repetition factor for a single shape:</b> 0 <sub>D</sub> ..15 <sub>D</sub> ... RS = 2 <sup>REPS</sup>
SH_EN	4	rw	<b>Enable shape:</b> 0 <sub>B</sub> ... Disabled 1 <sub>B</sub> ... Enabled Note: Values for disabled shapes are ignored. At least the first shape needs to be enabled (PLL1_7:SH_EN = 1 <sub>B</sub> ). Fields for unused shapes must be programmed to its default reset value.
RSVD	7:5	r	<b>Reserved</b>
CONT_MODE	8	rw	<b>Continuous mode. After last shape repetition RS, the specified power mode (PLLx_7:PD_MODE) is applied and</b> 0 <sub>B</sub> ... the FSM stops immediately 1 <sub>B</sub> ... after T_SED the next shape set is applied
PD_MODE	10:9	rw	<b>Power down mode. After the last repetition RS the chip enters the defined power mode (during T_SED):</b> 0 <sub>D</sub> ... Keep the same power mode (CSx + CSCx) 1 <sub>D</sub> ... Change to IDLE power mode (CSI + CSCi) 2 <sub>D</sub> ... Change to DS power mode (CSDS + CSCDS) 3 <sub>D</sub> ... Reserved
TR_SED	18:11	rw	<b>Timer for T_SED:</b> 0 <sub>D</sub> ... T <sub>SYS_CLK</sub> 1 <sub>D</sub> ..255 <sub>D</sub> ... T_SED = (TR_SED * 2 <sup>TR_SED_MUL</sup> * 8 + TR_SED_MUL + 3) * T <sub>SYS_CLK</sub>
TR_SED_MUL	23:19	rw	<b>Timer multiplier for T_SED:</b> 0 <sub>D</sub> ..31 <sub>D</sub> ... 2 <sup>TR_SED_MUL</sup>

### 4.37 Sensor ADC register

On chip sensor register settings.

**ADC1** Offset address: 050<sub>H</sub>  
Sensor ADC register Reset value: 00 0000<sub>H</sub>



Field	Bits	Type	Description
RSVD	15:0	r	<b>Reserved</b>
TR_PSSTART	21:16	rw	<b>Delay after pa_on after the power amplifier is activated and power sensing is started.</b> $T\_PSSTART = TR\_PSSTART * 8 * T_{SYS\_CLK}$ 0 <sub>D</sub> ... Minimum delay 50 <sub>D</sub> ... Maximum delay 51 <sub>D</sub> ..63 <sub>D</sub> ... Reserved Note: $T\_PSSTART \leq T\_SSTART - 1.3 \mu s$ (with 0.3 $\mu s$ for ADC conversion).
SENSOR_SEL	23:22	rw	<b>Sensor selection for ADC input:</b> 0 <sub>D</sub> ... RX channel (CSx:MADC_BBCH1_EN must be set) 1 <sub>D</sub> ... Power sensor (CSx:PD1_EN must be set) 2 <sub>D</sub> ... Temperature sensor (CSx:TEMP_MEAS_EN must be set) 3 <sub>D</sub> ... IFx

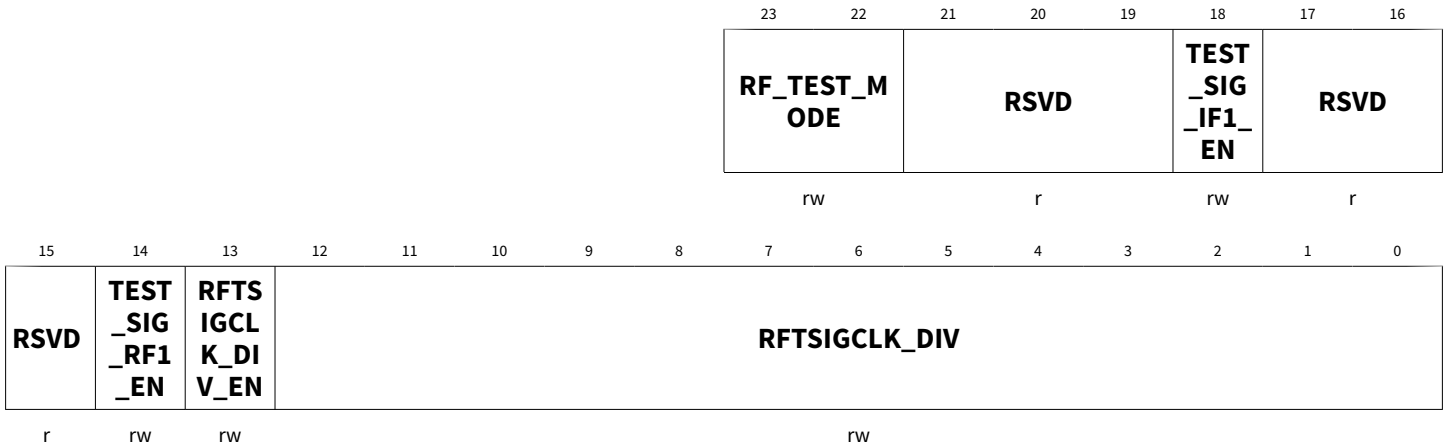
### 4.38 RF test register 0

Register contains several bits used to enable dedicated paths for self test.

**RFT0** Offset address: 055<sub>H</sub>  
RF test register 0 Reset value: 00 1F40<sub>H</sub>



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Field	Bits	Type	Description
RFTSIGCLK_DIV	12:0	rw	<b>RF test tone signal divider value.</b> $f_{RFTST} = f_{SYS\_CLK} / RFTSIGCLK\_DIV$ : 0 <sub>D</sub> ... Reserved 1 <sub>D</sub> ... Reserved 2 <sub>D</sub> ... Minimum value 8191 <sub>D</sub> ... Maximum value
RFTSIGCLK_DIV_EN	13	rw	<b>Enable the RF test tone signal output to the baseband:</b> 0 <sub>B</sub> ... Disabled 1 <sub>B</sub> ... Enabled
TEST_SIG_RF1_EN	14	rw	<b>Enable test signal for receiver RF1:</b> 0 <sub>B</sub> ... Disabled 1 <sub>B</sub> ... Enabled
RSVD	17:15, 21:19	r	<b>Reserved</b>
TEST_SIG_IF1_EN	18	rw	<b>Enable test signal for IF channel 1:</b> 0 <sub>B</sub> ... Disabled 1 <sub>B</sub> ... Enabled
RF_TEST_MODE	23:22	rw	<b>RF test mode.</b> 0 <sub>B</sub> ... Test mode disabled 1 <sub>B</sub> ... Mode 1: rf_bb:tx1_en toggles between 0 <sub>B</sub> and CSx:TX1_EN with $f_{RFTST}$ 2 <sub>B</sub> ... Mode 2: rf_bb:tx1_dac toggles between 0 <sub>B</sub> and CSx:TX1_DAC with $f_{RFTST}$ 3 <sub>B</sub> ... Mode 3: rf_bb:test_sig_rf1 toggles between 0 <sub>B</sub> and RFT0:TEST_SIG_RF1_EN with $f_{RFTST}$ Note: RF test mode is only active for MAIN:CW_MODE = 1 <sub>B</sub> . Note: RFTSIGCLK_DIV must be programmed and RFTSIGCLK_DIV_EN must be enabled.

### 4.39 EFUSE register 0

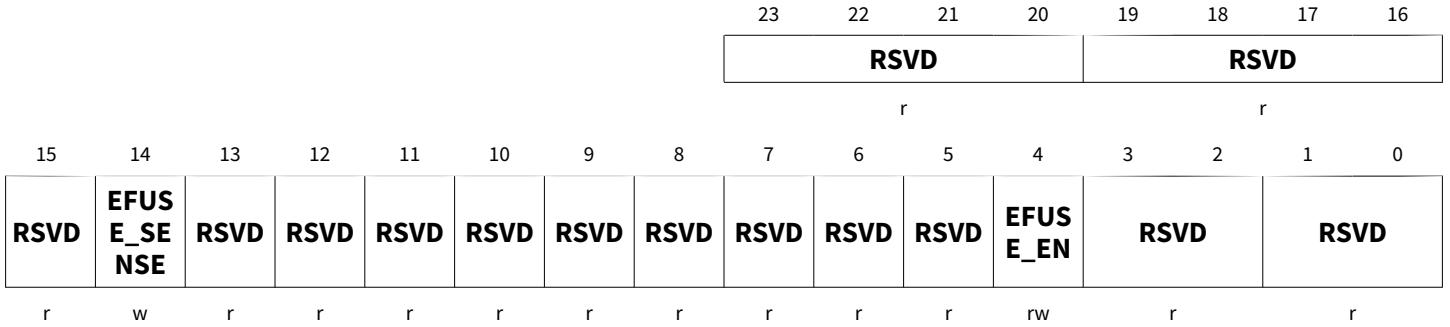
Register contains several bits used to read out eFuses.

#### EFUSE0

EFUSE register 0

Offset address: 057<sub>H</sub>

Reset value: 00 0200<sub>H</sub>



Field	Bits	Type	Description
RSVD	3:0, 13:5, 23:15,	r	<b>Reserved</b>
EFUSE_EN	4	rw	<b>Enable EFUSE:</b> 0 <sub>B</sub> ... Enabled 1 <sub>B</sub> ... Disabled
EFUSE_SENSE	14	w	<b>Start EFUSE read sequence:</b> 0 <sub>B</sub> ... No effect 1 <sub>B</sub> ... Executes EFUSE reading and clears this bit

### 4.40 EFUSE register 1

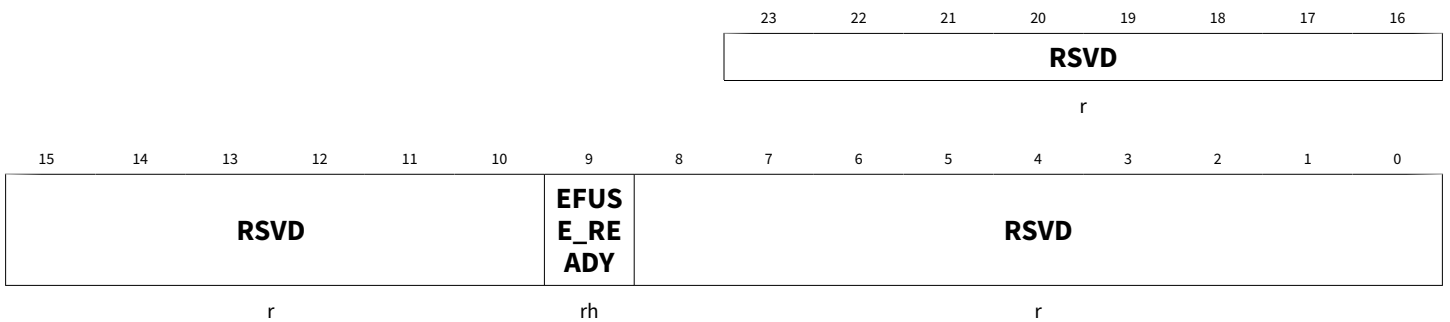
Register contains several bits used to read out eFuses.

#### EFUSE1

EFUSE register 1

Offset address: 058<sub>H</sub>

Reset value: 00 0300<sub>H</sub>



Field	Bits	Type	Description
RSVD	8:0, 23:10	r	<b>Reserved</b>

(table continues...)

(continued)

Field	Bits	Type	Description
EFUSE_READY	9	rh	<b>EFUSE ready:</b> 0 <sub>B</sub> ... Not ready 1 <sub>B</sub> ... Ready Note: Only valid after EFUSE_SENSE was executed! Result stored in CHIP_ID0 and CHIP_ID1.

#### 4.41 PLL test register 0

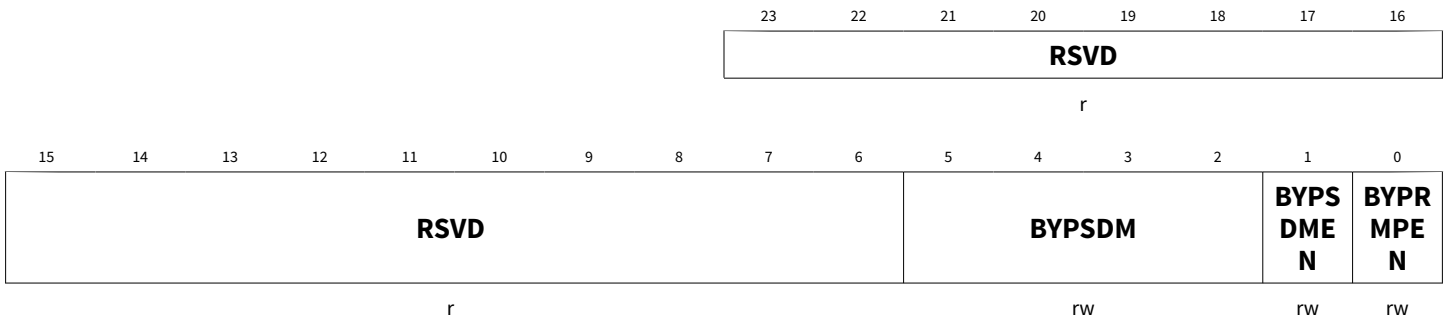
The setting in this register should be used when the CW mode is enabled. Sigma delta modulator (SDM) is bypassed in CW mode.

##### PDFT0

Offset address: 059<sub>H</sub>

PLL test register 0

Reset value: 00 0000<sub>H</sub>



Field	Bits	Type	Description
BYPRMPEN	0	rw	<b>Enable bypass ramp generator:</b> 0 <sub>B</sub> ... Ramp generator enabled 1 <sub>B</sub> ... Ramp generator disabled (bypassed)
BYPSDMEN	1	rw	<b>Enable bypass for sigma delta modulator:</b> 0 <sub>B</sub> ... Disabled 1 <sub>B</sub> ... Enabled
BYPSDM	5:2	rw	<b>Value used for bypassed sigma delta modulator:</b> 0 <sub>D</sub> ... Minimum value 15 <sub>D</sub> ... Maximum value
RSVD	23:6	r	<b>Reserved</b>

#### 4.42 Chip ID register 0

The unique chip ID consists of 48 bits. Register CHIP\_ID0 provides the first 24bits of the ID.

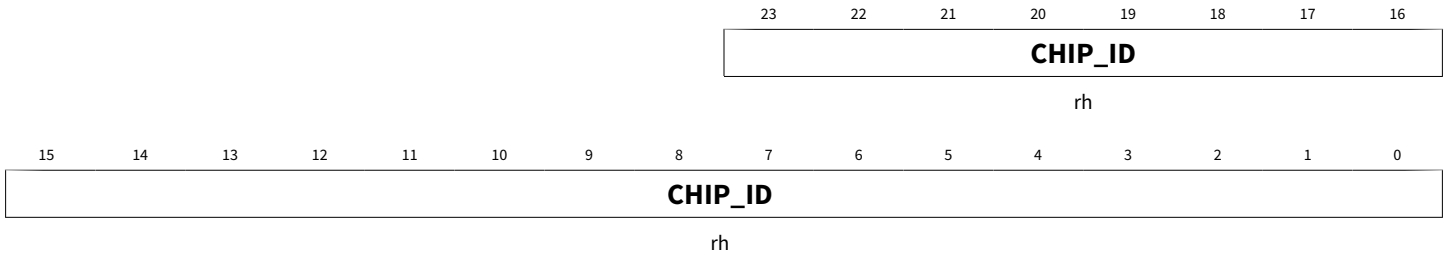
##### CHIP\_ID0

Offset address: 05D<sub>H</sub>

Chip ID register 0

Reset value: FF FFFF<sub>H</sub>

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Field	Bits	Type	Description
CHIP_ID	23:0	rh	<b>Chip ID[23:0].</b> Note: Valid after EFUSE_SENSE was executed.

**4.43 Chip ID register 1**

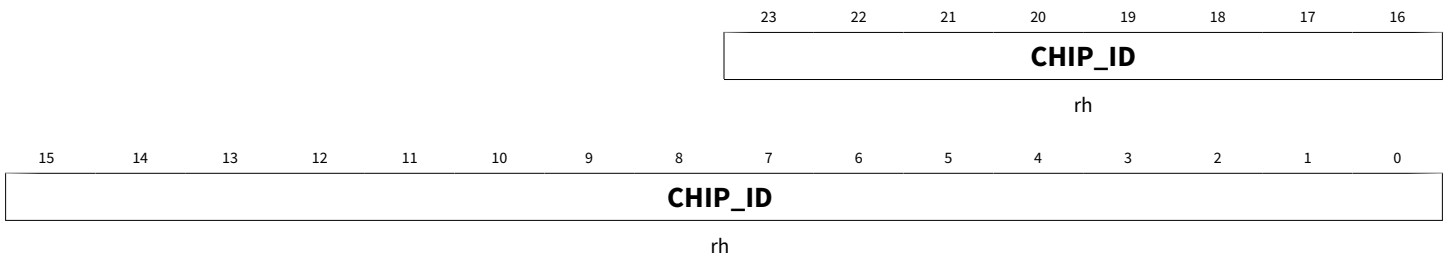
The unique chip ID consists of 48 bits. Register CHIP\_ID1 provides the second 24bits of the ID.

**CHIP\_ID1**

Chip ID register 1

Offset address: 05E<sub>H</sub>

Reset value: FF FFFF<sub>H</sub>



Field	Bits	Type	Description
CHIP_ID	23:0	rh	<b>Chip ID[47:24].</b> Note: Valid after EFUSE_SENSE was executed.

**4.44 Clock input register**

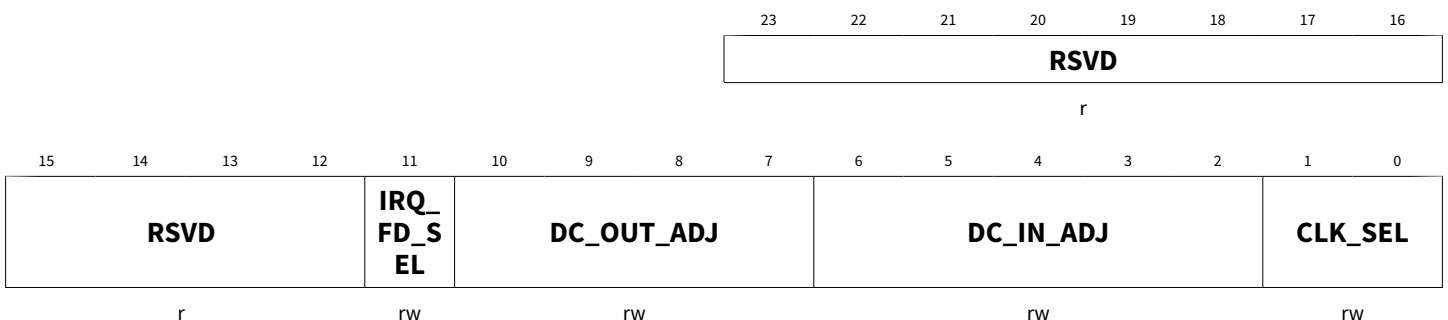
CLK\_IN register bit fields are used to program the input clock path.

**CLK\_IN**

Clock input register

Offset address: 05F<sub>H</sub>

Reset value: 00 0400<sub>H</sub>



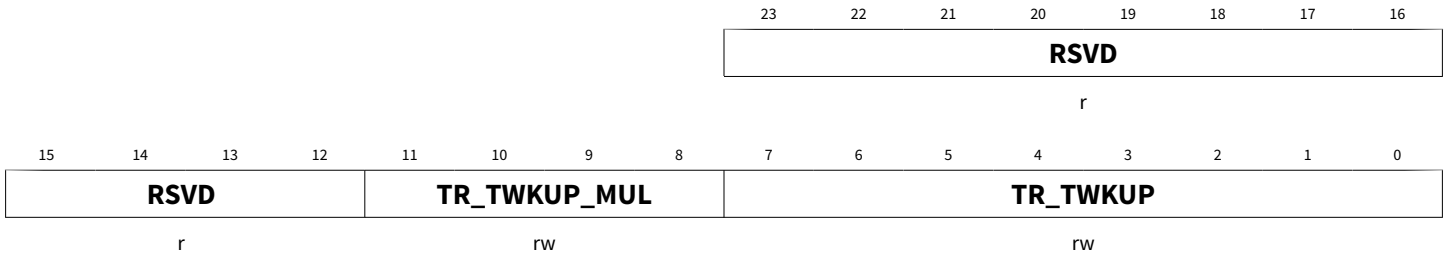
Field	Bits	Type	Description
CLK_SEL	1:0	rw	<p><b>Selection of input clock frequency and clock path:</b></p> <p>0<sub>D</sub> ... Frequency doubler bypassed            1<sub>D</sub> ... Frequency doubler without DC_IN            2<sub>D</sub> ... Frequency doubler with DC_IN            3<sub>D</sub> ... Frequency doubler with DC calibration for system clock and without DC calibration for PLL clock</p> <p><b>Note:</b> It is important to program FD register first and enable the system clock afterwards by programming PACR2(23) register.</p>
DC_IN_ADJ	6:2	rw	<p><b>Duty cycle of input clock can be adjusted before entering the internal clock doublers. This adjustment can be used for equalizing the input clock to a DC of 50 % by applying a positive or negative clock delay time to the input clock (from OSC_CLK pin). In case if MSB of DC_IN_ADJ = 0<sub>B</sub> a positive delay is used, while a MSB of DC_IN_ADJ = 1<sub>B</sub> applies a negative delay. Delay times are in steps of 125 ps.:</b></p> <p>0<sub>D</sub> ... +0.23 ns (minimal positive adjustment)            ...            15<sub>D</sub> ... +2.1 ns (maximal positive adjustment)            16<sub>D</sub> ... -0.23 ns (minimal negative adjustment)            ...            31<sub>D</sub> ... -2.1 ns (maximal negative adjustment)</p>
DC_OUT_ADJ	10:7	rw	<p><b>Duty cycle adjustment of clock doubler for system clock. The system clock pulse width can be adjusted by 15 delay cells, starting from 4.3 ns up to 4.3 ns + 15 * 0.45 ns. The duty cycle then is <math>DC_{SYS\_CLK} = (4.3\text{ ns} + DC\_OUT\_ADJ * 0.4\text{ ns}) / T_{SYS\_CLK}</math>.</b></p> <p>0<sub>D</sub> ... 4.3 ns            1<sub>D</sub> ... 4.7 ns            ...            4<sub>D</sub> ... 6.10 ns (preferred value for e.g. 80 MHz)            5<sub>D</sub> ... 6.55 ns (preferred value for e.g. 76.8 MHz)            ...            15<sub>D</sub> ... 11.05 ns</p> <p>Note: The duty cycle of the system clock can be adjusted via CLK_IN:DC_OUT_ADJ and can be monitored via IRQ pin.</p>
IRQ_FD_SEL	11	rw	<p><b>Select frequency doubler output at IRQ pin:</b></p> <p>0<sub>B</sub> ... Normal irq functionality at IRQ pin            1<sub>B</sub> ... Frequency doubler output at IRQ pin</p> <p>Note: Frequency doubler has higher priority as interrupt.</p>
RSVD	23:12	r	<b>Reserved</b>

#### 4.45 Wake up register

Wake up register can be used as chirp offset in case multiple devices are used and triggered together via SPI broadcast.

<b>WU</b>	Offset address:	060 <sub>H</sub>
Wake up register	Reset value:	00 0000 <sub>H</sub>

**4 BGT60UTR11AIP registers**



Field	Bits	Type	Description
TR_TWKUP	7:0	rw	<b>Timer for T_WU:</b> $0_D \dots T_{SYS\_CLK}$ $1_D \dots 255_D \dots T\_WU = (TR\_WKUP * 2^{TR\_WKUP\_MUL} * 8 + TR\_WKUP\_MUL + 3) * T_{SYS\_CLK}$ Note: $T\_WU_{TYP} = 1\text{ ms}$
TR_TWKUP_MU L	11:8	rw	<b>Timer multiplier factor for T_WU:</b> $0_D \dots 15_D \dots 2^{TR\_WKUP\_MUL}$
RSVD	23:12	r	<b>Reserved</b>

**4.46 Status register 0**

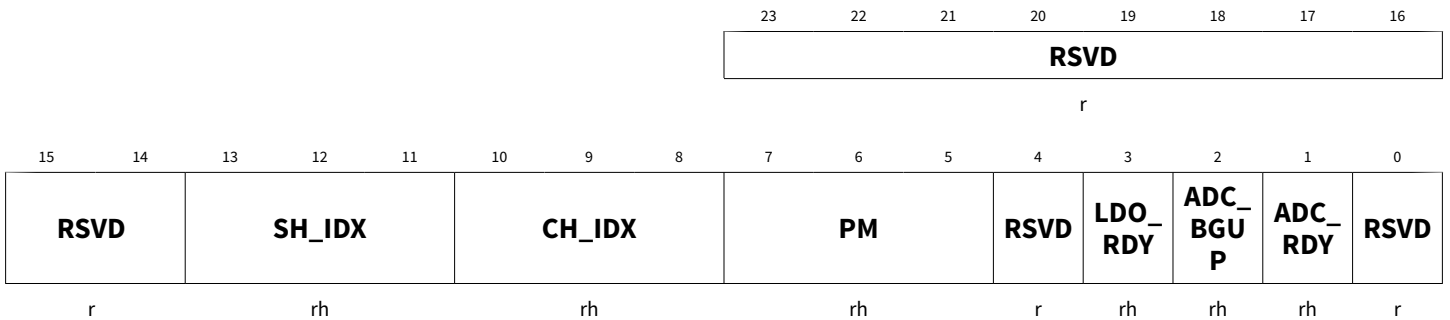
The status register STAT0 provides the actual value of some specific internal states. However it should be mentioned that for all status registers, STAT0, STAT1, and FSTAT, with the exception of the FIFO status and error flags, updates to each status register field can happen on different timing events relative to FSM states and the field content should be treated independently from one-another. In CW mode the status bits can be read properly after eg. 100 µs.

**STAT0**

Status register 0

Offset address: 061<sub>H</sub>

Reset value: 00 0008<sub>H</sub>



Field	Bits	Type	Description
RSVD	0, 4, 23:14	r	<b>Reserved</b>
ADC_RDY	1	rh	<b>ADC status:</b> $0_B \dots$ Not ready $1_B \dots$ Ready

**(table continues...)**

(continued)

Field	Bits	Type	Description
ADC_BGUP	2	rh	<b>ADC bandgap reference power up status:</b> 0 <sub>B</sub> ... Not ready 1 <sub>B</sub> ... Ready
LDO_RDY	3	rh	<b>LDO status (V<sub>DDC</sub> above the threshold):</b> 0 <sub>B</sub> ... Not ready 1 <sub>B</sub> ... Ready
PM	7:5	rh	<b>Power mode of the FSM:</b> 0 <sub>D</sub> ... Deep sleep mode (after reset) 1 <sub>D</sub> ... Active mode 2 <sub>D</sub> ... Interchirp mode 3 <sub>D</sub> ... Idle mode 4 <sub>D</sub> ... Reserved 5 <sub>D</sub> ... Deep sleep mode 6 <sub>D</sub> ... Reserved 7 <sub>D</sub> ... Reserved
CH_IDX	10:8	rh	<b>Channel set index enabled by the FSM:</b> 0 <sub>D</sub> ... CSU1 1 <sub>D</sub> ... CSD1 2 <sub>D</sub> ... CSU2 3 <sub>D</sub> ... CSD2 4 <sub>D</sub> ... CSU3 5 <sub>D</sub> ... CSD3 6 <sub>D</sub> ... CSU4 7 <sub>D</sub> ... CSD4
SH_IDX	13:11	rh	<b>Shape index enabled by the FSM:</b> 0 <sub>D</sub> ... PLLU1 1 <sub>D</sub> ... PLLD1 2 <sub>D</sub> ... PLLU2 3 <sub>D</sub> ... PLLD2 4 <sub>D</sub> ... PLLU3 5 <sub>D</sub> ... PLLD3 6 <sub>D</sub> ... PLLU4 7 <sub>D</sub> ... PLLD4

#### 4.47 Sensor ADC result register

The register SENSOR\_RESULT is used to monitor the temperature as well as the power.

##### SENSOR\_RESULT

Sensor ADC result register

Offset address: 062<sub>H</sub>

Reset value: 00 0000<sub>H</sub>





(continued)

Field	Bits	Type	Description
RSVD	16:15	r	<b>Reserved</b>
CLK_NUM_ERR	17	rh	<b>Clock number error bit is set when SPI clock number does not match the expected number of clock cycles:</b> 0 <sub>B</sub> ... No error 1 <sub>B</sub> ... Clock number error Note: Bit will be reset after HW or SW reset.
BURST_ERR	18	rh	<b>In case of burst error this bit is set:</b> 0 <sub>B</sub> ... No error 1 <sub>B</sub> ... Burst error Note: Bit will be reset after HW or SW reset.
FUF_ERR	19	rh	<b>FIFO underflow error shows if the host was reading more sampling data from the FIFO than available. The flag is also shown in GSR0 as a part of FIFO over or underflow error bit FOU_ERR:</b> 0 <sub>B</sub> ... No FIFO underflow 1 <sub>B</sub> ... FIFO underflow Note: Bit will be reset after HW, SW or FIFO reset.
EMPTY	20	rh	<b>FIFO empty status:</b> 0 <sub>B</sub> ... FIFO not empty 1 <sub>B</sub> ... FIFO empty
CREF	21	rh	<b>FIFO fill status exceeds compare reference:</b> 0 <sub>B</sub> ... Fill status below reference 1 <sub>B</sub> ... Fill status above reference
FULL	22	rh	<b>FIFO full status:</b> 0 <sub>B</sub> ... FIFO not full 1 <sub>B</sub> ... FIFO full
FOF_ERR	23	rh	<b>FIFO overflow error bit shows if more sample data are transferred to the FIFO than FIFO memory locations are available to store the data. The flag is also shown in GSR0 as a part of FIFO over or underflow error bit FOU_ERR:</b> 0 <sub>B</sub> ... No FIFO overflow 1 <sub>B</sub> ... FIFO overflow Note: Bit will be reset after HW, SW or FIFO reset.

## 4.49 Global status register

The global status register GSR0 is related to SPI read/write monitoring.

**GSR0** 0<sub>H</sub>  
Global status register Reset value: x1110100<sub>B</sub>

	7	6	5	4	3	2	1	0
<b>RSVD</b>				<b>FOU_ERROR</b>	<b>MISO_HS_R EAD</b>	<b>SPI_BURST_ ERROR</b>	<b>CLK_NUMBE R_ERROR</b>	
r				rh	rh	rh	rh	

Field	Bits	Type	Description
CLK_NUMBER_ERROR	0	rh	<b>Defined within the SPI chapter:</b> 0 <sub>B</sub> ... No clock number error 1 <sub>B</sub> ... Error condition occurred
SPI_BURST_ERROR	1	rh	<b>SPI burst error defined within the SPI chapter:</b> 0 <sub>B</sub> ... No burst read/write error 1 <sub>B</sub> ... Burst error
MISO_HS_READ	2	rh	<b>SPI MISO high speed mode:</b> 0 <sub>B</sub> ... Not active 1 <sub>B</sub> ... Active
FOU_ERROR	3	rh	<b>Shows if FIFO overflow or underflow condition occurred. The error will be cleared after the following resets: FIFO reset or SW reset or HW reset:</b> 0 <sub>B</sub> ... No error 1 <sub>B</sub> ... Error condition occurred
RSVD	7:4	r	<b>Reserved</b>

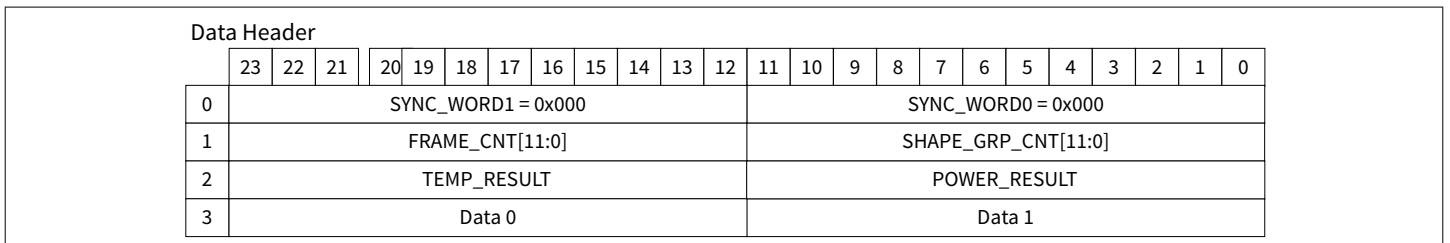
## 5 Data organization and SPI interface

### 5.1 Data header

The main FSM is capable of generating a data header to be attached to the actual radar raw data. The structure of the header is shown in the following figure and table. The data header can be disabled by controlling the bit SFCTL:PREFIX\_EN (see [Chapter 4.9](#)).

A sync-word is sent at the beginning of each acquisition to make the radar raw-data from each shape unique. This can be useful in case of broken communication with the application processor or in case of errors. Supposing the FIFO will generate a “FIFO overflow flag” the sync-word 0x000000 can be evaluated by the host controller and used to resync with the BGT60UTR11AIP and discard the data received before this sync word (if header or sync-word not used then the controller should reset the FIFO, discarding the actual FIFO data). On “FIFO underflow flag”, the received data bits from the host are 111111111111<sub>B</sub>.

Following, the header includes also the frame counter and shape group counter, as well as the actual APU/APD value (see [PLL shape x register 3](#)) and temperature value.



**Figure 20** Data header

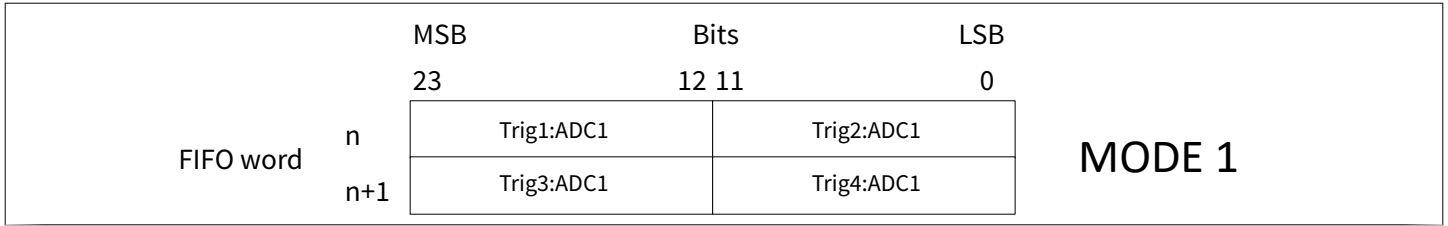
**Table 22** Data header description

Symbol	Word	Bits	Description	RST
SYNC_WORD1	#0	23:12	The sync-word can be used to identify the start of a new chirp. In case the MADC will output also a sequence of 0x000000, to make the sync-word unique, the data from the MADC will be automatically changed to 0x001 before transferring it to the FIFO.	0 <sub>D</sub>
SYNC_WORD0	#0	11:0	See SYNC_WORD1.	0 <sub>D</sub>
FRAME_CNT	#1	23:12	Same as STAT1:FRAME_CNT (see <a href="#">Status register 1</a> )	0 <sub>D</sub>
SHAPE_GRP_CNT	#1	11:0	Same as STAT1:SHAPE_GRP_CNT (see <a href="#">Status register 1</a> ).	0 <sub>D</sub>
TEMP_RESULT	#2	23:12	Temperature value from the end of the previous chirp.	0 <sub>D</sub>
POWER_RESULT	#2	11:0	Power value from the beginning of the shape.	0 <sub>D</sub>
DATA0	#3	23:12	MSB data (see <a href="#">Chapter 5.2</a> ).	
DATA1	#3	11:0	LSB data (see <a href="#">Chapter 5.2</a> ).	

### 5.2 FIFO and data flow

The memory in the BGT60UTR11AIP is based on a *FIFO*. The FIFO consists of a circular shift register organized in 2048 words of 24 bits each. Following data flow mode from multi *ADC* to the FIFO is supported by the *FSM* (see following figure):

- Mode 1: One ADC active
  - Data from 1<sup>st</sup> sample, 12 bits, are temporarily stored in a buffer
  - When the 2<sup>nd</sup> sample, 12 bits, are available, both, 1<sup>st</sup> and 2<sup>nd</sup> (24 bits), are stored into one data word



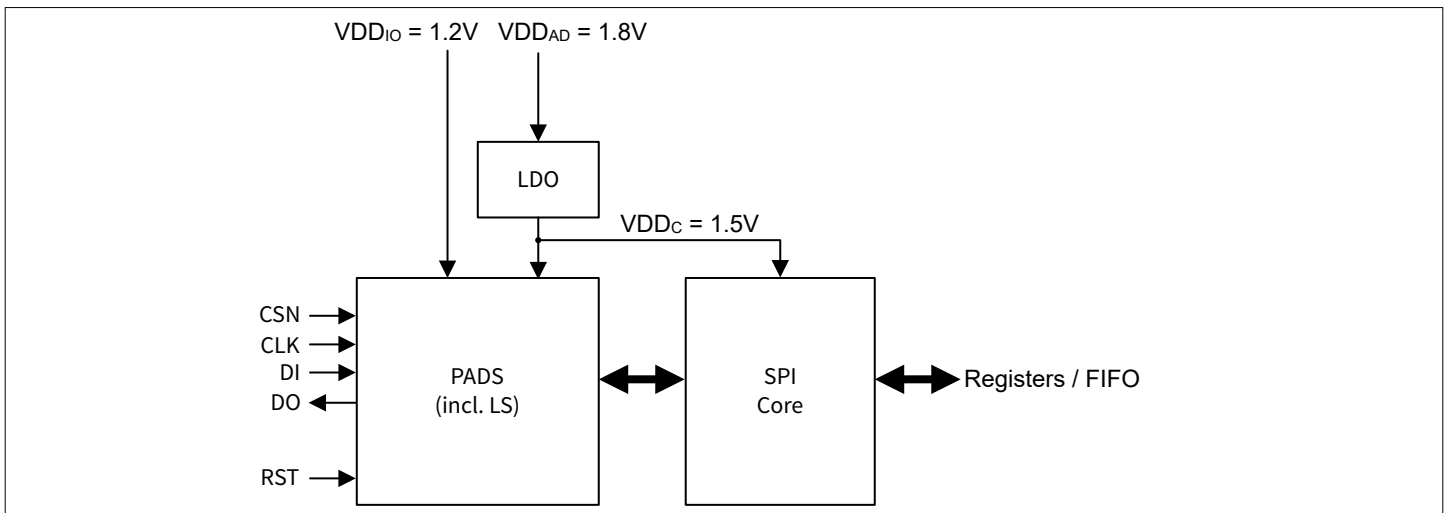
**Figure 21** FIFO organization

Readout from the FIFO should be executed from the host controller using memory address with correct data length. Data length can be derived from the data header or based on the “sync-word”.

*Note:* An illegal write to memory address space will lead to lost FIFO data!

### 5.3 SPI – Serial Peripheral Interface module

The *SPI* is the communication interface between the host and the BGT60UTR11AIP. It enables the host to read from, or write to (program) the registers as well as reading from the FIFO.



**Figure 22** SPI module

BGT60UTR11AIP device features four I/O pins for SPI communication and one for chip reset. DIO pins are pulled up to logic high inside the pad.

- CSN to be connected to SS of the SPI master
- CLK to be connected to CLK of the SPI master
- DI to be connected to MOSI of the SPI master
- DO to be connected to MISO of the SPI master
- RST to be connected to reset

**Table 23** SPI pins

Pin name	Standard SPI mode function	Remarks
CSN	CSN	Chip select not
CLK	CLK	SPI clock
DI	MOSI	HiZ, bidirectional
DO	MISO	HiZ, bidirectional

(table continues...)  
Datasheet

**Table 23** (continued) SPI pins

Pin name	Standard SPI mode function	Remarks
RST	RESET	HiZ

The SPI interface can be clocked up to 50 MHz. To meet the timing requirements for higher SPI clock frequencies (e.g. >25 MHz) the BGT60UTR11AIP device offers an additional high speed mode (SFCTL:MISO\_HS\_RD) which increase the timing budget on SPI master side by sending out data via DO with the rising edge instead of the falling edge of the CLK.

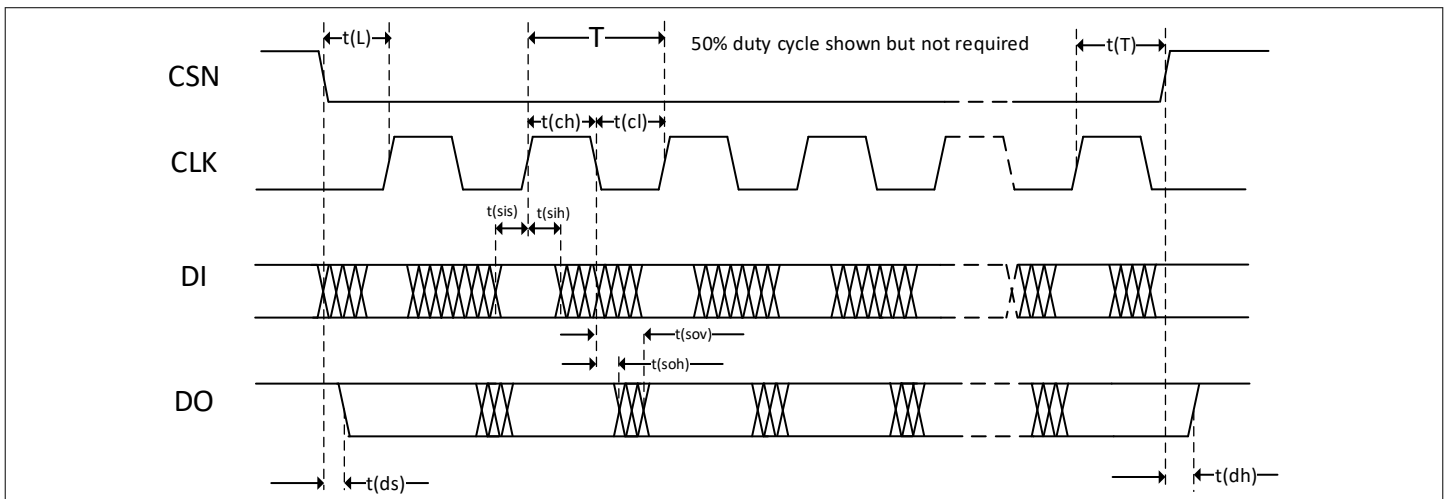
### 5.3.1 Standard SPI timing

The timing diagram for normal SPI mode (SFCTL:MISO\_HS\_RD = 0<sub>B</sub>) is presented in the following figure. A SPI transfer is started with a falling edge of chip select signal CSN generated by the SPI master. At the same time the SPI master shall drive the level of the data input signal DI (*master out slave in (MOSI)*) according to the first bit. Also with the falling edge of the chip select signal CSN the SPI slave applies the level of the data on the output signal DO (*master in slave out (MISO)*) according to the first bit which shall be transferred to the SPI master, the level becomes stable after the period  $t(ds)$ . The SPI master has to wait for the time  $t(L)$  before the clock signal CLK can be generated.

With the rising edge of CLK the SPI slave captures the level of DI. The SPI master must keep the DI level stable for  $t(sis)$  before and for  $t(sih)$  after the rising edge of CLK to ensure valid setup and hold time of the SPI slave. With the falling edge of CLK the SPI master shall set the level of DI according to the next bit the master wants to send.

The SPI master is supposed to read the level of DO with the rising edge of CLK. The SPI slave keeps the DO level stable for  $t(soh)$  after the falling edge of CLK. With the falling edge of CLK the SPI slave drives the level of DO according to the next bit, DO becomes stable after latest  $t(sov)$ .

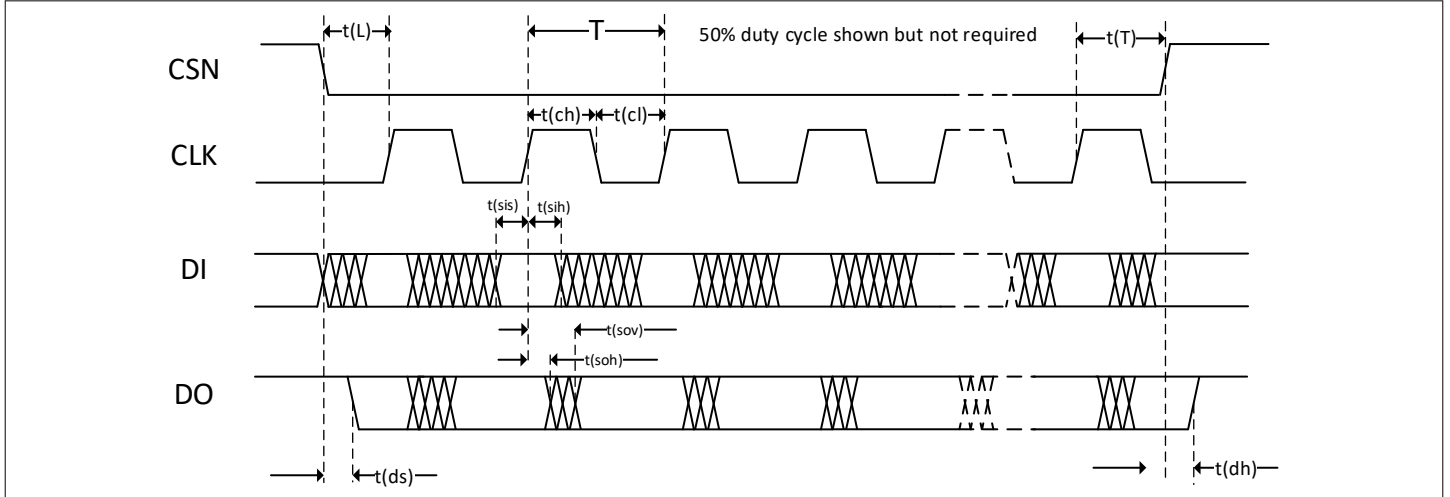
After the last bit has been transferred and CLK has gone to low level, the SPI master must set CSN to high level to stop the transfer. The master must take care that the period between the last rising edge of CLK and the rising edge of CSN is not shorter than  $t(T)$ . Within the period  $t(dh)$  after the rising edge of CSN the SPI slave drives DO to high impedance state again.



**Figure 23** SPI interface timing diagram for SFCTL:MISO\_HS\_RD = 0<sub>B</sub>

BGT60UTR11AIP can operate at SPI clock frequencies up to 50 MHz, but the maximum achievable SPI clock frequency is limited by DI related setup and hold times of SPI master and SPI slave. If for example the SPI master requires a longer setup time than  $T/2 - t(sov)$ , the SPI clock speed in normal SPI mode must be reduced. Alternatively BGT60UTR11AIP can be switched to SPI high speed mode by setting SFCTL:MISO\_HS\_RD = 1<sub>B</sub>.

The timing diagram for high speed SPI mode is presented in Figure 24. In this mode the SPI master is still supposed to capture the level of DO with the rising edge of CLK. The SPI slave keeps the level of DO stable for  $t(\text{soh})$  after the rising edge of CLK, and then sets the level of DO according to the next bit which is send out.



**Figure 24** SPI interface timing diagram for SFCTL:MISO\_HS\_RD = 1<sub>B</sub>

**Table 24** SPI Timing Requirements

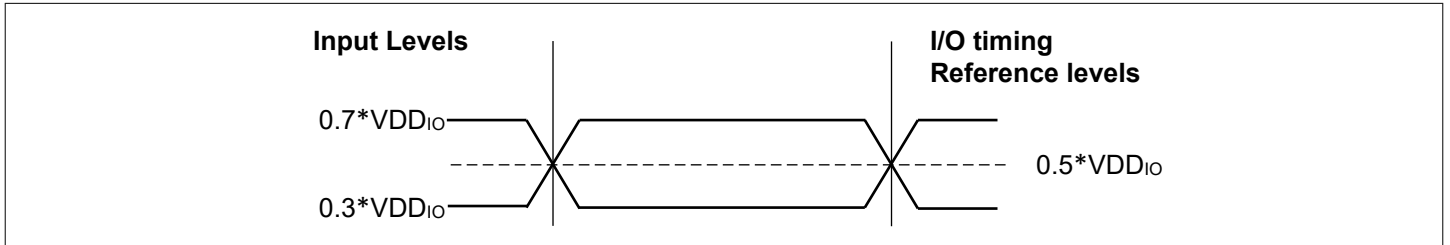
$VDD_{IO} = 1.08\text{ V to }1.32\text{ V}$ ,  $T_b = -20\text{ °C to }+70\text{ °C}$ .

Parameter	Symbol	Values			Unit	Condition
		Min.	Typ.	Max.		
SPI clock period: 50 MHz, with 1% clock jitter	$T$	20	-	-	ns	-
Clock high	$t(\text{ch})$	9.0	-	-	ns	-
Clock low	$t(\text{cl})$	9.0	-	-	ns	-
Slave input setup	$t(\text{sis})$	5.0	-	-	ns	-
Slave input hold	$t(\text{sih})$	5.0	-	-	ns	-
Slave output valid	$t(\text{sov})$	-	-	15.0	ns	see note
Slave output hold	$t(\text{soh})$	1.0	-	-	ns	-
Lead time before the first working clock edge occurs	$t(\text{L})$	9.0	-	-	ns	-
Tailing time after the last working clock edge	$t(\text{T})$	1	-	-	ns	-
Data setup time after the DO goes in low impedance state	$t(\text{ds})$	-	-	5	ns	Ensured by design
Data hold time before DO goes in hi impedance state	$t(\text{dh})$	-	-	5	ns	Ensured by design

- Note:
- If SFCTL:MISO\_HS\_RD is not set properly then data read on MISO may not be correct.
  - The timing is ensured for worst case condition:  $VDD_{IO} = 1.08\text{ V}$ ,  $T_b = +70\text{ °C}$ , output load of  $C_{load} = 50\text{ pF}$ .
  - Better conditions results in a much shorter  $t(\text{sov})$  time.

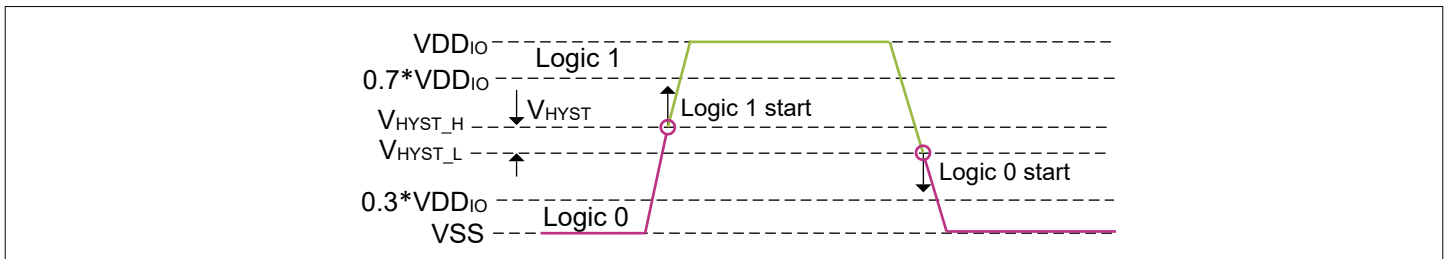
### 5.3.2 Logic levels

The digital inputs and outputs are fully *complementary metal-oxide semiconductor (CMOS)* compatible. All IO input / output timings are based on 50% voltage reference levels (see following figure). I/O interfaces are shown in [Figure 28](#) and [Figure 29](#), which include internal pull-ups.



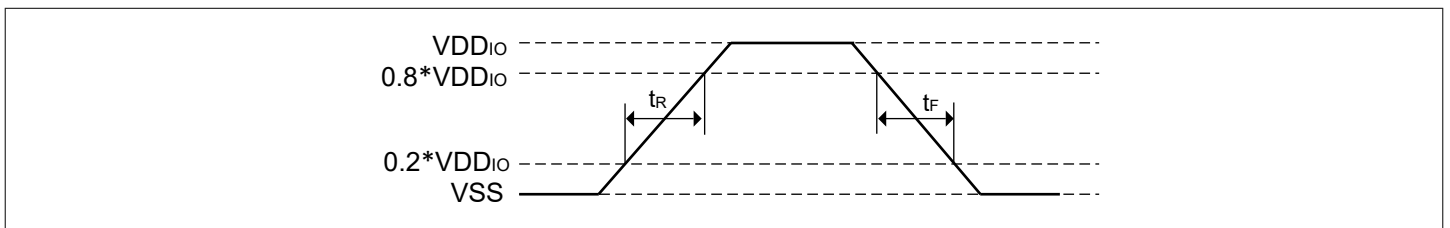
**Figure 25 AC timing input/output reference levels**

The input logic hysteresis prevents input buffers from oscillation. The minimum hysteresis range  $V_{HYST}$  is in between the lower ( $0.3 * VDD_{IO}$ ) and upper logic level ( $0.7 * VDD_{IO}$ ) boundaries (see [Figure 26](#)). Above  $0.7 * VDD_{IO}$  the input signal is a logical '1' while below  $0.3 * VDD_{IO}$  it is a logical '0' regardless of hysteresis. Due to temperature drifts and device variation the hysteresis range  $V_{HYST}$  can be up to  $0.7 * VDD_{IO}$  or down to  $0.3 * VDD_{IO}$  but typically around  $0.5 * VDD_{IO}$ . Parameters are reported in [#unique\\_124/unique\\_124\\_Connect\\_42\\_title\\_kdz\\_mqc\\_3vb](#).



**Figure 26 Logic input levels and hysteresis**

The digital output pads have a programmable output pad strength that gives a specific slew-rate for rising signals,  $dV_{TR}$ , and falling signals,  $dV_{TF}$  (see following figure). Minimum slew rates were simulated considering a total capacitive load of 15 pF. Results reported in [#unique\\_124/unique\\_124\\_Connect\\_42\\_title\\_kdz\\_mqc\\_3vb](#).



**Figure 27 Rise/fall time, slew rate specified between  $0.2 * VDD_{IO}$  and  $0.8 * VDD_{IO}$**

**Table 25 Logical Levels for Input Pins**

$VDD_{IO} = 1.08$  to  $1.32$  V,  $T_b = -20$  to  $+70$  °C, ambient temperature not below  $-40$  °C; all voltages with respect to  $VSS_{IO}$  digital ground, positive current flowing into pin (unless otherwise specified)

Parameter	Symbol	Values			Unit	Condition
		Min.	Typ.	Max.		
LOW level	$V_{IN(L)}$	0	-	$0.3 * VDD_{IO}$	V	-

(table continues...)

**Table 25 (continued) Logical Levels for Input Pins**

$V_{DDIO} = 1.08$  to  $1.32$  V,  $T_b = -20$  to  $+70$  °C, ambient temperature not below  $-40$  °C; all voltages with respect to  $V_{SSIO}$  digital ground, positive current flowing into pin (unless otherwise specified)

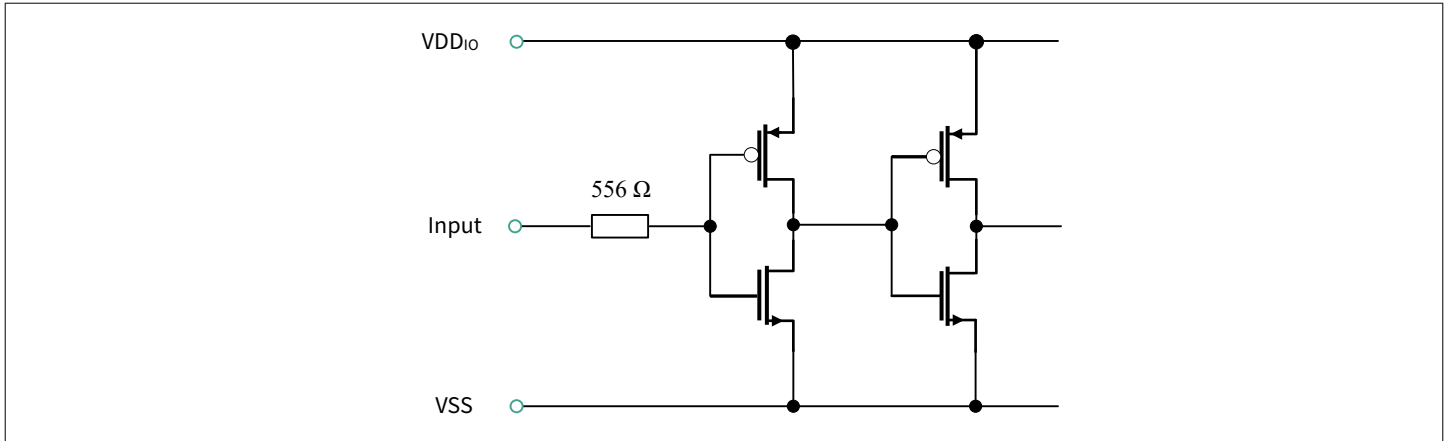
Parameter	Symbol	Values			Unit	Condition
		Min.	Typ.	Max.		
HIGH level	$V_{IN(H)}$	0.7 * $V_{DDIO}$	-	$V_{DDIO}$	V	-
Input current ( $0$ V < $V_{IN}$ < $V_{DDIO}$ )	$I_{IN}$	-150	-	150	µA	-
Input capacitance CLK/CSN/DI/RST	$C_{IN}$	1.3	-	-	pF	-
Minimum hysteresis voltage range between $0.3 * V_{DDIO}$ and $0.7 * V_{DDIO}$	$V_{HYST}$	250	-	-	mV	$V_{HYST\_H} - V_{HYST\_L}$
Upper hysteresis signal level	$V_{HYST\_H}$	-	$0.5 * V_{DDIO} + V_{HYST} / 2$	$0.7 * V_{DDIO}$	V	-
Lower hysteresis signal level	$V_{HYST\_L}$	$0.3 * V_{DDIO}$	$0.5 * V_{DDIO} - V_{HYST} / 2$	-	V	-

**Table 26 Logic Levels for Output Pins**

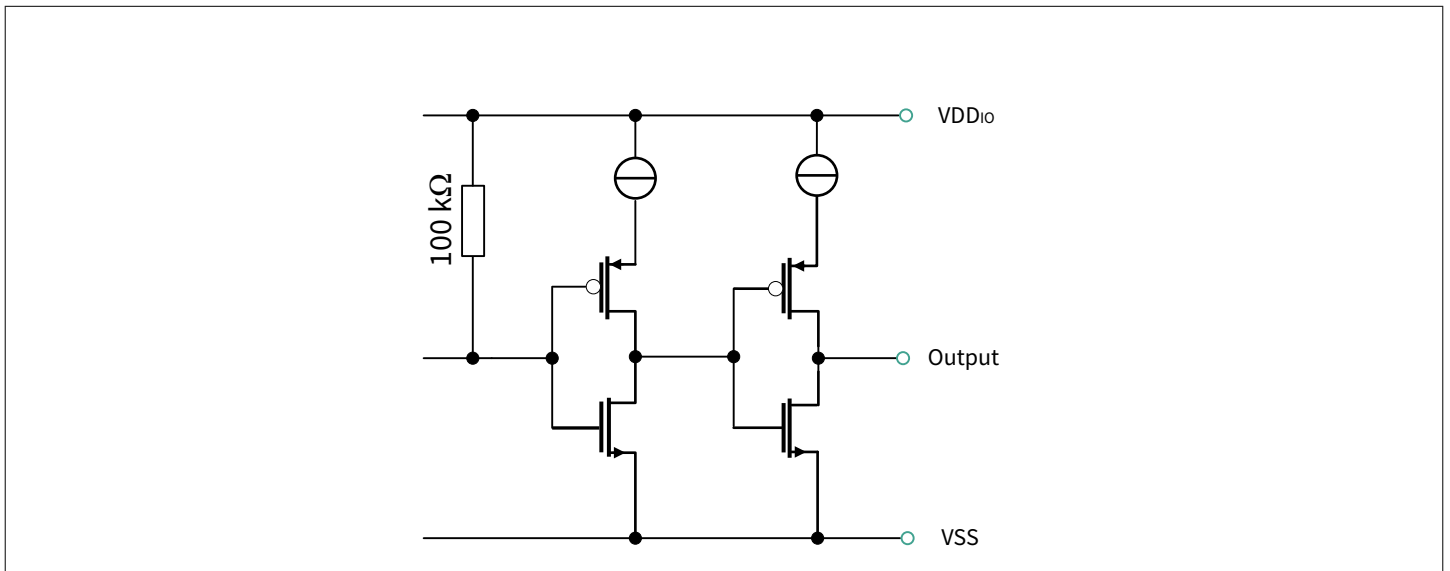
$V_{DDIO} = 1.08$  to  $1.32$  V,  $T_b = -20$  to  $+70$  °C, ambient temperature not below  $-40$  °C; all voltages with respect to  $V_{SSIO}$  digital ground, positive current flowing into pin (unless otherwise specified).

Parameter	Symbol	Values			Unit	Condition
		Min.	Typ.	Max.		
LOW level	$V_{OUT(L)}$	0	-	$0.2 * V_{DDIO}$	V	-
HIGH level	$V_{OUT(H)}$	$0.8 * V_{DDIO}$	-	$V_{DDIO}$	V	-
Output current (LOW)	$I_{OUT(L)}$	-2	-	-	mA	
Output current (HIGH)	$I_{OUT(H)}$	-	-	2	mA	
Allowed load capacitance to provide maximum signal frequency on DO	$C_{LOAD}$	-	-	15	pF	-
Output pad slew rate for rising wave form	$dV_{TR}$	0.15	-	-	V/ns	$0.2 * V_{DDIO}$ to $0.8 * V_{DDIO}$ with 50 pF load
Output pad slew rate for falling wave form	$dV_{TF}$	0.13	-	-	V/ns	$0.2 * V_{DDIO}$ to $0.8 * V_{DDIO}$ with 50 pF load





**Figure 28** Interface for input pins



**Figure 29** Interface for output pins

### 5.3.3 Overshoot and undershoot waveform definition

During operation the applied signals and supply levels should not exceed absolute maximum *direct current (DC)* levels specified in datasheet. Digital signals can have positive or negative overshoots due to inductive and/or capacitive loads. [Table 28](#) reports the allowed overshoot timings and signal levels for all logic signals.

**Table 27** Overshoot and undershoot signal levels

Parameter	Symbol	Values			Unit	Condition
		Min.	Typ.	Max.		
Maximum absolute overshoot voltage level	$V_{os}$	-	-	$VDD_{IO} + 0.5 V$	V	see note
Maximum absolute undershoot voltage level	$V_{us}$	-	-	$VSS_{IO} - 0.5 V$	V	see note

*Note:* Maximum pad current not exceeding  $\pm 2 mA$  (see also [Chapter 5.3.2](#)). No slew rate limitation existing on digital signals for overshoots/undershoots.

### 5.3.4 IBIS model

A BGT60UTR11AIP *input-output buffer information specification (IBIS)* model is available under *non-disclosure agreement (NDA)* upon request. It is based on timing simulations. In order to better reflect the real timing behavior, different pad models for input/output signals are used and summarized in the following table. The driver strength and the pull-up can be modified via registers.

**Table 28 IBIS Pad types and models (see IBIS model)**

Pin	Ibis PAD Model
CSN	IN: Selection_0
CLK	IN: Selection_0
DI	IN: Selection_0
DO	OUT: Selection_1
DIO2	Not available on BGT60UTR11AIP
RST	IN: Selection_0
IRQ	OUT: Selection_1

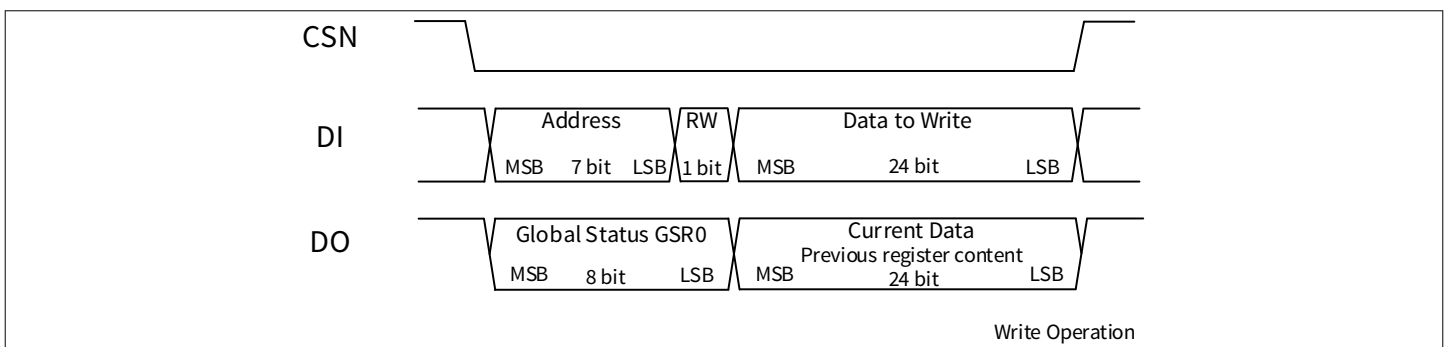
### 5.3.5 SPI functionality

Each word transferred over the *SPI* bus has a length of 1 command byte + 3 data Bytes. The communication is done bitwise. First the address is transferred with *most significant bit (MSB)* first. The address is followed by the R/W-bit and then followed by the data which is sent MSB first, too. At the same time, while command byte is received, a freely from system level configurative global status register (8 bits, GSR0) is serial shifted out on DO (MSB first). On the following 24 clock cycles the selected register content is shifted out on DO, MSB first.

Depending on sent R/W-bit there are two different operation modes available, the write mode and the read mode. Every write mode is a read mode too.

#### Write mode

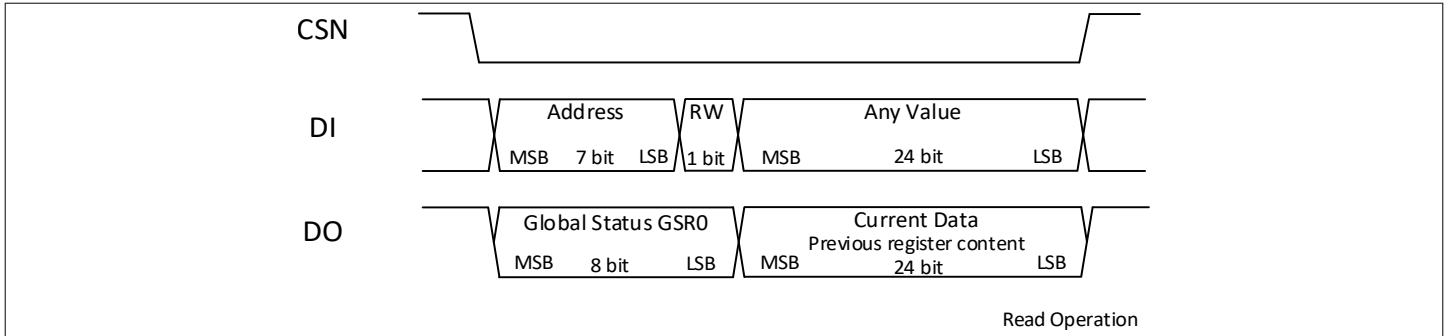
After the start condition the desired address is sent. The address is 7 bits long followed by a bit that is a data direction bit (read/write). A one indicates a write operation (see following figure).



**Figure 30 SPI timing write mode**

#### Read mode

After the start condition, the desired address is sent like in the write operation. A zero of the R/W-bit indicates a read access. The data on DI after the command byte may contain any value. The DO behavior is the same as in write mode.



**Figure 31** SPI timing read mode

### 5.3.6 SPI burst mode

The burst mode can be used to read or write out several registers or some data from the *SPI* instead of reading just single registers or data. The burst mode command is sent by the host. The burst mode command consists of several bit fields and is shown in the following table.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
ADDR							RW	SADDR							RWB

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
NBURSTS							RSVD								

Field	Bits	Description
RSVD	8:0	<b>Reserved</b>
NBURSTS	15:9	Number of processed data blocks: $0_H \dots$ “unbounded” burst accesses $1_H \dots 7E_H \dots$ number of words to transfer
RWB	16	Burst read or write: $0_B \dots$ Perform a read burst $1_B \dots$ Perform a write burst, (writes to <i>FIFO</i> not supported)
SADDR	23:17	Starting address where the burst starts processing: $< 64_H$ Register access $= 64_H$ FIFO access $> 64_H$ Reserved Address is incremented automatically inside a burst.
RW	24	Read/Write register access: $1_B \dots$ write to address $7F_H$
ADDR	31:25	To enter the burst mode the following address is used: $7F_H \dots$ request the burst read/write.

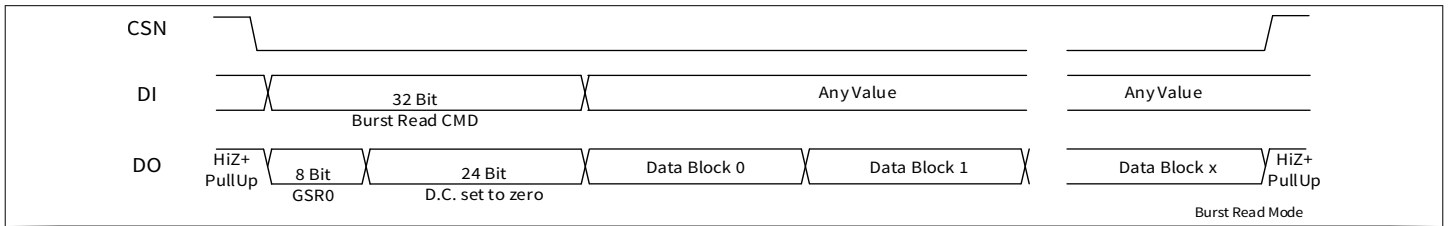
*Note:* A single data block is 24 bits width for both, the sampling memory and the registers.

**Burst mode operation**

After the start condition the 32 bits burst mode command is sent from the SPI master on DI. At the same time, the status register GSR0 (four 1<sub>B</sub> bits + four status bits) followed by 24 padding bits set to 0<sub>B</sub> is shifted out on DO. After the command sequence is done, the register/FIFO data is shifted out to the SPI master on DO. In burst write mode, the register data to be written is shifted in from the SPI master (application processor e.g.).

**Burst mode read sequence**

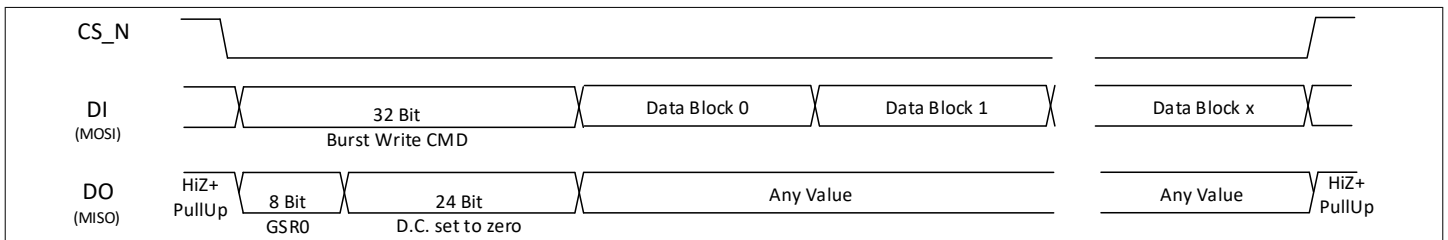
In the read sequence, the SPI master reads from the device.



**Figure 32** Burst mode read sequence

**Burst mode write sequence**

In the burst write mode, the SPI master writes to the device.

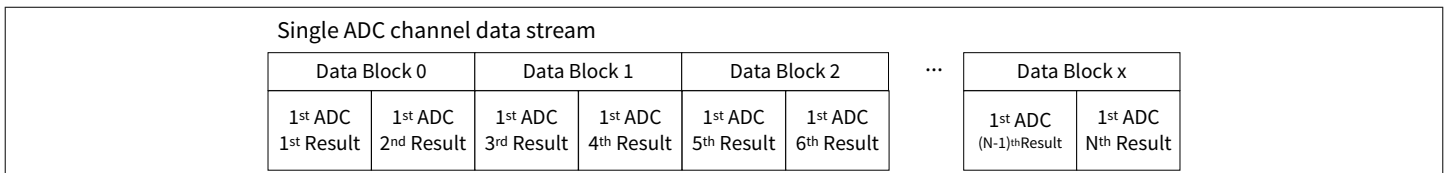


**Figure 33** Burst mode write sequence

**Sampling data arrangements in data blocks**

The data from the FIFO are streamed out during the burst read request, starting from the FIFO address zero. The 1<sup>st</sup> ADC is the ADC channel with the lowest channel number. As far as the sampling memory is organized in 24 bits and up to 1 ADC channels are selectable through the ADC channel selection bits (CSx:MADC\_BBCH\_SEL, see [Channel set up x register 1](#)) the data blocks are arranged as follows.

In case a single ADC is selected the data blocks are shown in the following figure.



**Figure 34** Single ADC channel selected

**Example: Burst mode read sampling memory sequence**

The following burst mode command is sent from the host to initialize the burst mode to read from the FIFO an undefined number of sampling data:

- BMCMD\_RS = (ADDR = 7F<sub>H</sub>, RW = 1, SADDR = 64<sub>H</sub>, RWB = 0, NBURSTS = 0<sub>H</sub>)

Remark: For each burst read request to the sampling memory, the sampling-memory address pointer is reset to the initial value. So that memory can be read out from the beginning until the application processor stops burst reading.

**Example: Burst mode read registers sequence**

The following burst mode command is sent from the host to initialize the burst mode to read out 10 registers starting from register address 3:

- BMCMD\_RR10 = (ADDR = 7F<sub>H</sub>, RW = 1, SADDR = 3<sub>H</sub>, RWB = 0, NBURSTS = A<sub>H</sub>)

**5.3.7 SPI error detection**

SPI BURST\_ERR and CLK\_NUM\_ERR (see [FIFO status register](#)) will be cleared after these resets:

- *software (SW)* reset
- *hardware (HW)* reset

SPI BURST\_ERR and CLK\_NUM\_ERR are reported in the global status bits of the next *SPI* transaction and latched as sticky bits in the FSTAT register.

In order to understand if the captured sample data are corrupted, the host can evaluate the bit field CLK\_NUM\_ERR and SPI BURST\_ERR as reported in the following table.

**Table 29 SPI BURST\_ERR and CLK\_NUM\_ERR Definitions**

Length Range	Transaction	SPI BURST_ERR	CLK_NUM_ERR	Behavior on read/write
0	Null command	0 <sub>B</sub>	0 <sub>B</sub>	Ignored
1-31	Short length error in single	0 <sub>B</sub>	1 <sub>B</sub>	Command ignored
>32	Long length error in single	0 <sub>B</sub>	1 <sub>B</sub>	Extra bits ignored
1-31	Short length error in SPI burst header	0 <sub>B</sub>	1 <sub>B</sub>	Command ignored
<24xN	Missing whole data word in bounded burst	1 <sub>B</sub>	0 <sub>B</sub>	Available data words used
>24xN	Extra whole data word in bounded burst	1 <sub>B</sub>	0	Extra data word(s) ignored
%24>0	Misaligned bit-count for bounded burst	1 <sub>B</sub>	1 <sub>B</sub>	Extra bits ignored
%24>0	Misaligned bit-count for infinite burst	0 <sub>B</sub>	1 <sub>B</sub>	Partial data word may be discarded

- Note:*
- *Ignored write transaction means that no register (or memory) content is affected by the partial write command, or incomplete data word.*
  - *Ignored read transaction means that the returned data is invalid, and for the FIFO no words are removed by the partial read command, or incomplete data word.*
  - *Discarded read transaction means that the data is already read from the FIFO but only partially transferred; subsequent read pops next word from FIFO.*
  - *Data from the FIFO may be discarded after a length error in the infinite burst (NBURST=0) occurs. The FIFO read has to happen, since at that stage the data is required to be shifted out, but if not all bits are shifted out the FIFO is already read and the partial data word may be discarded.*

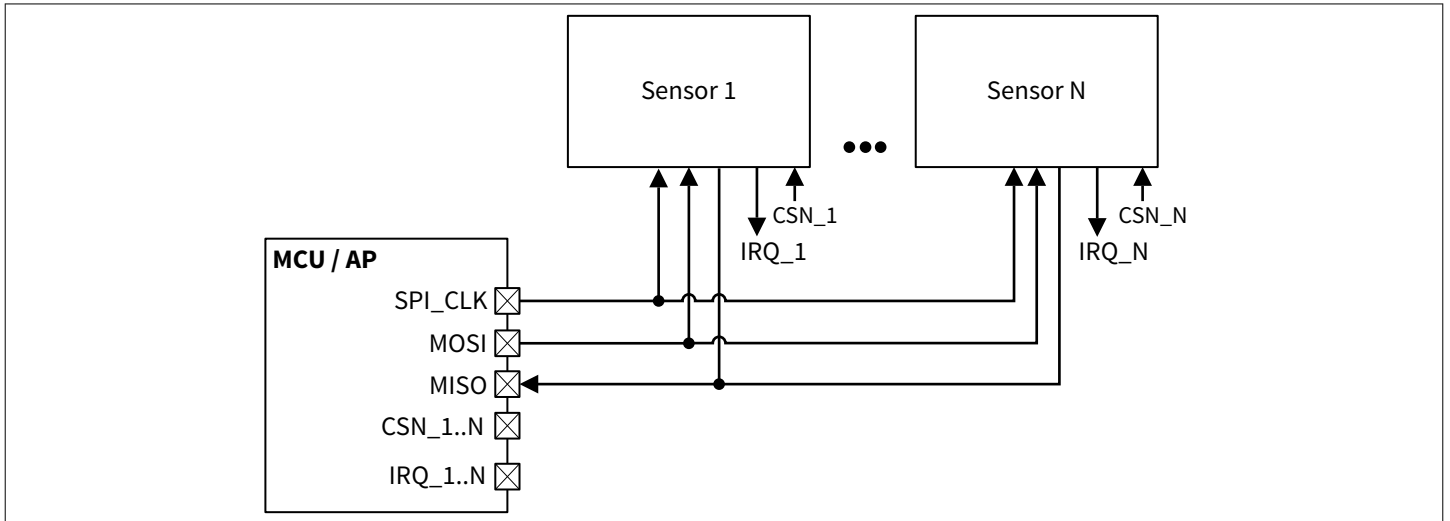
**5.3.8 SPI broadcast mode**

BGT60UTR11AIP comes with a special *SPI* feature called broadcast mode. This mode gives the user the capability to program multiple radar sensors which shares the same SPI bus.

To avoid driver conflicts of contradictory logic levels on the shared *MISO* line the SPI broadcast mode deactivates the output driver of the DO pin. This change becomes active with the rising edge of CS after MAIN:SPI\_BC\_MODE is programmed to 1<sub>B</sub>. The deactivation of this mode is done in a similar way by programming MAIN:SPI\_BC\_MODE to 0<sub>B</sub> which activates the output driver of the DO pin again with the rising edge of CS.

There are two main use cases to benefit from this SPI broadcast mode:

- To speed up initial radar sensors configuration by programming all devices at the same time
- To synchronize multiple radar sensors by triggering a frame at the same time (single SPI write command with MAIN:FRAME\_START = 1<sub>B</sub>)



**Figure 35** SPI broadcast block diagram

A SPI broadcast system with multiple sensors (e.g. sensor 1, sensor 2 ...) shares the same SPI bus including SPI clock (SPI\_CLK), data input and output (*MOSI*, *MISO*) and maybe also the same oscillator clock (OSC\_CLK). However, each sensor requires an own chip select (CSN) pin on the SPI master (e.g. *MCU, AP*) side to enable individual control over each sensor. Also a dedicated interrupt input pin is needed on SPI master side for each sensor interrupt output (IRQ).

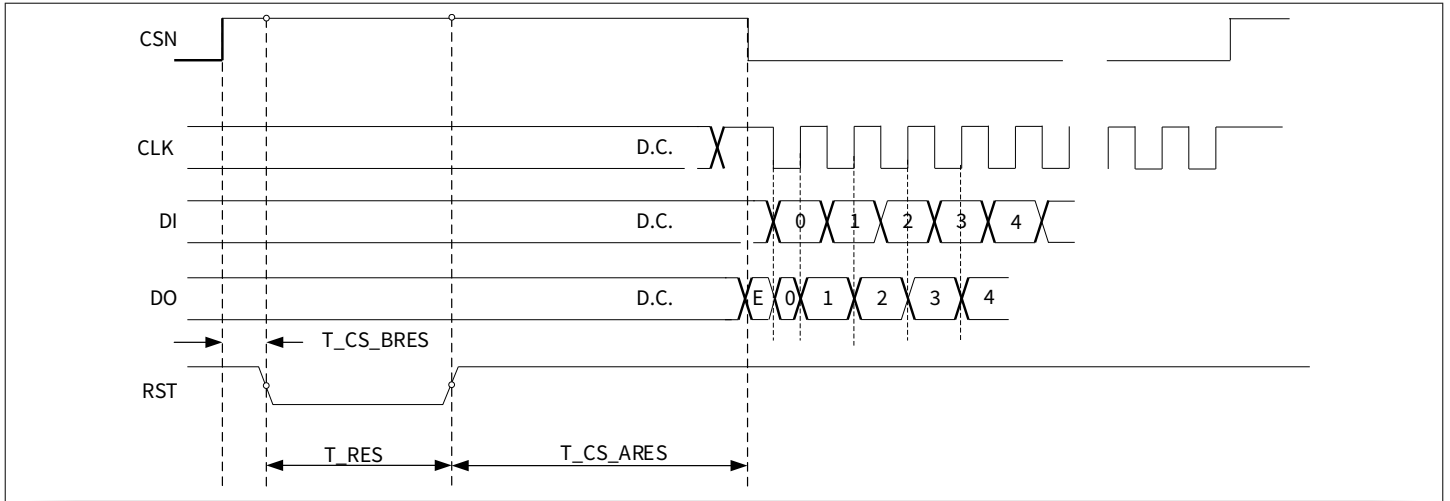
## 5.4 Hardware reset sequence

The chip should not be in reset state after any reset condition (*SW, HW, FIFO*, and *FSM* reset) especially when no external clock OSC\_CLK is applied (see [Table 3](#)). For a proper device reset a special reset sequence is required:

While CSN is = '1<sub>B</sub>' RST must perform a 1<sub>B</sub> 0<sub>B</sub> 1<sub>B</sub> transition

The behavior is presented in the following figure with:

- T\_CS\_BRES = 100 ns
- T\_RES = 100 ns
- T\_CS\_ARES = 100 ns



**Figure 36** Hardware reset sequence

## 5.5 Software triggered resets

Besides the hard reset, three reset sequences are supported and can be triggered in the MAIN register (see also [Main register](#)). They are defined according to the following hierarchy:

- *SW* reset -> *FIFO* reset -> *FSM* reset

### Software reset

- Resets all registers to default state
- Resets all internal counters (shape, frame e.g. )
- Perform FIFO reset
- Performs FSM reset
- A delay of 100 ns after the SW reset is needed before the next *SPI* command is sent

### FIFO reset

- Reset the read and write pointers of the FIFO
- Array content will not be reset, but cannot be read out
- FIFO empty is signaled, filling status = 0<sub>D</sub>
- Resets register FSTAT FIFO status register
- Performs an implicit FSM reset

### FSM reset

- Resets FSM to DS power mode
- Resets FSM internal counters for channel/shape set and timers
- Resets Status register 0 and Status register 1 register
- Reset *PLL* ramp start signal
- Reset PA\_ON
- Terminates frame (shape and frame counters incremented although maybe not complete)

## 6 PLL domain functional specification

The *PLL* is designed to generate high performance frequency chirps in the range of 57.4 GHz to 63.0 GHz. The modulation is performed inside the PLL bandwidth (in-band-modulation) with an analog charge pump based fractional-N RF-PLL architecture. It furthermore features a shape generator with high flexibility to allow different ramp shapes and duration times. The loop requires a low noise reference clock with a nominal frequency of SYS\_CLK.

### 6.1 PLL interfaces and clock distribution

Figure 37 shows the interfaces to the *PLL* and the distribution of the internal system clock.

Supported are two different external oscillator input clock frequency ranges  $f_{OSC\_CLK}$  #1 and #2, which requires different settings of the PLL and the correct configuration of the clock input stages DC\_IN (see Clock input register). Each clock-input stage consists of multiplexers for path selection and a selectable frequency doubler. In addition to this, the clock input-stage for the system includes different correction and adjustment options used for the frequency doubling DC\_OUT (see Clock input register).

In case of  $f_{OSC\_CLK}$  #1 the register bits CLK\_IN:CLK\_SEL should be set to  $0_D$ , for  $f_{OSC\_CLK}$  #2 the register bits CLK\_SEL should be set to  $1_D$  in order to use only the clock frequency doubler (see section 4.26).

The frequency doubler correction and adjustment options are the following:

- CLK\_IN:CLK\_SEL =  $1_D$ : enables both frequency doublers without an input duty cycle adjustment.
- CLK\_IN:CLK\_SEL =  $2_D$ : enables frequency doubling with an input duty cycle adjustment via the bits CLK\_IN:DC\_IN\_ADJ. This adjustment is applied to the input clock. The corrected clock is then the input to both duty cycle dependent frequency doublers (PLL and system clock).
- CLK\_IN:CLK\_SEL =  $3_D$  enables the frequency doubling but only uses the input duty cycle correction for the frequency doubler that generates the system clock.

For the case the frequency doubler is used (CLK\_IN:CLK\_SEL  $\geq 1_D$ ) the duty cycle of the generated doubled clock can be modified with the bits CLK\_IN:DC\_OUT\_ADJ to a value close to 50%. This adjustment only applies to the system clock as the PLL only requires a minimum duty cycle for the reference clock, which is ensured by design.

### 6.2 Reference clock distribution

The external reference clock signal is provided via a short, low jitter path directly to the clock input port of the *PLL* analog part (PLL analog). Inside the PLL analog part the clock path is split and goes to two different clock input-stages. One stage is dedicated to the PLL and is under the internally regulated low noise supply of the PLL. The second input stage is used to provide the system clock through the *simplified timing shell (STS)* to the output of the PLL macro (osc\_clk2dig). The STS is a defined timing interface between the PLL analog and the digital part. Since osc\_clk2dig serves as the clock for the main *FSM* it must have an independent path to ensure availability even when the PLL is put into power down. Therefore the usage of supplies generated inside the PLL is avoided for this path. The main FSM clock can be gated via a dedicated register bit called PACR1:OSCCLKEN (see PLL analog control register 1) which gates the clock path already at its beginning.



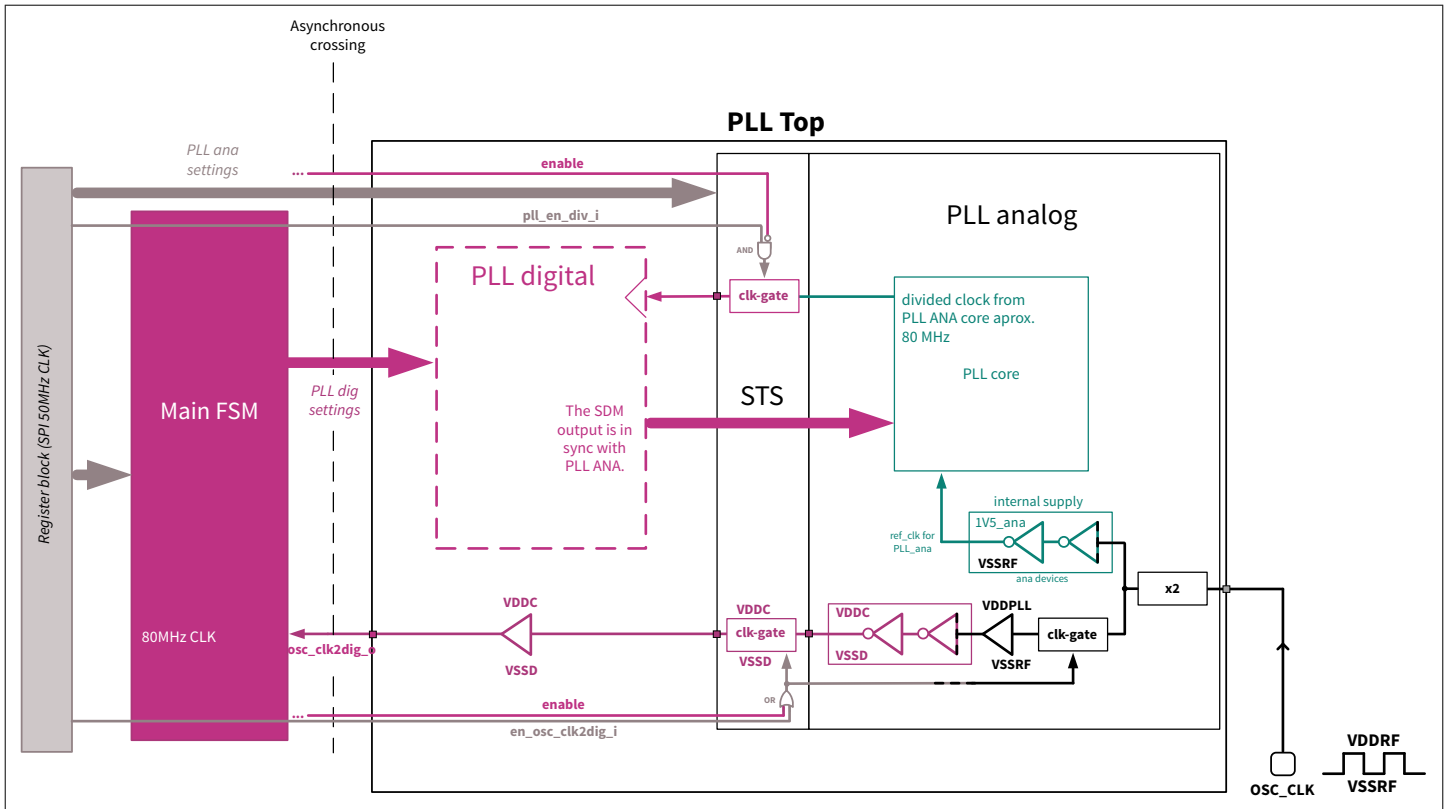


Figure 37 PLL and SYS\_CLK interface to the main FSM

### 6.2.1 Interfaces to the PLL

Most static settings and control signals dedicated to the analog part of the *PLL* are treated as asynchronous signals and are passed from the register bank to the *STS* of the *PLL*. This applies to digital signals that are not timing critical. Ramp generation parameters provided from the main *FSM* to the digital part of the *PLL* are registered inside the *PLL* digital. The start signal of the ramp also acts as a synchronization signal of the ramp parameters. This is required since the *PLL* digital runs on the divided clock of the *PLL* which ensures a known and synchronous timing relation between the sigma-delta bit stream and the analog part of the *PLL* that realizes the ramping behavior. The divided clock is only available if the *PLL* macro and the *voltage controlled oscillator (VCO)* are activated. Other control signals from *PLL* digital to the analog part are kept asynchronous. In order to close the *PLL* loop the analog part of the *PLL* core has interfaces to the *RF* macro where the *VCO* and a part of the divider chain are located.

### 6.3 PLL parameters and specification

The following table summarizes the target parameters of the *PLL* based frequency generator.

Table 30 PLL specifications

$VDD_{PLL} = 1.71$  to  $1.89$  V,  $VDD_{LF} = 2.5$  to  $3.63$  V,  $T_b = -20$  °C to  $+70$  °C.

Parameter	Symbol	Values			Unit	Condition
		Min.	Typ.	Max.		

#### PLL Chirp Parameters

Output Frequency Range	$f_{RF}$	57.4	-	63.0	GHz	Range depends on the $VDD_{LF}$ value
Continuous FM-Chirp Bandwidth	$BW$	0	-	5.6	GHz	PLL tuning range

(table continues...)

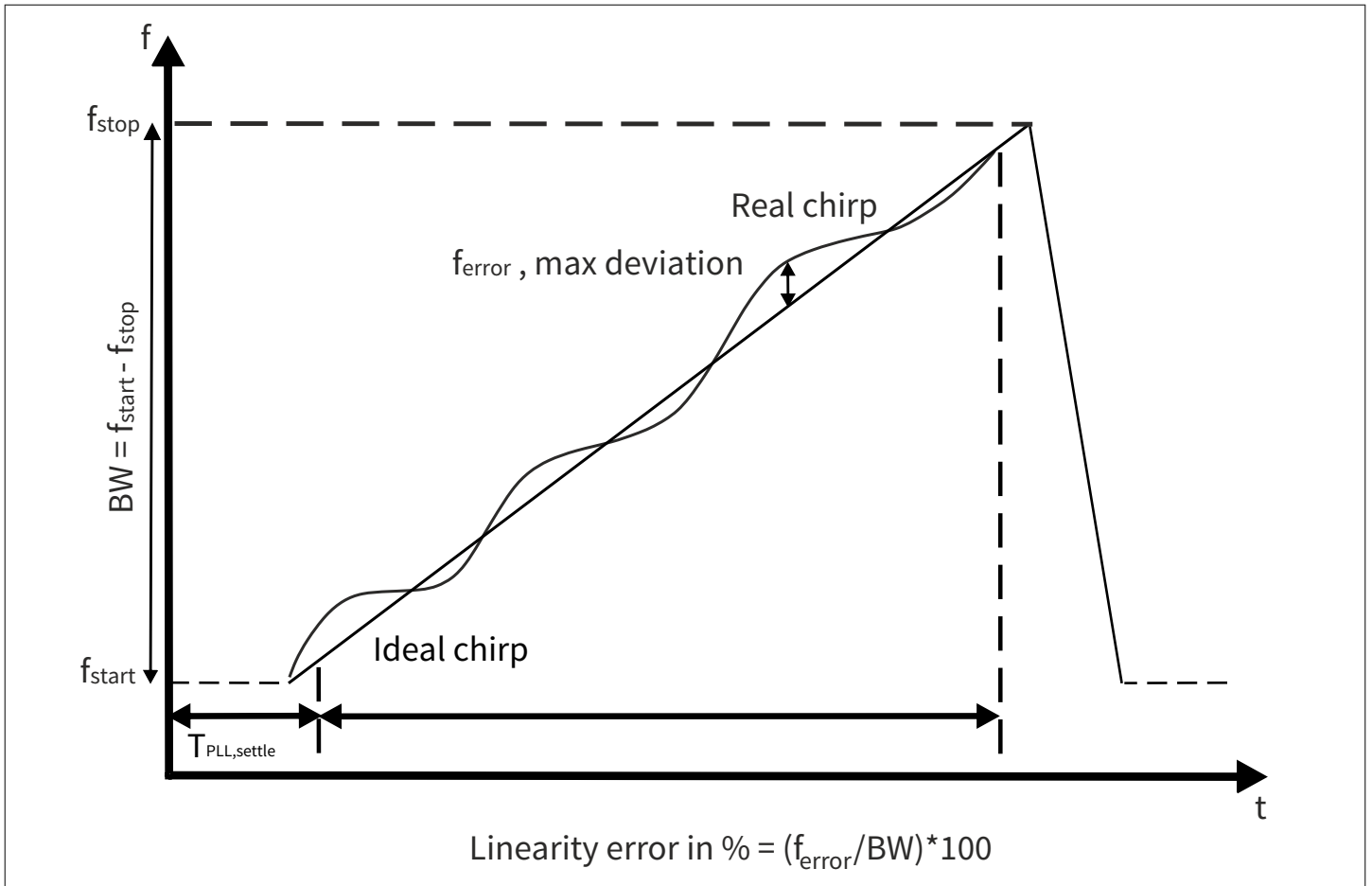
**Table 30 (continued) PLL specifications**

$VDD_{PLL} = 1.71$  to  $1.89$  V,  $VDD_{LF} = 2.5$  to  $3.63$  V,  $T_b = -20$  °C to  $+70$  °C.

Parameter	Symbol	Values			Unit	Condition
		Min.	Typ.	Max.		
$VDD_{LF}$ Range	$VDD_{LF}$	2.5	-	3.63	V	Complete specified <i>BW</i> requires at least $VDD_{LF} = 3.3$ V
Chirp slope	Slope	-	-	400	MHz/ $\mu$ s	-
Frequency Ramp Linearity Error	Error	-	-	1	%	For 2 GHz <i>BW</i> minimum See <a href="#">Figure 38</a>
Frequency Ramp Settling Time (fast chirp feature active)	$t_{PLL, settle}$	-	5	-	$\mu$ s	See <a href="#">Figure 39</a>
PLL Phase Noise Single Sideband	$PN_{PLL}, 100$ kHz	-	-80	-75	dBc/Hz	at 100 kHz offset

### 6.3.1 Frequency ramp linearity definition:

Frequency ramp linearity error is defined to be < 1% of the *frequency-modulated (FM)* chirp bandwidth. The linearity error is calculated as the deviation from an “ideal” frequency ramp. The specification needs to be fulfilled after the frequency ramp settling time (see also [Chapter 3.3](#)). The assumed worst case FM chirp bandwidth for linearity evaluations is 2 GHz.

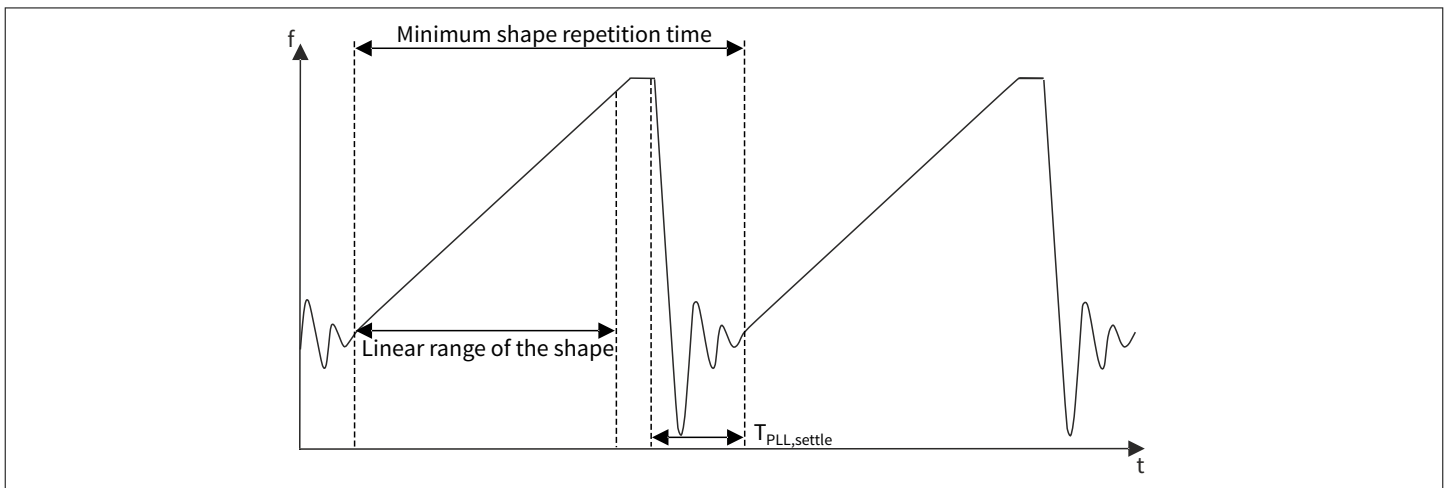


**Figure 38** Frequency linearity definition

The max frequency error expected, assuming 2 GHz minimum *BW* and a max deviation of 1%, will be 20 MHz.

### 6.3.2 Frequency ramp settling time

It is the time required by the *PLL* to damp undershoot and overshoot in case of saw-tooth shapes. A qualitative view is shown in the following figure. See [Chapter 3.3](#) for a more detailed definition of the timings.

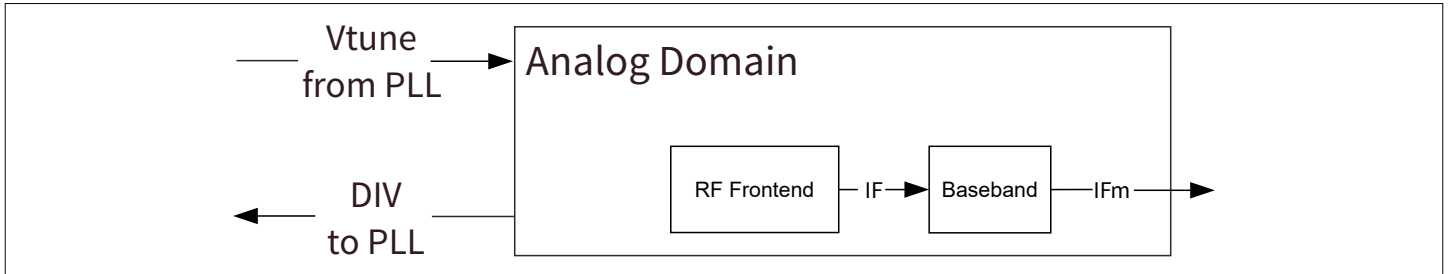


**Figure 39** Chirp settling time

## 7 Analog-RF domain functional specification

In the analog functional specification all analog components like *RF* frontend (RF FE), baseband amplifiers, and filters are described in more details.

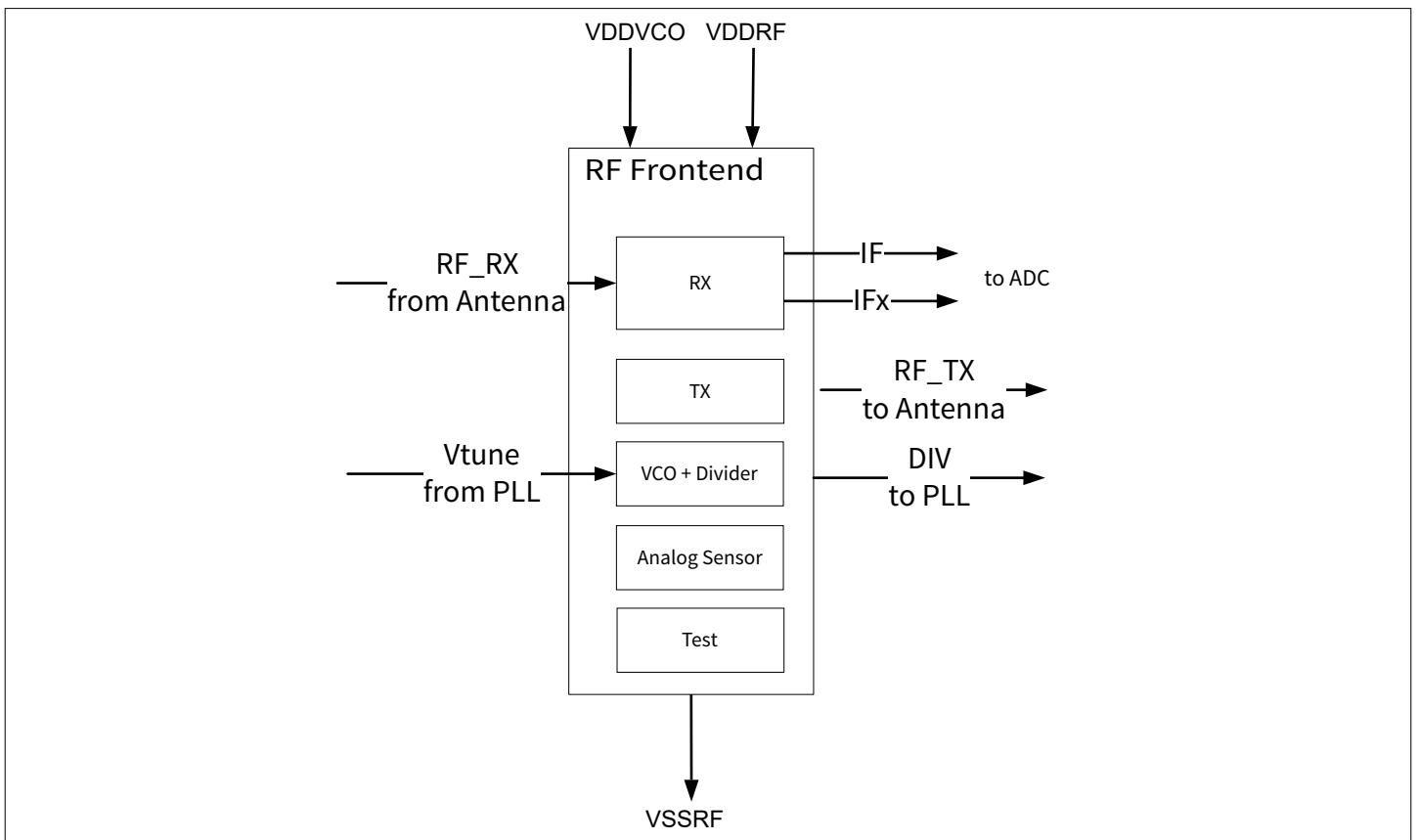
The register definitions for the components are in [Channel set up x register 0](#).



**Figure 40** Analog domain simplified block diagram

### 7.1 RF frontend (RF FE)

In the *RF* frontend, all features to enable the radar functionality are implemented.



**Figure 41** Simplified block diagram of transceiver frontend

#### 7.1.1 On-chip analog sensor output

The analog sensor outputs are connected to the SADC. See for the SADC input configuration. See [Channel set up x register 0](#) for enable pins definition.

## 7.1.2 RF FE specifications

In the table below the target specifications for the RF frontend measured at die PAD interface.

**Table 31 RF FE specifications**

Min and max values cover the specified frequency range,  $f_{RF} = 57.4$  GHz to 63.0 GHz. Temperature range,  $T_b = -20$  °C to +70 °C, and voltage supply range,  $VDD_{RF} = 1.71$  V to 1.89 V (unless otherwise specified).

Parameter	Symbol	Values			Unit	Condition
		Min.	Typ.	Max.		
Frequency Range	$f_{RF}$	57.4	-	63.0	GHz	-

### Transmitter

Transmit Output Power <sup>1)</sup>	$P_{TX}$	-	5.0	-	dBm	Conducted power
Output Power Variation over Temperature	$P_{TX\_Temp}$	-2.0	-	2.0	dB	For TX DAC set to 31 <sub>D</sub>
Transmitter Power Control Dynamic Range	$P_{TXD}$	-	15	-	dB	-
DAC Resolution Transmitter Power Control	$P_{TXC}$	-	5	-	Bits	-

### Receiver (for all RX channels)

Receiver Conversion Gain <sup>2)</sup>	$CG_{RX}$	12	14	16	dB	-
Conversion Gain Variation Over Temperature	$CG_{RX\_Temp}$	-3	-	3	dB	Including the complete baseband chain
Receiver Single Sideband Noise Figure	$NF_{SSB_{RX}}$	-	12	14	dB	at 100 kHz offset
Receiver 1-dB Compression Point	$P_{-1dB_{RX}}$	-10	-5	-	dBm	-
LO feedthrough at the RX port	$LO_{feed_{RX}}$	-	-30	-	dBm	-
TX-to-RX Isolation	$ISO_{TXRX}$	-	50	-	dB	-

### Sensors

Temperature Sensor Range <sup>3)</sup>	$T_b$	-40	-	105	°C	-
Chip Backside Temperature ( $Temp$ ) Vs Temperature Sensor Readout ( $Tsense$ ) Relation	$Temp$ $Tsense$	$Temp = \frac{Tsense - a}{b}$			°C V	-
Temperature Sensor Offset (a)	$a$	-0.19025	-0.17530	-0.15925	V	-
Temperature Sensor Slope (b)	$b$	-	0.001530	-	V/K	-

(table continues...)

**Table 31 (continued) RF FE specifications**

Min and max values cover the specified frequency range,  $f_{RF} = 57.4 \text{ GHz}$  to  $63.0 \text{ GHz}$ . Temperature range,  $T_b = -20 \text{ }^\circ\text{C}$  to  $+70 \text{ }^\circ\text{C}$ , and voltage supply range,  $VDD_{RF} = 1.71 \text{ V}$  to  $1.89 \text{ V}$  (unless otherwise specified).

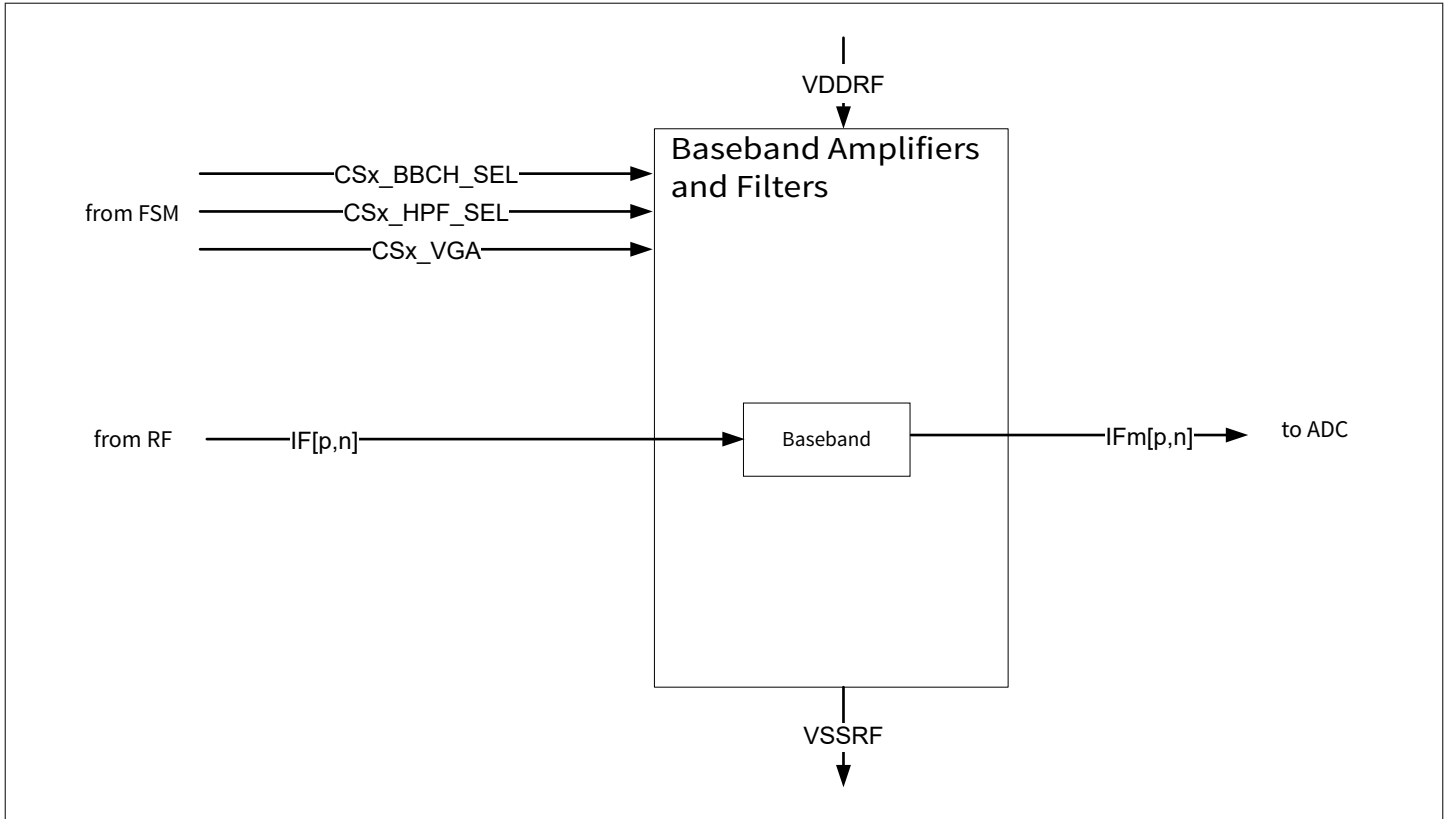
Parameter	Symbol	Values			Unit	Condition
		Min.	Typ.	Max.		
Output Power at Chip Pad Vs TX Peak Detector Readout Relation	$P_{out}$ $PPD\_PA^4)$	$P_{out} = t_1 * \ln\left(\frac{PPD\_PA + y_0}{A_1}\right)$ $y_0 = 0.02933 \text{ V}$ $A_1 = 0.19253 \text{ V}$ $t_1 = 8.912 \text{ dBm}$			dBm V	$PPD\_PA$ selected
TX Peak Detector Accuracy	$PPD\_PA_{acc}$	-2	-	2	dB	Over $f_{RF}$
TX Peak Detector Dynamic Range	$PPD\_PA_{DR}$	-10	-	10	dBm	Min. 8 bits

- 1) At die pad.
- 2) Power to voltage gain.
- 3) If storage temperature exceeds  $125^\circ \text{C}$  an additional drift of the temperature sensor readout up to  $\pm 10 \text{ K}$  might occur.
- 4) Output power can be evaluated by sampling the level of the peak detector level at the output of the TX power amplifier. This signal has to be compared to a reference to de-embed thermal drift of the sensor.

*Note: The spurs of the system clock signal could affect the sensor readout. In order to have a more stable read out for the sensors an average over 16 samples for each sensor measurement is recommended.*

## 7.2 Analog baseband: amplifiers and filters

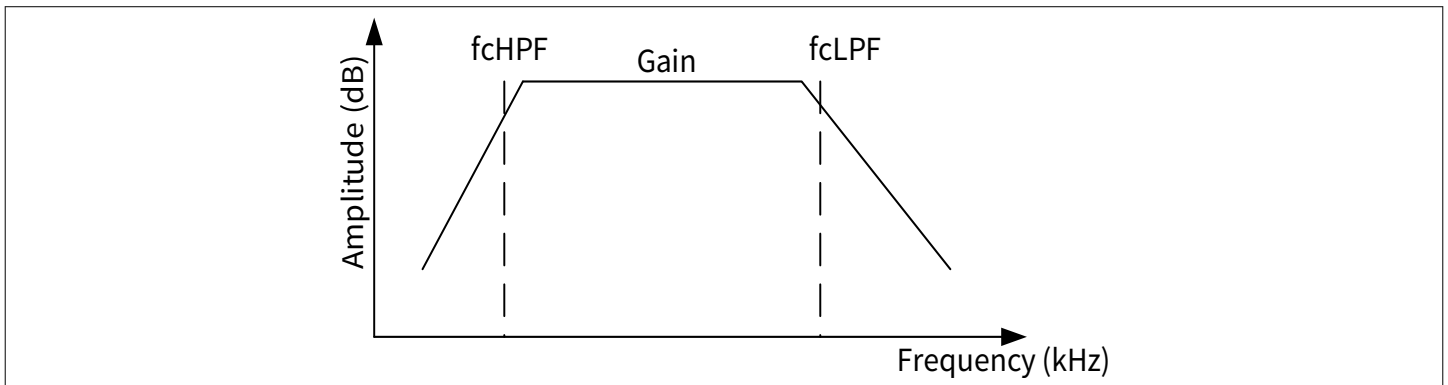
The baseband amplifiers and filters adjusts the *IF* signals to fulfill the system requirements. They set the signal levels to drive full scale the *ADC* inputs without clipping.



**Figure 42** Baseband amplifiers and filters block diagram

### 7.2.1 Baseband characteristics

The baseband block consists of 1 channels. Each channel consists of a *HPF*, a *VGA*, and *AAF* plus a driver for the *ADC* (see [Figure 44](#)).



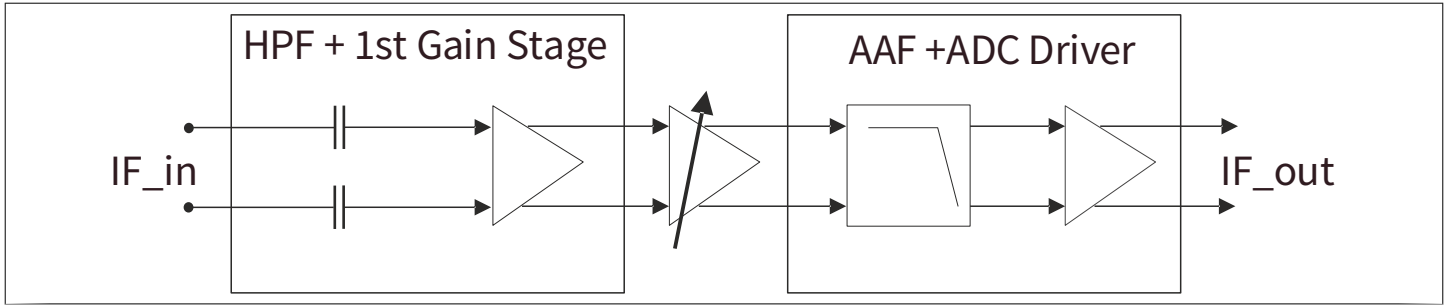
**Figure 43** Baseband characteristics

The *HPF* is used in order to remove the *DC* offset at the output of the *RX* mixer and also suppress the reflected signal from close in unwanted targets (radome, e.g.).

### 7.2.2 Baseband requirements

The *HPF* can be tuned to accommodate different *fcHPF* according to different modulation parameters. As presented in the following table, four different settings are possible.

Given the expected power levels the radar system will deal with, the *HPF* should not degrade the linearity of the system.



**Figure 44** Baseband simplified block diagram, one for each channel

After the *alternating current (AC)* coupling, the *IF* signals are amplified by the first amplifier stage. The first stage shows a selectable voltage gain of 18 or 30 dB. The gain can be adjusted in the *VGA* in 6 steps of 5 dB each up to a maximum gain of 30 dB. The *VGA* is followed by two stages, four poles *AAF*.

The *AAF* cutoff can be set to either 600 kHz or 1 MHz. The signal is then applied to an *ADC* driver amplifier, which has a gain of 1. The *ADC* driver shows a cut-off behavior above 1 MHz.

Overall the baseband chain can be set to a maximum gain of 60 dB.

The specific parameters of the baseband chain are summarized in the following tables.

**Table 32** High pass filter selection

$VDD_{RF} = 1.71\text{ V to }1.89\text{ V}$ ,  $T_b = -20\text{ }^\circ\text{C to }+70\text{ }^\circ\text{C}$

Parameter	Value			Unit	Description
	Min.	Typ.	Max.		
Fc_HPF_0	-	20	-	kHz	HPF 3 dB cutoff frequency
Fc_HPF_1	-	40	-	kHz	HPF 3 dB cutoff frequency
Fc_HPF_2	-	80	-	kHz	HPF 3 dB cutoff frequency
Fc_HPF_3	-	140	-	kHz	HPF 3 dB cutoff frequency
Fc_HPF_4	-	160	-	kHz	HPF 3 dB cutoff frequency

**Table 33** Baseband gain stages

$VDD_{RF} = 1.71\text{ V to }1.89\text{ V}$ ,  $T_b = -20\text{ }^\circ\text{C to }+70\text{ }^\circ\text{C}$ .

Parameter	Value			Unit	Description
	Min.	Typ.	Max.		
1 <sup>st</sup> Gain Stage	-	18/30	-	dB	Selectable, by design
VGA	-	30	-	dB	6 steps
VGA Step Size	4	5	6	dB	-

**Table 34** Anti aliasing filter specification

$VDD_{RF} = 1.71\text{ V to }1.89\text{ V}$ ,  $T_b = -20\text{ }^\circ\text{C to }+70\text{ }^\circ\text{C}$ .

Parameter	Value			Unit	Description
	Min.	Typ.	Max.		
fcLPF1	450	500	650	kHz	3 dB cutoff frequency
fcLPF2	-	1000	-	kHz	3 dB cutoff frequency

(table continues...)



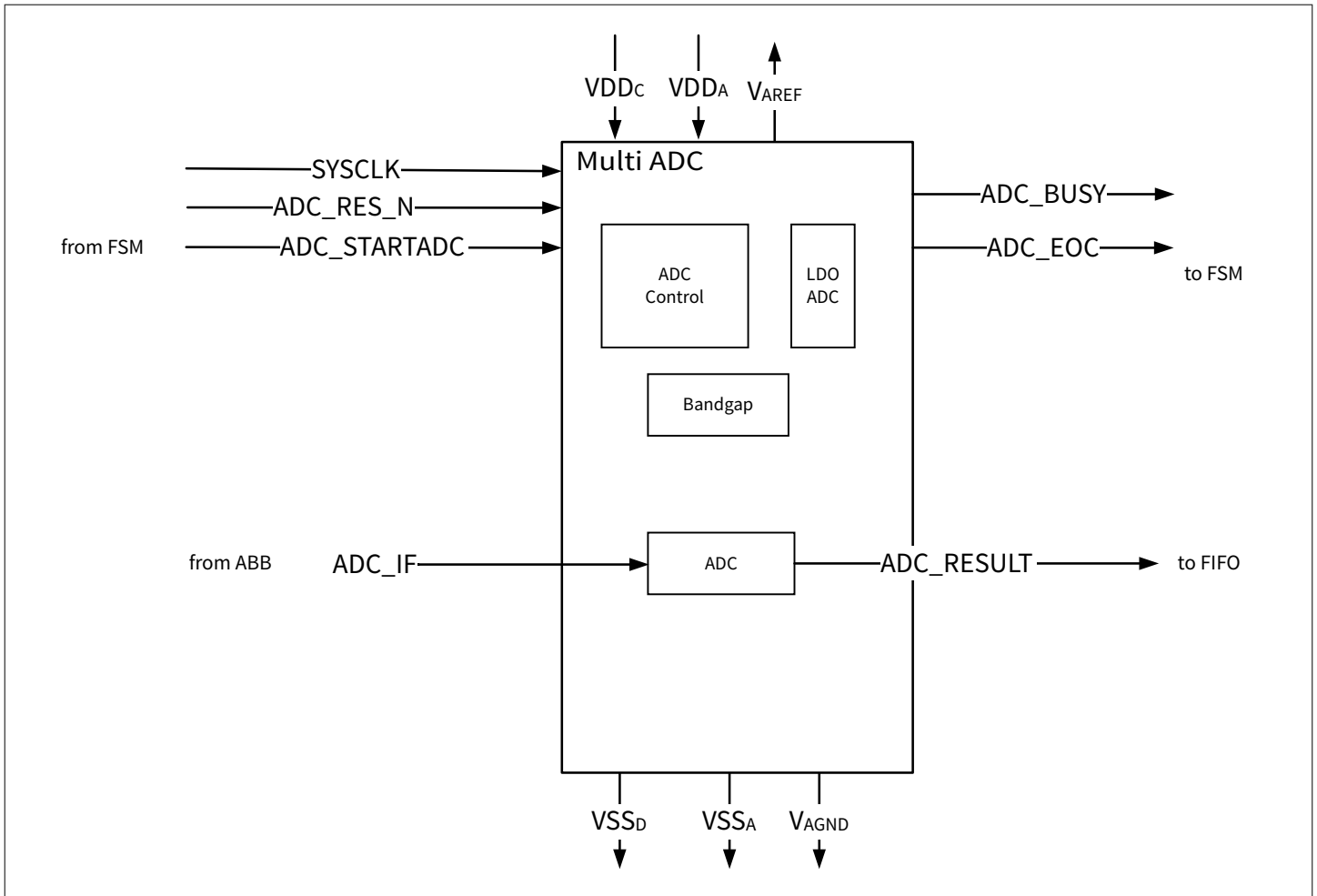
**Table 34** (continued) Anti aliasing filter specification

$VDD_{RF} = 1.71\text{ V to }1.89\text{ V}$ ,  $T_b = -20\text{ °C to }+70\text{ °C}$ .

Parameter	Value			Unit	Description
	Min.	Typ.	Max.		
LPF_Order	-	2 <sup>nd</sup>	-	-	Four poles, by design
LPF_Flatness	-	1	-	dB	In band flatness, ensured by design

## 8 MADC domain functional specification

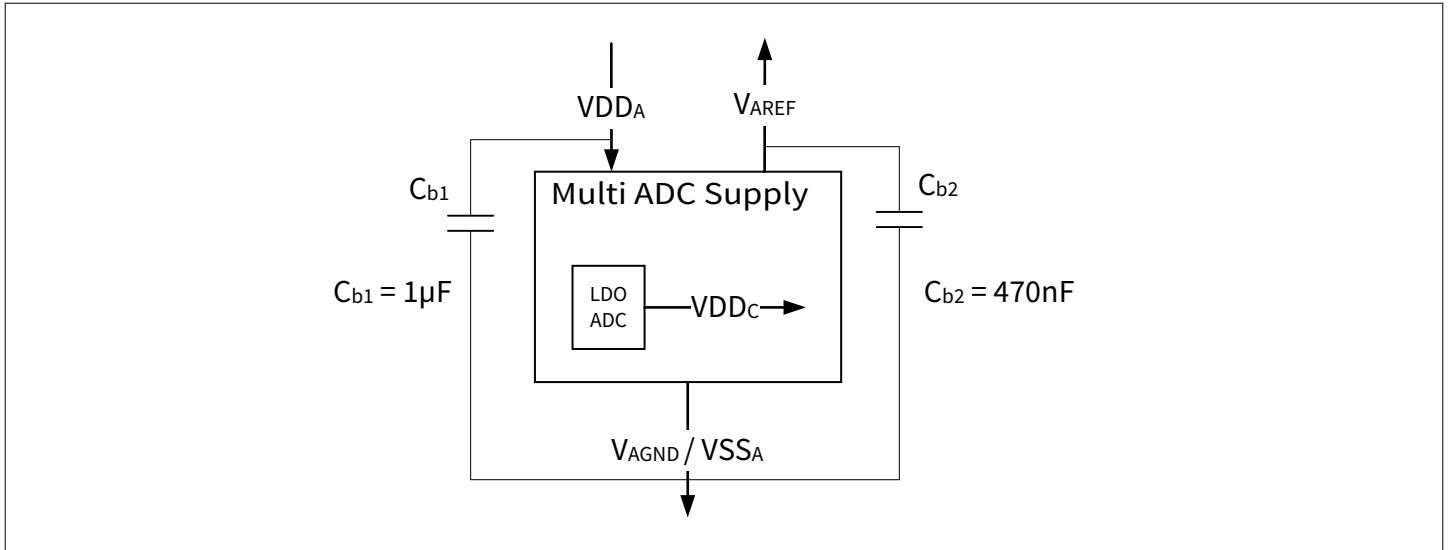
The multichannel *ADC* (MADC) block consists of 1 differential *successive approximation register (SAR)* ADC. The ADC captures the differential *IF* output signals from the *ABB* and convert it into a digital representation of the same. The 1.5 V supply ( $V_{DDC}$ ) is internally generated by a dedicated *LDO* (see [Figure 5](#)). For the ADC the parameters are set in [ADC control register](#). Each channel of the MADC can be enable/disable together with the respective baseband channel by the bits `MADC_BBCH_EN` in [Channel set up x register 1](#). To simplify the dataflow to the channel can be selected via the `BBCH_SEL` in [Channel set up x register 1](#). See also `APU` and `APD` in [PLL shape x register 3](#) and [Chapter 5.2](#).



**Figure 45** MADC block diagram

### 8.1 MADC supply voltage requirements

The voltage supply to the *ADC* domain is provided on pin  $V_{DDA}$  and the output of the internal ADC reference voltage is provided on pin  $V_{AREF}$ . In order to filter out the voltage ripples due to switching effects a low *equivalent series resistance (ESR)* bypass capacitor of  $C_{b2} = 470$  nF should be used on the *printed circuit board (PCB)*.



**Figure 46** MADC input pin requirements

$V_{AGND}$  shares the same analog ground connection pin  $VSS_A$  on PCB. The bypass capacitors should be mounted as close as possible to that pin.

**Table 35** MADC voltage reference

$VDD_A = 1.71\text{ V to }1.89\text{ V}$ ,  $T_b = -20\text{ °C to }+70\text{ °C}$ .

Parameter	Symbol	Values			Unit	Condition
		Min.	Typ.	Max.		
Positive reference voltage with respect to $V_{AGND}$ , generated internally	$V_{AREF}$	1.10	1.21	1.29	V	-
Negative analog reference voltage	$VSS_A$	-0.1	0	-	V	Refers to board design ground plane

## 8.2 MADC specifications

The following table specifies the [ADC](#) parameters. The numbers include one over-conversion. All parameters are only valid with executed start-up calibration. No parameter is targeted for production test.

Note:  $f_{ADC\_CLK} = f_{SYS\_CLK}$

**REMARK:**

If the ADC starts sampling before the bandgap is powered up (BG\_EN in [Channel set control x register](#)), the results will show some gain errors. To avoid this, follow the bandgap power up timing presented in section [Chapter 8.4](#).

**Table 36 MADC specifications**

$V_{DDA} = 1.71 \text{ V to } 1.89 \text{ V}$ ,  $T_b = -20 \text{ }^\circ\text{C to } +70 \text{ }^\circ\text{C}$ .

Parameter	Symbol	Value			Unit	Condition
		Min.	Typ.	Max.		
Resolution	Resolution	-	12	-	-	With default settings and tracking conversion <a href="#">Table 39</a>
Analog input voltage	$V_A$	0.145	-	1.455	V	-
ADC Clock Frequency	$f_{ADC\_CLK}$	75	80	85	MHz	$f_{ADC\_CLK} = f_{SYS\_CLK}$ See <a href="#">Chapter 2.2</a> 78 MHz not allowed
Signal to noise ratio	$SNR$	55	64	-	dB	@ -6 dB FS
Spurious free dynamic range	$SFDR$	58	69	-	dB	@ -6 dB FS @ 600 kHz
Inter modulation product	$IM3$	-62	-69	-	dB FS	@ -12 dB FS each input tone @ 600 kHz max $f$ @ 50 kHz $\Delta f$
Bandwidth input buffer	$BW$	600	-	-	kHz	1 <sup>st</sup> order Filter in input Buffer
Conversion time – excluding sample time	$N_{conv}$	-	24	-	Counts of clk	Including one tracking conversion, sampling time not included
Sampling time	$T_s$	4	-	-	Counts of clk	@ 76.8/80 MHz
Wake up time – bandgap and BG reference Buffer	$T_{WUBGB}$	300	600	1000	us	-
Wake up time – ADC <sup>1)</sup>	$T_{WUADC}$	-	660	-	Counts of clk	without start-up calibration
Startup calibration time <sup>2)</sup>	$T_{SUCAL}$	3361	6049	16801	Counts of clk	ADC0:DSCAL= 0 <sub>B</sub> Typical conditions: ADC0:STC=1 <sub>B</sub> ADC0:MSB_CTRL= 1 <sub>B</sub>
Setup time common mode input voltage	$T_{VCM}$	-	-	1	μs	-
Power supply Rejection Ration on $V_{DD_S}$	$PSRR$	20	-	-	dB	-

1) Overall wake up time when calibration time is enabled =  $T_{WUADC} + T_{SUCAL}$ .

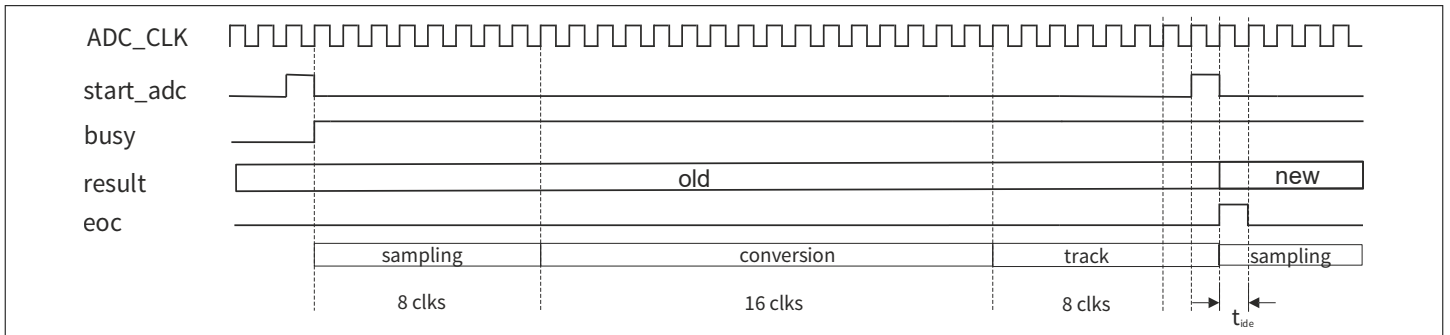
2)  $T_{SUCAL} = (1792 * 2^{ADC0:STC} + 896 * ADC0:MSB\_CTRL + 1569) * T_{SYS\_CLK}$ .

Parameters ensured by design

### 8.3 MADC timing diagrams

The interface is fully synchronized to the main clock. The following figure shows the 12 bits conversion timing in case of one tracking and no oversampling. Thus, the maximum speed of the *ADC* is set to 2.5 MSps at 80 MHz clock input. [Figure 47](#) shows the *SAR* ADC timing.

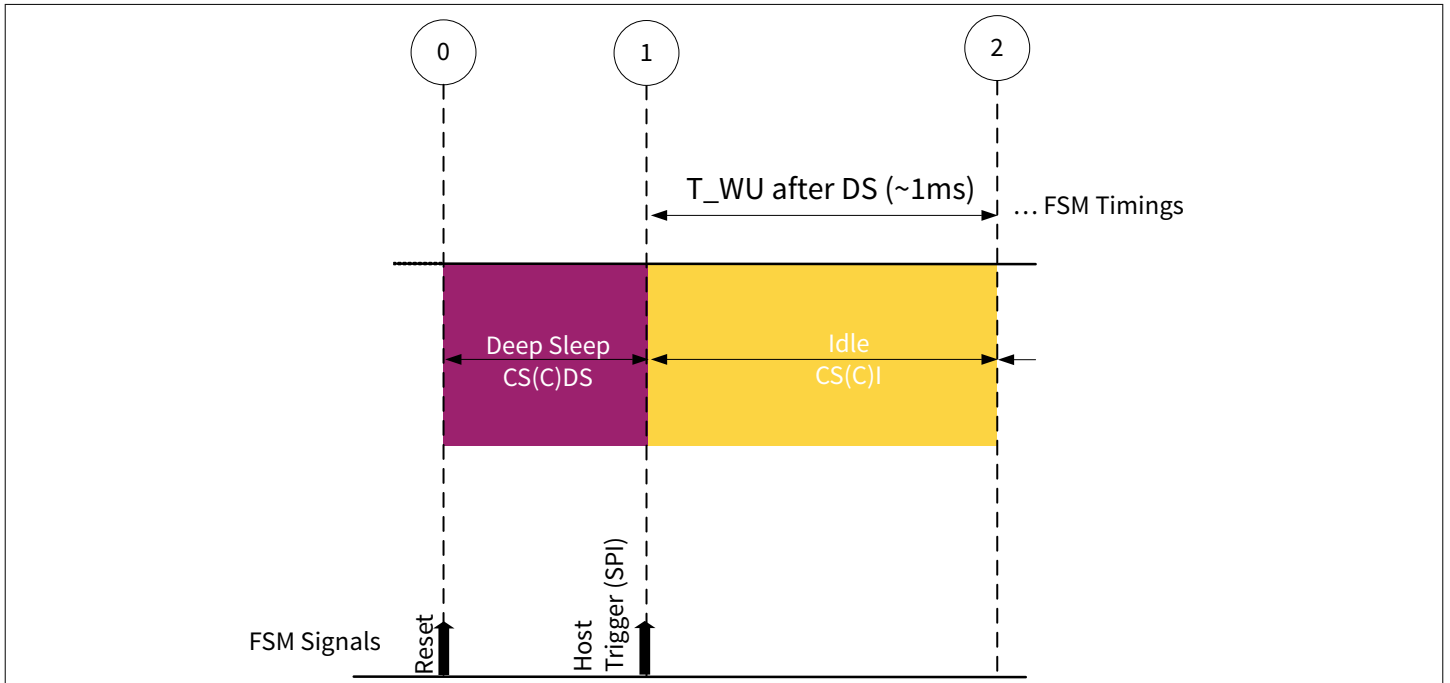
**Important:** All configuration signals must be stable during a running conversion (between start\_adc and one cycle before eoc).



**Figure 47 SAR ADC conversion timing diagram**

### 8.4 MADC start-up sequence

The following figure shows the start-up sequence for the complete *ADC*.



**Figure 48 MADC start-up timing constraints**

After a reset and trigger from the host, the *FSM* will move from the DS power mode into the Idle power mode. Here  $T_{WKUP}$  represents the overall time required by the bandgap to settle and it is the longest time required in the settling of the *ADC*.

**Table 37 MADC start-up timing constraints**

$V_{DDA} = 1.71 \text{ V to } 1.89 \text{ V}$ ,  $T_b = -20 \text{ }^\circ\text{C to } +70 \text{ }^\circ\text{C}$ .

Parameter	Symbol	Values			Unit	Condition
		Min.	Typ.	Max.		
Wake up time	$T_{WUADC}$	8.25			$\mu\text{s}$	@ $f_{\text{SYS\_CLK}}$
Setup time common mode input voltage	$T_{VCM}$			1	$\mu\text{s}$	
Wake-up time for bandgap and bandgap reference buffer	$T_{WU}$	300		1000	$\mu\text{s}$	

## 8.5 MADC conversion rate

The **ADC** clock input is  $f_{\text{ADC\_CLK}} = f_{\text{SYS\_CLK}} = 76.8/80 \text{ MHz}$  and is derived from the system clock.

A conversion can include three different phases:

- Sampling
- Conversion
- Tracking

### 8.5.1 Sampling

During the first phase, the analog input voltage is sampled onto the input capacitor. The duration is controlled using the ADC0:STC bits (see ADC control register). The following table shows the link between the register value ADC0:STC the clock periods STC\_NUM and the sampling time.

**Table 38 ADC0:STC value table**

ADC0:STC	Sampling clock periods STC_NUM	Sampling time $t_{\text{sample}}$ in ns ( $f_{\text{ADC\_CLK}} = 80 \text{ MHz}$ )
$0_D$	4	50
$1_D$	8	100
$2_D$	16	200
$3_D$	32	400

The sampling time is calculated as:  $N_{\text{sample}} = \text{STC\_NUM}$ .

### 8.5.2 Conversion

The charge from the sampling capacitor is redistributed to 13 + 2 capacitors. To identify the *least significant bit (LSB)* bits of the result, 13 clock cycles are needed.

To identify the *MSB* bit of the result, one or two clock cycles are used, depending on register setting ADC0:MSB\_CTRL (see ADC control register):

- In case of MSB\_CTRL is set to  $0_B$ , just a single (1) clock cycle is used
- In case of MSB\_CTRL is set to  $1_B$ , two (2) clock cycles are used

The redistribution time is calculated as:  $N_{\text{conv}} = (13 + 2 + \text{ADC0:MSB\_CTRL})$ .

### 8.5.3 Tracking

In this mode, the *ADC* performs a single sample conversion followed by several tracking conversions, depending on the setting of bits *ADC0:TRACK\_CFG* (see *ADC control register*).

**Table 39** *ADC0:TRACK\_CFG* value

<i>ADC0:TRACK_CFG</i>	Additional conversions <i>TRACK_CFG_NUM</i>	Remarks
0 <sub>D</sub>	0	
1 <sub>D</sub>	1	Default
2 <sub>D</sub>	3	
3 <sub>D</sub>	7	

The duration of one tracking conversion is:  $N_{\text{track}} = 8$ .

The duration of all tracking conversions for a single result is:  $N_{\text{track\_all}} = 8 * \text{TRACK\_CFG\_NUM}$ .

### 8.5.4 ADC conversion rate

Based on what is defined in [Chapter 8.5.1](#), [Chapter 8.5.2](#), and [Chapter 8.5.3](#), the following cycles are defined for a single conversion:

$$N_{\text{ADC\_CONV}} = N_{\text{samp}} + N_{\text{conv}} + N_{\text{track\_all}} \quad (20)$$

with  $N_{\text{samp}}$  the number of sampling,  $N_{\text{conv}}$  conversion and  $N_{\text{track}}$  tracking cycles, respectively.

*ADC* are synchronized to  $f_{\text{SYS\_CLK}}$ .

### 8.5.5 ADC sampling rate

The *ADC* sampling rate is controlled by the *ADC0:ADC\_DIV* value (see [ADC control register](#)). The sampling rate of the *ADC* is given then by  $f_{\text{ADC\_SAMP}} = f_{\text{ADC\_CLK}} / \text{ADC\_DIV}$ . The *ADC0:ADC\_DIV* value needs to be greater than the number of clock cycles needed by a single *ADC* conversion as described in [Chapter 8.5.4](#).

The sampling rate of the *ADC* is:

$$f_{\text{ADC\_SAMP}} = f_{\text{ADC\_CLK}} / \text{ADC\_DIV} \quad (21)$$

with  $\text{ADC\_DIV} > N_{\text{ADC\_CONV}}$ .

**Table 40** *ADC Sampling Rate*

$V_{\text{DDA}} = 1.71 \text{ V to } 1.89 \text{ V}$ ,  $T_{\text{b}} = -20 \text{ }^\circ\text{C to } +70 \text{ }^\circ\text{C}$ .

Parameter	Symbol	Values			Unit	Condition
		Min.	Typ.	Max.		
ADC sampling rate	$f_{\text{ADC\_SAMP}}$	-	2	4	MHz	-
Effective number of bits resolution	<i>ENOB</i>	-	10.5	-	Bit	-

## 9 On chip analog sensor

To measure RF power of TX output and temperature of BGT60UTR11AIP, the chip provides additional sensors. For this the input of the on chip ADC is switched between RX front-end, power sensor and temperature sensor. The conversion time depends on the settings of the ADC programmed in ADC0 register.

During normal operation the switching is done by the FSM without any interaction with the application processor or microcontroller. However, the correct timing and the correct settings must be ensured by the user. Each sensor can be enabled or disabled by programming the corresponding bit fields e.g. CSUx\_0:PD\_EN for power sensor and e.g. CSDx\_0:TEMP\_MEAS\_EN for temperature sensor.

There is also the option to trigger and read out the on-chip sensors manually when no frame is active. For this the CW mode (see [CW mode](#)) can be activated, the required sensor be selected and a conversion be triggered.

### 9.1 Power sensor

To measure the RF power of TX output in the up chirp the following must be ensured (see #6).

1. CSUx\_0:PD\_EN = 1<sub>B</sub>
2. T\_PAEN + T\_PSSTART  $\geq$  1  $\mu$ s (switching time)
3. T\_PSSTART  $\geq$  0.5  $\mu$ s (PA settling time)
4. T\_SSTART  $\geq$  T\_PSSTART + 1  $\mu$ s + T\_CONV (ADC conversion time)

After the conversion, the result is stored in the register [Sensor ADC result register](#).

**Anomaly:** In some remote cases, due to a timing violation, the power sensor readout may show a 0<sub>D</sub> value. 0<sub>D</sub> is not a valid value.

**Workaround:** In that case the sensor result readout should be repeated. Up to 5 times readouts should avoid a wrong value.

### 9.2 Temperature sensor

To measure the temperature in the up chirp (sawtooth shape) or in the down chirp (triangular shape) following must be ensured.

Triangular shape (see #17)

1. CSDx\_0:TEMP\_MEAS\_EN = 1<sub>B</sub>
2. T\_START + T\_RAMP + T\_END  $\geq$  T\_PAEN + T\_SSTART + T\_ACQx + 1  $\mu$ s
3. T\_EDDMIN  $\geq$  T\_CONV<sup>1)</sup>

After the conversion, the result is stored in the register [Sensor ADC result register](#).

**Anomaly:** In some remote cases, due to a timing violation, the temperature sensor readout may show a 0<sub>D</sub> value. 0<sub>D</sub> is not a valid value.

**Workaround:** In that case the sensor result readout should be repeated. Up to 5 times readouts should avoid a wrong value.

### 9.3 Manual sensor conversion

To measure the temperature or the RF power manually at any time outside of an active frame, the [CW mode](#)) can be used. For this the temperature sensor or power sensor must be enabled and the chip in a corresponding state. While the temperature can be measured in any [finite state machine](#) state the RX power can only be measured when the power amplifier is active. For this exact six (TRIG#6) FRAME\_START trigger needs to be programmed to get the [finite state machine](#) to the state where the PA is active.

<sup>1)</sup> T\_CONV : conversion time of ADC depends on the ADC setting



After the required sensor is selected via ADC1:SENSOR\_SEL and triggered with ADC0:TRIG\_MADC the sensor result can be read from the SENSOR\_RESULT register. If the result is equal to the value 0<sub>D</sub>, the sensor measurement procedure must be repeated again as only values different to 0<sub>D</sub> are valid results.

A repeated measurement can be performed directly after a sensor reading of SENSOR\_RESULT = 0<sub>D</sub> by first toggling bit field ADC1:SENSOR\_SEL to 0<sub>D</sub> and back to the desired ADC channel (1<sub>D</sub> ... Power sensor, 2<sub>D</sub> ... Temperature sensor) followed by a manual ADC trigger via ADC1:TRIG\_MADC.

## 10 Enhanced functions

### 10.1 CHIP ID readout

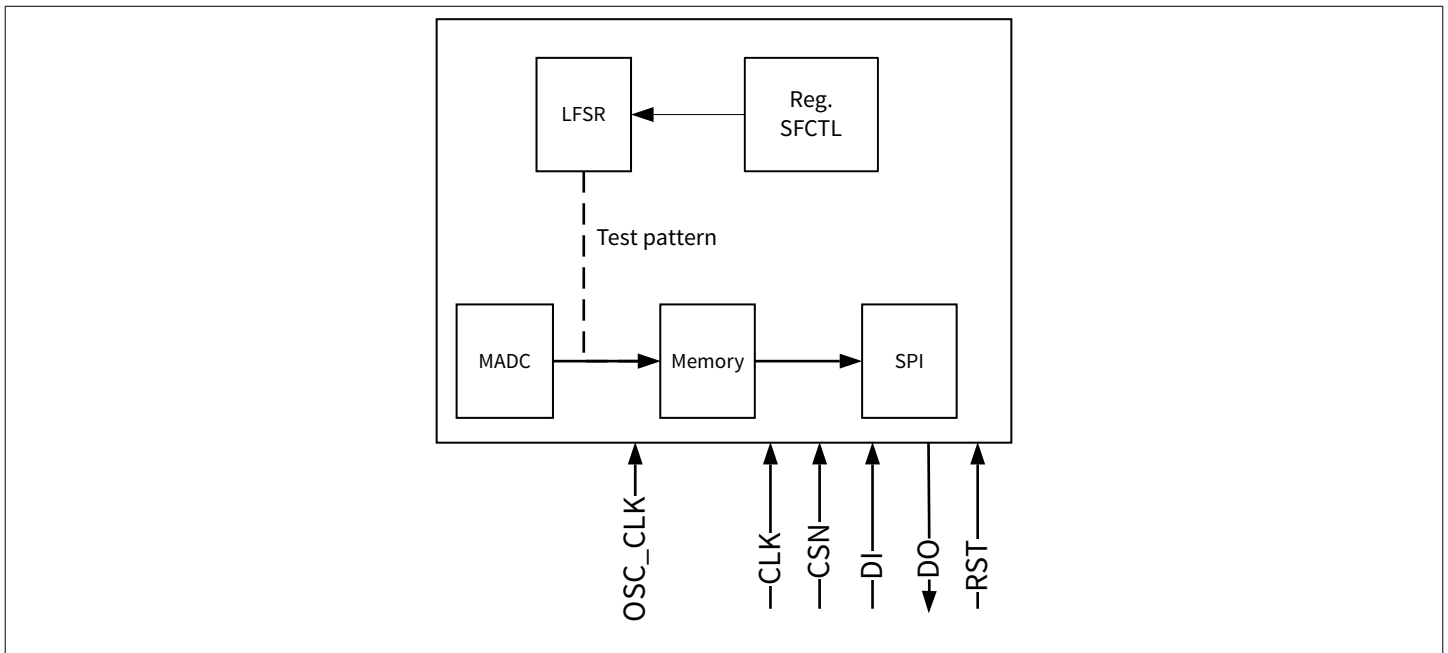
Readout sequence:

1. Enable the EFUSE block by setting EFUSE0:EFUSE\_EN = 1<sub>B</sub> with a single dedicated *SPI* write (see [EFUSE register 0](#))
2. Initiate the sense operation by setting EFUSE0:EFUSE\_SENSE = 1<sub>B</sub> with a single dedicated *SPI* write
3. Wait for 2 μs or poll the register field EFUSE1:EFUSE\_READY = 1<sub>B</sub> (see [EFUSE register 1](#))
4. Read out the device ID from CHIP\_ID1 and CHIP\_ID2 (see [Chip ID register 1](#) and )
5. Disable the EFUSE block EFUSE0:EFUSE\_EN = 0<sub>BHD</sub>

### 10.2 Data test mode

A *LFSR* is built-in on chip. It will generate a pseudo random bit M-sequence that can be used to fill up the *FIFO*. This module can be used to develop and test the complete pipeline from the *FIFO* on the BGT60UTR11AIP up to the *AP* memory, including firmware and drivers, with a defined bit sequence.

The implemented LFSR is described by the following polynomial:  $x^{12}+x^{11}+x^{10}+x^4+1$ .



**Figure 49** Digital pipeline simplified block diagram

The first *ADC* channel output data stream is bypassed by the data sequence coming from the LFSR generator. The other channels can be disabled or used in normal operation.

- This test mode can be started with bit SFCTL:LFSR\_EN = 1<sub>B</sub> (see [SPI and FIFO control register](#))
- Activate test data instead of ADC data
- Initialization with MAIN:FSM\_RESET = 1<sub>B</sub>

### 10.3 CW mode

In the *continuous wave (CW)* mode the device will be set to provide a constant output frequency. During CW mode no shapes are executed.

During the execution of this mode:

- Freq/timing parameters defined in shape registers are ignored
- [PLL](#) / [RF](#) / [ADC](#) runs with values programmed in PLL DFT0 (see [PLL test register 0](#)) and CSU1 (see [Channel set up x register 1](#)).
- All other CSx / shape settings are not handed over to functional blocks
- The values for REPS/REPC/REPT and frame relevant timings are used to shape a “virtual frame”
- Data from the [FIFO](#) can be read out following the structure of that “virtual frame”

Note: For test purposes the “virtual frame” definition should be kept simple: 1 shape, 1 CS, e.g.

### 10.3.1 Enabling the CW mode

The [CW](#) mode should be preceded by at least a [HW](#) reset after power up. In case the chip is already up and running a [SW](#) reset may be used instead.

After this in order to enable the CW mode, the steps below should be followed:

- Enable the MAIN: CW\_MODE = 1<sub>B</sub> (see [Main register](#))
- Initialize the chip registers according to defined “virtual frame” (settings in [Channel set up x register 0](#) and [PLL shape x register 0](#))
- Enable the clock: PACR1: OSCCLKEN (see [PLL analog control register 1](#))
- Set frequency via PLLx: FSU setting from shape 1
- Set channel set for CSDS/CSI/CSU1 (see [Channel set deep sleep register 0](#))
- set PLL DFT0: byprmpen = 1<sub>B</sub> (see [PLL test register 0](#))

By using the FRAME\_START as trigger, the chip can be set in the different states of a shape as shown in the following figure.

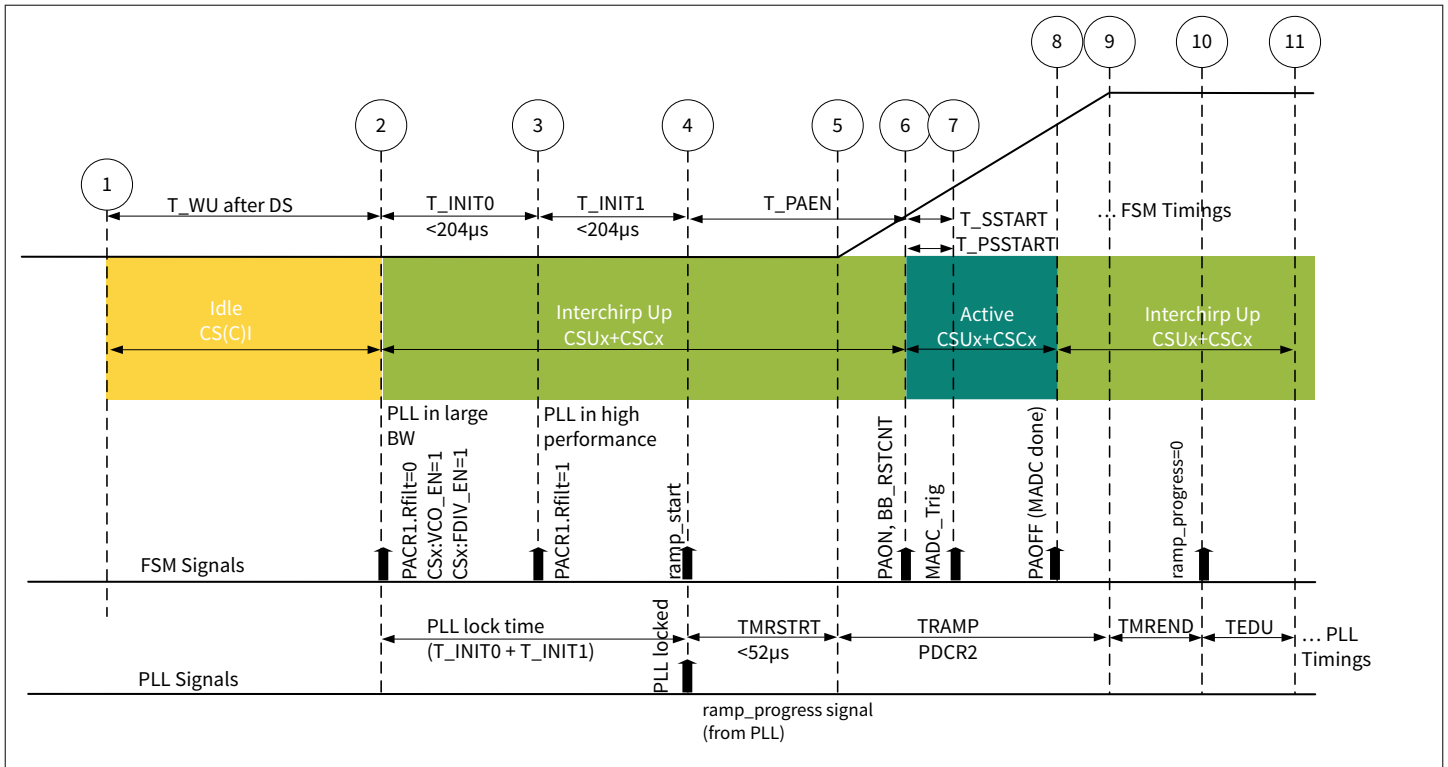
- TRIG#1: jump to 1 (DS -> Idle)
- TRIG#2: jump to 2 (Idle -> Init0)
- TRIG#3: jump to 3 (Init0 -> Init1)
- TRIG#4: jump to 4
- TRIG#5: jump to 6

Frequency update: at this stage the output frequency can be updated/programed (FSU) to any value and the current frequency will be updated immediately after PLL transition of PDFT0: byprmpen = 0<sub>B</sub> -> 1<sub>B</sub>.

- TRIG#6: jump to 7

At this stage the APU number of samples is generated by the [ADC](#) according to the ADC0 settings. In case if APU = 0<sub>D</sub> no triggers are generated, manual triggering of MADC can be done via ADC0: TRIG\_MADC. Once the APU number of samples is generated another automatic generation of samples can be done after [FSM](#) reset.

- TRIG7: jump to 8
- TRIG8: jump to 10
- TRIG9: jump to 11
- TRIGx



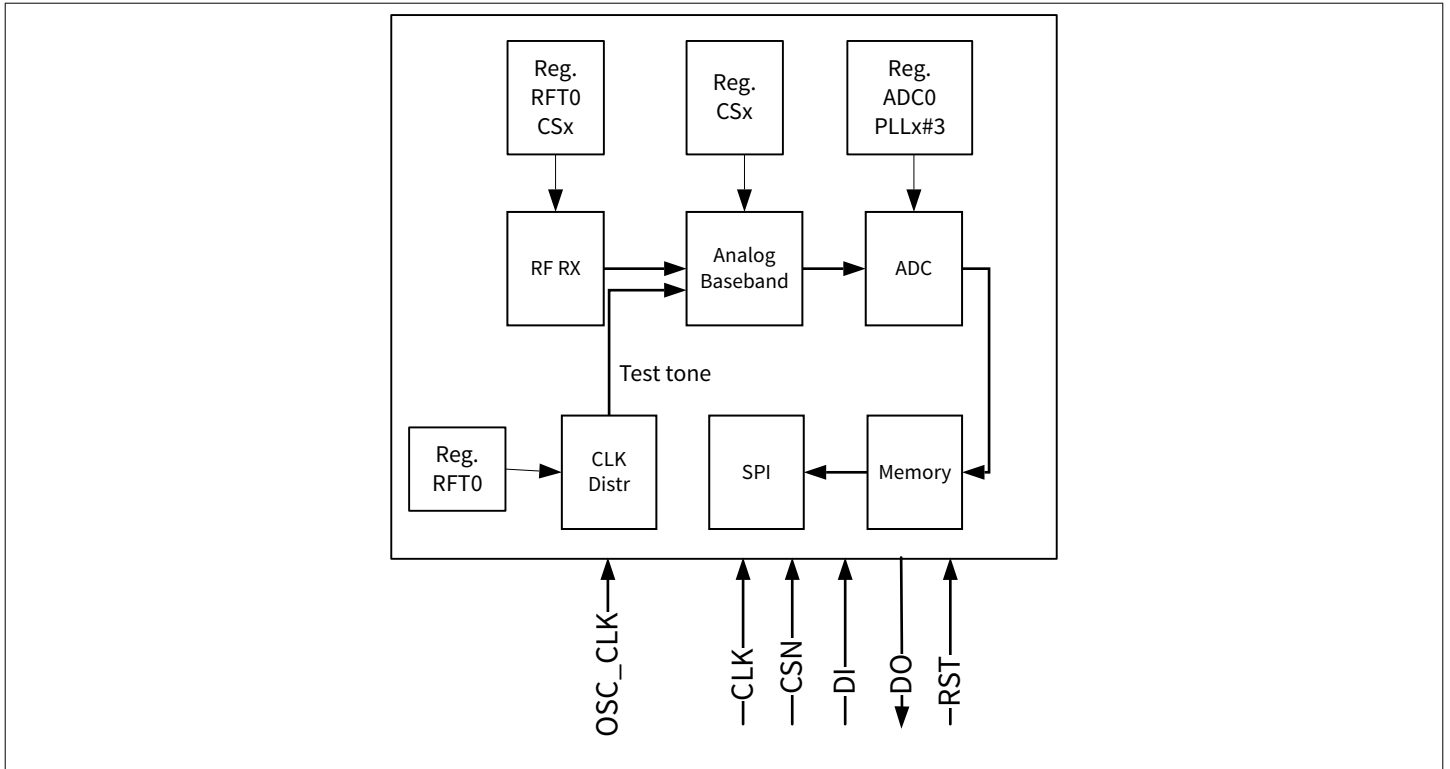
**Figure 50** Steps that can be followed during a “virtual frame”

The FSM-reset will set back the FSM to initial state to start again with TRIG1.

This specific mode is intended also to test the power consumption of the chip during a specific sequence. It will offer the opportunity to break the expected shape that should be run during the radar (active) mode in static steps where the current consumption can be measured.

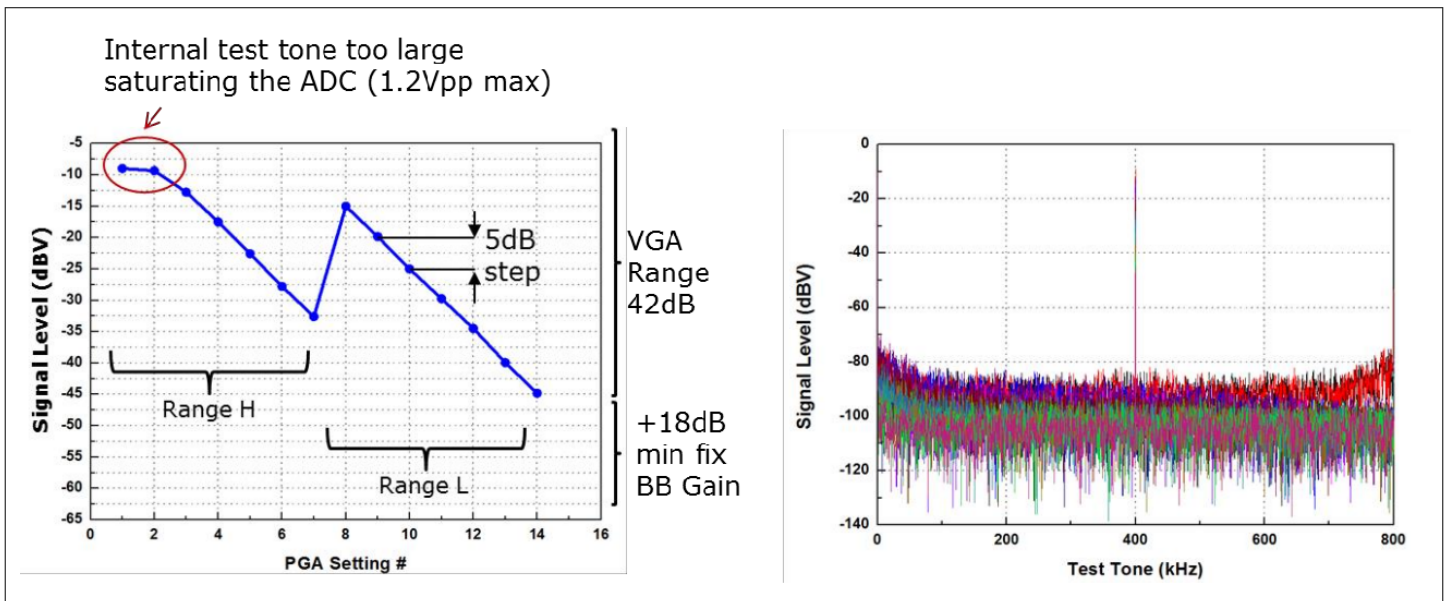
### 10.3.2 Baseband and ADC test mode

A test-tone generator can be used together with the CW mode. A test signal source derived from the OSC\_CLK input can be activated in the analog receiver chain; the same in each Rx chain. This test signal can be programmed in the register RFT0 (see RF test register 0). The test tone can propagate through to each baseband chain by enabling a dedicated path. The MADC is triggered by the TRIG7 and will sample the number of samples specified in the APU1 (see PLL shape x register 3). To run a new measurement, an FSM-reset is required.



**Figure 51 Baseband/ADC test block diagram**

This feature represents a very convenient way to test and debug a complete system. The customer can program a dedicated frequency, set the baseband gain and cutoff filter of the *HPF* (Channel set up x register 2), set the *ADC*, and readout via *SPI* the sampled data into the *AP* or *MCU* to verify if the complete baseband chain is working as expected. The following figure shows one example of *ADC* readout when the baseband is fed with a test tone at 400 kHz internally derived from the *OSC\_CLK* input. Different readouts from different *VGA* settings are reported.



**Figure 52 Example: ADC readout after FFT**

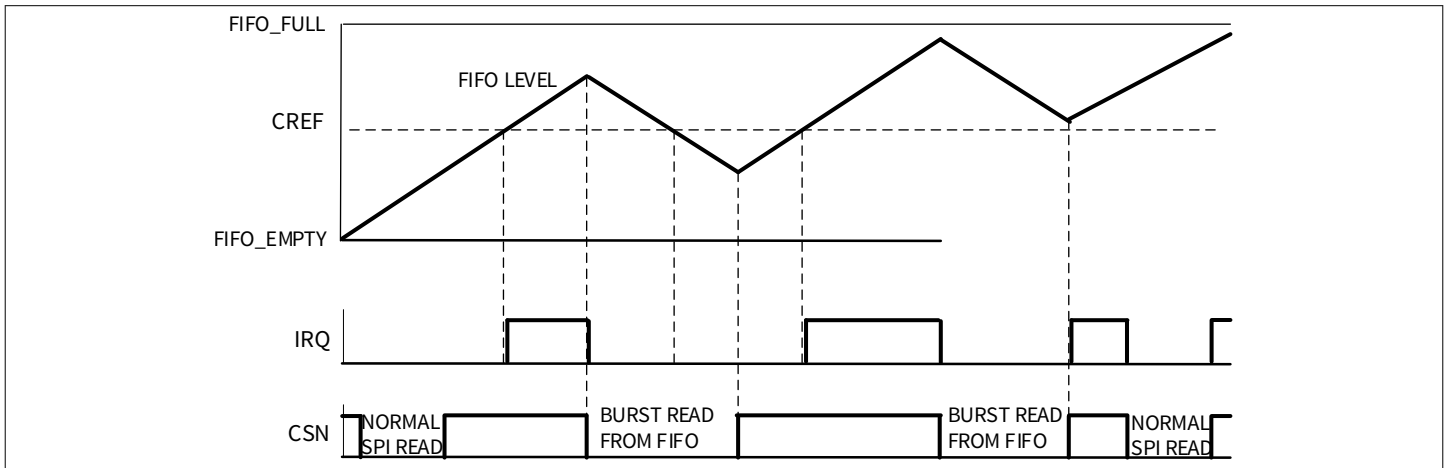
## 10.4 IRQ output

BGT60UTR11AIP provides one interrupt pin output IRQ. In default mode, the IRQ pin is used to monitor the filling level of the *FIFO* as described below.

### IRQ status definition:

- IRQ is high after:
  - CSN goes high and  $FSTAT:FILL\_STATUS \geq SFCTL:FIFO\_CREF$  (see [SPI and FIFO control register](#) and [FIFO status register](#))
- IRQ is low (as a consequence of):
  - CSN goes high and  $FSTAT:FILL\_STATUS < SFCTL:FIFO\_CREF$  (see also [Chapter 4.9](#) and [Chapter 4.48](#))
  - CSN is active low

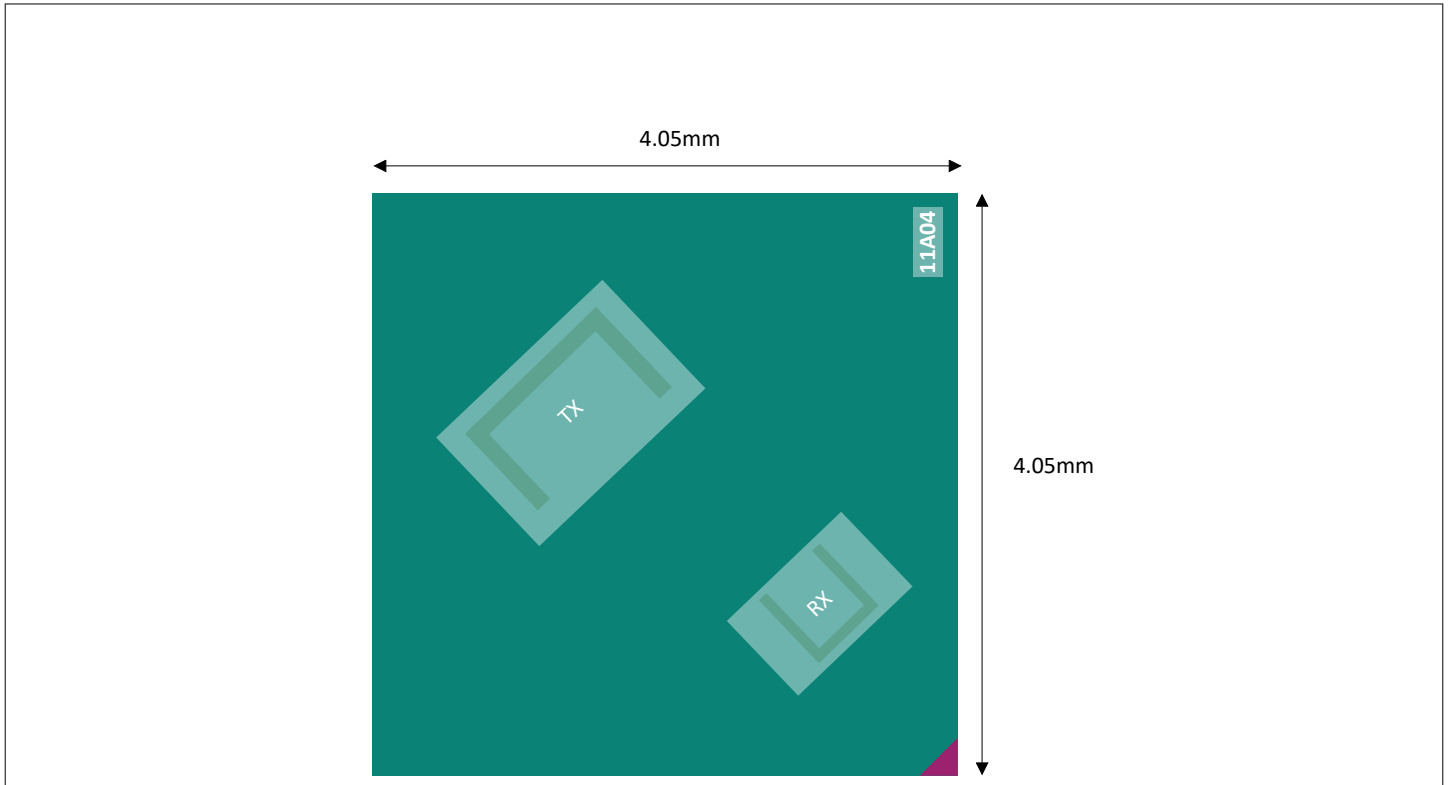
The following figure shows the IRQ signal in case of FIFO burst reads.



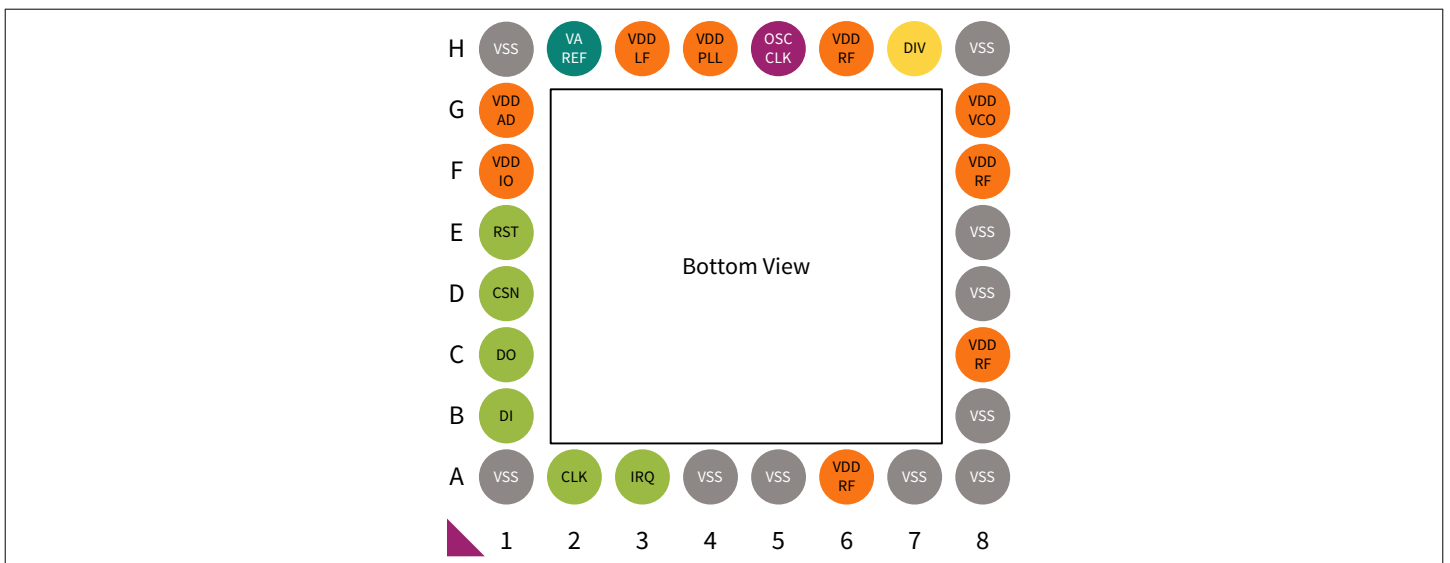
**Figure 53** IRQ status behavior during radar mode with FSM capturing data

## 11 Package

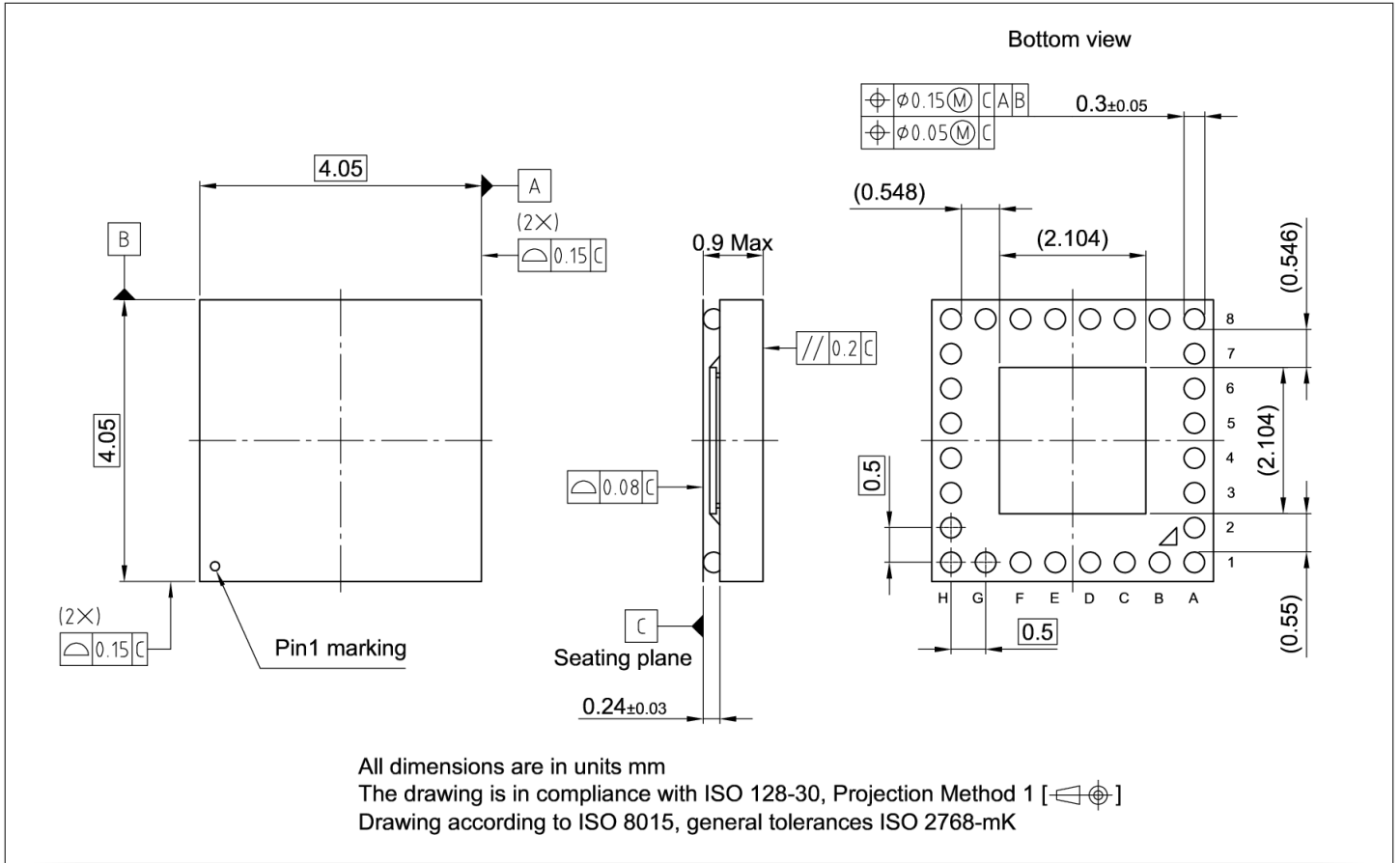
The BGT60UTR11AIP chip is housed in a laminate package with solder balls of 300 µm diameter and integrates the antennas. According to IPC/JEDEC's J-STD0, the *moisture sensitivity level (MSL)* is 3. Figure 54 shows the top view of BGT60UTR11AIP package and its physical dimension. The bottom view is presented in Figure 55. The package size is 4.05 x 4.05 x 0.86 mm<sup>3</sup> with ball pitch of 500 µm. Package outline is reported on Figure 56. Package name: PG-VF2BGA-28-1.



**Figure 54** Top view of BGT60UTR11AIP

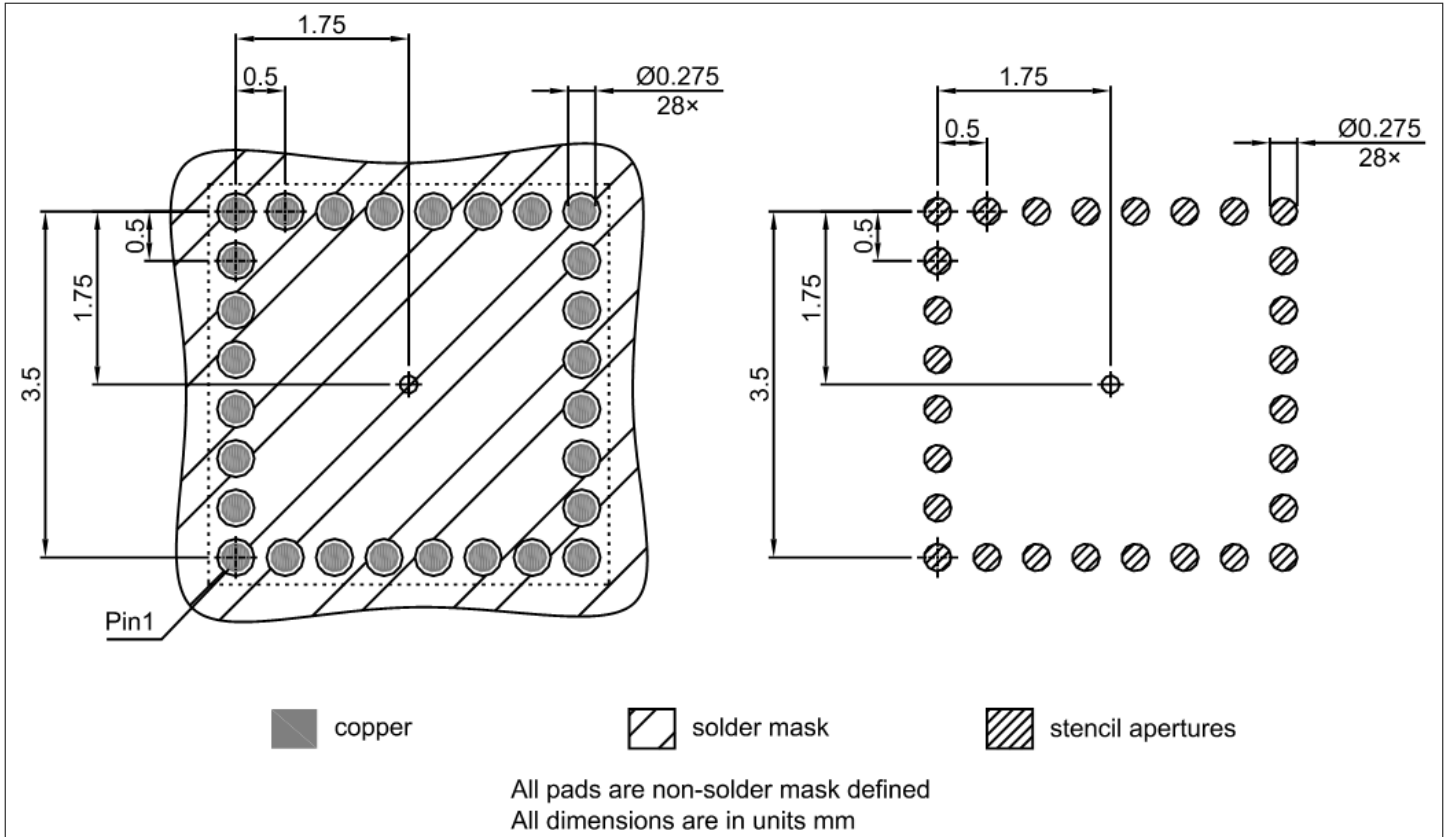


**Figure 55** Bottom view of BGT60UTR11AIP



**Figure 56** Package outline PG-VF2BGA-28-1





**Figure 57** Footprint of BGT60UTR11AIP

**Figure 58** Tape of PG-VF2BGA-28-1

### 11.1 Built-in antenna specifications

Antenna performance reported in the following table are ensured by design. Typical antenna behavior is measured on Infineon reference board. Typical antenna beam plots are available in a specific application note and upon specific request.

**Table 41** Antennas in package specifications

Parameter	Value			Unit	Condition
	Min.	Typ.	Max.		
$RX_{BW}$	57.4	61	63.0	GHz	Receiver antenna bandwidth
$TX_{BW}$	57.4	61	63.0	GHz	Transmitter antenna bandwidth
$G_{TX}$	-	3.0	-	dBi	Antenna gain of a single TX antenna
$G_{RX}$	-	3.0	-	dBi	Antenna gain of a single RX antenna
$HPBW_{RX\_E}$	-	120	-	Deg	Half-power beam width of a single RX antenna in the E-plane direction
$HPBW_{RX\_H}$	-	90	-	Deg	Half-power beam width of a single RX antenna in the H-plane direction
$HPBW_{TX\_E}$	-	120	-	Deg	Half-power beam width of a single TX antenna in the E-plane direction

(table continues...)

**Table 41** (continued) Antennas in package specifications

Parameter	Value			Unit	Condition
	Min.	Typ.	Max.		
$HPBW_{TX\_H}$	-	90	-	Deg	Half-power beam width of a single TX antenna in the H-plane direction
$ISO_{TX\_RX}$	-	25	-	dB	Isolation from TX antenna to RX antenna in package.

## Glossary

### **AAF**

*anti-aliasing filter (AAF)*

A filter used before a signal sampler to restrict the bandwidth of a signal to satisfy the Nyquist–Shannon sampling theorem over the band of interest.

### **ABB**

*analog base band (ABB)*

A signal that has a near-zero frequency range, this is, a spectral magnitude that is nonzero only for frequencies in the vicinity of the origin and negligible elsewhere.

### **AC**

*alternating current (AC)*

A form of power supply in which the flow of electric charge periodically reverses direction.

### **ADC**

*analog-to-digital converter (ADC)*

A device that converts a continuous physical quantity (usually voltage) to a digital number that represents the quantity's amplitude.

### **AP**

*application processor (AP)*

A chip that is used to run primary user applications.

### **BITE**

*built-in test equipment (BITE)*

Passive diagnosis equipment built into a system to support test processes during production.

### **CDM**

*charge device model (CDM)*

A model for characterizing the susceptibility of an electronic device to damage from electrostatic discharge.

### **CMOS**

*complementary metal-oxide semiconductor (CMOS)*

A technology for constructing integrated circuits that uses a combination of p-channel and n-channel metal–oxide–semiconductor field-effect transistors (MOSFETs) to implement logic gates.

### **CW**

*continuous wave (CW)*

The emission of a sinusoidal radio wave, which may be modulated by signals.

### **DC**

*direct current (DC)*

A form of power supply in which the flow of electric charge is only in one direction.

### **EOL**

*end of line (EOL)*

The last stage of a production process where functional tests are executed.

**ESR**

*equivalent series resistance (ESR)*

The internal alternating current resistance that appears in series with an ideal capacitance or an ideal inductance of the device.

**FIFO**

*first in first out (FIFO)*

A method for organizing the manipulation of a data structure where the first entry is processed first.

**FMCW**

*frequency-modulated continuous wave (FMCW)*

A type of radar system where a known frequency continuous wave radio energy is transmitted and then received from any reflecting object.

**FM**

*frequency-modulated (FM)*

A angle modulation in which the instantaneous frequency deviation varies in accordance with a given function, generally linear, of the instantaneous value of the modulating signal.

**FSM**

*finite state machine (FSM)*

An abstract machine that can be in exactly one of a finite number of states at any given time.

**HBM**

*human body model (HBM)*

A model for characterizing the susceptibility of an electronic device to damage from electrostatic discharge based on a human body.

**HPF**

*high-pass filter (HPF)*

An electronic filter that passes signals with a frequency higher than a certain cutoff frequency and attenuates signals with frequencies lower than the cutoff frequency.

**HW**

*hardware (HW)*

The collection of physical components that comprise a computer or any other electronic system.

**IBIS**

*input-output buffer information specification (IBIS)*

A specification of a method for integrated circuit vendors to provide information about the input/output buffers of their product to their prospective customers without revealing the intellectual property of their implementation.

**IF**

*intermediate frequency (IF)*

The frequency corresponding to the carrier frequency or another characteristic frequency of an input radio-frequency signal in a signal resulting from each frequency translation.

**LDO**

*low-dropout voltage regulator (LDO)*

A direct current linear voltage regulator that can regulate the output voltage even if the supply voltage is very close to the output voltage.

**LFSR**

*linear feedback shift register (LFSR)*

A shift register whose input bit is a linear function of its previous state.

**LO**

*local oscillator (LO)*

An electronic oscillator used with a mixer to change the frequency of a signal.

**LSB**

*least significant bit (LSB)*

The binary digit of the least significance within a code word.

**MCU**

*microcontroller unit (MCU)*

A small computer on a single integrated circuit containing a processor core, memory, and programmable input/output peripherals.

**MISO**

*master in slave out (MISO)*

The input line of a serial peripheral interface master.

**MOSI**

*master out slave in (MOSI)*

The output line of a serial peripheral interface master.

**MSB**

*most significant bit (MSB)*

The binary digit of the most significance within a code word.

**MSL**

*moisture sensitivity level (MSL)*

An electronic standard for the time period in which a moisture-sensitive device can be exposed to ambient room conditions.

**NDA**

*non-disclosure agreement (NDA)*

A legal contract or part of a contract between at least two parties that outlines confidential material, knowledge, or information that the parties wish to share with one another for certain purposes, but wish to restrict access to.

**PCB**

*printed circuit board (PCB)*

A board that mechanically supports and electrically connects electronic components using conductive tracks, pads, and other features etched from copper sheets laminated onto a non-conductive substrate.

**PLL**

*phase-locked loop (PLL)*

A feedback circuit for synchronizing an oscillator with the phase of an input signal.

**RF**

*radio frequency (RF)*

A frequency of a periodic radio wave or of the corresponding electric oscillation.

**RSVD**

*reserved (RSVD)*

A placeholder for future functionalities or features.

**RX**

*receiver (RX)*

A device that accepts signals from remote transmitters.

**SAR**

*successive approximation register (SAR)*

A type of analog-to-digital converter that converts a continuous analog waveform into a discrete digital representation using a binary search through all possible quantization levels.

**SPI**

*serial peripheral interface (SPI)*

A synchronous serial communication interface specification used for inter-chip communication, primarily in embedded systems.

**STS**

*simplified timing shell (STS)*

A wrapper around a module that includes timing information to enable static timing checks for this module.

**SW**

*software (SW)*

The collection of non-physical components that comprise a set of instructions executed by a processor.

**TX**

*transmitter (TX)*

A device that sends out signals.

**VCO**

*voltage controlled oscillator (VCO)*

An oscillator whose frequency is a function of the voltage of an input signal.

**VGA**

*variable gain amplifier (VGA)*

An electronic amplifier that varies its gain depending on a control voltage.

## Revision history

Document version	Date of release	Description of changes
1.0	2023-06-06	Initial datasheet