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Ultrasonic-Flow-Converter

Data Sheet

TDC-GP30

System-Integrated Solution for Ultrasonic Flow Meters
Volume 1: General Data and Frontend Description

July 31th, 2015
Document-No: DB_GP30Y_Vol1_en V0.1

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Notational Conventions

Throughout the GP30 documentation, the following stile formats are used to support efficient reading and understanding of the documents:

- Hexadecimal numbers are denoted by a leading 0x, e.g. 0xAF = 175 as decimal number. Decimal numbers are given as usual.
- Binary numbers are denoted by a leading 0b, e.g. 0b1101 = 13. The length of a binary number can be given in bit (b) or Byte (B), and the four bytes of a 32b word are denoted B0, B1, B2 and B3 where B0 is the lowest and B3 the highest byte.
- Abbreviations and expressions which have a special or uncommon meaning within the context of GP30 application are listed and shortly explained in the list of abbreviations, see following page. They are written in plain text. Whenever the meaning of an abbreviation or expression is unclear, please refer to the glossary at the end of this document.
- **Variable names** for hard coded registers and flags are in bold. Meaning and location of these variables is explained in the datasheet (see registers CR, SRR and SHR).
- ***Variable names*** which represent memory or code addresses are in bold italics. Many of these addresses have a fixed value inside the ROM code, others may be freely defined by software. Their meaning is explained in the firmware and ROM code description, and their physical addresses can be found in the header files. These variable names are defined by the header files and thus known to the assembler as soon as the header files are included in the assembler source code. Note that different variable names may have the same address, especially temporary variables.
- *Physical variables* are in italics (real times, lengths, flows or temperatures).

Abbrevations

AM	Amplitude measurement
CD	Configuration Data
CPU	Central Processing Unit
CR	Configuration Register
CRC	Cyclic Redundancy Check
DIFTOF, DIFTOF_ALL	Difference of up and down ->TOF
DR	Debug Register
FEP	Frontend Processing
FDB	Frontend data buffer
FHL	First hit level (physical value V_{FHL})
FW	Firmware, software stored on the chip
FWC	Firmware Code
FWD	Firmware Data
FWD-RAM	Firmware Data memory
GPIO	General purpose input/output
Hit	Stands for a detected wave period
HSO	High speed oscillator
INIT	Initialization process of ->CPU or -> FEP
IO	Input/output
I2C	Inter-Integrated Circuit bus
LSO	Low speed oscillator
MRG	Measurement Rate Generator
NVRAM, NVM	Programmable Non-Volatile Memory
PI	Pulse interface
PP	Post Processing
PWR	Pulse width ratio
R	RAM address pointer of the CPU, can also stand for the addressed register
RAA	Random Access Area
RAM	Random Access Memory
RI	Remote Interface
ROM	Read Only Memory
ROM code	Hard coded routines in ROM
SHR	System Handling Register
SPI	Serial Peripheral Interface
SRAM	Static RAM
SRR	Status & Result Register
SUMTOF	Sum of up and down TOF
Task	Process, job
TDC	Time-to-digital-converter
TOF, TOF_ALL	Time of Flight
TS	Task Sequencer
TM	Temperature measurement
UART	Universal Asynchronous Receiver & Transmitter
USM	Ultrasonic measurement
V_{ref}	Reference voltage
X,Y,Z	Internal registers of the CPU
ZCD	Zero cross detection, physical level V_{ZCD}

For details see the glossary in section 9.

Content

1 Overview

TDC-GP30 is the next generation in acam's development for ultrasonic flow converters. The objectives of the TDC-GP30 development are as follows:

- Easy-to-adapt two-chip solution for ultrasonic heat and water meters (GP30 + simple µP)
- Single-chip solution for many industrial applications or pure flow meter parts
- All flow and temperature calculations are done by GP30
- External µP needed only for interfaces (e.g. LCD, wireless, etc.) and other general-purpose tasks
- Integrated standard pulse interface enables one-to-one replacement of mechanical meters by GP30 based single-chip heat and water meters – customer µP and software remains unchanged.

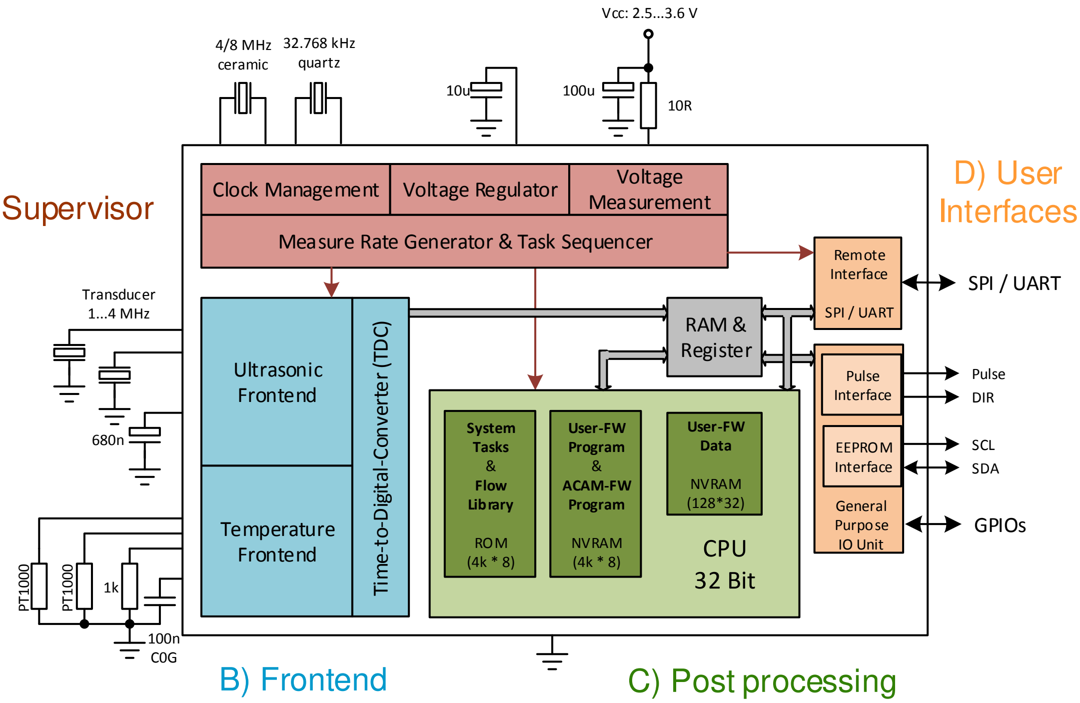
All in all, the TDC-GP30 is the next step in ultrasonic flow metering. It drastically simplifies the design of ultrasonic heat and water meters and is the necessary step for compact energy-saving ultrasonic water meters. The ultra-low-current capabilities allow the use of standard 2/3 AA or AA lithium thionyl chloride batteries at 6-8 Hz measuring frequency even in the water meter version. The TDC-GP30 is a system-on-chip approach that allows you to perform all measurement tasks in one IC.

1.1 Key Features

- High performance + ultra-low power 32-Bit CPU with
    - 128 * 32 bit NVRAM (non-volatile RAM) for user firmware parameter & data
    - 4k * 8 bit NVRAM (non-volatile RAM) for user firmware program code
    - 4k * 8 bit ROM for system task code and special flow library code
- Capability of MID-compliant flow & temperature calculation, GP30-supported
- Flexible interfaces, SPI, UART, pulse (flow only)
- Advanced high-precision analog part
- Transducers can be connected directly to GP30, no external components required
- Amplitude measurements of receiving signal for secure bubble, aging and empty spool piece detection
- Up to 31 multi-hits for flow measurement yield the highest accuracy
- High update rates with very low power consumption of for example 6 µA at 8 Hz, including flow and temperature calculations, measure rate adopted to the flow
- Very low space and component requirements

1.2 Block diagram

Figure 1-1: Block diagram



Main functional blocks of TDC-GP30:

A)	Supervisor:	Timing and voltage control
B)	Frontend:	TOF and sensor temperature measurements
C)	Post processing:	CPU operations, including initialization and firmware operations
D)	User interfaces:	Chip communication over SPI or UART, Pulse interface and GPIOs

1.3 Ordering Numbers

Part#	Package	Carrier, Quantity	Order number
TDC-GP30YA	QFN40	T&R, 3000	502030004
TDC-GP30YD	QFN32	T&R, 3000	502030003
GP30-DEV-KIT	System	Box, 1	220260003

This product is RoHS-compliant and does not contain any Pb.

2 Characteristics & Specifications

2.1 Electrical Characteristics

Absolute Maximum Ratings

Stresses beyond those listed under “Absolute Maximum Ratings“ may cause permanent damage to the device. These are stress ratings only. Functional operation of the device at these or any other conditions beyond those indicated under “Electrical Characteristics” is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

Table 2-1 Absolute maximum ratings

Symbol	Parameter	Min	Max	Units
V_{CC}	Supply voltage V_{CC} vs. GND	-0.3	4.0	V
	All other pins	-0.3	V_{CC} + 0.6	V
T_{amb}	Ambient temperature	-40	+125	°C
T_{strg}	Storage temperature	-55	+150	°C
T_{body}	Body temperature JEDEC J-STD-020		260	°C
ESD	ESD rating (HBM), each pin	±2		kV

Table 2-2 Recommended operating conditions

	Parameter	Conditions	Min.	Typ.	Max.	Unit
V_{CC}	Supply voltage	main supply voltage	2.5	3.0	3.6	V
V_{DD18}	Core supply	Internally derived from V_{CC} and regulated	1.65	1.80	1.92	V
f_{LSO}	Low speed oscillator (LSO) frequency			32.768		kHz
f_{HSO}	High-speed oscillator (HSO) frequency	For Standard transducers, max. 2 MHz,	3.6	4	4.4	MHz
		For 4 MHz transducers, not in combination with UART	7.2	8	8.8	MHz
		Other frequencies in the range from 2 MHz to 8 MHz may be possible with limitations				
f_{SPI}	SPI Interface Clock Frequency	SPI communication			10	MHz
f_{TOF}	TOF measurement frequency	$f_{TOF} = \frac{1}{(TOF\_RATE * t_{cycle})}$	0.004	1 … 8	80	Hz
t_{cycle}	Measurement cycle time	LSB = 976.5625 µs			4000	ms

Table 2-3 DC Characteristics (V_{CC} = 3.0 V, T_j = -40 to +85 °C)

Symbol	Parameter	Conditions	Min.	Typ.	Max.	Unit
$I_{Standby}$	Supply current only 32 kHz, Standby mode	only 32 kHz oscillator running @ 25 °C, V_{CC} = 3.6 V = 3.0 V		3.6 2.2		µA µA
I_{hs}	Operation current 4 MHz oscillator	V_{CC} = 3.6 V = 3.0 V off		80 65 < 1		µA µA nA
I_{tmu}	Current into time measuring unit including analog frontend	Only during active TOF time measurement		1.3		mA
I_{CCq}	Quiescent current GP30	all clocks off, @25 °C 1.8V LDO running		1.9		µA
I_{DDqc}	Quiescent current 1.8V digital core	all clocks off		0.08		µA
I_{AFE}	Average operating current analog front end only	TOF_UP+DOWN, 1/s		0.42		µA
I_o	Average operating current incl. CPU processing current	TOF_UP+DOWN, 1/s		0.9		µA
V_{oh}	High level output voltage	I_{oh}= 4 mA	V_{CC} - 0.4			V
V_{ol}	Low level output voltage	I_{ol} = 4 mA			0.4	V
V_{ih}	Logic High level input voltage	for proper logic function for low leakage current	0.7* V_{CC} V_{CC} - 0.2			V
V_{il}	Logic Low level input voltage	for proper logic function for low leakage current			0.3* V_{CC} 0.2	V

Note: See also section 4.5.2 for more information about the current consumption

Table 2-4 Terminal Capacitance

Symbol	Terminal	Condition	Rated Value			Unit
			Min.	Typ.	Max.	
C_i	Digital input	measured @ V_{CC} = 3.0 V f = 1 MHz, T_a = 25 °C		7		pF
C_o	Digital output			7		
C_{io}	Bidirectional			7		

Table 2-5 Analog Frontend

Symbol	Terminal	Condition	Rated Value			Unit
			Min.	Typ.	Max.	
	Comparator input offset voltage (chopper stabilized)				< 1.6	mV

Table 2-6 NVRAM

Symbol	Terminal	Condition	Minimum Value	Unit
	Data retention @ 125 °C	V_{CC} = 3.0 to 3.6 V	20	Years
	Endurance *	@ 25 C V_{CC}= 3.0 to 3.6 V	10^5	Cycles
		@ 125 C V_{CC}= 3.0 to 3.6 V	10^4	Cycles

* See 6.2 EEPROM interface for backup applications.

Converter Specification

Table 2-7 Time Measuring Unit (V_{CC} = 3.0 V, T_j = 25 °C)

Symbol	Terminal	Condition	Rated Value			Unit
			Min.	Typ.	Max.	
LSB	TDC Resolution (BIN-Size)			11		ps
LSB	TDC rms Noise			1.2		LSB
t_m	Measurement range	TOF measurement	10		4096	µs
t_m	Measurement range	Temperature interface measurement	10		1024	µs

Table 2-8 Temperature Measuring Unit[1]

Symbol	Terminal	PT1000	PT500	Unit
		Typical.	Typical	
	Resolution RMS	17.0	17.0	Bit
	Absolute Gain[2]	1.0004	1.0002	
	Gain-Drift vs. V_{CC}	0.01	0.01	%/V
	Gain-Drift vs. Temp	< 2	< 3	ppm/K
	Initial Zero Offset T_{cold} <-> T_{hot}	< 2	< 4	mK
	Initial Zero Offset T_{ref} <-> (T_{cold}, T_{hot})	< 20	< 40	mK
	Offset Drift vs. Temp	< 0.05	< 0.05	mK/K

[1] 2-Wire measurement with compensation of $R_{ds(on)}$ and gain (Schmitt trigger). All values measured at V_{CC} = 3.0 V, C_{load} = 100 nF for PT1000 and 200 nF for PT500 (C0G-type)

[2] Compared to an ideal gain of 1.0

2.2 Timings

At V_{CC} = 3.0 V ± 0.3 V, ambient temperature -40 °C to +85 °C unless otherwise specified

2.2.1 Oscillators

Table 2-9 Oscillator specifications

Symbol	Parameter	Min.	Typ.	Max.	Unit
LSO_CLK	32 kHz reference oscillator at frequency f_{LSO}		32.768		kHz
ST_{LSO}	32 kHz oscillator start-up time after power-up		< 1		Sec.
HSO_CLK	High-speed reference oscillator at frequency f_{HSO}	2	4	8	MHz
ST_{HSO_CER}	Oscillator start-up time with ceramic resonator		<100		µs
ST_{HSO_CRY}	Oscillator start-up time with crystal oscillator (not recommended)		3		ms

Remark:
It is strongly recommended that a ceramic oscillator be used for HSO_CLK because a quartz oscillator needs much longer time to settle than a ceramic oscillator. This consumes a lot of current, but using a quartz oscillator has no advantage when high speed clock calibration is done as supported by GP30.

2.2.2 Power-On

Table 2-10 Power-on timings

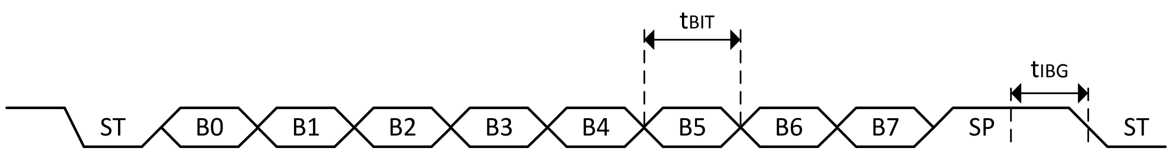
Symbol	Parameter	Min.	Typ.	Max.	Unit
t_{VDD18_STB}	Time when V_{DD18} is stable after power on of V_{CC} (C_L=100µF on VDD18_OUT)			20	ms
t_{RC_RLS}	Time when remote communication is released after power on of V_{CC}		27	40	ms

2.2.3 UART Interface

Table 2-11UART timings

Symbol	Parameter	Min.	Typ.	Max.	Unit
Baud rate	Baud rate	4800		115200	bps
t_{BIT}	Bit time (baud rate = 4800 Baud)		208.33		µs
	Bit time (Baudrate = 115200 Baud)		8.68		µs
t_{IBG}	Inter-Byte Gap	1		50	t_{BIT}

Figure 2-1 UART timing



2.2.4 SPI Interface

Table 2-12 SPI timings

Symbol	Parameter	min	max	Unit
f_{SCK}	Serial clock frequency		10	MHz
t_{SCK}	Serial clock time period	100		ns
t_{pwh}	Serial clock, pulse width high	0.4 * t_{SCK}		ns
t_{pwl}	Serial clock, pulse width low	0.4 * t_{SCK}		ns
t_{sussn}	SSN enable to valid latch clock	0.5 * t_{SCK}		ns
t_{hssn}	SSN hold time after SCK falling	0.5 * t_{SCK}		ns
t_{pwssn}	SSN pulse width between two cycles	t_{SCK}		ns
t_{sud}	Data set-up time prior to SCK falling	5		ns
t_{hd}	Data hold time before SCK falling	5		ns
t_{vd}	Data valid after SCK rising		20	ns

Serial interface (SPI compatible, clock phase bit =1, clock polarity bit =0):

Figure 2-2 SPI Write

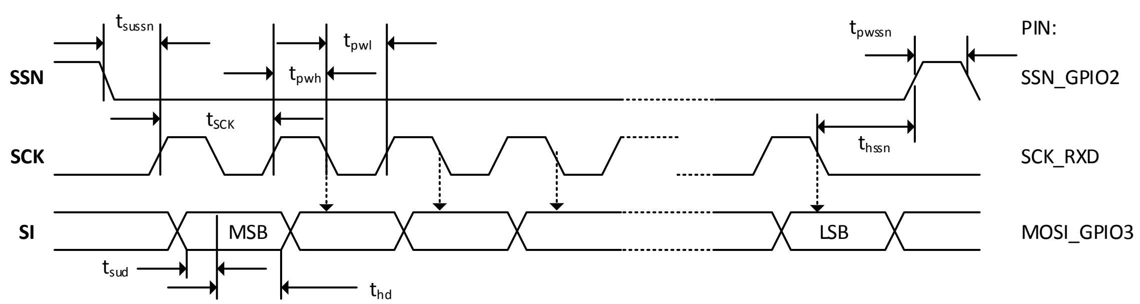
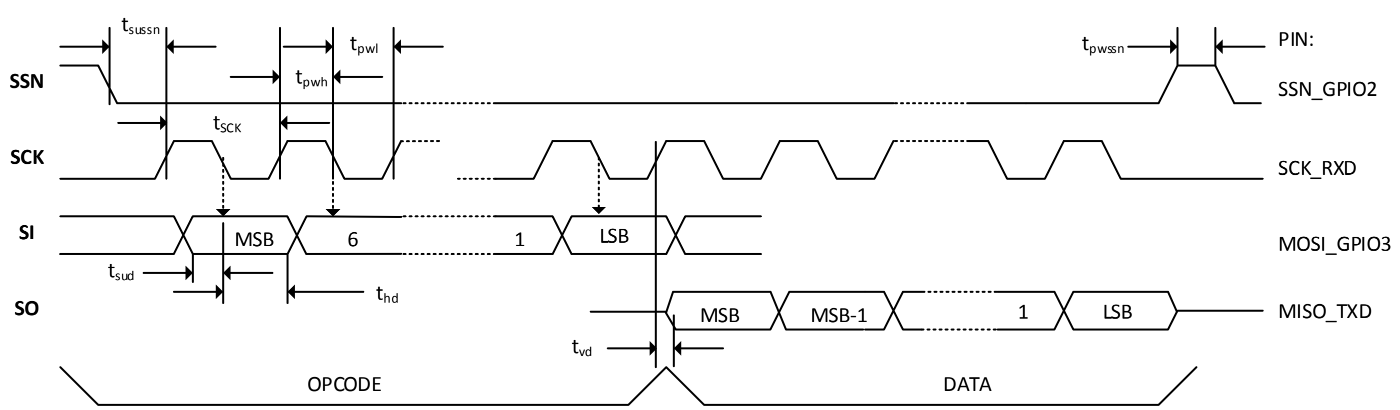


Figure 2-3 SPI Read



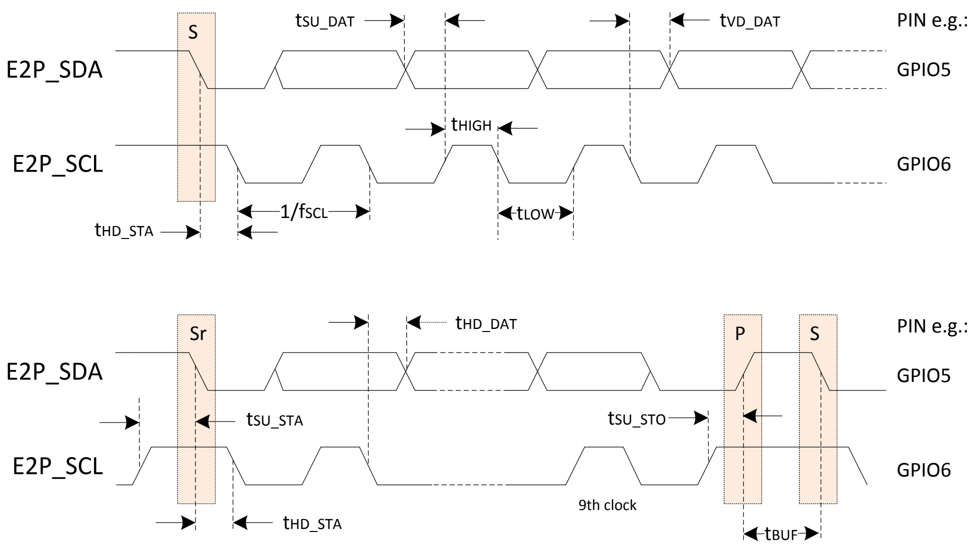
2.2.5 EEPROM Interface

(f_{HSO} = 4MHz)

Table 2-13 EEPROM timings

Symbol	Parameter	Min.	Typ.	Max.	Unit
f_{SCL}	SCL clock frequency	400			kHz
t_{LOW}	Low period of SCL clock	1300	1500		ns
t_{HIGH}	High period of SCL clock	600	1000		ns
t_{HD_STA}	Hold time for (repeated) START condition (S & Sr)	600	1000		ns
t_{SU_STA}	Setup time for repeated START condition (Sr)	600	750		ns
t_{SU_DAT}	Setup time data	100	750		ns
t_{HD_DAT}	Hold time data	0	750		ns
t_{VD_DAT}	Valid time data		750	900	ns
t_{SU_STO}	Setup time for STOP condition (P)	600	1750		ns
t_{BUF}	Bus free time between STOP and START condition	1300			ns

Figure 2-4 EEPROM timing



2.3 Pin Description

2.3.1 Device Marking

Example: GP30 Y A 15 03

Device family → GP30

Silicon revision (Y) → Y

Chip package (A = QFN40; D = QFN32) → A

Year (15 = YEAR 2015) → 15

Calendar week (03 = CW 03) → 03

2.3.2 QFN Packages Chips

QFN40 QFN32

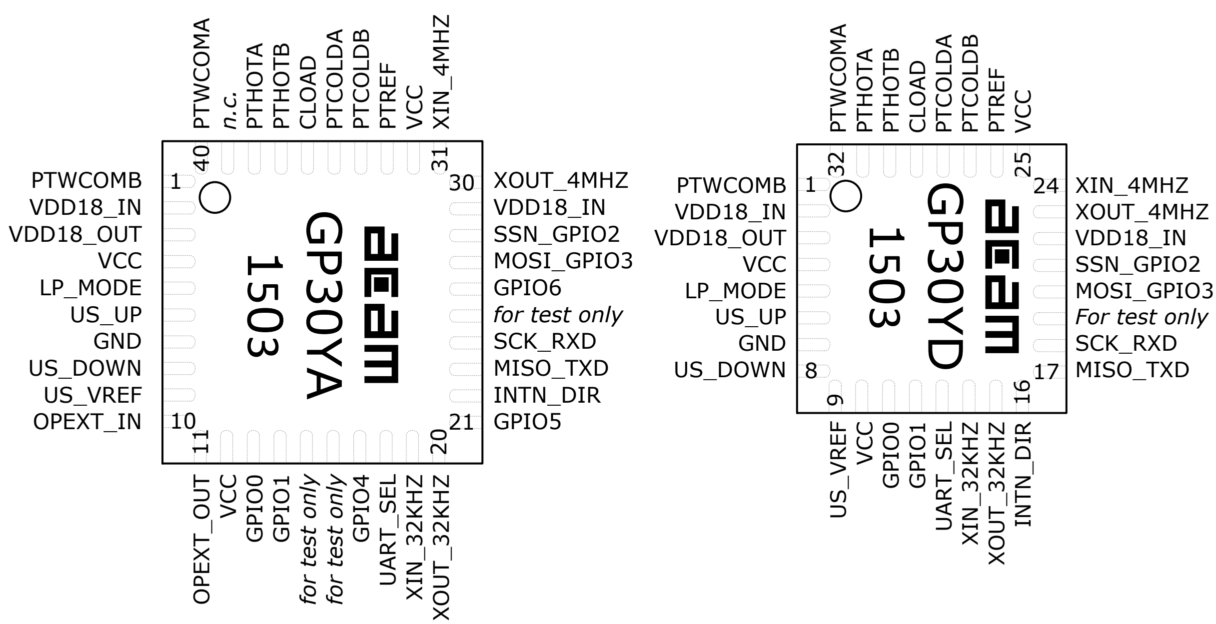


Figure 2-5 GP30 Pinout

QFN 40	QFN32	Name	Description	Buffer type
1	1	PTWCOMB	Temperature Sensor Port Common B	Analog
2	2	VDD18_IN	V_{DD18} TDC Supply Input (1.8 V)	Supply
3	3	VDD18_OUT	V_{DD18} voltage regulator output (1.8 V)	Supply
4	4	VCC	V_{CC} IO & Analog Supply (2.5..3.6 V)	Supply
5	5	LP_MODE	Low Power Mode (analog/digital)	Digital IN(Pull-up)
6	6	US_UP	Ultrasonic Transducer (Fire Up / Receive Down)	Analog
7	7	GND	Ground plane	
8	8	US_DOWN	Ultrasonic Transducer (Fire Down / Receive Up)	Analog
9	9	US_VREF	Ultrasonic Reference Voltage V_{ref} (typ. 0.7 V)	Power

QFN 40	QFN32	Name	Description	Buffer type
10	-	OPEXT_IN	External OP In (connect the input of the optional external OpAmp for amplifying ultrasonic echo here)	Analog
11	-	OPEXT_OUT	External OP Out (connect the output of the optional external OpAmp for amplifying ultrasonic echo here)	Analog
12	10	VCC	V_{CC} IO & Analog Supply (2.5..3.6 V)	Supply
13	11	GPIO0	General Purpose IO 0	Digital IO
14	12	GPIO1	General Purpose IO 1	Digital IO
15	-	TST_I	for test only	
16	-	TST_O	for test only	
17	-	GPIO4	General Purpose IO 4	Digital IO
18	13	UART_SEL	UART Select (0:SPI / 1:UART)	Digital IN
19	14	XIN_32KHZ	Low-Speed Oscillator (32.768 kHz)	Clock
20	15	XOUT_32KHZ	Low-Speed Oscillator (32.768 kHz)	Clock
21	-	GPIO5	General Purpose IO 5	Digital IO
22	16	INTN_DIR	SPI: Interrupt (low active) UART: Direction (0:Receive / 1:Send)	Digital OUT
23	17	MISO_TXD	SPI: Master In / Slave Out UART: Transmit Data	Digital OUT
24	18	SCK_RXD	SPI: Serial Clock UART: Receive Data	Digital IN
25	19	TEST_MODE_N	for test only	Digital IN(Pull-up)
26	-	GPIO6	General Purpose IO 6	Digital IO
27	20	MOSI_GPIO3	SPI: Master Out / Slave In UART: GPIO	Digital IN
28	21	SSN_GPIO2	SPI: Slave Select (low active) UART: GPIO	Digital IN
29	22	VDD18_IN	V_{DD18} Digital Core Supply Input (1.8 V)	Supply
30	23	XOUT_4MHZ	High-Speed Oscillator (4 or 8 MHz)	Clock
31	24	XIN_4MHZ	High-Speed Oscillator (4 or 8 MHz)	Clock
32	25	VCC	V_{CC} IO & Analog Supply (2.5..3.6 V)	Supply
33	26	PTREF	Temperature Sensor Port Reference Resistor	Analog
34	27	PTCOLDB	Temperature Sensor Port Cold B	Analog
35	28	PTCOLDA	Temperature Sensor Port Cold A	Analog
36	29	CLOAD	Temperature Measurement Load Capacitor	Analog
37	30	PTHOTB	Temperature Sensor Port Hot B	Analog
38	31	PTHOTA	Temperature Sensor Port Hot A	Analog
39	-	n.c.	not connected	
40	32	PTWCOMA	Temperature Sensor Port Common A	Digital IN

2.4 Package Drawings

Figure 2-6 QFN-40 package outline, 6 x 6 x 0.9 mm³, 0.5 mm lead pitch, bottom view

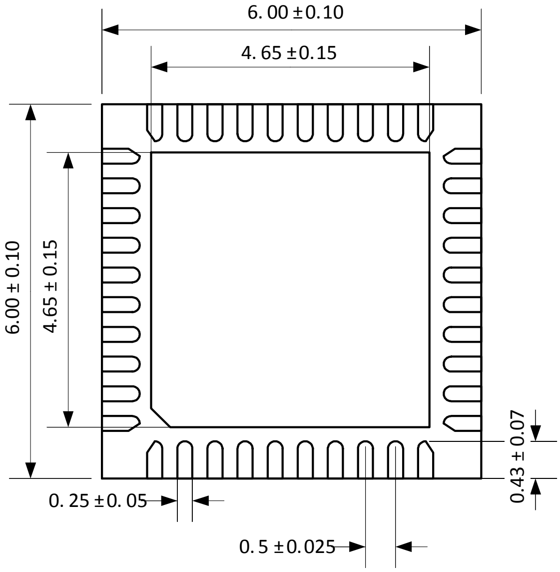
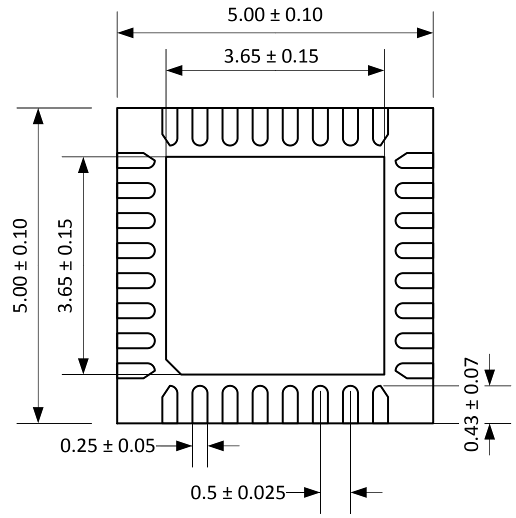
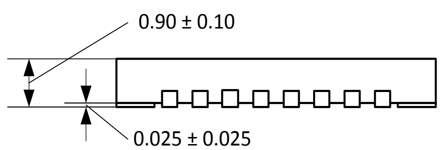


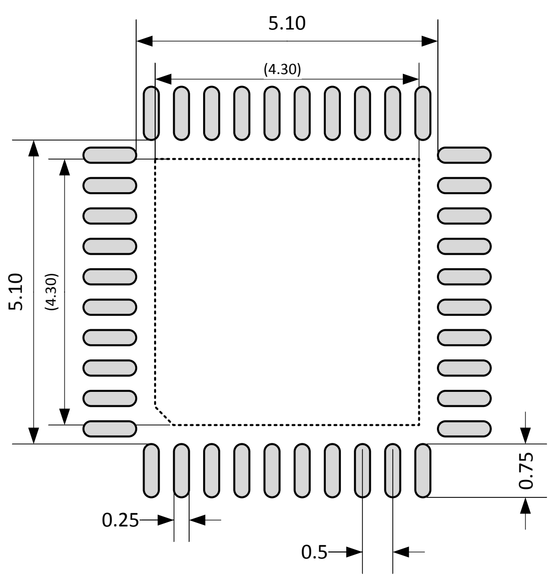
Figure 2-7 QFN-32 package outline, 5 x 5 x 0.9 mm³, 0.5 mm lead pitch, bottom view



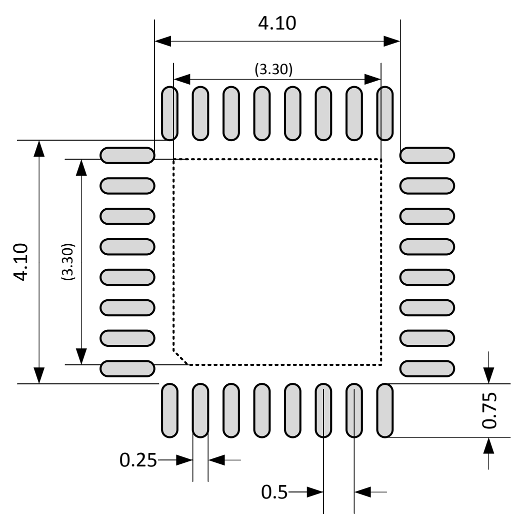
Side view



Landing pattern QFN40:

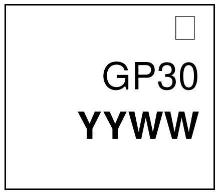


Landing pattern QFN32:



Caution: The center pad is internally connected to GND. No wires other than GND are allowed underneath. It is **not necessary** to connect the center pad to GND.

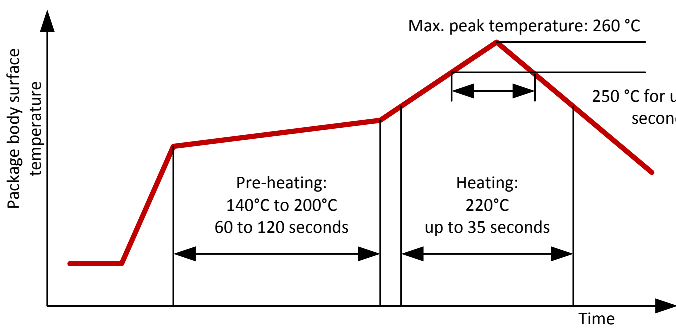
Marking:



: **Date Code:** YYWW: YY = Year, WW = week

Thermal resistance: Roughly 28 K/W (value just for reference).
Environmental: The package is RoHS-compliant and does not contain any lead.
Moisture Sensitive Level (MSL)
Based on JEDEC 020 moisture sensitivity level definition the TDC-GP30 is classified as MSL 3.
Soldering Temperature Profile
The temperature profile for infrared reflow furnace (in which the temperature is the resin’s surface temperature) should be maintained within the range described below.

Figure 2-8 Soldering profile



Maximum temperature

The maximum temperature requirement for the resin surface, where 260ºC is the peak temperature of the package body’s surface, is that the resin surface temperature must not exceed 250ºC for more than 10 seconds. This temperature should be kept as low as possible to reduce the load caused by thermal stress on the package, which is why soldering is recommended only for short periods. In addition to using a suitable temperature profile, we also recommend that you check carefully to confirm good soldering results.

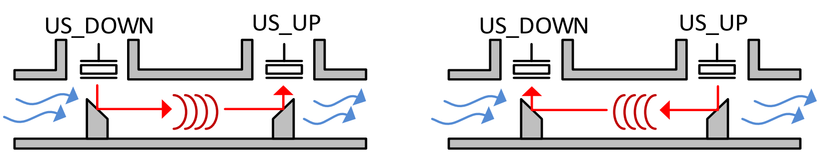
3 Flow and Temperature Measurement

The TDC-GP30 incorporates the complete system to measure and calculate the flow through a spool piece for ultrasonic flow metering: the driver for the piezo transducers, the offset stabilized comparator, the analog switches, the CPU to calculate the flow, the clock control unit and, above all, the measure rate control and task sequencer which manage the timing and interaction of all the units during measurement.

3.1 Measuring principle

The GP30 measures flow by measuring the difference in time-of-flight (TOF) of an ultrasonic pulse which travels with the flow (downstream) and opposite to the flow (upstream). For water meters, water temperature can be calculated from the time-of-flight data, too.. For heat meters, a high-precision temperature measurement unit is additionally integrated (see section 3.3).

Figure 3-1 Ultrasonic time-of-flight principle: Cross sections of an example spool piece with down- and upstream measurement



$$t_{down} = \frac{L}{c_0 + v} \qquad t_{up} = \frac{L}{c_0 - v} \qquad v \approx \frac{\Delta t * {c_0}^2}{2 * L}$$

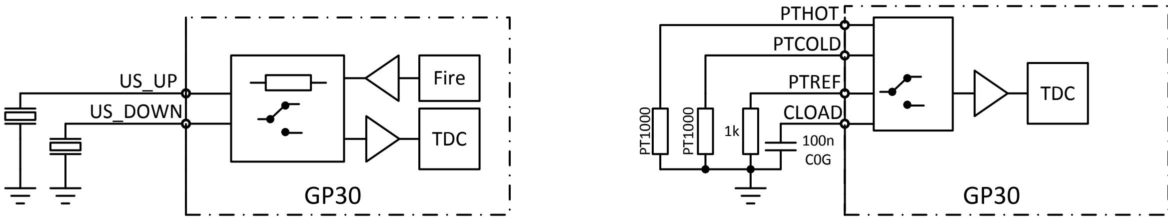
t_{up}, t_{down}:	Signal travel times TOF_{UP} and TOF_{DOWN}
$\Delta t = t_{up} - t_{down}$:	$DIFTOF$
L:	ultrasonic signal path length parallel to flow
c_0:	speed of sound in water
v:	flow speed

The flow speed *v* is a measure for the actual flow through the spool piece, and integrating the flow over time yields the flow volume.

Connecting the sensors is very simple. The ultrasonic transducer which sends against flow (in up direction) is directly connected to the US_UP pin, the ultrasonic transducer which sends with flow (in down direction) is directly connected to the US_DOWN pin. The resistors and capacitors in the transducer driver path are integrated in TDC-GP30 .

The temperature sensors, reference resistor and charge capacitors are connected to the temperature ports and GND. The temperature unit is suitable for sensors with 500 Ohm and higher like PT500 or PT1000. The chip supports 2-wire sensors and 4-wire sensors and is good for 1.5 mK rms resolution.

Figure 3-2 External connection of sensors: ultrasonic transducers (left) and temperature sensors (right for 2-Wire; for 4-wire sensors, see section 3.3)



3.1.1 Measurement Sequence

The GP30 is designed for autonomous operation. In self-controlled flow meter mode it triggers all measurements and does data processing to deliver final results, independent of external control. It can also be configured to wake up an external microcontroller for communication of results.. Alternatively, the GP30 can act as a pure converter that controls the measurement but without any data processing (time conversion mode, self-controlled). For debugging, individual tasks can also be triggered remotely by an external microcontroller (time conversion mode, remote controlled).

Table 3-1 Operating modes

Operating Mode	Measure Rate Generation	Application Setup	Post Processing
Flow meter mode (self-controlled)	by GP30	by GP30	by GP30
Time conversion mode (self-controlled)		per Remote	per Remote
Time conversion mode (remote controlled, only for test or debug purpose)	per Remote		

The various functional blocks of the TDC-GP30 are controlled by hard-wired configuration registers (CR) and system handling registers (SHR) in the random access memory area (RAA). For self-controlled applications the configurations are stored in the firmware data section FWD2 of the RAA. From there the configuration data is automatically copied into the direct mapped registers during a boot sequence. The various configuration registers and system handling registers are described in detail in section 7. The variable names are formatted in bold in this document for better reading.

In low power mode, the GP30 generally needs a 32.768 kHz oscillator to act as a continuously running clock (LSO). For time measurement the GP30 typically uses a high speed oscillator (HSO), typically featuring a 4 MHz ceramic resonator. The HSO is activated only for the short period of the measurement. In the same manner, the comparator and other analog elements are powered only for the short period of the measurement.

The low-frequency clock LSO is used as

- Base for the task sequencer cycle
- Base for the pulse interface
- Base for the time stamp
- Base for an initial UART baud rate of 4.800 baud

In self-controlled modes, the supervisor function block of TDC-GP30 fully controls the entire operation sequence. It determines cycle timing through the measurement rate generator (MRG), which triggers the task sequencer (TS). The task sequencer calls and coordinates the different tasks according to configuration.

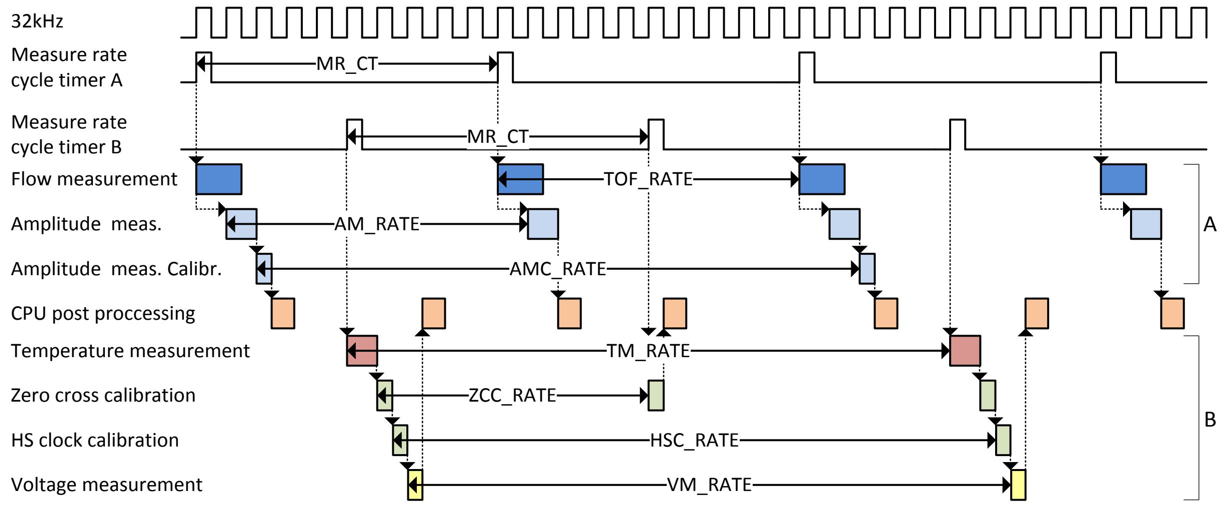
The tasks themselves can be grouped as shown in the following table.

Table 3-2 GP30 Tasks

System tasks	▪ Initialization ▪ V_{CC} voltage measurement
Frontend measurement tasks	▪ Ultrasonic measurement (time-of-flight and/or amplitude measurement) ▪ Temperature measurement (external or internal)
Frontend calibration tasks	▪ Calibration of high-speed clock ▪ Calibration of amplitude measurement ▪ Calibration of comparator offset ▪ TDC Calibration (automatically)
Post processing	▪ Activation of CPU for any calculation through firmware
Remote communication initialization	▪ Sending out communication requests to initialize remote communication

The rate of measurement and calibration tasks can be configured, while initialization, post processing and communication are typically controlled by various flags which indicate the preceding measurement processes or resets. For example, post processing by the firmware typically depends on the flag register **SRR_FEP_STF**, it decides for flow or sensor temperature calculations according to the most recent measurements done. See section 7.5 for details on status and result registers. The following figure illustrates rate settings for various tasks.

Figure 3-3 Rate settings of various tasks



The most important parameters are set in configuration registers (**CR**, see section 7.3):

Register **CR_MRG_TS**, address 0xC6

- **MR_CT**: Task sequencer cycle time. The actual physical cycle time is t_{cycle} = **MR_CT*** 976.5625 µs [0, 1…8191]. The measurement rate generator triggers measurements in two alternating channels, one **MR_CT** (A) triggering the flow and amplitude measurement, the other one (B) triggering temperature and voltage measurement as well as the high speed clock (HSO) and the comparator offset calibration. Channel B triggers a half cycle time after channel A, to avoid mutual influences among the measurements.

Register: **CR_TM**, address 0xC7

- **TM_RATE**: Defines the number of sequence cycle triggers between sensor temperature measurements [0=off, 1, 2…1023].
  The sensor temperature measurement frequency is 1 / (t_{cycle} * **TM_RATE)**

Register: **CR_USM_AM**, address 0xCB

- **AM_RATE**: Defines the number of sequence cycle triggers between amplitude measurements [0=off, 1, 2, 5, 10, 20, 50, 100].
- **AMC_RATE** sets the number of amplitude measurements between amplitude calibration measurements [0=off, 1, 2, 5, 10, 20, 50, 100].

Register: **SHR_TOF_RATE**, address 0xD0
TOF_RATE: Defines the number of sequence cycle triggers between TOF measurements [0=off, 1…63]. The TOF measurement frequency is 1 / (t_{cycle} * **TOF_RATE)** Register **CR_CPM**, address 0xC5

- **HSC_RATE**: Defines the number of sequence cycle triggers between high-speed clock calibration measurements (4 MHz ceramic against 32.768 kHz quartz) [0=off, 1, 2, 5, 10, 20, 50, 100].
- **VM_RATE**: Defines the number of sequence cycle triggers between low battery detection measurements [0=off, 1, 2, 5, 10, 20, 50, 100].

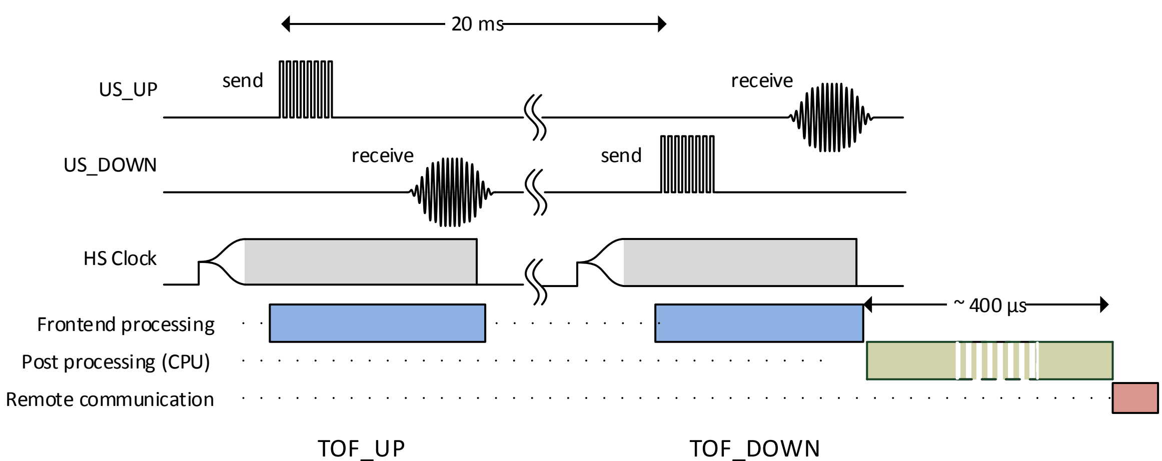
The following sections describe the front end measurement tasks in more detail.

3.2 Ultrasonic Measurement

The measurement rate generator in channel A typically triggers the task sequencer (TS) for a complete sequence of flow measurement, starting with an ultrasonic time-of-flight (TOF) measurement, and – if desired – ending in front end processing which does all necessary calculations. .The TOF measurement is made up of the two time-of-flight measurements in up and down direction (in other words, against flow and with flow). The pause time between the two measurements can be configured in multiples of ¼ period of the base frequency (50 Hz or 60 Hz) in several steps, to optimize rejection of mains frequency distortions.

The time-of-flight measurement triggers the amplitude measurement. The GP30 can automatically toggle the measurement direction sequence between up /down- and down/up-measurement from cycle to cycle. This helps suppress errors caused by temperature drift.

Figure 3-4 Timing of the ultrasonic measurement with 20 ms pause interval (example)



Important configuration parameters are:

Register **CR_CPM**, address 0xC5

- **HS_CLK_ST**: Settling time for the high-speed clock HSO, from 76 µs to 5 ms
- **BF_SEL**: Selection of base frequency (50 Hz/ 60 Hz) with period t_{base}

Register **CR_MRG**, address 0xC6

- **PP_EN**: Enables post-processing

Register **CR_USM_PRC**, address 0xC8

- **USM_TO**: sets the timeout for the TOF measurement [128 µs … 4096 µs]
- **USM_DIR_MODE**: defines start direction or the toggling of start direction
- **USM_PAUSE**: pause time between measurements [0=only one measurement, 2: 0.25* t_{base}, 3..7: 0.5..2.5*t_{base}]

Register **CR_USM_FRC**, address 0xC9

- **FPG_FP_NO**: number of fire pulses [1…128]
- **FPG_CLK_DIV**: HSO frequency divided by this factor +1 gives the actual frequency of the measurement signal (fire frequency)

Further important parameters configure the first wave detection and amplitude measurement as described in the following sections.

3.2.1 First Wave Detection

To do a time-of-flight measurement, the received signal needs to be identified and its arrival time needs to be measured thoroughly. This can be done by defining a first wave, and then counting subsequent waves and storing the relevant arrival times. This is elaborated in the following: The receive signal, typically a burst-like signal, is converted into a digital signal using an internal comparator. While receiving, the reference voltage of the comparator most of the time equals the zero line of the receive signal to identify zero crossings (Actually, the zero line is the overlaid reference voltage V_{ref}, and the comparator's reference is set to the zero cross detection level V_{ZCD}, which is calibrated to V_{ref}). This way, received wave periods are converted into digital hits. To determine an absolute numbering of the hits, a so-called first wave is defined by adding a well-defined voltage level, the first hit level (V_{FHL}), to the comparator's reference. This first wave detection, at a comparator level which differs from the zero cross level, is implemented to make the time-of-flight measurement independent from temperature and flow. The offset level V_{FHL} practically represents the level of receive signal at which the first wave is detected, which generates the first hit. After the first hit was detected, the comparator's reference is brought back to zero cross detection level (V_{ZCD}) at the 2nd hit, and the subsequent hit measurements are done at zero crossing. The following parameters define the first wave detection and the TOF hits:

- The trigger level **ZCD_FHL**, which defines the comparator offset level V_{FHL}
- The count number of the first subsequent TOF hit (TOF Start hit) which is actually measured
- The number of measured TOF hits
- The interval between measured TOF hits
- The TOF start hit delay: This delay disables hit detections for some defined lead time. This parameter is used as alternative to the first wave detection.

The diagram 3-5 below shows the measurement flow in TDC-GP30 first wave mode.

Starting the measurement with the comparator offset V_{FHL} different from zero, e.g. 100 mV, helps suppressing noise and allows the detection of a dedicated wave of the receive burst that can be used as reference. Once this first wave is detected, the offset is set back to the zero cross detection level V_{ZCD}. It is recommended to start actual TOF hit measurements after at least two more wave periods. The count number of the TOF start hit, the total number of TOF hits and the number of ignored hits between TOF hits are set by configuration. Ignored hits are in particular helpful when signal frequencies approaching half of the HSO frequency are used (e. q. 2 MHz signals when using a 4-MHz HSO). In such cases, the internal arithmetic unit is not fast enough to do all necessary calculations for each single hit, so at least every second hit must be ignored.