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Time-to-Digital Converter

Target Specification

TDC-GP2

2-channel Universal
Time-to-Digital Converter

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1 Overview

1.1 Introduction

TDC-GP2 is the next generation of acam generalpurpose TDCs. Higher resolution and smaller package size make it ideal for cost sensitive industrial applications. With special functional blocks like a fire-pulse generator, stop-enable, temperature measurement, and clock control it is perfectly suited for ultrasonic flow-meter and heat-meter applications.

1.2 Features

Measurement Mode 1

- 2 channels with typ. 50 ps resolution rms
- Measurement range 3.5 ns to 1.8 µs (0 to 1.8µs between stop channels)
- 15 ns pulse-pair resolution with 4-fold multihit capability
- 4 events can be measured arbitrarily against each other
- Trigger to rising or/and falling edge
- Windowing for precise stop enable

Measurement Mode 2

- 1 channel with typ. 50 ps resolution rms
- Measurement range 500 ns to 4 ms
- 2 x CLKHS pulse-pair resolution with 3-fold multihit capability
- Trigger to rising or/and falling edge
- Each of the 3 events can be assigned to an adjustable measuring window with 10ns resolution

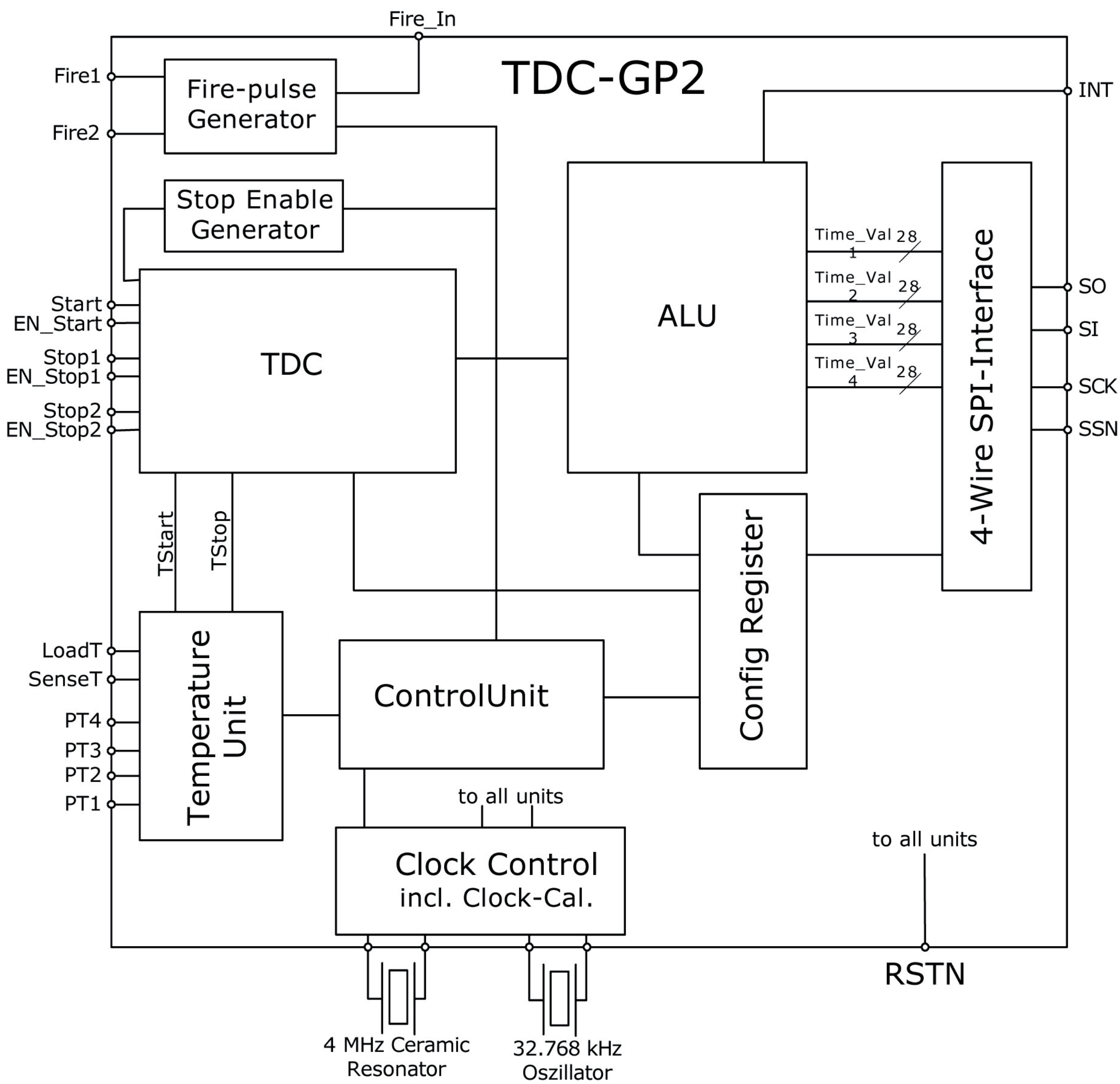
Temperature Measurement

- 2 or 4 sensors
- PT500/PT1000 or higher
- Very high resolution: 16 Bit eff. (0.004 °C resolution for platinum sensors)
- Ultra low current (0.08 µA when measuring every 30 seconds)

General

- QFN 32 package
- I/O voltage 1.8 V to 5.5 V
- Core voltage 1.8 V to 3.6 V
- 1 MHz continuous data rate max.
- Temperature range – 40 °C to 125 °C
- 4 wire SPI interface
- Fire pulse generator
- Clock calibration unit
- Precise stop enable by windowing
- Trigger to rising and/or falling edge

1.3 Blockdiagram



2 Characterisitcs & Specifications

2.1 Electrical Characteristics

Absolute Maximum Ratings

Supply voltage		
Vcc vs. GND	- 0.3 to 4.0	V
Vio vs. GND	- 0.3 to 7.0	V
Continous current into Output-Pin (Iout)	30	mA
Storage temperature (Tstg)	- 65 to 150	°C
Junction temperature (Tj)	max.125	°C

Recommended Operating Conditions

Symbol	Parameter	Conditions	Min	Typ	Max	Unit
Vcc	Core supply voltage*	Vio > Vcc	1.8		3.6	V
Vio	I/O supply voltage		1.8		5.5	V
tri	Normal Input Rising Time				50	ns
tfa	Normal Input Falling Time				50	ns
tri	Schmitt Trigger Rising Time				5	ms
tfa	Schmitt Trigger Falling Time				5	ms
Ta	Ambient Temperature	Tj must not exceed 125°C	-40		120	°C

*including the oscillator pins XIN, XOUT, Clk32In, Clk32Out

DC Characteristics (Vio = Vcc = 3.3 V ± 0.3 V, Tj = -40 to +85°C)

Symbol	Parameter	Conditions	Min	Typ	Max	Unit
I32	Current 32 kHz	Icc + Iio, only 32kHz oscillator running, Vcc = 3.6 V		4.5		µA
Ihs	Current 4 Mhz	Icc + Iio, only ClkHS running cont. at 4MHz, Vcc = 3.6 V		260		µA
Itmu	Current time measuring unit	only during active time measurement		15		mA
Iddq	Quiescent current	all clocks off, Vio = Vcc = 3.6 V @ 85 °C		<150		nA
Il	Input Leakage Current		-1		+1	µA
Voh	High Level Output Voltage	Ioh= tbd mA Vio=Min.	Vio-0.4			V

Symbol	Parameter	Conditions	Min	Typ	Max	Unit
Vol	Low Level Output Voltage	Iol = tbd mA, Vio=Min			0.4	V
Vih	High Level Input Voltage	LVTTL Level, Vio = Max.	2.0			V
Vil	Low Level Input Voltage	LVTTL Level, Vio = Min.			0.8	V
Vth	High Level Schmitt Trigger Voltage		1.1		2.4	V
Vtl	Low Level Schmitt Trigger Voltage		0.6		1.8	V
Vh	Schmitt Trigger Hysteresis		0.1			V

Terminal Capacitance

Symbol	Terminal	Condition	Rated Value			Unit
			Min.	Typ.	Max.	
Ci	Input	measured @ Vcc = Vio, f = 1 MHz, Ta = 25°C			10	pF
Co	Output				10	
Cio	Bidirectional				10	

Time Measuring Unit

Symbol	Terminal	Condition	Rated Value			Unit
			Min.	Typ.	Max.	
	LSB	Vio = Vcc = 3.3 V	-40 °C 3.6 V	25 °C 3.3 V	85 °C 3.0 V	ps
			35	63	111	
		Vio = Vcc = 2.5 V	-40 °C 2.75 V	25 °C 2.5 V	85 °C 2.25 V	
			38	76	156	
	Standard Deviation	Vio=3.3 V, Vcc =3.3 V	2.75 V	2.5 V		
		Ta = 25°C	-	50	-	

Temperature Measuring Unit

Symbol	Terminal	Condition	Rated Value			Unit
			Min.	Typ.	Max.	
	Resolution RMS	Vio = Vcc =3.3 V PT1000 150 nF Capacitance		16.0		Bit
	SNR			96		dB
	Absolute Gain-Error			0,1		%
	Gain-Drift vs. Vio			0,08		%/V
	Gain-Drift vs. Temp			0,0008		%/K
	Uncalibrated Offset			<0.01		%
	Offset Drift vs. Temp			<0,2		ppm/K
	PSRR			>100		dB

2.2 Timings

At Vcc = 3.3 V ± 0.3 V, ambient temperature -40 °C to +85 °C unless otherwise specified

Oscillator

Symbol	Parameter	Min.	Typ.	Max.	Unit
Clk32	32 kHz reference oscillator		32,768		kHz
toszst	Oscillator start-up time with ceramic resonator		200		µs
toszst	Oscillator start-up time with crystal oscillator		5		ms
ClkHS	High-speed reference oscillator	2		8	MHz

Serial Interface

Symbol	Parameter	Max. @ Vio =			Unit
		2.0 V	2.5 V	3.3 V	
fclk	Serial clock frequency	10	20	25	MHz

Symbol	Parameter	Min. @ Vio =			Unit
		2.0 V	2.5 V	3.3 V	
tpwh	Serial clock, pulse width high	50	25	20	ns
tpwl	Serial clock, pulse width low				ns
tsussn	SSN enable to valid latch clock	20	40	10	ns
tpwssn	SSN pulse width between write cycles	50	30	20	ns
thssn	SSN hold time after SCLK falling	70	40	25	ns
tsud	Data set-up time prior to SCLK falling	10	5	5	ns
thd	Data hold time before SCLK falling	10	5	5	ns

Symbol	Parameter	Max. @ Vio =			Unit
		1.8 V	2.5 V	3.3 V	
tvd	Data valid after SCLK rising	30	20	16	ns

Serial Interface (SPI compatible, Clock Phase Bit =1, Clock Polarity Bit =0):

Figure 2-1: SPI Write

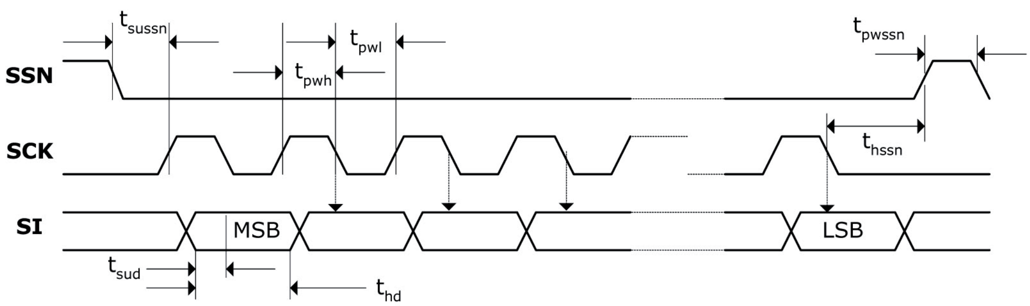
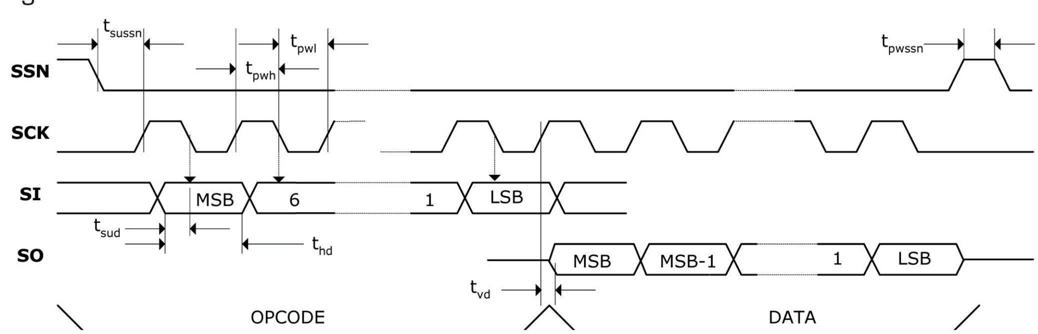


Figure 2-2: SPI Read

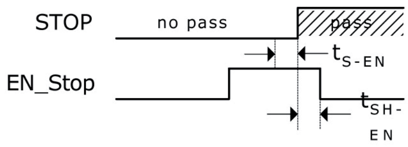


8-Bit Opcodes:

MSB							LSB	Description
1	0	0	0	0	ADR2	ADR1	ADR0	Write into address ADR
1	0	1	1	0	ADR2	ADR1	ADR0	Read from address ADR
0	1	1	1	0	0	0	0	Init
0	1	0	1	0	0	0	0	Power On Reset
0	0	0	0	0	0	0	1	Start_Cycle
0	0	0	0	0	0	1	0	Start_Temp
0	0	0	0	0	0	1	1	Start_Cal_Resonator
0	0	0	0	0	1	0	0	Start_Cal_TDC

Disable Timings

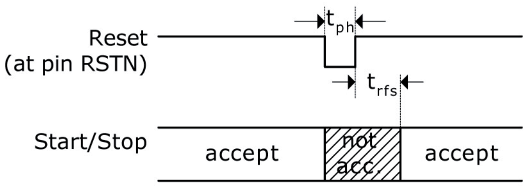
Figure 2-3:



Spec	Description	Min (ns)	Max (ns)
tS-EN	Enable Setup Time	5 ns	-
tSH-EN	Enable Hold Time	5 ns	-

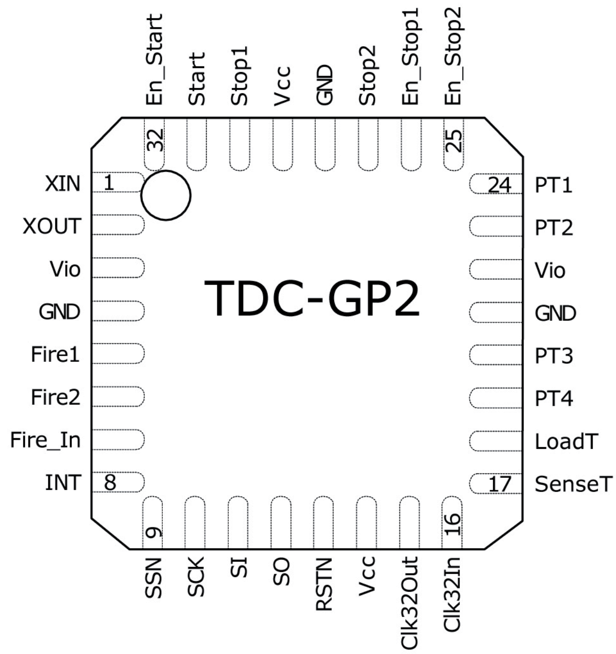
Reset Timings

Figure 2-4:



Spec	Description	Min (ns)	Max (ns)
tph	Reset pulse width	50 ns	-
trfs	Time after rising edge of reset pulse before hits are accepted	200 ns	-

2.3 Pin Description



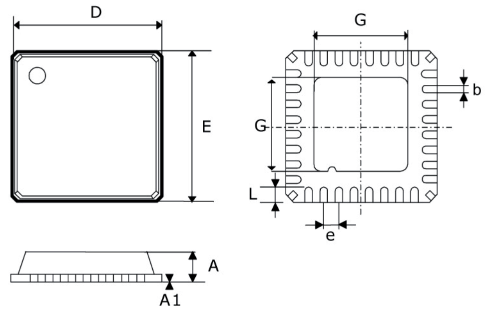
No.	Name	Description	Buffer type	Value	If not used
1	Xin	Oscillator driver in			GND
2	Xout	Oscillator driver out			
3	Vio	I/O – supply voltage			
4	GND	Ground			
5	Fire1	Fire pulse generator output 1	48 mA		
6	Fire2	Fire pulse generator output 2	48 mA		
7	Fire_In	Signal input for quasi “Sing Around”			GND
8	INTN	Interrupt flag	12 mA	LOW active	
9	SSN	Slave select	Schmitt trigger	LOW active	
10	SCK	Clock serial interface	Schmitt trigger		
11	SI	Data input serial interface	Schmitt trigger		
12	SO	Data output serial interface	12 mA tristate		
13	RSTN	Reset input	Schmitt trigger	LOW active	
14	Vcc	Core supply voltage			
15	Clk32Out	Output 32 kHz clock generator			n. c.
16	Clk32In	Input 32 kHz clock generator			GND

No.	Name	Description	Buffer type	Value	If not used
17	SenseT	Sense input temperature measurement	Schmitt trigger		GND
18	LoadT	Load output temperature measurement	24 mA		n.c.
19	PT4	Port 4 temperature measurement	48 mA		
20	PT3	Port 3 temperature measurement	48 mA		
21	GND	Ground			
22	Vio	I/O – supply voltage			
23	PT2	Port 2 temperature measurement	48 mA		
24	PT1	Port 1 temperature measurement	48 mA		
25	En_Stop2	Enable pin stop input 2	Schmitt trigger	HIGH active	Vio
26	En_Stop1	Enable pin stop input 1	Schmitt trigger	HIGH active	Vio
27	Stop2	Stop input 2			GND
28	GND	Ground			
29	Vcc	Core supply voltage			
30	Stop1	Stop input 1			GND
31	Start	Start input			
32	En_Start	Enable pin start input	Schmitt trigger	HIGH active	Vio

2.4 Package Drawings

Suitable socket: Plastronics 32QN50S15050D

Symbol	Dimension in Millimeters		
	Min.	Nom.	Max.
D	-	5	-
E	-	5	-
A	-	-	1
A1	0	-	-
b	0.17	-	0.3
e	-	0.5	-
L	0.3	-	0.5
G		3.24	



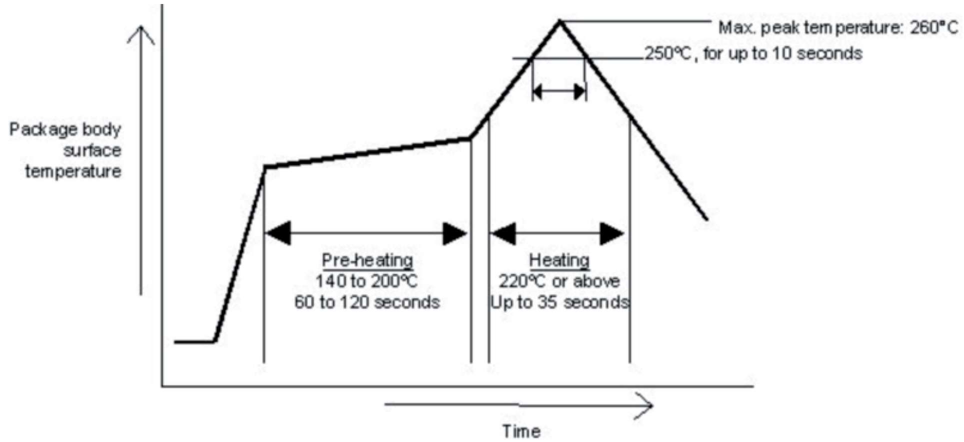
Center pad shall not be connected to GND.

Thermal resistance

Roughly 40 K/W at 0 m/s air flow, 37 K/W at 1 m/s air flow, 35 K/W at 2m/s air flow (values just for reference).

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.



Maximum temperature

The maximum temperature requirement for the resin surface, given 260°C as the peak temperature of the package body's surface, is that the resin surface temperature must not exceed 250°C 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 for short periods only is recommended. In addition to using a suitable temperature profile, we also recommend that you check carefully to confirm good soldering results.

2.5 Power Supply

Supply voltage

Although the TDC-GP2 is a fully digital circuit, some analog measures affect the circuit. The reason is that the TDC is based on the internal analog measure ‚propagation delay time' which is influenced by temperature and supply voltage. A good layout of the supply voltage is essential for good measurement results. It should be high capacitive and of low in-ductance.

The TDC-GP2 provides two pairs of power supply terminals:

Vio - I/O supply voltage

Vcc - Core supply voltage

All ground pins should be connected to a ground plane on the printed circuit board. Vio and Vcc should be provided by a battery or fixed linear voltage regulator. Do not use switched regulators to avoid disturbances caused by the I/O supply.

The measurement quality of a time-to-digital converter depends on a good power supply. The chip sees mainly pulsed current and therefore a sufficient bypassing is mandatory:

Vcc	100 µF	(minmum 47 µF)
Vio	10 µF	(minimum 1 µF)

The supply voltage should be provided through analog regulators. We strongly recommend not to use switch mode power supplies.

Current consumption

The current consumption is the sum from different parties (all data for Vio = Vcc = 3.6V):

Iddq	< 150 nA	Quiescent current,
I32	typ. 4.5 µA	Current into the 32 kHz oscillator, turned on only if the 32 kHz oscillator is connected
Ihs	typ. 260 µA/s * (active runtime)	Current into the high speed oscillator, Example: In ultrasonic flow-meters the high-speed oscillator is on for about 2ms only. The average current consumption is 260 µA/s * 2 ms = 0.52 µA
Itmu	typ. 15 mA/s * (active measuring time)	Current into the time measuring unit, In measurement range 1 the time measuring unit is active for the start-stop time inter val plus the calibration time interval of 2 periods of the refe rence clock per measurement. In measurement range 2 the time measuring unit is on for average 4 periods of the reference clock per measurement, two for the time measurement and two for calibration. Example: With 10 measurements per second in measurement range 2 and a 4 MHz reference clock the time measuring unit is active for only about 10 µs. The average current is 15 mA/s * 10 µs = 0.150 µA.
Ialu	typ. 7 nA per calculation	Current into ALU during data proccesing including a calibration calculation. Example: At 1000 measurements per second with 3 stops per

		start the ALU average current is 7 nA * 3000 = 21 µA.
IT	typ. 2.5 µAs * measure rate	The current for a full temperature measurement is typ.2.5µAs. In heat-meters the temperature is measured typically once every 30 seconds. The average current is about 0.085 µA

2.6 Register settings

Service bits are for acam testing and security purposes only, Please use the recommended values.

2.6.1 Write registers

Default values in second rows

Bit	Reg0	(*)	Reg1	(*)	Reg2	(*)	Reg3	(*)	Reg4	(*)	Reg5	(*)
23	FIRE#	0	HIT2	0	EN_INT	0	s.c.	0	s.c.	0	CONF_FIRE	0
22		0		1		0	s.c.	0	s.c.	0		0
21		0		0		1	EN_ERR_VAL	0	s.c.	1		0
20		0		1	RFEDGE2	0	SEL_TIMO_MR2	1	s.c.	0	EN_STARTNOISE	0
19	DIV_FIRE	0	HIT1	0	RFEDGE1	0		1	s.c.	0	DIS_PhaseNoise	0
18		0		1	DELVAL1	0	DELVAL2	0	DELVAL3	0	REPEAT_FIRE	0
17		0		0		0		0		0		0
16		0		1		0		0		0		0
15	CALRES#	0	EN_FAST_INIT	0		0		0		0	PHASE_FIRE	0
14		0	s.c.	1		0		0		0		0
13	ClkHSDiv	0	HITIN2	0		0		0		0		0
12		0		0		0		0		0		0
11	START_ClkHS	0		0		0		0		0		0
10		1	HITIN1	0		0		0		0		0
9	PORT#	1		0		0		0		0		0
8	TCycle	0		0		0		0		0		0
7	No_FAKE	0	n.c	0		0		0		0		0
6	SelClkT	1	n.c	0		0		0		0		0
5	Calibrate	1	n.c	0		0		0		0		0
4	DisAutoCal	0	n.c	0		0		0		0		0
3	MRange2	1	n.c	0		0		0		0		0
2	NEG_STOP2	0	n.c	0		0		0		0		0
1	NEG_STOP1	0	n.c	0		0		0		0		0
0	NEG_START	0	n.c	0		0		0		0		0

s.c. = Special acam configuration bits, n.c. = not in use

(*) = Default value after Power On Reset

Short description of the bits:

Bits	Name	Descritpion	Value
Reg 0			
0	NEG_START	Negation start input	0 = non-inverted input signal – rising edge 1 = inverted input signal – falling edge
1	NEG_STOP1	Negation stop 1 input	0 = non-inverted input signal – rising edge 1 = inverted input signal – falling edge
2	NEG_STOP2	Negation stop 2 input	0 = non-inverted input signal – rising edge 1 = inverted input signal – falling edge
3	MRange2	Switch to measurement range 2	0 = measurement range 1 1 = measurement range 2
4	DisAutoCal	Enables/disables auto-calibration run in the TDC	0 = auto-calibration after measurement 1 = auto-calibration disabled
5	Calibrate	Enables/disables calibration calculation in the ALU	0 = calibration off (only MR 1) 1 = calibration on
6	SelClkT	Select reference signal for internal cycle clock for tem-perature measurement	0 = use 32,768 kHz as cycle clock 1 = use 128 * CLKHS as period for cycle clock (32µs with 4 MHZ high speed clock signal)
7	FAKE#	Number of dummy cycles at the beginning of a tempera-ture measurement	0 = 2 Fake measurements 1 = 7 Fake measurements
8	TCycle	Sets cycle time for tempera-ture measurement	0 = 128 µs cycle time @ 4 MHz 1 = 512 µs cycle time @ 4 MHz (recommended)
9	PORT#	Sets number of ports used for temperature measure-ment	0 = 2 temperature ports (PT1 and PT2) 1 = 4 temperature ports
10-11	START_CLKHS	Switch on high-speed oscilla-tor	0 = Oscillator off 1 = Oscillator on 2 = settling time = 640 µs 3 = settling time = 1280 µs (see Bug Report)
12-13	ClkHSDiv	Sets predivider for CLKHS	0 = divided by 1 1 = divided by 2 2 = divided by 4 3 = divided by 4
14-15	CALRES#	Sets number of periods used for calibrating the ceramic resonator	0 = 2 periods = 61.035 µs 1 = 4 periods = 122.07 µs 2 = 8 periods = 244.14 µs 3 = 16 periods = 488.281 µs
16-19	DIV_FIRE	Sets predivider for internal clock signal of fire pulse generator	0 = not permitted1 = divided by 2 2 = divided by 3 3.= divided by 4 … 15 = divided by 16

20-23	FIRE#	Sets number of pulses gen-erated by fire pulse generator	0 = off 1 = 1 pulse 2 = 2 pulses 3 = 3 pulses ... 15 = 15 pulses

Reg 1				
8-10	HITIN1	Number of expected hits on channel 1	0 = stop channel 1 disabled 1 = 1 hit 2 = 2 hits 3 = 3 hits 4 = 4 hits 5 to 7 = not permitted	
11-13	HITIN2	Number of expected hits on channel 2	0 = stop channel 2 disabled 1 = 1 hit 2 = 2 hits 3 = 3 hits 4 = 4 hits 5 to 7 = not permitted	
15	EN_FAST_INIT	Enables fast init operation	0 = Fast init mode disabled 1 = Fast init mode enabled	
16-19	HIT1	Defines operator for ALU data post-processing MRange1: HIT1-HIT2 MRange2: HIT2-Start	MRange1: 0 = Start 1 = 1. Stop Ch1 2 = 2. Stop Ch1 3 = 3. Stop Ch1 4 = 4. Stop Ch1 5 = no action 6 = Cal1 Ch1 7 = Cal2 Ch1 9 = 1. Stop Ch2 A = 2. Stop Ch2 B = 3. Stop Ch2 C = 4. Stop Ch2	MRange2: 1 = Start
20-23	HIT2	Defines operator for ALU data post-processing MRange1: HIT1-HIT2 MRange2: HIT2-Start	MRange1: 0 = Start 1 = 1. Stop Ch1 2 = 2. Stop Ch1 3 = 3. Stop Ch1 4 = 4. Stop Ch1 5 = no action 6 = Cal1 Ch1 7 = Cal2 Ch1 9 = 1. Stop Ch2 A = 2. Stop Ch2 B = 3. Stop Ch2 C = 4. Stop Ch2	MRange2: 2 = 1. Stop Ch1 3 = 2. Stop Ch1 4 = 3. Stop Ch1

Reg 2			
0-18	DELVAL1	Delay value for internal stop enable unit, hit 1 channel 1. Fixed point number with 14 integer and 5 fractional digits in multiples of Tref	DELVAL1 = 0 to 16383.96875
19	RFEDGE1	Edge sensitivity channel 1	0 = rising or falling edge 1 = rising and falling edge
20	RFEDGE2	Edge sensitivity channel 1	0 = rising or falling edge 1 = rising and falling edge
21-23	EN_INT	Activates interrupt sources wired by OR	Bit 23 = Timeout interrupt enable Bit 22 = End Hits interrupt enable Bit 21 = ALU interrupt enable

Reg 3			
0-18	DELVAL2	Delay value for internal stop enable unit, hit 2 channel 1. Fixed point number with 14 integer and 5 fractional digits in multiples of Tref	DELVAL1 = 0 to 16383.96875
19-20	SEL_TIMO_MR2	Select predivider for timeout in measurement range 2	0 = 64 µs 1 = 256 µs 2 = 1024 µs 3 = 4096 µs @ 4 MHz ClkHS
21	EN_ERR_VAL	Timeout forces ALU to write 0xFFFFFFFF into the output register	0 = disabled 1 = enabled

Reg 4			
0-18	DELVAL1	Delay value for internal stop enable unit, hit 3 channel 1. Fixed point number with 14 integer and 5 fractional digits in multiples of Tref	DELVAL1 = 0 to 16383.96875

Reg 5			
0-15	PHASE_FIRE	Enables phase reversing for each pulse of a sequence of up to 15 possible pulses	0 = no inversion 1 = inversion
16-18	REPEAT_FIRE	Number of pulse sequnce repetition for "quasi-sing-arround"	0 = no signal repetition 1 = 1 signal repetition 2 = 2 signal repetition ... 7 = 7 signal repetition
19	DIS_PHASENOISE	Phase noise unit, has to be disabled, See bug report section 7.2	1 = disable phase shift Setting 1 is mandatory
20	EN_STARTNOISE	Enables additional noise for start channel	1 = switch on noise unit
21-23	CONF_FIRE	Output configuration for pulse generator	Bit 23 = 1: negate output Fire2 Bit 22 = 1: disable output Fire2 Bit 21 = 1: disable output Fire1

2.6.2 Read registers / Output data format

ADR	Symbol	Bits	Description							
0	RES_0	32	Measurement result 1, fixed-point number with 16 integer and 16 fractional digits 2^{15} ... 2^{0},2^{-1} ... 2^{-16}							
1	RES_1	32	Measurement result 2, fixed-point number with 16 integer and 16 fractional digits							
2	RES_2	32	Measurement result 3, fixed-point number with 16 integer and 16 fractional digits							
3	RES_3	32	Measurement result 4, fixed-point number with 16 integer and 16 fractional digits							
4	STAT	16	15 - 13	12	11	10	9	8 - 6	5 - 3	2 - 0
			n.c.	Error short	Error open	Timeout Precounter	Timeout TDC	# of hits Ch2	# of hits Ch1	Pointer result register
5	REG_1	8	Content of highest 8 Bits of write register 1, to be used for testing the communication							

The data structure and the occupancy of the result registers depends on the operation mode and whether calibrated or non-calibrated data are stored. Several cases must be distinguished:

- Only in measurement range 1 negative results are possible.
- In measurement range 2 only positive results are possible, given as unsigned numbers.
- A non-calibrated measurement is only possible in measurement range 1.
- In measurement range 1 with calibrated data (ALU) the time intervals that have to be measured can not exceed twice the period of the calibration clock. When measuring bigger time intervals an ALU - overflow will occur and 0xFFFFFFFF is written in the appropriate result register.

a. Measurement range 1 with calibrated data (Calibrate = 1)

The results are given in multiples of the internal reference clock (= external reference clock divided by 1, 2 or 4 (DIV_CLKHS)). Calibrated data are 32 bit fixed point numbers with 16 integer bits and 16 fractional bits. Any calibrated result covers therefore 1 result register. The serial output begins with the highest bit (2^{15}) and ends with the lowest one (2^{-16}). The numbers are available in complements of 2.

$$Time = RES\_X * T_{ref} * 2^{ClkHSDiv} = RES\_X * T_{ref} * N \text{ , with } N = 1, 2 \text{ or } 4$$

$$Time < 2 * T_{ref} * 2^{ClkHSDiv}$$

b. Measurement range 1 without calibration (Calibrate = 0)

Non-calibrated data are of the type ‚Signed Integer' and are stored as a 16 bit value in the high word of the result registers. The bits of the low word are set to zero. The result is represented as number of LSB and is available in complements of 2.

$$Time = RES\_X * LSB \sim RES\_X * 65 \text{ ps}$$

c. Measurement range 2

In measurement range 2 the TDC-GP2 only supports calibrated measurement. The results are given in multiples of the internal reference clock (= external reference clock divided by 1, 2 or 4 (DIV_CLKHS)). Calibrated data are 32 bit fixed point numbers with 16 integer bits and 16 fractional bits. Any calibrated result covers therefore 1 result register. The serial output begins with the highest bit (2^{15}) and ends with the lowest one (2^{-16}). The numbers are available in complements of 2.

$$Time = RES\_X * T_{ref} * 2^{ClkHSDiv} = RES\_X * T_{ref} * N \text{ , with } N = 1, 2 \text{ or } 4$$

d. Temperature measurement

Discharge tiem in the same format as in c. measurement mode 2.

2.6.3 Status register

Bits	Name	Description	Values
2 – 0	Pointer result register	Pointer to the next free result register	
5 – 3	# of hits Ch 1	Number of hits registered on channel 1	
8 – 6	# of hits Ch 2	Number of hits registered on channel 2	
9	Timeout TDC	Indicates an overflow of the TDC unit	1 = overflow
10	Timeout Precounter	Indicates an overflow of the 14 bit precounter in MR 2	1 = overflow
11	Error open	Indicates an open sensor at temperature measurement	1 = open
12	Error short	Indicates a shorted sensor at temperature measurement	1 = short

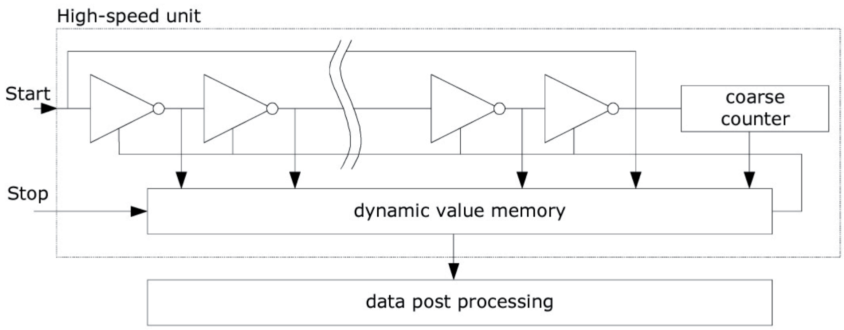
3 Measurement Mode 1

3.1 General Description

- 2 stop channels referring to one start channel
- Each of typ. 50 ps RMS resolution
- LSB width typ. 65 ps
- 15 ns pulse pair resolution
- 4-fold multihit capability for each stop channel
- Measurement range 3.5 to 1.8 µs (0 to 1.8µs between stop channels)
- Selectable rising/falling edge sensitivity for each channel
- Enable pins for powerful windowing functionality
- The possibility to arbitrarily measure all events against each other

Digital TDCs use internal propagation delays of signals through gates to measure time intervals with very high precision. Figure 5 clarifies the principal structure of such an absolute-time TDC. Intelligent circuit structures, redundant circuitry and special methods of layout on the chip make it possible to reconstruct the exact number of gates passed by the signal. The maximum possible resolution strongly depends on the maximum possible gate propagation delay on the chip.

Figure 3-1



The measuring unit is actuated by a START signal and stopped by a STOP signal. Based on the position of the ring oscillator and the coarse counter the time interval between START and STOP is calculated with a 20 Bit measurement range.

The BIN size (LSB) is typically 65 ps at 3.3 V and 25 °C ambient temperature. The RMS noise is about 50 ps (0.7 LSB). The gate propagation delay times strongly depend on temperature and voltage. Usually this is solved doing a calibration. During such a calibration the TDC measures 1 and 2 periods of the reference clock.

The measurement range is limited by size of the counter:

$$t_{yy} = BIN \times 26224 \sim 1.8\ \mu s$$

	Time (Condition)	Description
tph	2,5 ns (min.)	Minimum pulse width
tpl	2,5 ns (min.)	Minimum pulse width
tss	3.5 ns ns (min) 1.8 µs (max.)	Start to Stop
trr	15 ns (typ.)	Rising edge to rising edge
tff	15 ns (typ.)	
tva	560 ns uncalibrated 4.6 µs calibrated	Last hit to data valid
txx	No timing limits	
tyy	1,8 µs (max)	Max. measuring range

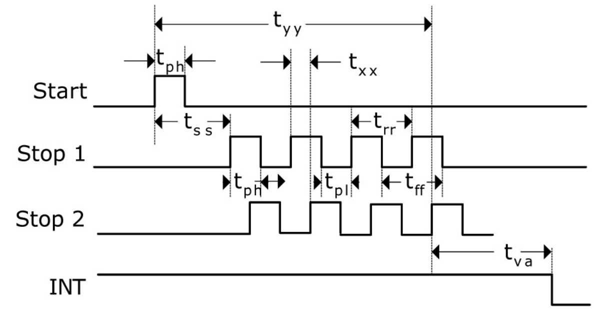


Figure 3-2

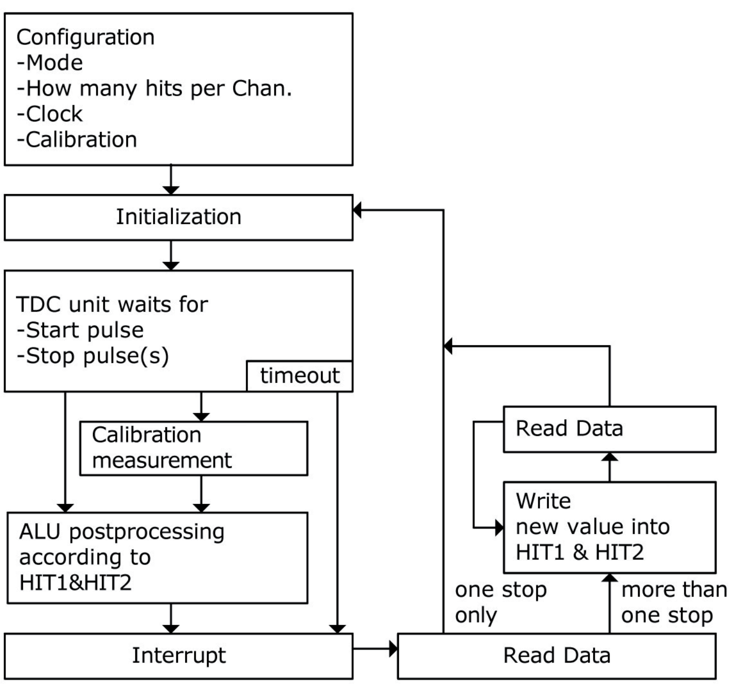
Input circuitry

Each input separately can be set to be sensitive to rising or falling edge or both edges. This is done in register 0, Bits 0 to 2. (NEG_START, NEG_STOP1, NEG_STOP2) and register 2, Bit 19&20, RFEDGEx.

Furthermore all Start/Stop-inputs support a high active enable pin.

3.2 Measurement Flow

Figure 3-3



3.2.1 Configuration

At the beginning the TDC-GP2 has to be configured. The main settings for measurement range 1 are:

a. Select measurement range1

setting register 0, Bit3, MRange2 = 0.

b. Select the reference clock

(see also section 5.1)

Register 0, Bits 10&11, START_CLKHS defines the switch-on behavior of the high-speed clock. If only the 32kHz is used this is be set to „0“. If only the high-speed clock is used this is be set to „1“(continuously on). In case both oscillators are used for current saving reasons this should be set to „2“ for ceramic oscillators and to „3“ for quartz oscillators“.

Register 0, Bits 12&13, ClkHSDiv sets an additional internal divider for the reference clock (1,2 or 4). This is important for calibrated measurements in measurement range 1 because the ALU works correctly only if 2*Tref(intern) is bigger than the maximum time interval to be measured. Otherwise the ALU output is 0xFFFFFFFF.
Make also sure that 2*Tref(intern) < 1.8 µs to avoid a timeout during calibration.

c. Set the number of expected hits
In register 1, Bits 8 to 10 and 11 to 13, HITIN1 and HITIN2 the user has to define the number of hits the TDC-GP2 has to wait for. A maximum of 4 on each channel is possible. The TDC-GP2 measures until the set number of hits is registered or a timeout occurs.

d. Select calibration
As the BIN size varies with temperature and voltage the TDC-GP2 ALU can internally calibrate the results. This option is switched on by setting register 0, Bit5, Calibrate = „1“. It is recommended to do this.

For the calibration the TDC measures 1 and 2 cycles of the reference clock. The two data are stored as Cal1 and Cal2.

There are two ways to update the calibration data Cal1 and Cal2:
- Separate calibration by sending opcode Start_Cal_TDC via the SPI interface
- Automatic update by setting register 0, Bit 4, DisAutoCal = „0“. In most applications this will be the preferred setting.

e. Define ALU data processing
While the TDC unit can measure up to 4 hits on each channel the user is free in his definition what the ALU shall calculate. The settings are done in register 1, Bits 16 to 19 and 20 to 23, HIT1 and HIT2. Both parameters can be set to:

0 = Start	
1 = 1. Stop Ch1	9 = 1. Stop Ch2
2 = 2. Stop Ch1	A = 2. Stop Ch2