Time-to-Digital Converter

Overview

MS1002 is the next generation general purpose TDC. 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.

QFN-32

LQFP32

Features

Measurement Mode 1

- 2 channels with typ.50 ps resolution rms
- Measurement range 0 to 1.8us
- 15 ns pulse pair resolution with 4 fold multi-hit
- 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 500ns to 4ms
- 2×CLKHS pulse pair resolution with 3 fold multi-hit capability
- Trigger to rising or/and falling edge
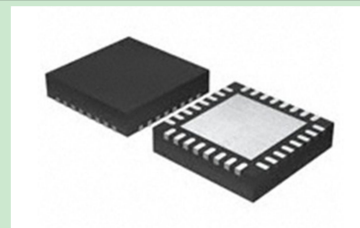- Windowing for precise stop enable

Temperature Measurement

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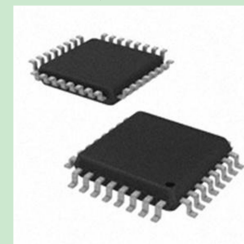- Ultra low current (0.08 μA when measuring every 30 seconds)

General：

- 4 wire SPI interface
- 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 to 125℃
- Fire pulse generator
- Clock calibration unit
- Precise stop enable by windowing
- Trigger to rising and/or falling edge

Application

- ultrasonic flow-meter
- heat-meter applications
- Ultrasonic density meter
- Magnetostriction apparatus
- Laser range finder
- Laser scanner
- The field of scientific research
- ATE(Automatic Test Equipment)
- OTDR(Optical Time-Domain Reflectometer)

Package

Product	Package	label
MS1002	QFN-32	MS1002
MS1002P	LQFP32	MS1002P

MS1002 and MS1002P'difference is only the package.

Block Diagram
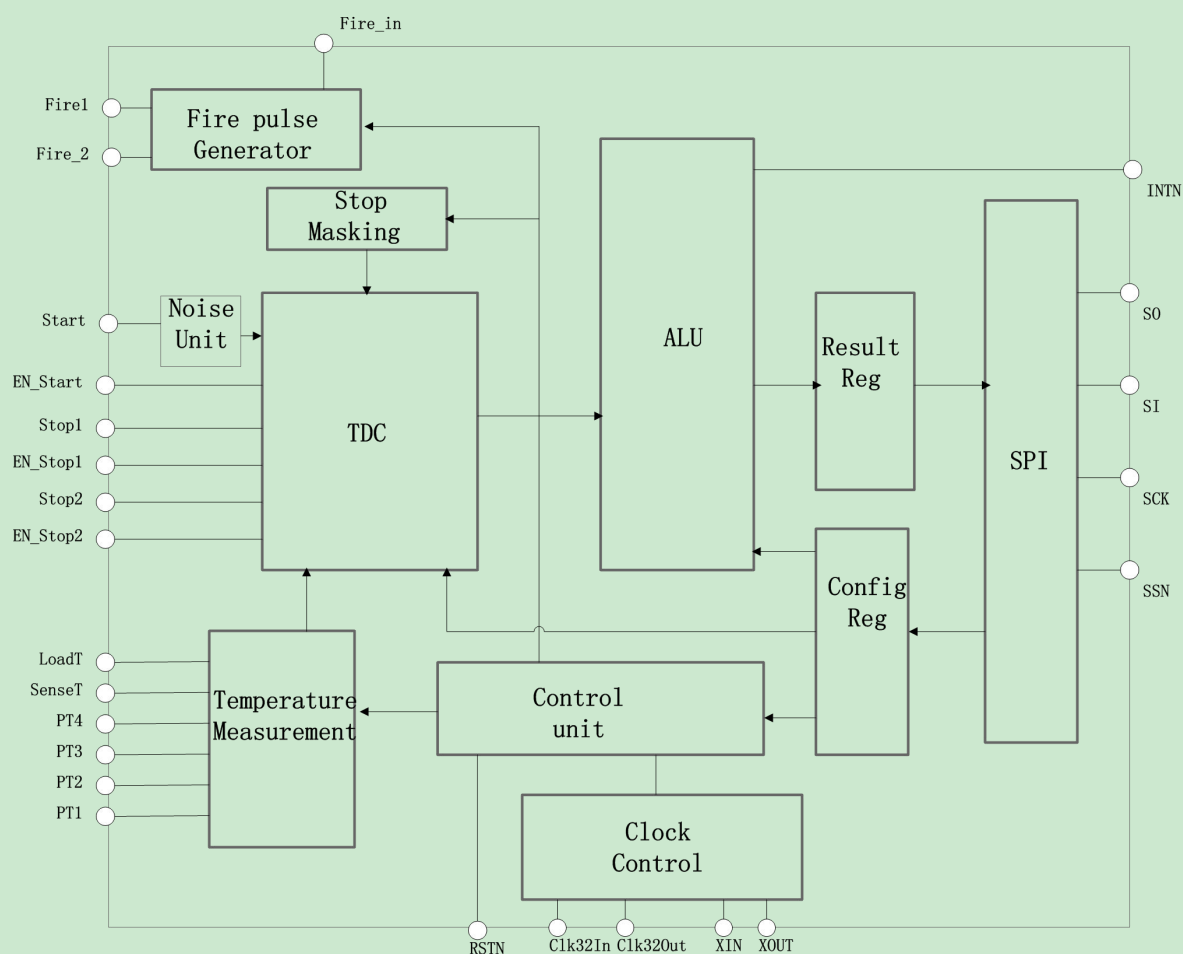
Absolute Maximum Ratings

Parameter	Symbol	Range	Unit
Core supply voltage	V_{cc}	-0.3～4	V
I/O supply voltage	V_{io}	-0.3～7	V
Continuous current into Output-Pin	Iout	30	mA
Storage temperature	T_{stg}	-55～150	°C
Junction temperature	T_j	125	°C
ESD	HBM	>2	kV

Electrical Characteristics

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
T_{ri}	Normal input rising time				50	ns
T_{fa}	Normal input falling time				50	ns
T_{ri}	Schmitt trigger rising time				5	ms
T_{fa}	Schmitt trigger falling time				5	ms
T_a	Ambient temperature	Tj must not exceed 125℃	-40		120	℃

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

DC Characteristics (Vio = Vcc = 3.0 V, Tj = -40 到 +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
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	

Conversion Characteristics

Time Measuring Unit(V_{io}=V_{cc}=3.0V,T_j=25℃)

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

Timings

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

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

串行接口

Symbol	Parameter	Max. @ Vio =			Unit
		2.0 V	2.5V	3.3V	
fclk	Serial clock frequency	10	20	25	MHz
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
tvd	Data valid after SCLK rising	30	20	16	ns

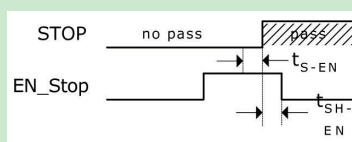Serial Interface (SPI compatible, Clock Phase Bit =1, Clock Polarity Bit =0):

SPI Write
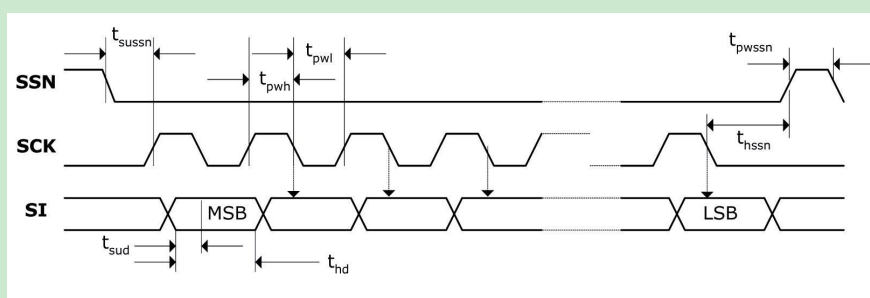
SPI Read
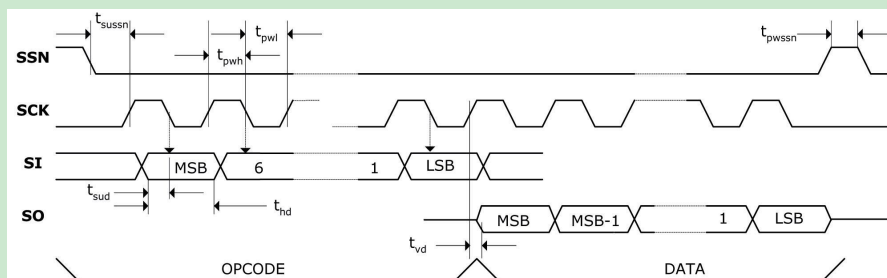
8 Bit Opcodes

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

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

Reset Timings
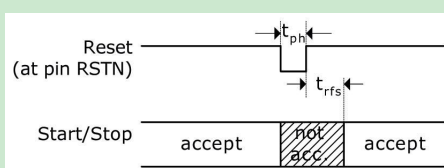
| Spec	Description	Min[ns]	Max[ns]
tph	Reset pulse width	50ns	-
trfs	Time after rising edge of reset pulse before hits are accepted	200ns	-

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 re-flow 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.
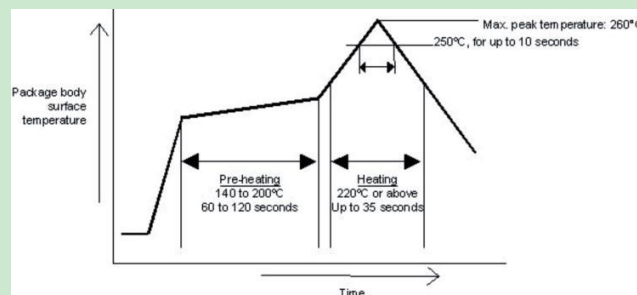
MS1002 Pinout
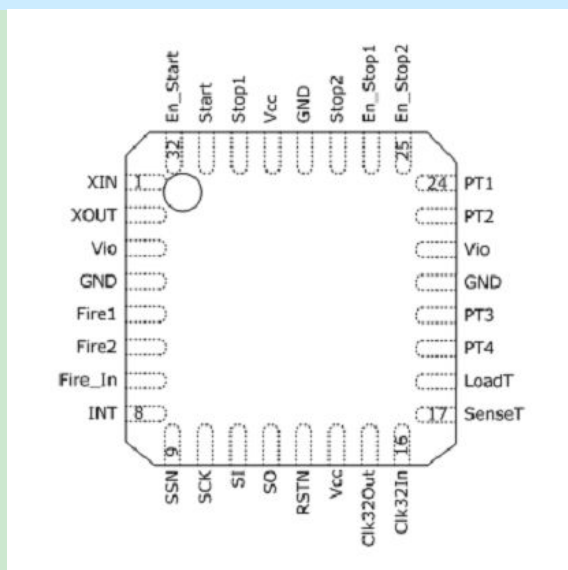
Pin Description

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	48mA		
6	Fire2	Fire pulse generator output 2	48mA		
7	Fire_In	Signal input for quasi"Sing Around"			GND
8	INTN	Interrupt flag	12mA	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	12mA tristate		
13	RSTN	Reset input	Schmitt trigger	LOW active	
14	Vcc	Core supply voltage			
15	Clk32Out	Output 32KHz clock generator			n.c.
16	Clk32In	Input 32KHz clock generator			GND
17	SenseT	Sense input temperature measurement	Schmitt trigger		GND
18	LoadT	Load output temperature measurement	24mA		
19	PT4	Port4 temperature measurement	48mA		
20	PT3	Port3 temperature measurement	48mA		

21	GND	Ground			
22	Vio	I/O-supply voltage			
23	PT2	Port2 temperature measurement	48mA		
24	PT1	Port1 temperature measurement	48mA		
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

Power Supply

Although the MS1002 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 inductance.

◆   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.

Current consumption

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

Iddq	< 150 nA	Quiescent current
I32	typical 4.5 µA	Current into the 32 kHz oscillator, turned on only if the 32 kHz oscillator is connected.
Ihs	typical 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	typical 15 mA/s	Current into the time measuring unit, In measurement range 1the time measuring unit is active for the start-stop time interval plus the calibration time interval of 2 periods of the reference 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	typical 7 nA per calculation	Current into ALU during data processing 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	typical 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

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

1. registers

Default values in second rows.

Reg0~Reg2

Bit	Reg0	*def	Reg1	*def	Reg2	*def
23		0		0		0
22	FIRE#	0	HIT2	1	EN_INT	0
21		1		0		1
20		0		1	RFEDGE2	0
19		0		0	RFEDGE1	0
18	DIV_FIRE	0	HIT1	1		0
17		1		0		0
16		0		1		0
15	CALRES#	0	EN_FAST_INIT	0		0
14		0	s.c.	1		0
13	ClkHSDiv	0		0		0
12		0	HITIN2	0		0
11	START_ClkHS	0		0		0
10		1		0		0
9	PORT#	1	HITIN1	0	DELVAL1	0
8	TCycle	0		0		0
7	FAKE	0	n.c.	0		0
6	SelClkT	1	n.c.	0		0
5	Calibrate	1	n.c.	0		0
4	DisAutoCal	0	n.c.	0		0
3	MRange2	1	n.c.	0		0
2	NEG_STOP2	0	n.c.	0		0
1	NEG_STOP1	0	n.c.	0		0
0	NEG_START	0	n.c.	0		0

Reg3~Reg5：

Bit	Reg3	*def	Reg4	*def	Reg5	参数
23	s.c.	0	s.c.	0		0
22	s.c.	0	s.c.	0	CONF_FIRE	0
21	EN_ERR_VAL	0	s.c.	1		0
20	SEL_TIMO_MR	1	s.c.	0	EN_STARTNoise	0

19	2	1	s.c.	0	DIS_PhaseNoise	0
18		0		0	REPEAT_FIRE	0
17		0		0	REPEAT_FIRE	0
16		0		0		0
15		0		0		0
14		0		0		0
13		0		0		0
12		0		0		0
11		0		0		0
10		0		0		0
9	DELVAL2	0	DELVAL3	0		0
8		0		0	PHASE_FIRE	0
7		0		0		0
6		0		0		0
5		0		0		0
4		0		0		0
3		0		0		0
2		0		0		0
1		0		0		0
0		0		0		0

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

(*) = Default value after Power On Reset

寄存器各位的简单描述

Bits	Symbol	Description	Value
Reg0			
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	disables auto-calibration run in the TDC	0 = auto-calibration after measurement 1 = auto-calibration disabled
5	Calibrate	Enables calibration calculation in the ALU	0 = calibration off (only MR 1) 1 = calibration on

6	SelClkT	Select reference signal for internal cycle clock for temperature measurement	0 = 32.768 kHz as cycle clock 1 = 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 temperature measurement	0 = 2Fake measurements 1 = 7 Fake measurements
8	TCycle	Sets cycle time for temperature 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 measurement	0 = 2 temperature ports (PT1 and PT2) 1 = 4 temperature ports
10-11	START_CLKHS	Switch on high-speed oscillator	0 = Oscillator off 1 = Oscillator on 2 = settling time = 640 μs 3 = settling time = 1280 μs (see Bug Report)
12-13	ClkHSDiv	Sets pre divider 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 pre divider for internal clock signal of fire pulse generator	0 = not permitted 1 = divided by 2 2 = divided by 3 3 = divided by 4 … 15 =divided by 16
20-23	FIRE#	Sets number of pulses generated by fire pulse generator	0 = off 1 = 1 pulse 2 = 2 pulses 3 = 3 pulses … 15 = 15 pulses

Reg1				
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 initial operation	0 = Fast initial mode disabled 1 = Fast initial mode enabled	
16-19	HIT1	Defines operator for ALU data post-processing MRange1: HIT1-HIT2 MRange2: HIT2-Start	MRange1: 0 = Start 1 = 1st Stop Ch1 2 = 2nd Stop Ch1 3 = 3rd Stop Ch1 4 = 4th Stop Ch1 5 = no action 6 = Cal1 Ch1 7 = Cal2 Ch1 9 = 1st Stop Ch2 A = 2nd Stop Ch2 B = 3rd Stop Ch2 C = 4th 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 = 1st Stop Ch1 2 = 2nd Stop Ch1 3 = 3rd Stop Ch1 4 = 4th Stop Ch1 5 = no action 6 = Cal1 Ch1 7 = Cal2 Ch1 9 = 1st Stop Ch2 A = 2nd Stop Ch2 B = 3rd Stop Ch2 C = 4th Stop Ch2	MRange2: 2 = 1st Stop Ch1 3 = 2nd Stop Ch1 4 = 3rd Stop Ch1

Reg2			
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

Reg3			
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	DELVAL2 = 0 to 16383.96875
19-20	SEL_TIMO_MR2	Select pre divider for timeout in measurement range 2	3 = 4.096ms 2 = 1.024ms 1 = 256µs 0 = 64µs @ 4 MHZ CLKHS
21	EN_ERR_VAL	Timeout forces ALU to write 0xFFFFFFFF into the output register	0 = disabled 1 = enabled

Reg4			
0-18	DELVAL3	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	DELVAL3 = 0 … 16383.96875

Reg5			
0-15	PHASE_FIRE	Enables phase reversing for each pulse of a sequence of up to 15 possible pulses 位	0 = no inversion 1 = no inversion
16-18	REPEAT_FIRE	Number of pulse sequence repetition for quasi-sing-around	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	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 Fire 2 Bit 22 = 1 negate output Fire 2 Bit 21 = 1 negate output Fire 1

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 Pre counter	Time out TDC	Hits of Ch2	Hits of 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:

1. Only in measurement range 1 negative results are possible.
2. In measurement range 2 only positive results are possible, given as unsigned numbers.
3. 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.

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

$$Time < 2 \times T_{ref} \times 2^{ClkHSDiv}$$

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.

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

c．Measurement range 2

In measurement range 2 the MS1002 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.

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

Status register

Bits	Symbol	Description	Values
0-2	Pointer Result-Register	Pointer to the next free result register	
3-5	# of Hits Ch 1	Number of hits registered on channel 1	
6-8	# of hits Ch 2	Number of hits registered on channel 2	
9	Timeout TDC	Indicates an overflow of the TDC unit	1 = overfow
10	Timeout Pre counter	Indicates an overflow of the 14 bit pre counter in MR 2	1 = overfow
11	Error open	Indicates an open sensor at temperature measurement	1 = open
12	Error short	Indicates a shorted sensor at temperature measurement	1 = short

2. Measurement Mode 1

2.1 General Description

a. 2 stop channels referring to one start channel
b. Each of typ. 50 ps RMS resolution
c. LSB width typ. 65 ps
d. 15 ns pulse pair resolution
e. 4-fold multihit capability for each stop channel
f. Measurement range 3.5 to 1.8 μs (0 to 1.8μs between stop channels)
g. 每 Selectable rising/falling edge sensitivity for each channel
h. Enable pins for powerful windowing functionality
i. 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. The following figure 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.
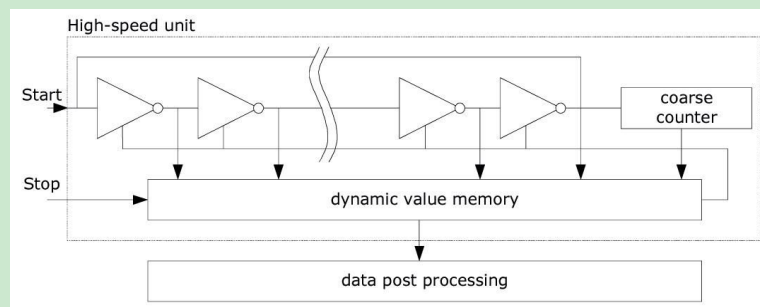
The measuring unit is actuated by a START signal and stopped by a STOP signal. Based on the position of the ring oscillator and the coarse counter the time interval between START and STOP is calculated with a 20 Bit measurement rang

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:

$$t_{yy} = BIN \times 26224 = 1.8 \ \mu s$$
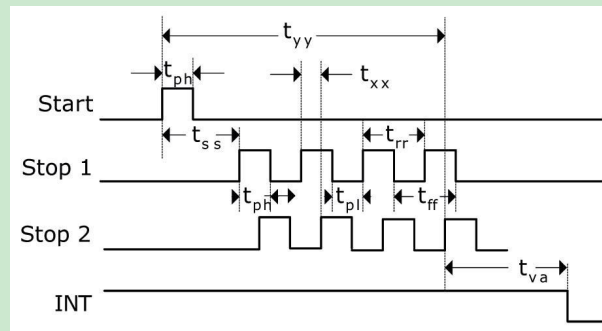
|	Time (Condition)	Description
t_{ph}	2.5 ns (min.)	Minimum pulse width
t_{pl}	2,5 ns (min.)	Minimum pulse width
t_{ss}	3.5 ns ns (min) 1.8 µs (max.)	Start to Stop
t_{rr}	15 ns (typ.)	Rising edge to rising edge
t_{ff}	15 ns (typ.)	
t_{va}	560 ns uncalibrated 4.6 µs calibrated	Last hit to data valid
t_{xx}	No timing limits	
t_{yy}	1.8 µs (max)	Max. measuring range

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.

2.2 Measurement Flow
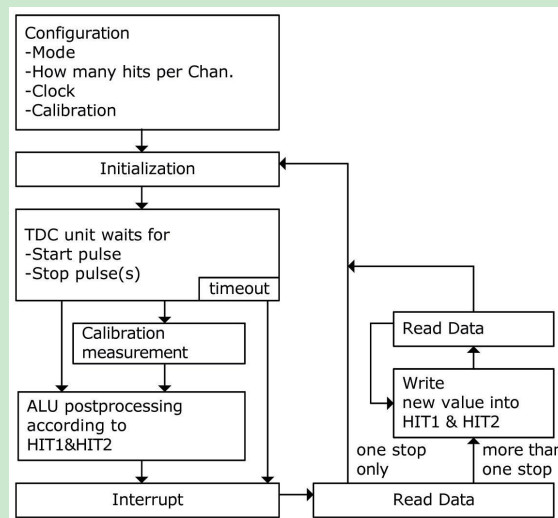
2.2.1 Configuration

At the beginning the MS1002 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

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 MS1002 has to wait for. A maximum of 4 on each channel is possible. The MS1002 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 MS1002 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

$1 = 1^{st}$ Stop Ch1 $9 = 1^{st}$ Stop Ch2
$2 = 2^{nd}$ Stop Ch1 $A = 2^{nd}$ Stop Ch2
$3 = 3^{rd}$ Stop Ch1 $B = 3^{rd}$ Stop Ch2
$4 = 4^{th}$ Stop Ch1 $C = 4^{th}$ Stop Ch2
$6 =$ Cal1 Ch1
$7 =$ Cal2 Ch1

The ALU calculates: Hit1-Hit2.

Example:

Reg1 = 0x01xxxx ≡ 1st Stop Ch1-Start
Reg1 = 0x23xxxx ≡ 3rd Stop Ch2-2nd Stop Ch1
Reg1 = 0x06xxxx ≡ Cal1

In case calibration is active the ALU does the full calibration calculation (except when reading the calibration values. In this case the ALU writes the Cal1/Cal2 raw data to the output

$$RES\_X = \frac{(HIT1 - HIT2)}{Cal2 - Cal1}$$

register). $Cal2 - Cal1 = gradient$

$$Time = RES\_X \times T_{ref} \times 2^{ClkHSDiv} = RES\_X \times T_{ref} \times N, N = 1, 2 \, or \, 4$$
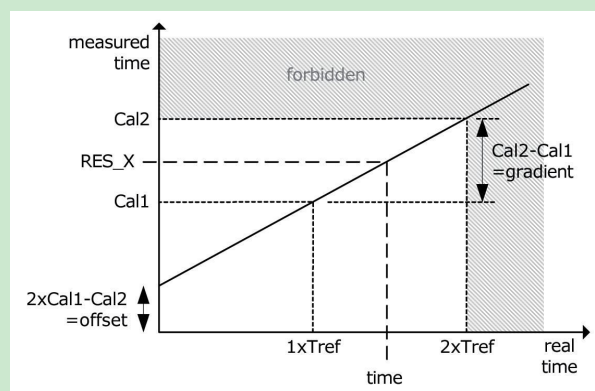
f.Select input sensitivity

In register 2, Bits 19 & 20, RFEDGE1 and RFEDGE2, the user can select whether the stop inputs are sensitive to either rising or falling edges (RFEDGE = 0) or to both rising and falling edge (RFEDGE = 1).

In register 0, Bits 0 to 2 the user can add an internal inverter to each input, Start, Stop1 and Stop2. With RFEDGE = „0 " this is the same as rising edge (NEG_X = 0) or falling edge (NEG_X = 1).

g.Interrupt behavior

The interrupt pin 8, INT can have different sources. They are selected in register 2, Bits 21 to 23, EN_INT.

EN_INT＝   0   no Interrupt source

1   ALU ready

2   The set number of hits is there

4   Timeout of the TDC unit

The different options are wired by OR to enable more than one source.

There are further configuration options that will be described later in this chapter.

 After the configuration the user has to initialize the MS1002 by sending opcode "Init" so that the TDC accepts Start and Stop hits.

2.2.2 Measurement

After an initialization the TDC unit will start with the first pulse on the Start input. It will run until:

• the set number of hits has been seen (maximum 4 on both stop channels in MR1)

• or until a timeout occurs at the end of the measurement range (at about1.8μs in ,MR1)

The time measurement raw data are internally stored. The number of hits can be seen from the status register, bits 3 to 8. In case calibration is active the TDC now measures one and two periods of the internal reference clock (Tref * 1,2 or 4). The calibration raw data Cal1 and Cal2 are also internally stored
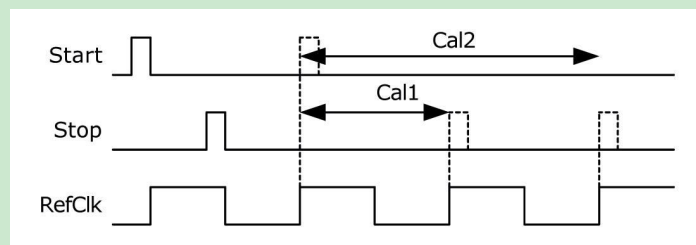
2.2.3 Data Processing

At the end of the measurement the ALU starts to process the data according to the HIT1, HIT2 settings and transfers the result to the output register. In case calibration is off the ALU transfers the 16 Bit raw data to the output register. With calibration the ALU calculates according to setting and transfers the 32Bit fixed point number to the output register.

The ALU can be switched off configuring HIT1=HIT2=5.

The time it takes the ALU depends on whether calibration is on or not and the supply voltage.

表 1：ALU timings

	un-calibrated	calibrated
3.3V	220ns	1.8us
2.5V	310ns	2.5us
2.0V	580ns	4.6us

As soon as the data is available from the output register the interrupt fag is set (assumed that the ALU interrupt is enabled, see reg 2, EN_INT). Further the load pointer of the output register is increased by 1 and points to the next free memory. The actual position of the load pointer can be seen in the status register, Bits 0 to 2.

2.2.4 Reading Data

Now the user can read the data sending the opcode 10110ADR. With the next 16 cycles (un-calibrated data) or 32 cycles (calibrated data) the MS1002 will send the result, beginning with the most significant Bit (MSB).

a. Un-calibrated data format:

16 Bit Signed integer in complements of 2. 1BIN = un-calibrated gate delay is about 65ps at 5V and 25℃.

$$Time = RES\_X \times 65ps$$

b.Calibrated data format:

32 Bit fixed-point number in complements of 2. Given in multiples of the reference clock.

$$Time = RES\_X \times T_{ref} \times N，\quad N = 1, 2 \text{ or } 4$$

The measured time interval may not exceed$(2 \times T_{ref} \times ClkHSDiv)$, otherwise the ALU will go into overflow and will write the data 0xFFFFFFFF to the output register.

The configuration of the ALU allows only one hit calculation at the time. In case more than one hit has been measured it is necessary to write new commands to HIT1/HIT2 to instruct the ALU for calculating the other hits. After writing to HIT1/HIT2 it is necessary to wait for minimum 4.6µs (calibrated data) or 580ns (un-calibrated data) before reading or writing again to HIT1/HIT2.

```
Example:
configuration
...
write reg1=0x104400   '4 hits on channel 1, calculate
Hit1-Start
...
Initialize
...
while(Check interrupt flag)
write reg1=0x204400   calculate Hit2-Start
wait(4.6μs)
write reg1=0x304400   calculate Hit3-Start
wait(4.6μs)
write reg1=0x404400   calculate Hit4-Start
wait(4.6μs)


Now all Hit data are available from registers 0 to 3.
The load pointer value is 4.
```

At the end the MS1002 has to be initialized again to be ready for the next measurement. This is done by sending the opcode "Init" so that the TDC accepts new Start and Stop hits.

3. Measurement Mode 2

3.1 General Description

◆ 1 stop channels referring to one start channel
◆ Typ. 50 ps RMS resolution
◆ LSB width typ. 65 ps
◆ 2 x Tref pulse pair resolution
◆ 3-fold multihit capability
◆ Measurement range 2 x Tref to 4 ms @ 4MHz
◆ Integrated programmable windowing for each single stop with 10 ns precision

   Digital TDCs use internal propagation delays of signals through gates to measure time intervals with very high precision .

   In measurement range 2 the maximum time interval is extended using a pre-divider. The resolution in LSB remains unchanged by that. In this mode the high-speed unit of the TDC does not measure the whole time interval but only time intervals from START and STOP to the next rising edge of the reference clock (fine-counts). In between the fine-counts the TDC counts the number of periods of the

reference clock (coarse-count).
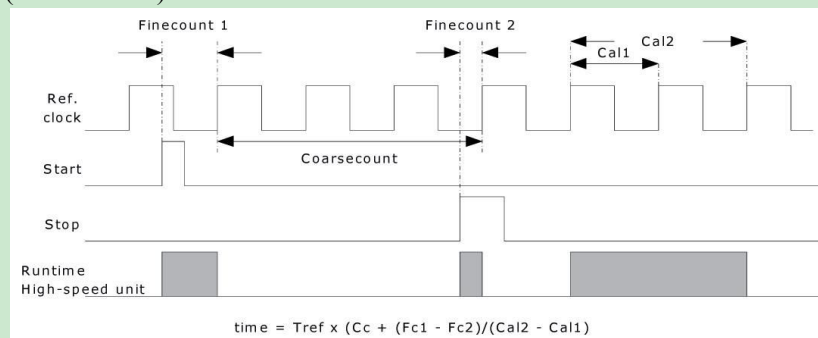
The BIN size (LSB) is typically 65 ps at 3.3 V and 25 ° C ambient temperature. The RMS Noise is approx. 50 ps (0.7 LSB). The gate propagation delay times strongly depend on temperature and voltage. In measuring range 2 the result is the sum of different fine and coarse-count results. Therefore it is necessary in measuring range 2 to make a calibration. During a calibration the TDC measures 1 and 2 periods of the reference clock.

The measurement range is limited by size of the coarse counter:

$$t_{yy} = T_{ref} \times 2^{14} = 4 \text{ms} @ 4\text{MHz}$$

The time interval between START and STOP is calculated with a 26 Bit measurement range.
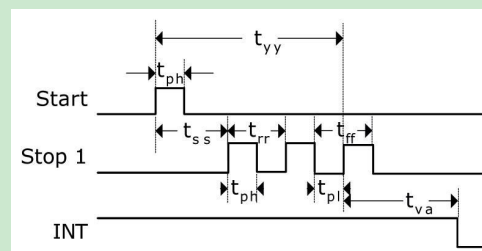
	Time (Condition)	Description
t_{ph}	2.5 ns (min.)	Minimum pulse width
t_{pl}	2.5 ns (min.)	Minimum pulse width
t_{ss}	$2*T_{ref}$	Start to Stop @ Dis_Phasenoise=1
	$12*T_{ref}$	Start to Stop @ Dis_Phasenoise=0
t_{rr}	$2*T_{ref}$	Rising edge to rising edge
t_{ff}	$2*T_{ref}$	Falling edge to falling edge
t_{va}	4.6 µs (max.)	ALU start to data valid
t_{yy}	4 ms (max)	Max. measuring range

Input circuitry

Each input separately can be set to be sensitive to rising or falling edge. This is done in register 0, Bits 0 to 2. (NEG_START, NEG_STOP1).

Note: Further all Start/Stop-inputs support a high active enable pin.

3.2 Measurement Flow
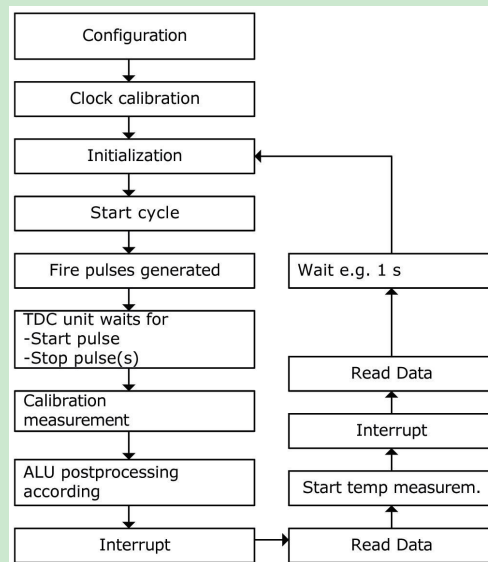
3.2.1 Configuration

At the beginning the MS1002 has to be configured. The main settings for measurement range 2 are:

a.Select measurement range2:

setting register 0, Bit3, MRange2 = 1.

b.Select the reference clock

In measurement range 2 the MS1002 needs the high-speed clock for the time measurement. In case of low-power applications this clock can be switched of in between measurements. The a 32.768 kHz clock is necessary for the timing control during the oscillator power-on.

Register 0, Bits 10&11, START_CLKHS defines the switch-on behavior of the high-speed clock. 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). The choice has an influence on the minimum time interval

$$t_{\min} = 2 \times T_{ref} \times 2^{ClkHSDiv}$$

and the maximum time interval

$$t_{\max} = 2^{14} \times T_{ref} \times 2^{ClkHSDiv}$$

Further, it is necessary that

$$2 \times T_{ref} \times 2^{ClkHSDiv} < 1.8us$$

Otherwise the ALU will go into an overflow during calibration and write 0xFFFFFFFF as output data.

c.Set the number of expected hits

In register 1, Bits 8 to 10, HITIN1 the user has to define the number of hits the MS1002 has to wait for. A maximum of 3 on channel 1 is possible. The number HITIN1 always has to be higher by 1 than the number of expected hits. The reason is that the Start is also counted as a hit. The MS1002 measures until the set number of hits is registered or a timeout occurs. register 0, Bits 11 to 13, HITIN2 have to be set to 0.

d. Select calibration

The calibration is switched on by setting register 0, Bit5, Calibrate = 1. It is mandatory 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. 定义 ALU 数据处理

While the TDC unit can measure up to 3 hits the ALU can calculate only one hit at once. The settings are done in register 1, Bits 16 to 19 and 20 to 23, HIT1 and HIT2. The Start pulse is internally handled like a Stop pulse because of the special measuring method in measurement range 2.

Reg1 = 0x21xxxx ≡ 1st Stop Ch1-Start

Reg1 = 0x31xxxx ≡ 2nd Stop Ch1-Start

Reg1 = 0x41xxxx ≡ 3rd Stop Ch1-Start

The ALU calculates the time interval as:

$$RES\_X = CoarseCount + \frac{(HIT1 - HIT2)}{Cal2 - Cal1}$$

$$Time = RES\_X \times T_{ref} \times 2^{ClkHSDiv}$$

f.Select input sensitivity

In register 2, Bits 19 & 20, RFEDGE1 and RFEDGE2, the user can select whether the stop inputs are sensitive to either rising or falling edges (RFEDGE = 0) or to both rising and falling edges (RFEDGE = 1). In register 0, Bits 0 to 2 the user can add an internal inverter to each input, Start, Stop1 and Stop2. With RFEDGE = „0" this is the same as rising edge (NEG_X = 0) or falling edge (NEG_X = 1).

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g. Interrupt behavior

The INT pin can have various sources, to be selected in register 2, Bits 21 to 23, EN_INT.

EN_INT＝0　no Interrupt source

　　　　　1　ALU ready

　　　　　2　The set number of hits is there

　　　　　3　Timeout of the TDC unit

The different options are wired by OR.

After the configuration the user has to initialize the MS1002 by sending opcode "Init" so that the TDC accepts Start and Stop hits.

3.2.2 Measurement

After an initialization the TDC unit will start with the frst pulse on the Start input. It will run until:

SEL_TIMO_MR2 (@ 4 MHz, ClkHSDiv = 0)

　　　　＝ 0　　　＝ 64 μs

　　　　＝ 1　　　＝ 256 μs

　　　　＝ 2　　　＝ 1024 μs

　　　　＝ 3　　　＝ 4096 μs

At the end of the time measurement the TDC measures 2 periods of the reference clock for calibration.。

3.2.3 数据处理

在测量结尾，ALU 开始依照 HIT1 和 HIT2 的设置处理数据并把结果送入输出寄存器。ALU 进行计算并传输 32 位的固定浮点数到输出寄存器。设置 HIT1＝HIT2＝5，切断 ALU。ALU 进行计算所花费的时间由供电电压决定:

表 2：ALU 时序

3.3V	1.8us
2.5V	2.5us
2.0V	4.6us

假定选择 ALU 空闲作为中断源（在 reg 2, EN_INT 中设置），只要输出寄存器中有可读的数据，中断标志位就会置位。然后输出寄存器的载入指针增 1，并指向下一个要存储的单元。状态寄存器的 Bits0-2 可以显示出载入指针的实际位置。

3.2.4 Reading Data

Now the user can read the data sending the opcode 10110ADR. With the next 32 cycles (calibrated data) the MS1002 will send the result, beginning with the main significant Bit (MSB).The time it takes

the ALU depends on the supply voltage:The ALU calculates the time interval as:

The 32 Bit fixed-point number in complements of 2 represent the time interval in multiples of the reference clock.

$$Time = RES\_X \times T_{ref} \times 2^{ClkHSDiv}$$

The configuration of the ALU allows only one hit calculation at the time. In case more than one hit has been measured it is necessary to write new commands to HIT1/HIT2 to instruct the ALU for calculating the other hits. After writing to HIT1/HIT2 it is necessary to wait for minimum 4.6μs (calibrated data) or 580ns (un-calibrated data) before reading or writing again to HIT1/HIT2.

```
Example：
configuration
...
write reg1=0x214400   '3 hits on channel 1, calculate
Hit1-Start
...
Initialize
...
while(Check interrupt flag)
write reg1=0x314400   calculate Hit2-Start
wait(4.6μs)
write reg1=0x414400   calculate Hit3-Start
wait(4.6μs)


Now all hit data are available from registers 0 to 2. The load pointer value is 3.
```

At the end the MS1002 has to be initialized again to be ready for the next measurement. This is done by sending the opcode "Init" so that the TDC accepts new Start and Stop hits.

3.3 Stop Masking

The MS1002 can set time-based masking windows for each of the 3 hits on Stop1 input when no hits are accepted. The masking refers to the start event and has an accuracy of less than 10 ns.

The internal enable unit is connected to the external enable pin by a logical AND. The external enable pin must be set to "1" to use the internal masking unit. The configuration settings are made in registers 2 to 4, DELVAL1, DELVAL2 and DELVAL3:

◆ DELVAL1 ⋯ DELVAL3 are fixed point numbers with 14 bit integer and 5 bit fractional digits, in multiples of the internal reference clock

$$Delay_{min} = DELVALX \times T_{ref} \times ClkDivHS$$

◆ The minimum mask size is 3 clock cycles.
◆ The mask values must have an ascending order. Each mask value must be 3 clock cycles bigger than the previous value
◆ It is mandatory that if not all registers are used the mask values that are not required are set to 0. When all DELVAL registers are set to 0, the complete unit is disabled.

Example:
4 Mhz reference, ClkHSDiv = 1
DELVAL1 = 0x3200   1st Stop not accepted before
  ($\equiv$400*T_{ref})   200 μs after Start
DELVAL2 = 0x3300   2nd Stop not accepted before
  ($\equiv$408*T_{ref})   204 μs after Start
DELVAL1 = 0x3400   3rd Stop not accepted before
  ($\equiv$416*T_{ref})   208 μs after Start

4. Details and Special Functions

4.1 Oscillator

The MS1002 uses up to 2 clock signals depending on the operating mode:
  a. High speed clock, typically 4 MHz, for calibration and as a pre-divider for the TDC measuring unit in measurement range 2.
  b. 32 kHz clock signal used for internal timer functions.

4.1.1 High-Speed Oscillator

Generally the MS1002 needs a 2 to 8 MHz high-speed clock for calibration. Operating in measurement range 2 the MS1002 needs the high-speed clock signal also as a part of the time measuring unit. The oscillator takes an average current of 260 μA when running all the time.
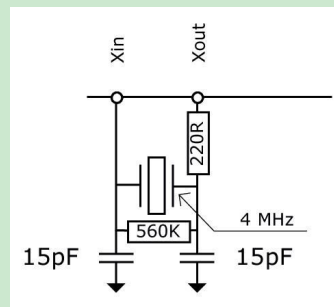
Because it is needed only during the time measurement the MS1002 has the capability to control the on time by itself. The high-speed clock can be switched on automatically with a INIT opcode only for the period of time measurement. An additional delay cares for the settling time of the oscillator. The settings are done in register 0, Bits 10 & 11, START_CLKHS:

START_CLKHS = 0   Oscillator off

= 1   Oscillator always on

= 2   The measurement is started with 640 μs delay.

= 3   The measurement is started with 1280 μs delay

The programmable delay guarantees that the oscillator has settled before the measurement starts. For ceramic resonators 640 μs will be sufficient.。

Note:

Notice the Bug report in section 7 when using Start_CLKHS with quartz oscillators.

By this measure the average current consumption can be drastically reduced.


Example:

At one ToF measurement in an ultrasonic flow meter (forth/back) per second the high speed oscillator is active only for about 2 ms.

The average current consumption is 260 μAs * 2 ms = 0.52 μA.

4.1.2 32.768kHz Oscillator

The MS1002 needs a 32.768 kHz reference for the start-up control of the high-speed clock and the clock calibration. It therefore offers a an integrated driver:

There is no need for the 32.768 kHz clock if the high speed clock is permanently running (START_ CLKSHS = 1) and the high speed clock calibration is not used (e.g. in case of a quartz oscillator).
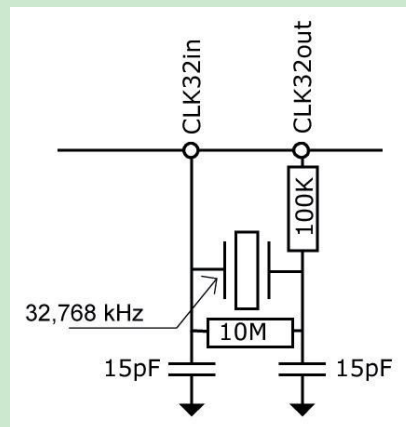
The 32.768 kHz oscillator is permanently running and has a current consumption of about 4.5 µA at frequency rectangular clock at the CLK32Out pin (3.6 V max.). This signal could be generated by an external microprocessor. It will reduce the current consumption down to 1.2 µA. For this reason the 32 kHz oscillator should only be used if no external low-current 32.768 kHz clock is available. The settling time of this oscillator is about 2 s.The external circuit is necessary only if the 32.768 kHz oscillator is used. Otherwise CLK32In has to be connected to GND.

4.1.3 Calibrating a Ceramic High-speed Oscillator

Using a ceramic oscillator for the 2 to 8 MHz clock will be attractive because it is of low cost and has a fast settling time. Unfortunately it has a poor tolerance of 0.3 to 0.5 % and shows a temperature drift. For this reason the MS1002 allows to execute a calibration measurement that allows to compensate this behavior. This measurement is based on the very precise 32.768 kHz clock. The MS1002 generates start/stop pulses from the 32.768 kHz and measures this time interval with its TDC unit. The result is stored in the result register and the interrupt fag is set. The frequency error of the ceramic resonator can be calculated by the microprocessor. The calibration is configured by setting register 0, CALRES# and is started with "START_Cal_Resonator" - instruction by the microprocessor.

The time interval to be measured is set by CALRES# which defines the number of periods of the 32.768kHz clock:

CALRES# = 0 2 periods = 61.035 µs

    = 1 4 periods = 122.07 µs

    = 2 8 periods = 244.14 µs

    = 3 16 periods = 488.281µs

The results is given in multiples of the high-speed clock and (divided by 1, 2 or 4 (DIV_CLKHS)) as 32 bit fixed point numbers with 16 integer bits and 16 fractional bits.

$$Time = RES\_X \times T_{HSCLK} \times 2^{DIV\_CLKHS}$$

The micro controller can compare this measured value to the theoretical value and calculate the correction factor RES_X / RES_{theor}

Example:

The system shall work with a 4 MHz resonator.

With CLKHSDIV=0 and CALRES#=1 the theoretical result is

$122.0703125\mu s/250ns = 488.28125$ (RES_0 = 0x01E84800).

If the ceramic resonator in use is not exactly at 4MHz but only 3.98MHz the

---

Note:

During clock calibration the start input has to be enabled.

4.1.4 How to use Clock Calibration

a. Application

This option is dedicated especially to ultrasonic flow and heat meters. In those applications the use of ceramic oscillators shows two main advantages: lower cost and less current consumption. Mainly because of the short oscillation start up time of the ceramic oscillator the operating current can be reduced by several μA. Referring to 10 years of operation this saves several 100 mAh in battery capacitance. There is no negative effect on the resolution when using this option the correct way.

b. Jitter of the 32 kHz clock and consequences

The 32 kHz clock is very precise in frequency with only a few ppm error. However the phase jitter is about 3 to 5 ns peak-peak. For this reason also a calibration measurement (Start_Cal_Resonator) has this error. When multiplying a measurement result with the calibration result, the jitter of the calibration is transferred to the result by the ratio calibration measurement time (see CALRES#) to measurement time. Using a permanently updated calibration value will add a considerable jitter to the measurement result.

c. Application of this option in ultrasonic flow meters

A measurement result is always made of two single time-of-fight measurements in ultrasonic flow meters, with and against the flow direction. The difference between those measurements is a measure for the flow. To avoid an influence of the calibration jitter on this measurement result it is necessary only to use the same calibration for both ToF measurements. Following this the difference between the two ToF measurements will be free of the jitter of the clock calibration measurement. The clock can be calibrated only between measurements that are not directly subtracted from each other.

4.2 Fire-pulse Generator

4.2.1 General Description

The fire pulse generator generates a sequence of pulses which is highly programmable in frequency, phase and number of pulses. The high-speed oscillator frequency divided by the factor selected for ClkHSDiv is used as the basic frequency. This frequency is internally doubled and can freely be divided by a factor of 2 to 15. It is possible to generate 1 to 15 pulses. For each pulse the phase can be adjusted per register configuration. The fire-pulse generator is activated by sending opcode Start_Cycle.

The fire pulse generator provides 2 outputs, Fire1 and Fire2. The driver strength of each output is 48mA @5V. These 2 outputs can be paralleled to increase the driver strength up to 96 mA. Furthermore Fire2 output signal can be inverted to double the signal amplitude. The outputs can be set individually high-Z.

The fire pulse generator allows to generate and send pulse sequences multiple times for use in a quasi "sing-around" method. Using this feature the received pulse sequence is fed into MS1002 Fire_In input. It is digitally amplified and directly forwarded to the output buffer for an immediate remittance without any clock delay.

Note: When the fire pulse generator is use it is mandatory to send a start pulse.

4.2.2 Configuration

Number of pulses:
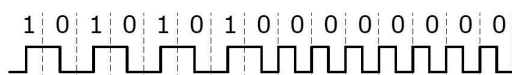
FIRE# =   0   Switch off fire-pulse generator

         1   1 pulse

         2   2 pulses

        …   …

       15   15 pulses

Phase:

The phase of each pulse can be defined in register 5, Bits 0 to 15, PHASE_FIRE. 0 stands for HIGH-LOW and 1 for LOW-HIGH. The pulse sequence begins with the LSB and ends with the MSB
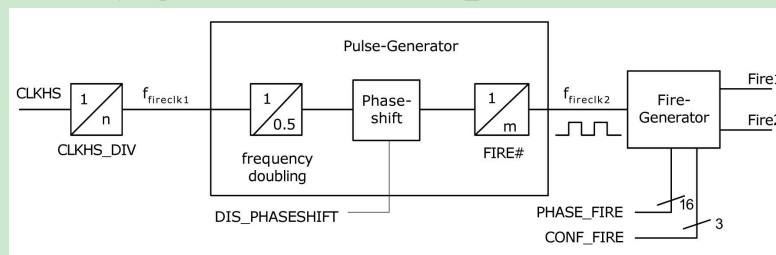
Example:

Fire# = 7, PHASE_FIRE = 0x0055

1 0 1 0 1 0 1 0 0 0 0 0 0 0 0 0

Fire-pulse frequency:

The input signal freclk1 for the fire pulse generator is derived from the high speed clock CLKHS and the selected value for the high speed clock divider CLKHS_DIV.

This Signal is internally doubled and divided by DIV_FIRE.

DIV_FIRE =   0   not permitted

1   divided by 2

2   divided by 3

...   ...

15 divided by 16

Register 5, Bit 19, DIS_PHASESHIFT actives the phase shift, which introduces additional noise to improve statistical behaviour when averaging.

DIS_PHASESHIFT = 0   Phase shift on

DIS_PHASESHIFT = 1   Phase shift off

$$f_{fireclk2} = f_{fireclk1} \times \frac{2}{DIV\_FIRE + 1}$$

freclk2 is used as reference signal for the Fire1 / Fire2 - signal which is emitted by the output buffers of the fire pulse generator.
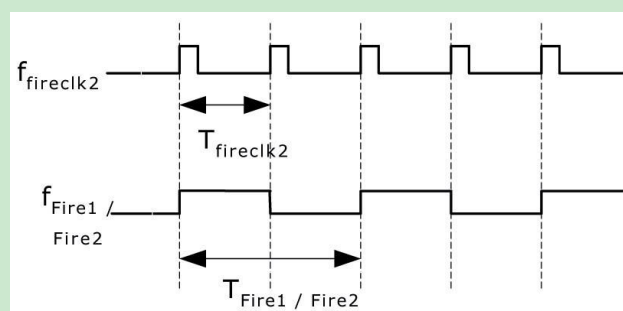
As shown in Figure at least 2 clock periods Tfreclk2 are required to send one Fire_Pulse. One for the high phase and one for the low phase of the Fire1/Fire2 output signal.

例如:

CLKHS = 4 MHz, CLKHS_DIV = 1, DIV_FIRE = 1

$$f_{fireclk2} = f_{fireclk1} \times \frac{2}{DIV\_FIRE+1} = 2MHz$$

Max. frequency of the Fire1 / Fire2 output signal:

$$f_{Fire1/Fire2} = \frac{1}{2} \times f_{fireclk2} = 1MHz$$

Driver outputs:

The output drivers are configured in register 5, Bits 21 to 23, CONF_FIRE:

Bit 23 = 1   Inverted output on FIRE2

Bit 22 = 1   FIRE2 disabled （High－Z）

Bit 21 = 2   FIRE1 disabled（High－Z）

Pulse-burst repetition (quasi sing-around):

In register 5, Bits 16 to 18, REPEAT_FIRE the number of repetitions of the pulse sequence is defined.

REPEAT_FIRE = 0   no repetition

= 1   1 repetition

...   ...

= 7   7 repetitions

Only the number of pulses set under FIRE# will be repeated. With a period of 5 μs without a pulse the MS1002 detects the end of a pulse sequence.

Note:

It is strongly recommend that the summarized time of fight of the up to 7 repetitions does not exceed the measurement range of the MS1002!
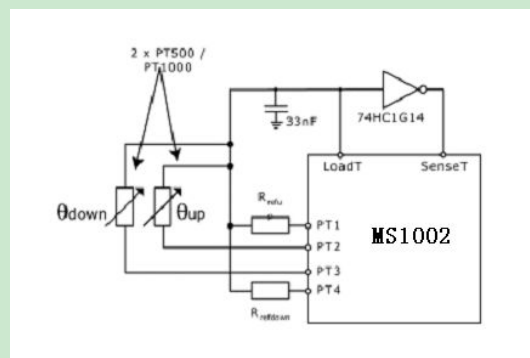
4.3 Temperature Measurement

Especially for heat meter applications the MS1002 has a PICOSTRAIN based temperature measuring unit that offers high resolution and very low current consumption.

The measurement is based on measuring discharge times. Therefore a capacitor is discharged alternately through the sense resistors and the reference resistors.
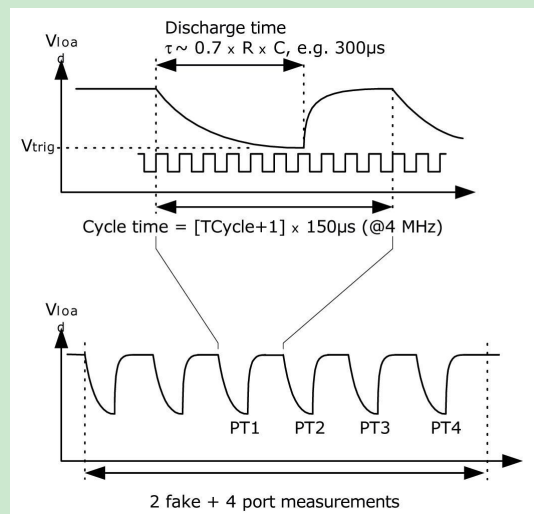
The unit has 4 resistor ports with the following function:

    PT1 reference resistor lower temperature

    PT2 sense resistor lower temperature

    PT3 sense resistor higher temperature

    PT4 reference resistor higher temperature

The temperature sensor should have a minimum resistance of 500 Ohm. The MS1002 measures the discharge times of the RC-networks made of each resistor and the capacitor.

The precision of the temperature measurement is about 0.004℃ several times better than needed for heat meters.

The temperature measurement is fully automated. It is triggered by the μC sending the opcode "Start_Temp". MS1002 controls the 4 measurements by itself. After the 4 measurements have finished the interrupt fag is set. The four data are found in registers 0 to 3.

From Res_2/RES_1 and RES_3/RES_4 the micro controller can calculate the ratio Rtemp/Rref. By means of a look-up table it can calculate the temperature for the special type of sensor in use.

It is not possible with MS1002 to use 4-wire temperature sensors.

Configuration：

    Register 0, Bit 8, Tcycle sets the cycle time for the temperature measurement.

Tcycle = 0   128 μs cycle time @ 4MHz
Tcycle = 1   512 μs cycle time @ 4MHz

Register 0, Bit9, Port# sets the number of ports that will be used.
Port＃＝0   2 ports = 1 sensor
Port＃＝1   4 ports = 2 sensors

Register 0, Bit 7, Fake sets the number of dummy measurements at the beginning of a temperature measurement. This is necessary to overcome mechanical effects of the load capacitor.
Fake = 0   2 dummy measurements
Fake = 1   8 dummy measurements
A full temperature measurement last for: 2 x (# of ports) + (# of fakes) cycles.

Recommended Capacitor Values.
The discharge time should be about 150 μs. Therefore the capacitor should have the following value:
PT500:   220 nF
PT1000:   100 nF
Please set Tcycle = 1 to avoid Timeout Error.

Recommended Capacitor Type
To get accurate results we recommend capacitor types with very low dC/dU. We recommend:
CfCap Series from Tayo Yuden
For heat meter application please do note use X7R or similar capacitors.

Current consumption
By means of the TDC technology the temperature measurement needs an extremely low current, much less than an A/D converter does.

A full temperature measurement with 2 sensors, 2 references am PT1000 sensor type, including all calculations takes less than 2.5μAs. With one temperature measurement in 30 seconds (typical for heat meters) the average current consumption is 0.08 μA only. This is about 50 times less than other solutions. A PT500 sensor doubles the current.

Note:During temperature measurement the start input has to be enabled.

Error detection
Additionally the temperature unit checks the plausibility of the results. It is able to detect a short circuit of the sensor or an open sensor. The MS1002 provides in the relevant output register an error code instead of a measurement value.
1. Short circuit: equivalent to a very short time interval (< 8 x Tref = 2 μs @ 4 MHz). The MS1002 writes a 0x0 to the output register of the shorted sensor.

2. Broken sensor: equivalent to no stop signal or timeout. The ms1002 writes a 0xFFFFFFFF into the output register of the open sensor.

Parameter	Value typ.	Unit
Resolution RMS	16.0	Bit
SNR	96	dB
Absolut Gain-Error	0.1	%
Gain-Drift vs. Vio	0.08	%/V
Gain-Drift vs. Temp	0.0008	%/C
Uncalibrated Offset	<0.01	%
Offset Drift vs. Temp	<0.2	ppm/C
PSRR	>100	dB

Analog specifkation

Condition: Vio = Vcc = 3.3 V, PT1000, 150nF charging capacitor

4.4 SPI interface

The serial interface is compatible with the 4-wire SPI standard. It needs the Serial Select Not (SSN) and can not operated as 3-wire interface

SSN   - Slave Select
SCK   - SPI Clock
SI   - SPI Data In
SO   - SPI Data Out

MS1002 does only support the following SPI mode:
   Clock Phase Bit =1
   Clock Polarity Bit =0
   The timings are shown in figure1 and 2. It is mandatory to set the SSN line to High-state for at least 50ns between each Read/Write sequence.

The Serial Select Not (SSN) line is the HIGH-active reset for the serial interface. After SSN is set to LOW different operations can be addressed, not depending on the status of the interface before the reset.

8 bit OPCode

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

The transfer starts with the MSB and is finished sending the LSB. After sending the last Bit MS1002 transfers the data into the target register or executes the command. It is not possible to do incremental writing. Each register must be addressed separately.

When reading from the chip it is necessary to send the opcode first, too. With the first positive edge of the clock following the opcode the MS1002 sends the MSB of the addressed register to SO output. Each positive edge transfers the next lower Bit to the output.

4.5 Fast Initialization

In measurement range 1 the MS1002 offers the possibility of a fast initialization. Activated by setting register 1, Bit 15, EN_FAST_INIT = 1 the interrupt fag automatically initializes the TDC. So the TDC is already prepared for the next measurement while the data can be read out. This mode is for highest speed applications only. It is most reasonable for un-calibrated measurements with only one stop.

4.6 Noise Unit

In case the user wants to improve the measuring results by averaging it is necessary that the values do not always display exactly the same time difference. Instead the user should provide some , noiseso that different quantization steps of the characteristic curve of the TDC are involved. This can not happen with very constant time differences. One would constantly hit the same LSB.

The noise unit enables the use of weighted averaging even for constant time differences. The noise unit adds a random offset to the start. It is dedicated to applications where the TDC gets a dummy start and measures the time difference between STOP1 and STOP2 (e.g. laser range finders).
The noise unit is switched on by setting register 5, Bit 20, EN_STARTNOISE = 1.

Ultrasonic Heat-meter Applications

1. General Description

The MS1002 is perfectly suited for low-cost ultrasonic heat-meter designs. Thanks to the implemented functionality, including precision temperature measurement, fire pulse generation, windowing and clock calibration it is sufficient to add a simple microprocessor (without A/D converter) and a transducer dependant driver and receiver. The extremely low current consumption guarantees the necessary long battery lifetime in such applications.

The measurement is fairly automated by the MS1002. The microprocessor just sends a start command. The TDC then fires the transducers and measures the time of fight. It calibrates the results and provides them to the microprocessor.
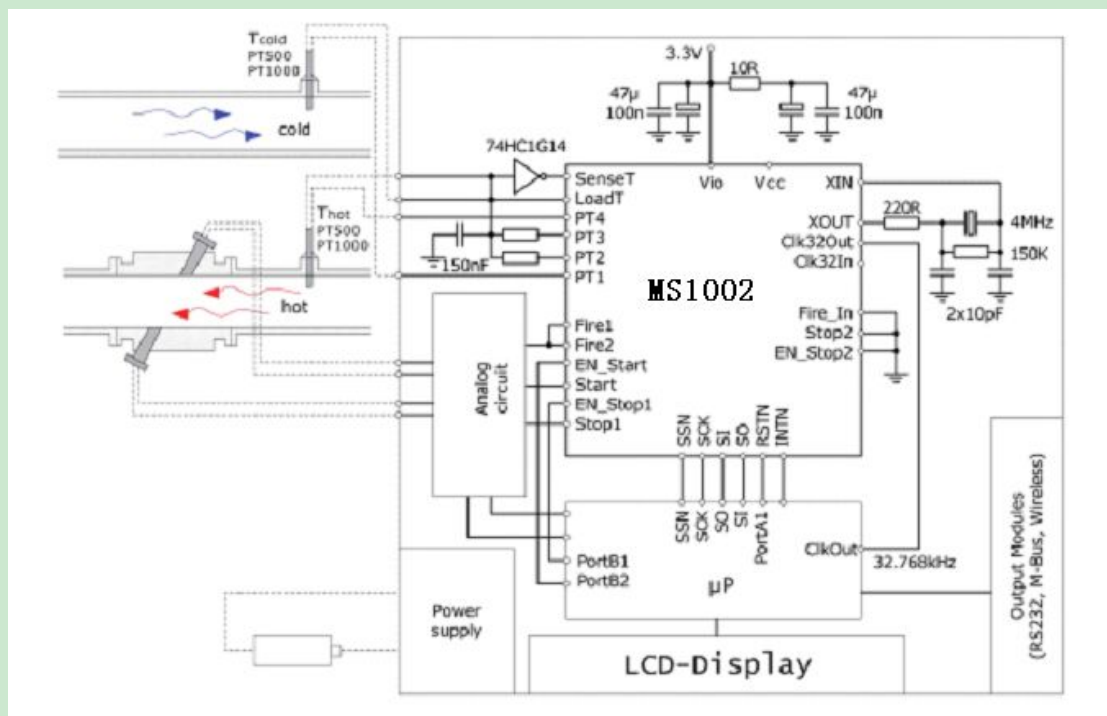
2. Configuration

Reg0~2

Bit	Reg0	Value	Reg1	Value	Reg2	Value
23		0		0		1
22	FIRE#	0	HIT2	0	EN_INT	1
21		1		1		1
20		1		0	RFEDGE2	0
19		0		0	RFEDGE1	0
18	DIV_FIRE	0	HIT1	0		0
17		1		0		0
16		1		1		0
15	CALRES#	1	EN_FAST_INIT	0		0
14		0	s.c.	1		0
13	ClkHSDiv	0		0		1
12		0	HITIN2	0		1
11	START_ClkHS	1		0		0
10		0		1		0
9	PORT#	1	HITIN1	0	DELVAL1	1
8	TCycle	0		0		0
7	FAKE	0	n.c.	0		0
6	SelClkT	1	n.c.	0		0
5	Calibrate	1	n.c.	0		0
4	DisAutoCal	0	n.c.	0		0
3	MRange2	1	n.c.	0		0
2	NEG_STOP2	0	n.c.	0		0
1	NEG_STOP1	0	n.c.	0		0
0	NEG_START	0	n.c.	0		0

Reg3~5

Bit	Reg3	参数	Reg4	参数	Reg5	参数
23	s.c.	0	s.c.	0		0
22	s.c.	0	s.c.	0	CONF_FIRE	0
21	EN_ERR_VAL	0	s.c.	1		0
20	SEL_TIMO_MR2	0	s.c.	0	EN_STARTNoise	0
19		1	s.c.	0	DIS_PhaseNoise	1
18		0		0		0
17	DELVAL2	0	DELVAL3	0	REPEAT_FIRE	0
16		0		0		0
15		0		0	PHASE_FIRE	0

Bit			
14	0	0	0
13	1	1	0
12	1	1	0
11	0	0	0
10	0	1	0
9	1	0	0
8	1	0	0
7	0	0	0
6	0	0	0
5	0	0	0
4	0	0	0
3	0	0	0
2	0	0	0
1	0	0	0
0	0	0	0

- ◆ All inputs are set to rising edges.
- ◆ Measurement range 2 is used with Auto-calibration.
- ◆ The temperature measurement uses the high-speed clock with 128μs cycle time and 2 fake measurements on 4 ports (2 sensors, for cold and hot water).
- ◆ The high-speed clock is switched on only for the time measurement with 640μs delay.
- ◆ The 4 MHz high-speed clock is used without a divider.
- ◆ The 4 MHz clock calibration is based on 8 periods of the 32.768 kHz clock (244.14 μs).
- ◆ For the fire pulse generation the 4 MHz is internally doubled and the divided by 4 making 1 MHz. The generator sends 3 pulses100μs.
- ◆ The first stop is accepted after 100 μs, the second one after 102 μs and the third one after 104 μs.
- ◆ The TDC is set to measure 3 hits on STOP1.
- ◆ The ALU is set to calculate first Hit1 – Start.
- ◆ All interrupt options are activated, timeout will be given after 1024 μs.
- ◆ Phase-shifting is disabled.

3.Measurement Flow

Power-on reset:

Send SO = 0x50

Configuration:

Send SO = 0x80338A68

Send SO = 0x81214400

Send SO = 0x82E03200

Send SO = 0x83083300

Send SO = 0x84203400

Send SO = 0x85080000

Calibrate Clock:

Send SO = 0x03 Start_Cal_Resonator

Check-loop INTN = 0?

Send SO = 0xB0, Read SI = RES_0

Correction factor = 488.28125/RES_0

Measurement loop:

Temperature measurement every 30 seconds:

Send SO = 0x02 Start_Temp

Check-loop INTN = 0?

Send SO = 0xB4, Read SI = STAT

STAT&0x1E00 > 0: -> Error routine

Send SO = 0xB0, Read SI = RES_0

Send SO = 0xB1, Read SI = RES_1

Send SO = 0xB2, Read SI = RES_2

Send SO = 0xB3, Read SI = RES_3

Rhot/Rref = RES_0/RES_1

Rcold/Rref = RES_3/RES_2

Go to look-up table to get the temperatures

Time-of-fight measurement every half second:

Send SO = 0x70 Initialize TDC

Send SO = 0x01 Start_Cycle triggers fire-pulse generator.

Check-loop INTN = 0?

Send SO = 0xB4, Read SI = STAT

STAT&0x0600 > 0: -> Error routine

Send SO = 0x81314400 calculate HIT2-Start

Wait for 4.6μs (ALU time)

Send SO = 0x81414400 calculate HIT3-Start

Wait for 4.6μs (ALU time)

Send SO = 0xB0, Read SI = RES_0

Send SO = 0xB1, Read SI = RES_1

Send SO = 0xB2, Read SI = RES_2

Micro controller can now start the data post-processing and calculate the flow and the heat.

4. Current consumption

a. Time measurement

    32.768kHz: are provided by the Micro controller: < 1.3 µA

    4 MHz: 0 µA in power down, 270 µA when active.

    TDC: < 150 nA if not active, 15 mA during active time of the high-speed unit.

With 2 measurements per second (forth and back flow) the total consumption is < 3 µA.

b.Temperature measurement

    A full measurement over all four ports takes less than 2.5 µAs current. Typically the temperature is measured once in 30 seconds. The average current then is about 0.085 µA. This is about 50 times less than with solutions without a TDC.

c. Quiescent current

     the current optimized 0.35µ technology the quiescent current is less than 150 nA typ.

d.Total system current

    The complete current for the measuring unit (TDC, analog part, Transducer) will depend on the analog circuit part. It will be in the range of 4 to 6 µA.

    With a low-power micro controller (e.g. MSP430 series from TI) the average current consumption of the total device might be in the range of 11 to 16 µA.

    It is possible to operate the system from a lithium-battery AA cell for 10 years without changing the battery. At 6 years run-time it maybe even possible to work with a low cost 3V CR2450 coin cell battery.

Bug Report

Quartz Oscillator Start Up time

BUG:

   When using a quartz resonator for the oscillator the oscillation start up time is about 3 ms even with an optimized circuit. MS1002's automatic on-time control for the high speed clock is based on 640 µs or 1280 µs delay without any activity. In case of a quartz resonator this delay is too short and will cause malfunction.

Corrective:

There are several options to deal with.

1.Oscillator permanently on

      The possibility of switching off the high speed oscillator is added only for current saving. This oscillator needs about 270 µA when running continuously. In all application without attention to current consumption we recommend to run the high speed oscillator continuously (START_CLKHS=1).

2.Ceramic Resonator

      With a ceramic resonator the oscillation start up time is about 200 µs. There is no problem with MS1002'S internal delays. We recommend the use of ceramic resonators in all applications targeting ratio measurements (like ultrasonic flow metering).

      In all applications that need a quartz resonator and the switch-off functionality we recommend the following measures:

3.Lower Clock Frequency at CLK32In

      A clock with lower frequency increases the internal timer delays. In this case we recommend about 4 kHz. The timer delay is increased to 10 ms then. This is enough for a save oscillation start up time of the quartz.

4.Start/Stop Oscillator by Software

      Writing a 1 or 0 into Start_CLKHS starts or stops the oscillator by software. This way a micro controller can start the oscillator by command and then after 10 ms can send a measurement opcode like START_CYCLE. At the end of the measurement the micro controller has to switch off the oscillator by a further command.

DIS_PHASENOISE

The MS1002 offers a Phase-Noise function that decouples the calibration clock from the fire pulse generator. This option was implemented to provide the necessary statistics for averaging in case the user is looking for a resolution much better than 1 LSB (about 65 ps) and has a a very strong coupling between the start and the reference clock.
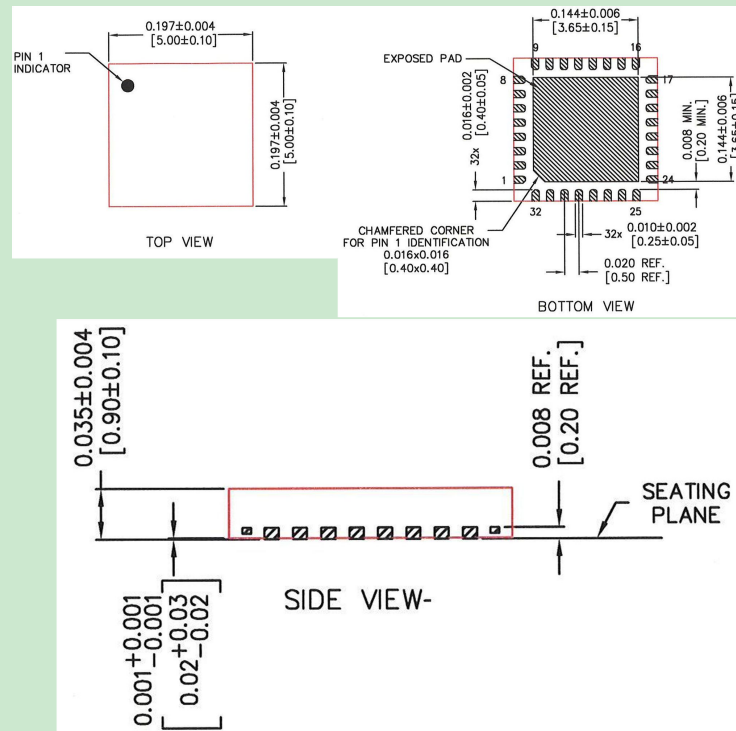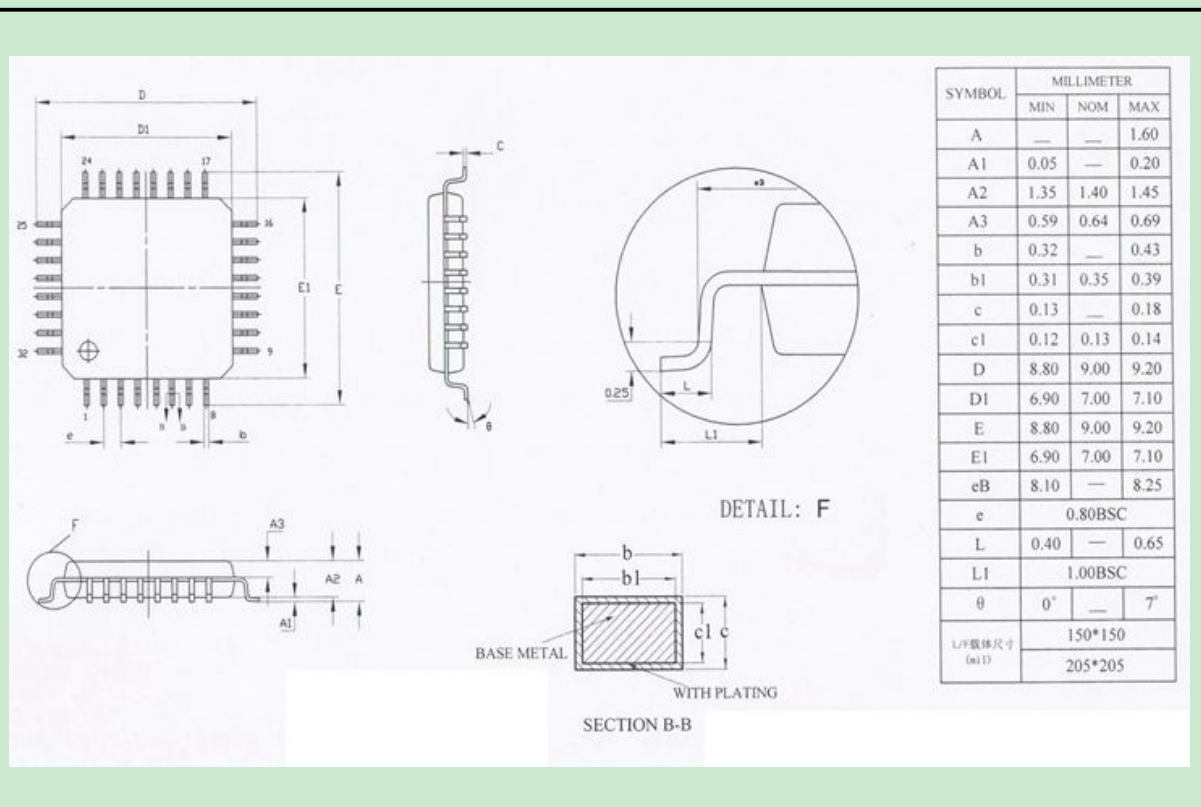
Bug:

Because of a design bug the phase noise unit might fail in case of distortions on the power supply. This is relevant only in measurement range 2.

Corrective:

The phase noise unit has to be switched off by setting DIS_PHASE_NOISE = 1. In case the start is already asynchronous to the reference clock this has no effect on the capability of averaging

Package Drawings

QFN-32   UNIT: mm

LQFP32   UNIT: mm

SYMBOL	MILLIMETER		
	MIN	NOM	MAX
A	—	—	1.60
A1	0.05	—	0.20
A2	1.35	1.40	1.45
A3	0.59	0.64	0.69
b	0.32	—	0.43
b1	0.31	0.35	0.39
c	0.13	—	0.18
c1	0.12	0.13	0.14
D	8.80	9.00	9.20
D1	6.90	7.00	7.10
E	8.80	9.00	9.20
E1	6.90	7.00	7.10
eB	8.10	—	8.25
e	0.80BSC		
L	0.40	—	0.65
L1	1.00BSC		
θ	0°	—	7°
L/F载体尺寸 (mil)	150*150		
	205*205		

QFN-32 package outline, 5 x 5 x 0.9 mm³ , 0.5 mm lead pitch

Note:

Center pad, 3.65 * 3.65 mm² , is internally connected to GND. No wires other than GND
are allowed underneath.

It is not necessary to connect the center pad to GND.

Suitable socket: Plastronics 32QN50S15050D.

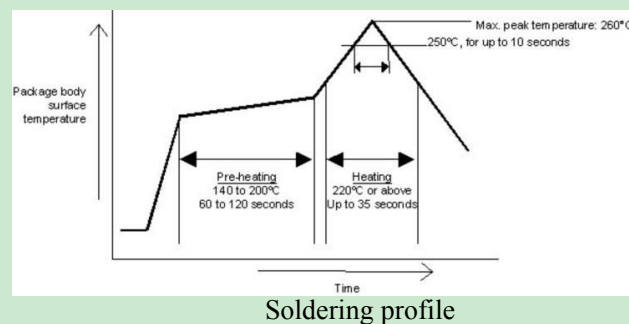Thermal resistance: Roughly 28 K/W (value just for reference).

Environmental: The package is RoHS compliant and does not contain any Pb.

Moisture Sensitive Level (MSL)

Based on JEDEC 020 Moisture Sensitivity Level definition the MS1022 is classified as MSL 1.

Soldering Temperature Profile

The temperature profile for infrared re-flow furnace (in which the temperature is the resin's surface
temperature) should be maintained within the range described below.

Soldering profile

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.

Date Code: YYWWA: YY = Year, WW = week, A = Assembly site code