# High-Precision Time-to-Digital Converter

PRODUCT DESCRIPTION

The MS1022 is high-precision time measurement circuit, which integrates analog comparator, analog switch and schmitt trigger and so on, thus greatly simplifying peripherals. In addition, the first wave detection function makes the MS1022 improve the anti-interference ability. According to read the relative width of first return pulse, user can get the strength indication of received signal. And by the indication, many fault conditions can be judged, such as ultrasonic transducer fault, increased tube coverings and bubbles in water. One measurement for ultrasonic time difference (forward flow and reverse flow) and data-read can be performed according to command, which greatly reduces software operation and electricity consumption.
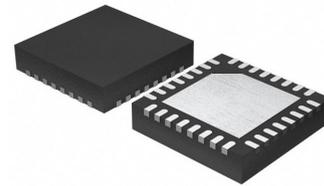
QFN32

FEATURES

Measurement Range 1:

- Dual-Channel, Single-Precision Mode 90ps
- Single-Channel, Dual-Precision Mode 45ps
- Measurement Range 3.5ns(0ns) to 2.4μs
- 20ns Minimum Pulse Interval, Receive Four Pulses at most

Measurement Range 2:

- Single-Channel, Single-Precision Mode 90ps
- Dual-Precision Mode 45ps, Quad-Precision Mode 22ps
- Measurement Range 500ns to 4ms (at 4M high-speed clock)
- Can Measure Three Pulses, Process Three Data Automatically

Analog Input Circuit:

- First Wave Detection
- Can Measure Pulse Width of the First Wave
- Internal Integrated Analog Switch for Input Select

Temperature Measurement:

- Two or Four Temperature Sensors, PT500/PT1000 or Higher
- Internal Integrated Schmitt Trigger
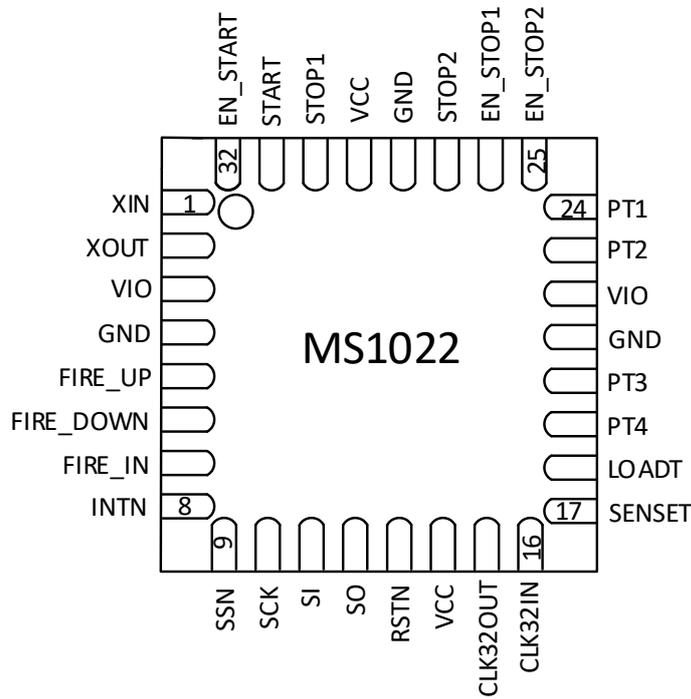- Ultra-low Power Dissipation (0.08uA every 30 seconds)

APPLICATIONS

- Ultrasonic Heat Meter, Water Meter
- Laser Ranging

PRODUCT SPECIFICATION

Part Number	Package	Marking
MS1022	QFN32	MS1022

PIN CONFIGURATION

PIN DESCRIPTION

Pin	Name	Type	Description
1	XIN	I	High-speed Oscillator Input. Connect to GND when not used
2	XOUT	O	High-speed Oscillator Output
3	VIO	-	I/O Power Supply
4	GND	-	Ground
5	FIRE_UP	O	Pulse Generator Output 1
6	FIRE_DOWN	O	Pulse Generator Output 2
7	FIRE_IN	I	"Sing Around" Signal Input. Connect to GND when not used
8	INTN	O	Interrupt Flag. Active Low
9	SSN	I	Serial Interface, Salve Select. Active Low
10	SCK	I	Serial Interface, Clock Input
11	SI	I	Serial Interface, Data Input
12	SO	O	Serial Interface, Data Output
13	RSTN	I	System Reset Input. Active Low

Pin	Name	Type	Description
14	VCC	-	Core Power Supply
15	CLK32OUT	O	32kHz Clock Output. Float when not used
16	CLK32IN	I	32kHz Clock Input. Connect to GND when not used
17	SENSET	I	Temperature Measurement Input. Connect to GND when not used
18	LOADT	O	Temperature Measurement Output. Float when not used
19	PT4	O	Temperature Measurement Port 4
20	PT3	O	Temperature Measurement Port 3
21	GND	-	Ground
22	VIO	-	I/O Power Supply
23	PT2	O	Temperature Measurement Port 2
24	PT1	O	Temperature Measurement Port 1
25	EN_STOP2	I	Enable Input for Stop Channel 2 . Active High. Connect to VIO when not used
26	EN_STOP1	I	Enable Input for Stop Channel 1 . Active High. Connect to VIO when not used
27	STOP2	I	Stop Channel 2. Connect to GND when not used
28	GND	-	Ground
29	VCC	-	Core Power Supply
30	STOP1	I	Stop Channel 1, Connect to GND when not used
31	START	I	Start Channel. Connect to GND when not used
32	EN_START	I	Enable Input for Start Channel . Active High. Connect to VIO when not used

BLOCK DIAGRAM
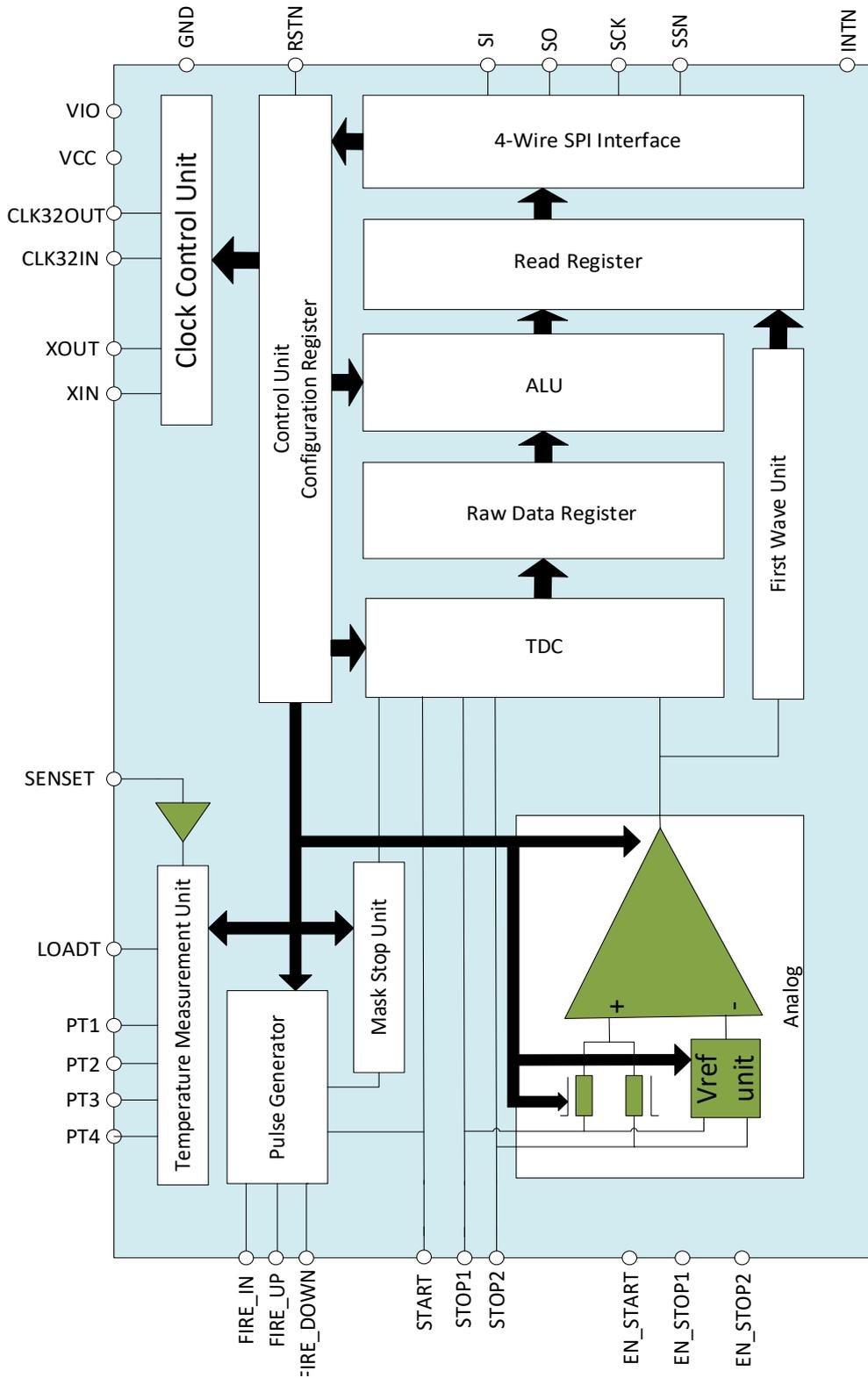
ABSOLUTE MAXIMUM RATINGS

Any exceeding absolute maximum rating application causes permanent damage to device. Because long-time absolute operation state affects device reliability. Absolute ratings just conclude from a series of extreme tests. It doesn't represent chip can operate normally in these extreme conditions.

Parameter	Symbol	Range	Unit
Core Supply Voltage	V_{CC}	-0.3 ~ 4	V
IO Supply Voltage	V_{IO}	7.0	V
Input Voltage	V_{IN}	-0.5 ~ V_{CC} + 0.5	V
Storage Temperature	T_{stg}	-55 ~ +150	°C
Maximum Junction Temperature	T_j	125	°C
ESD	HBM	>4	kV

RECOMMENDED OPERATING CONDITIONS

Parameter	Symbol	Condition	Min	Typ	Max	Unit
Core Supply Voltage	V_{CC}	$V_{CC}=V_{IO}$	2.5		3.6	V
IO Supply Voltage	V_{IO}		2.5		3.6	V
Normal Input Rise Time	t_{ri}				200	ns
Normal Input Fall Time	t_{fa}				200	ns
Schmitt Trigger Rise Time	t_{ri}				5	ms
Schmitt Trigger Fall Time	t_{fa}				5	ms
Ambient Temperature	T_a		-40		125	°C
Thermal Resistance	$R_{th(j-)}$	Junction-ambient		28		K/W

ELECTRICAL CHARACTERISTICS

DC Characteristics

$V_{IO} = V_{CC} = 3.0V$, Tj = -40 - +85$°C$

Parameter	Symbol	Condition	Min	Typ	Max	Unit
32kHz Oscillator Current	I_{32}	$I_{CC}+I_{IO}$, only 32kHz Oscillator Operation		1	25	µA
4MHz Oscillator Current	I_{hs}	$V_{CC}=V_{IO}=3.6V$		200		µA
		$V_{CC}=V_{IO}=3.0V$		130		µA
		Off		<1		µA
Time Measurement Unit Current	I_{tmu}	Only when time measurement is enabled		4		mA
Quiescent Current	I_{ddq}	All clocks off		<0.1		µA
Operating Current	I_O	TOF-UP/DOWN, 1/s		1.1		µA
		Normal Temperature, PT1000, 1/30s		0.15		µA
Temperature Measurement Current	I_T	One measurement every 30 seconds		0.085		µA
Current of Analog Part	I_{ana}	Enable analog part		0.8		mA
Total Current	I_{total}	Twice time measurements every second; One temperature measurement every 30 seconds		2.3		µA
Output High Voltage	V_{oh}	I_{oh}=tbd mA, V_{IO}=Min	0.8V_{IO}			V
Output Low Voltage	V_{ol}	I_{ol}=tbd mA, V_{IO}=Min			0.2V_{IO}	V
Input High Voltage	V_{ih}	LVTTL, V_{IO}=Max	0.7V_{IO}			V
Input Low Voltage	V_{il}	LVTTL, V_{IO}=Min			0.3V_{IO}	V
Schmitt Trigger High Voltage	V_{th}		0.7V_{IO}			V
Schmitt Trigger Low Voltage	V_{tl}				0.3V_{IO}	V
Schmitt Trigger Threshold	V_h			0.28		V

Termination Equivalent Capacitance

Parameter	Symbol	Condition	Min	Typ	Max	Unit
Digital Input	C_{IN}	$V_{CC} = V_{IO}$, f=1MHz, T=25$°C$		7		pF
Digital Output	C_O					
Bidirectional	C_{IO}			9		pF
PT Port				tbd		
Analog Input				tbd		

Analog Front End

Parameter	Symbol	Condition	Min	Typ	Max	Unit
Comparator Input Offset Voltage (Chopper Stable)				<1	2	mV
On-Resistance of Analog switches at STOP1/STOP2 Inputs	R$_{dson（AS）}$	Symmetrical outputs, Rdson(HIGH)=Rdson(LOW)		200		Ω
On-Resistance of FIRE_UP, FIRE_DOWN Output Buffers	R$_{dson（FIRE）}$			4		Ω
Output Current of FIRE_UP, FIRE_DOWN Output Buffers	I$_{FIRE}$			96		mA

Time Measurement Unit

V$_{IO}$ = V$_{CC}$ = 3.0V, Tj = 25°C

Parameter	Symbol	Condition	Min	Typ	Max	Unit
Measurement Resolution	LSB	Measurement Range 1&2, DOUBLE_RES = 0		90		ps
		Measurement Range 1&2, DOUBLE_RES = 1		45		ps
		Measurement Range 2, QUAD_RES = 1		22		ps
Standard Deviation	σ	Measurement Range 1&2		tbd		ps
		Measurement Range 2, QUAD_RES = 1		tbd		ps
Measurement Range	tm	Measurement Range 1	3.5ns		2.4μs	
		Measurement Range 2 (4M high-speed clock)	500ns		4ms	
Integral Non-linearity	INL			<0.1		LSB
Differential Non-linearity	DNL			<0.1		LSB

Temperature Measurement Unit

Parameter	Condition				Unit
	Internal Schmitt Trigger		External Schmitt Trigger		
	PT500	PT1000	PT500	PT1000	
Resolution RMS	17.5	17.5	16.0	16.0	Bit
SNR	105	105	96	96	dB
Absolute Gain	0.9912	0.9931	0.9960	0.9979	

Absolute Gain VS. V_{IO}	3.6V	0.9923	0.9940	0.9962	0.9980	
	3.0V	0.9912	0.9931	0.9960	0.9979	
	2.5V	0.9895	0.9915	0.9956	0.9979	
Gain Drift VS. V_{IO}		0.25	0.23	0.06	0.04	%/V
Maximum Gain Error (dT = 100K)		0.05%	0.05%	0.02%	<0.01%	
Gain Drift VS. Temperature		0.022	0.017	0.012	0.0082	%/10K
Gain Drift VS. V_{IO}				0.08		%/V
Initial Zero Drift		<20	<10	<20	<10	mK
Zero Drift VS.Temperature		<0.05	<0.03	<0.012	<0.082	mK/°C
PSRR			>100			dB

1. All measurements are at VIO = VCC =3.0V. Cload = 100nF is used in PT1000, while 200nF is used in PT500.

2. Apply external 74AHC14 Schmitt trigger.

3. Compare with the condition that ideal gain is 1.

Clock Oscillator

Parameter	Symbol	Min	Typ	Max	Unit
32kHz Reference Oscillator Clock	CLK_{32}		32.768		kHz
32kHz Oscillator Start-up Time after Power-up	T_{32st}		3		s
High-speed Oscillator Reference Clock	CLK_{HS}	2	4	8	MHz
Ceramic Oscillator Start-up Time	T_{oszst}		100		μs
Quartz Oscillator Start-up Time	T_{oszst}		1		ms

Serial Interface

Parameter	Symbol	Max		Unit
		V_{IO} = 2.5V	V_{IO} = 3.3V	
Serial Clock Frequency	f_{clk}	15	20	MHz

Parameter	Symbol	Min		Unit
		V_{IO} = 2.5V	V_{IO} = 3.3V	
Serial Clock, Pulse High	t_{pwh}	30	25	ns
Serial Clock, Pulse Low	t_{pwl}	30	25	ns
SSN Enable to Clock Edge Valid	t_{sussn}	40	10	ns
SSN Pulse Width Between Write Periods	t_{pwssn}	50	40	ns
SSN Hold Time after SCLK Falling Edge	t_{hssn}	40	25	ns

Parameter	Symbol	Min		Unit
		V_{IO} = 2.5V	V_{IO} = 3.3V	
Data Valid to SCLK Falling Edge	t_{sud}	5	5	ns
Data Hold Time after SCLK Falling Edge	t_{hd}	5	5	ns
Data Valid after SCLK Rising Edge	t_{vd}	20	16	ns

Serial Interface (SPI compatible, Clock phase=1, Clock polarity=0):

Serial Interface is 4-wire SPI, needing a SSN signal, so 3-wire SPI interface cannot be compatible.

The rising edge of the first SCK would reset the state of INTN pin (interrupt pin) .

Data transmission starts from MSB and ends at LSB by byte format. Data transmission can stop after each byte by sending a LOW-HIGH-LOW level to SSN.
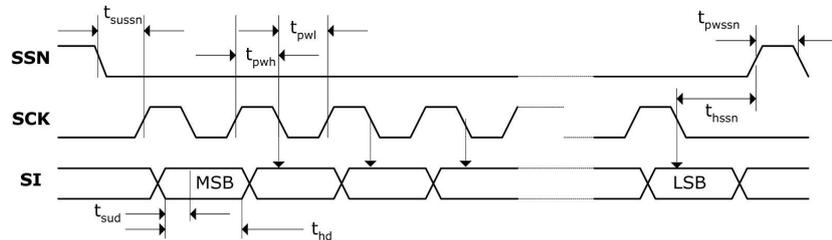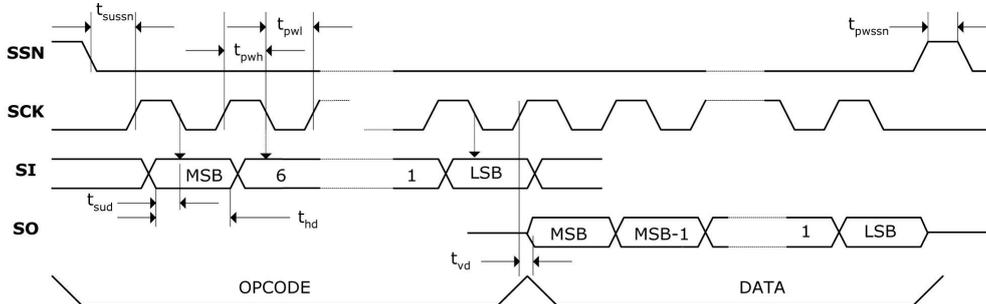

Figure 1. SPI Write Timing

Figure 2. SPI Read Timing

Disable STOP Channel Timing

Parameter	Symbol	Min	Max	Unit
Enable Setup Time	t_{S-EN}	3.5		ns
Enable Hold Time	t_{SH-EN}	15		ns
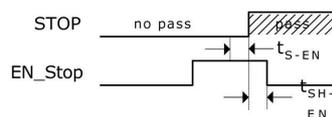
Figure 3. Disable STOP Channel Timing

System Reset Timing

Parameter	Symbol	Min	Max	Unit
Reset Pulse Width	t_{ph}	30		ns
Time Interval from Rising Edge of Reset Pulse to Receive Pulse	t_{rfs}	30		ns

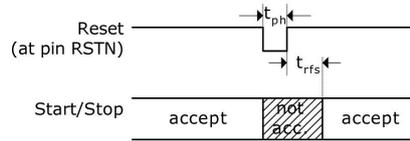After power-up reset, analog circuit part can be enabled after waiting for 500μs.

Figure 4. System Reset Timing

POWER SUPPLY

The MS1022 is high-end mixed device. In order to get best measurement effect, good power is very important. The power should have high capacitance and low inductance

The MS1022 provides two pairs of power supply terminals:

Vio - I/O Power Supply

Vcc - Core Power Supply

All Ground pins should connect to PCB ground plane. Vio and Vcc should be provided by a battery or fixed linear voltage regulator. Don't use switched regulator to avoid the interference caused by IO voltage.

Time-to-digital converter has good measurement effect, fully depending on good power supply. The measurement is mainly pulsed current and therefore a sufficient bypassing is very important:

Vcc   47 μF   (Minimum 22 μF)

Vio   100 μF   (Minimum 22 μF)

The power supply should be provided by a analog regulator and it's recommended not to use switched regulator.

FUNCTION DESCRIPTION

Operation Code and Register

1. Configuration Register

The MS1022 has 7 groups of 32bit configuration registers. The upper 24bits are used to set the configuration operation and only can be written. The lower 8bits are used as product ID and can be read and write.

Register 0 (Address 0)

Bit	Default	Parameter	Description	Setting
31	0	ANZ_FIRE[3:0]	Set pulse numbers of fire generator. The other 3bits are set in Register 6. If ANZ_FIRE >15, the phase setting PHFIRE can be used.	0 = Off
30	0			1 = 1 pulse
29	1			···
28	0			127 = 127 pulses
27	0	DIV_FIRE	Set division coefficient of internal clock signal	0 = No division
26	0			1 = Divided by 2
25	1			···
24	0			15 =Divided by 16
23	0	ANZ_PER_ CALRES	Set 32k clock periods used for calibrating ceramic oscillator	0 = 2 periods = 61.035 µs 1 = 4 periods= 122.07 µs 2 = 8 periods= 244.14 µs
22	0			3 = 16 periods= 488.281µs
21	0	DIV_CLKHS	Set division coefficient of CLKHS	0 = No division, 1 = Divided by 2,
20	0			2 = Divided by 4, 3 = Divided by 4
19	0	START_ CLKHS[1:0]	Set start-up time for high-speed oscillator. Note: The highest bit to adjust START_CLKHS is Register 6, bit 20. When start time is set as 2.44 ms and 5.14 ms, this bit must be set as 1.	0 = Oscillator off 1 = Oscillator on all time 2 = Start-up Delay 480 µs
18	1			3 = Start-up Delay 1.46 ms 4 = Start-up Delay 2.44 ms 5 to 7 = Start-up Delay 5.14 ms
17	1	ANZ_PORT	Set port numbers used for temperature measurement	0 = 2 temperature measurement ports (PT1 and PT2) 1 = 4 temperature measurement ports
16	0	TCYCLE	Set cycle time for temperature measurement	0 = 128 µs @ 4 MHz 1 = 512 µs @ 4 MHz (Recommended)
15	0	ANZ_FAKE	Fake measurement numbers before temperature measurement	0 = 2 fake measurements 1 = 7 fake measurements

14	1	SEL_ECLK_TMP	Select reference signal of internal cycle clock for temperature measurement	0 = use 32.768 kHz as clock 1 = use 128×CLKHS as clock period (32μs at 4MHz oscillator)
13	1	CALIBRATE	Enable/Disable calibration in the ALU	0 = Calibration off (only allowed in measurement range 1) 1 = Calibration off (Recommended)
12	0	NO_CAL_AUTO	Enable/Disable auto-calibration in the TDC	0 = Auto-calibration after measurement 1 = Auto-calibration off
11	1	MESSB2	Select measurement range 2	0 = Measurement Range 1 1 = Measurement Range 2
10	0	NEG_STOP2	Negative stop 2 Input	0 = Non-inverted input signal - rising edge 1 = Inverted input signal - falling edge
9	0	NEG_STOP1	Negative stop 1 Input	0 = Non-inverted input signal - rising edge 1 = Inverted input signal - falling edge
8	0	NEG_START	Negative start 1 Input	0 = Non-inverted input signal - rising edge 1 = Inverted input signal - falling edge
7-0	0	ID0	Free bit, such as version number	

Register 1 (Address 1)

Bit	Default	Parameter	Description	Setting	
31	0	HIT2	Set the method for ALU calculation result: MRange1: HIT1 - HIT2 MRange2: HIT2 - HIT1	MRange1: 0 = Start 1 = 1. Stop Ch1 2 = 2. Stop Ch1 3 = 3. Stop Ch1	MRange2: 2 =1.Stop Ch1 3 =2.Stop Ch1 4 =3.Stop Ch1
30	1				
29	0				
28	1				
27	0	HIT1	Set the method for ALU calculation result: MRange1: HIT1 - HIT2 MRange2: HIT2 - HIT1	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
26	1				
25	0				
24	1				
23	0	EN_FAST_INIT	Set fast initial function	0 = Off 1 = On	
22	1		Keep default		

Bit	Default	Parameter	Description	Setting
21	0	HITIN2	Set expected pulse numbers of stop 2	0 = stop channel off
20	0			1 = 1 pulse
19	0			2 = 2 pulses
18	0	HITIN1	Set expected pulse numbers of stop 1	3 = 3 pulses
17	0			4 = 4 pulses
16	0			5 to 7 = Not allowed
15	1	CURR32K	Set 32kHz oscillator power dissipation option. Generally, it is not necessary to use high-current option and low-current also can ensure the normal operation.	0 = Low current 1 = High current
14	0	SEL_START_FIRE	Fire pulse triggers TDC start, when it is 1, external Start input will be off.	0 = Trigger Start by external 1 = Trigger Start by fire internal
13	0	SEL_TSTO2	Set the EN_START function. EN_START can also be used for differential signal outputs. If SEL_TSTOP2 > 0, EN_START will be set as high-level internally and START input is enabled.	0 = EN_START function, EN_START high and START input is enabled 1 = START_TDC output 2 = STOP1 TDC output 3 = STOP2 TDC output 4 = Enable temperature measurement output 5 = DELVAL output by EN_STOP 6 = n.c. 7 = 4 kHz (32 kHz/8) clock
12	0			
11	0			
10	0	SEL_TSTO1	Set the FIRE_IN function. FIRE_IN can also be used for differential signal outputs. If SEL_TSTO1 >1, FIRE_IN will be set as low-level internally.	0 = Fire_in function, Fire_in input for sing-around 1 = START_TDC output 2 = STOP1 TDC output 3 = STOP2 TDC output 4 = Enable Stop temperature measurement output 5 = TOF_UP, it is high-level when TOF_UP measurement is enabled 6 = RUN_HA, it is high-level when hardmacro is enabled 7 = 32 kHz clock
9	0			
8	0			
7-0	0	ID1	Free bit, such as version number	

Register 2 (Address 2)

Bit	Default	Parameter	Description	Setting
31	0		Set interrupt trigger	Bit 31: Timeout interrupt trigger bit
30	0	EN_INT[2:0]	1: On	Bit 30: End Hits interrupt trigger bit
29	1		0: Off	Bit 29: ALU interrupt trigger bit
28	0	RFEDGE2	Edge sensitivity of channel 2 (after it is set as 1, Register 0, bit 10 is invalid)	0 = Rising or Falling Edge 1 = Rising and Falling Edge
27	0	RFEDGE1	Edge sensitivity of channel 1 (after it is set as 1, Register 0, bit 9 is invalid)	
26-8	0	DELVAL1	Set the first pulse delay of enable stop. Start timing beginning with start pulse. Include 14bit integer, 5bit decimal. Delay is multiple Tref.	DELVAL1 = 0 to 16383.96875
7-0	0	ID2	Free bit, such as version number	

Register 3(Address 3)

Set EN_FIRST_WAVE = 0

Bit	Default	Parameter	Description	Setting
31	0	EN_AUTOCALC_MB2	Set calculating all pulse measurements automatically. The sum of all these measurement results are written to result register 4. The setting is only valid in the measurement range 2.	0 = Off 1 = On
30	0	EN_FIRST_WAVE	Enable automatic first wave detection function. If EN_FIRST_WAVE=1, Register 3 and Register 4 would have other definitions.	0 = Off 1 = On
29	0	EN_ERR_VAL	Set timeout forcing writing 0xFFFFFFFF to result register	0 = Off 1 = On
28	1	SEL_TIMO_MB2	Set timeout of measurement range 2	0 = 64 µs 1 = 256 µs 2 = 1024 µs 3 = 4096 µs @ 4 MHz ClkHS
27	1			
26-8	0	DELVAL2	Set the second pulse delay of enable stop. Start timing beginning with start pulse. Include 14bit integer, 5bit decimal. Delay is multiple Tref.	DELVAL2 = 0 to 16383.96875
7-0	0	ID3	Free bit, such as version number	

Set EN_FIRST_WAVE = 1

Bit	Default	Parameter	Description	Setting
31	0	EN_AUTOCALC_MB2	Set calculating all pulse measurements automatically. The sum of all these measurement results are written to result register 4. The setting is only valid in the measurement range 2.	0 = Off 1 = On
30	0	EN_FIRST_WAVE	Enable automatic first wave detection function. If EN_FIRST_WAVE=1, Register 3 and Register 4 would have other definitions.	0 = Off 1 = On
29	0	EN_ERR_VAL	Set timeout forcing writing 0xFFFFFFFF to result register	0 = Off 1 = On
28	1	SEL_TIMO_MB2	Set timeout of measurement range 2	0 = 64 µs 1 = 256 µs 2 = 1024 µs 3 = 4096 µs @ 4 MHz ClkHS
27	1			
26	0		Keep default	
25-20	0	DELREL3	Sets the number of the periods after the first wave detection for the 3rd STOP	5 to 63 DELREL3 > DELREL2
19-14	0	DELREL2	Sets the number of the periods after the first wave detection for the 2nd STOP	4 to 63 DELREL2 > DELREL1
13-8	0	DELREL1	Sets the number of the periods after the first wave detection for the 1st STOP	3 to 63
7-0	0	ID3	Free bit, such as version number	

Register 4 (Address 4)

Set EN_FIRST_WAVE = 0

Bit	Default	Parameter	Description	Setting
31-27	2		Keep default	
26-8	0	DELVAL3	Set the third pulse delay of enable stop. Start timing beginning with start pulse. Include 14bit integer, 5bit decimal. Delay is multiple Tref.	DELVAL3 = 0 to 16383.96875
7-0	0	ID4	Free bit, such as version number	

Set EN_FIRST_WAVE = 1

Bit	Default	Parameter	Description	Setting
31-27	2		Keep default	
26-17	0		Keep default	
16	0	DIS_PW	Set pulse width measurement function	0 = Enable pulse width measurement 1 = Disable pulse width measurement
15	0	EDGE_FW	Set the edge sensitivity of first wave detection. It is significant to set as triggering on falling edge for negative amplitude.	0 = Rising edge 1 = Falling edge
14	0	OFFSRNG2	Set comparator offset + 20mV	0 = Off 1 = On
13	0	OFFSRNG1	Set comparator offset - 20mV	0 = Off 1 = On
12-8	0	OFFS	Set comparator offset in two's complement with 1mV unit	0 = 0 mV 1 = +1 mV ... 15 = +15 mV 16 = -16 mV 17 = -15 mV ... 31 = -1 mV
7-0	0	ID4	Free bit, such as version number	

Register 5 (Address 5)

Bit	Default	Parameter	Description	Setting
31	0	CONF_FIRE	Output configuration of pulse trigger. 3'b 011 can not be set	Bit 31 = 1: Both on (invert FIRE_DOWN) Bit 30 = 1: Enable output FIRE_UP Bit 29 = 1: Enable output FIRE_DOWN
30	0			
29	0			
28	0	EN_STARTNOISE	Set additional noise for start channel signal	1 = Enable noise unit 0 = Disable noise unit
27	0	DIS_PHASESHIFT	Set phase noise shift unit. When use the reference clock to generate start pulse (for example, fire is connected to start), the unit can be enabled. And system error would be reduced by average.	1 = Disable phase noise shift unit 0 = Enable phase noise shift unit

26	0			0 = No repeat
25	0	REPEAT_FIRE	Set repeat number of pulse sequence for sing around	1 = 1 repeat
				...
24	0			7 = 7 repeat
23-8	0	PHFIRE	Set pulse phase. Phase setting for each pulse in pulse sequence of 15 pulses	0 = Non-inverted 1 = Inverted
7-0	0	ID5	Free bit, such as version number	

Register 6 (Address 6)

Bit	Default	Parameter	Description	Setting
31	0	EN_ANALOG	Set analog measurement function. When analog measurement is enabled, analog part would be powered to save current and STOP1, STOP2 are selected as analog inputs automatically.	0 = Analog measurement off (STOP1, STOP2 are digital inputs) 1 = Analog measurement on
30	0	NEG_STOP_TEMP	Negative SenseT input signal	0 = Use external schmitt trigger(recommend74HC14) 1 = Use internal schmitt trigger
29	0		Keep default	
28	0			15 = - 1 mV 7 = 7 mV
27	0			14 = - 2 mV 6 = 6 mV
26	0	DA_KORR	Set comparator, offset from -8 mV to +7 mV in two's complement	... ...
				9 = - 7 mV 1 = 1 mV
25	0			8 = - 8 mV 0 = 0 mV
24	0		Keep default	
23	0			Charge time:
				0 = 90 µs
22	0	TW2	TRC charge time on STOP terminal when analog measurement is enabled	1 = 120 µs 2 = 150 µs
				3 = 300 µs
21	0		Keep default	
20	0	START_CLKHS[2]	Set the highest bit of start-up time for high-speed oscillator. The lower bits are set in Register 0.	0 = Off 1 = Continuous on 2 = 480 µs delay 3 = 1.46 ms 4 = 2.44 ms 5 to 7 = 5.14 ms

Bit	Default	Parameter	Description	Setting
19	0	CYCLE_ TEMP	Set timer for the second temperature measurement. The value is the 50/60Hz multiple	0 = 0.5 1 = 0.75
18	0			
17	0	CYCLE_TOF	Set timer for the second time measurement. The value is the 50/60Hz multiple	2 = 1 3 = 1.25
16	0			
15	0	HZ60	Set the time interval between two measurements. Optional 50Hz or 60Hz clock	0 = 50 Hz base, 20 ms 1 = 60 Hz base, 16.67ms
14	0	FIREO_DEF	Set the default state when fire channel is not in operation. When analog measurement is enabled, the bit must be set as 1.	0 = High-Z 1 = Low
13	0	QUAD_RES	Measurement precision is improved 4 times from 90ps to 22ps in the measurement range 2.	0 = Off 1 = On
12	0	DOUBLE_ RES	Measurement precision is improved 2 times from 90ps to 45ps in the measurement range 2.	0 = Off 1 = On
11		TEMP_ PORTDIR	Set the measurement sequence for temperature measurement port	0 = PT1 > PT2 > PT3 > PT4 1 = PT4 > PT3 > PT2 > PT1
10		ANZ_ FIRE[6:4]	Set the highest 3bits of fire pulse number. Lowest 4bits are seen in Register 0. If ANZ_FIRE > 15, PHFIRE would be invalid for the setting of pulse phase.	0 = Off 1 = 1 pulse 2 = 2 pulses ... 127 = 127 pulses
9				
8				
7-0	0	ID6	Free bit, such as version number	

2. Read Register

Result register and status register all can be read by operation code 0xBX. Operational code can be 4,2 or 1 byte according to differential address.

The ID register bit in the configuration register can be read by operation code 0xB7. The operational code will be followed by 7bytes in the order ID0, ID1 ... ID6 with the MSB first.

Address	Symbol	Bit	Description
0xB0	RES_0	32	Measurement result 1, fixed-point number, 16bit integer, 16bit decimal 2^{15} 2^0, 2^{-1} 2^{-16}
0xB1	RES_1	32	Measurement result 2, fixed-point number, 16bit integer, 16bit decimal
0xB2	RES_2	32	Measurement result 3, fixed-point number, 16bit integer, 16bit decimal
0xB3	RES_3	32	Measurement result 4, fixed-point number, 16bit integer, 16bit decimal

0xB4	STAT	13	12	Temperature measurement short-circuit	8-6	Received pulse number of channel 2
			11	Temperature measurement open-circuit	5-3	Received pulse number of channel 1
			10	Rough counter overflow	2-0	Result address pointer
			9	TDC unit overflow		
0xB5	REG_1	8	Higher 8bits of Register 1 to test communication		
0xB8	PW1ST	8	Measurement ratio of pulse width,fixed point number, highest bit integer and other 7 bits are decimals.		

2.1 Result Register

The data structure and the distribution of the result register depend on the operation mode and whether calibrated or non-calibrated data are stored. Note following cases:

· Only in the measurement range 1, negative results are possible.

· In the measurement range 2, only positive results are possible in unsigned numbers.

· A non-calibrated measurement is possible only in the measurement range 1.

· In the measurement range1 using calibrated measurement, the measured time intervals can not exceed two calibration clock periods. Otherwise ALU overflows and 0xFFFFFFFFh is written in the appropriate result register.

Measurement Range 1, Calibration Mode(Calibrate = 1)

The results are given in multiples of the internal reference clock period (= external reference clock divided by DIV_CLKHS (DIV_CLKHS=1, 2, 4)). Calibration data are 32 bit fixed point numbers with 16 integer bits and 16 decimals. Any one calibration result occupies one result register. The serial output begins with the highest bit (2^{15}) and ends with the lowest bit (2^{-16}). The data are available in two's complement.

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

$$Time < 2 \times Tref \times 2ClkHSDiv$$

Measurement Range 1, Non-Calibration Mode (Calibrate = 0)

Non-calibrated data are typical signed Integer and are stored as a 16 bit value in the higher 16bits in the result registers. The lower 16bits are set to zero. Therefore only 16 bits can be read in the non-calibration mode.

$$Time = RES\_X \times 90ps$$

Measurement Range 2

In the measurement range 2, the MS1022 only supports calibration measurement. The results are given in multiples of the internal reference clock period (= external reference clock divided by DIV_CLKHS (DIV_CLKHS=1, 2, 4)). Calibration data are 32 bit fixed point numbers with 16 integer bits and 16 decimals. Any one calibration result occupies one result register. The serial output begins with the highest bit (2^{15}) and ends with the lowest bit (2^{-16}). The data are available in two's complement.

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

Temperature Measurement

The measurement of discharge time is in the same format as measurement range 2.

The ratio of the discharge times is equal to the ratio of resistance: $RT = Rref \times \tau_T / \tau_{ref.}$

2.2 Status Register

Bit	Name	Description	Value
2-0	Pointer result register	Pointer to the next free result register	
5-3	# of hits Ch 1	Show the pulse number in channel 1	
8-6	# of hits Ch 2	Show the pulse number in channel 2	
9	Timeout TDC	Show the overflow of TDC measurement unit	1 = Overflow
10	Timeout Precounter	Show the overflow of 14bit rough counter in the measurement range 2	1 = Overflow
11	Error open	Show measurement temperature sensor is open-circuit	1 = Open-circuit
12	Error short	Show measurement temperature sensor is short-circuit	1 = Short-circuit

2.3 PW1ST Register

This register is a 8bit fixed-point number with 1 integer and 7 decimals.

PW1ST can only be used when automatic first wave detection is enabled. Output value is the ratio of the width of the first half wave (at a given offset) to the first STOP half period of the received signal. Data range: 0 to 1.99219.

3. Operational Code

Op HEX	MSB							LSB	Description	Readout
'h8x	1	0	0	0	0	A	A	A	Write into address A	24 bit or 32 bit data
'hBx	1	0	1	1	0	A	A	A	Read address A	8, 16 or 32 bit data
'hB7	1	0	1	1	0	1	1	1	Read ID bit	56 bit ID
'hB8	1	0	1	1	1	0	0	0	Read PW1ST	8 bit
'h70	0	1	1	1	0	0	0	0	Init	
'h50	0	1	0	1	0	0	0	0	Power_On_Reset	

Op HEX	MSB						LSB		Description	Readout
'h01	0	0	0	0	0	0	0	1	Start_TOF	
'h02	0	0	0	0	0	0	1	0	Start_Temp	
'h03	0	0	0	0	0	0	1	1	Start_Cal_Resonator	
'h04	0	0	0	0	0	1	0	0	Start_Cal_TDC	
'h05	0	0	0	0	0	1	0	1	Start_TOF_Restart	
'h06	0	0	0	0	0	1	1	0	Start_Temp_Restart	

The write register of the MS1022 can be 3-byte and 4-byte modes, for example:

h80 + 3 bytes written into configuration register 0 (not write IDO).

h80 + 4 bytes written into configuration register 0 (write IDO).

It is not possible to perform write operation successively. Each register must be addressed separately.

Operational Code Description

h01, Start_TOF: perform one time measurement. First, 4MHz oscillator is switched on. After the set delay (START_CLKHS), the comparator and the reference voltage are switched on. The STOP receiver capacitor is charged up to Vref while Fire is pulled down to GND. After the delay set to charge up the capacitor (TW2), the Fire port sends the fire pulses. After DELVAL delay, stop channel receives pulses. When receiving expected pulse number or timeout is reached, the measurement ends. The analog part and 4MHz are switched off and the total current drops down to near zero. The interrupt will be reset, and INTN = LOW.

h05, Start_TOF_Restart: perform Start_TOF twice, in up and down direction. The interrupt will be reset once when the time measurement for each direction is finished. So, after one Start_TOF_Restart command, the microprocessor receives two interrupts and must read data twice. The time interval between the up and down measurements is set by configuration parameter CYCLE_TOF in multiples of 50Hz or 60Hz. The right selection of the delay between the two measurements can suppress 50/60 Hz noise.

CYCLE_TOF Value	Factor	HZ60 = 0(50Hz)	HZ60 = 1(60Hz)
0	0.5	10 ms	8.3 ms
1	0.75	15 ms	12.48 ms
2	1	20 ms	16.6 ms
3	1.25	25 ms	20.78 ms

h02, Start_Temp: perform one temperature measurement. It begins with the fake measurements (ANZ_FAKE) on PT0 port. Then it measures ports PT0 > PT1 > PT2 > PT4. If TEMP_PORTDIR is set as 1, the port measurement sequence will be inverted, starting with the fake measurements at PT4 port.

h06, Start_Temp_Restart: perform Start_Temp twice. The time interval between the up and down measurements is set by configuration parameter CYCLE_TEMP in multiples of 50Hz or 60Hz. The right selection of the delay between the two measurements can suppress 50/60 Hz noise.

CYCLE_TEMP Value	Factor	HZ60 = 0(50Hz)	HZ60 = 1(60Hz)
0	0.5	10 ms	8.3 ms
1	0.75	15 ms	12.48 ms
2	1	20 ms	16.6 ms
3	1.25	25 ms	20.78 ms

h03, Start_Cal_Resonator: perform one calibration measurement for high-speed oscillator. TDC measures a time interval between 61μs and 488μs, specified in ANZ_PER_CALRES. The end of the measurement is indicated by the interrupt. The result, in multiples of high-speed clock period, is stored in result Register 0. Dividing this by the theoretical value gives the correction factor.

h04, Start_Cal_TDC: This command starts a measurement of two periods of the reference clock. It is used to update the calibration TDC data. If the chip is configured as auto-calibration, this command is not necessary.

Measurement Range 1

1. Overview

· Measurement range 3.5ns to 2.4us (0 to 2.4us between differential stop channels)

· Single-precision mode : Typical 90ps (two stop channels)

· Dual-precision mode : Typical 45ps (only stop 1 channel)

· 20ns pulse minimum interval

· Four pulses at most for each stop channel

· Selectable rising/falling edge sensitivity for each channel

· Can measure time interval between any two pulses

· Typical application: Laser time measurement, RF, ToF, ATE

Digital TDC uses internal logic gate delay to measure high-precision time interval. The follow figure shows the principal structure of such an absolute-time TDC. Intelligent circuit structure and special measurement method make it very precision when signal pass through logic gate. The maximum resolution fully depends on the propagation time of passing logic gate.
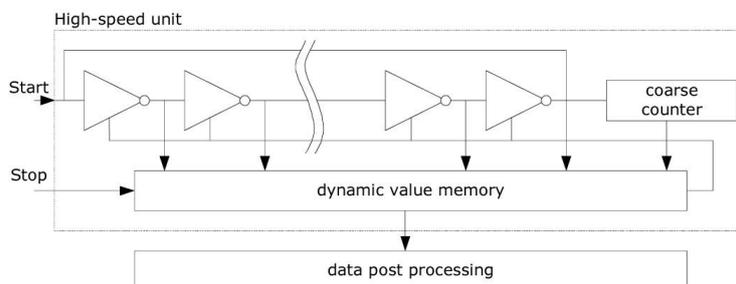
The measurement unit is triggered by a START signal and stopped by a STOP signal. Based on the position of the ring oscillator and the rough counter, the time interval between START and STOP can be calculated with 20bit measurement range.

The minimum resolution of the MS1022 is 90ps at 3.3 V and 25°C. The RMS noise is about 60ps (0.7LSB). The gate propagation delay time is greatly effected by temperature and voltage. Usually according to calibration, the errors caused by temperature and voltage are compensated. During calibration, TDC measures one and two periods of the calibration clock. The measurement range is limited by the counter size.

$$t_{yy} = BIN \times 26224 = 90ps \times 26224 \approx 2.4\mu s$$

	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) 2.4 µs (max.)	Start to Stop
trr	20 ns (typ.)	Rising edge to rising edge
tff	20 ns (typ.)	
tva	Non-calibrated: 150ns Calibrated: 2200ns	Last pulse to data valid
txx	No time limit	
tyy	2.4 µs (max)	Maximum measurement range= 26224 × LSB
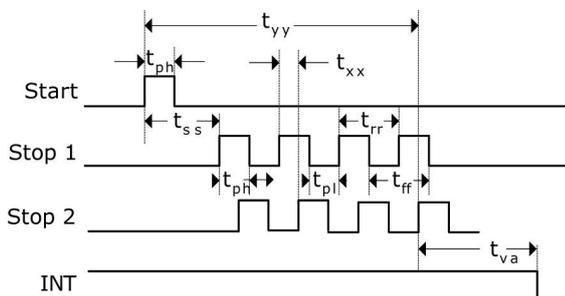
Each input terminal can separately be set as valid trigger on rising or falling edge or both edges. This is done in Register 0, bits 8 to 10 (EG_START, NEG_STOP1,NEG_STOP2) and Register 2, bit 27&28, RFEDGEx.

Furthermore, all Start/Stop inputs support active high.

2. Measurement Process
2.1 Setting

Before the MS1022 is used, it must be configured.

Main setting of measurement range 1:

a. Select measurement range 1

Set Register 0, bit 11, MESSB2 = 0。

Register 6, bit 12, DOUBLE_RES = 1, select du1l-precision mode. By the selection, typical 45ps rather than 90ps. But only stop 1 channel is available.

b. Select reference clock

Register 0, bits 18 & 19 and Register 6, bit 20, START_CLKHS are used to switch high-speed clock. If only 32kHz clock is used, it should be 0. If only high-speed clock is used, it should be 1 (continuous mode).

Register 0, bits 20 & 21, DIV_CLKHS are used to set internal divider number for the reference clock (1,2 or 4). This is important for calibration measurement in the measurement range 1. Because ALU works normally only if 2Tref (internal clock) is more than the maximum measured time interval. Otherwise the ALU output is 0xFFFFFFFF.

Make sure that 2Tref (internal clock) < 2.4us to avoid a timeout during calibration.
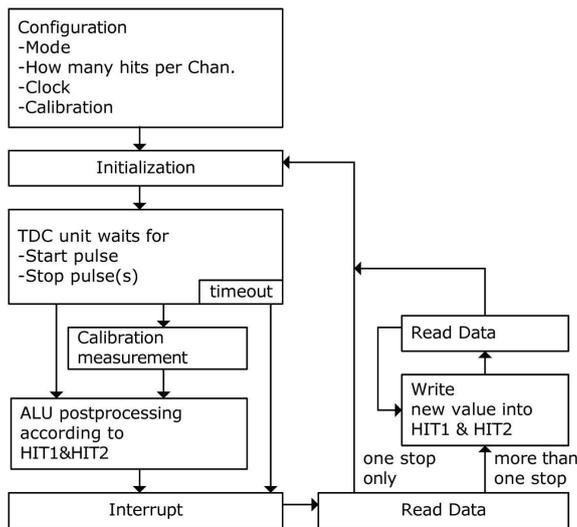
c. Set the number of received pulse

In Register 1, bits 16 to 18 (HITIN1) and bits 19 to 21 (HITIN2), user can set the measured pulse number of the MS1022. Each channel may measure 4 times at most. The MS1022 would measure until the setting number of hits has been reached or a timeout occurs.

d. Select calibration

Because measurement resolution varies with temperature and voltage, the MS1022 ALU needs internally calibrate the results. This option is switched on by setting Register 0, bit13, CALIBRATE=1. It is recommended to use calibration measurement.

For the calibration, TDC measures one and two periods 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 command Start_Cal_TDC via SPI interface.

- Automatic update by setting Register 0, bit 12, NO_CAL_Auto = 0. In most applications, this will be the preferred setting.

e. Define ALU data process

While TDC unit can measure up to 4 times on each channel, user can free definite what ALU shall calculate the time interval between which two signals. The settings are done in Register 1, bits 16 to 19 (HIT1) and 20 to 23 (HIT2). The specified settings are as follows.

0 = Start

1 = 1. Stop Ch1 9 = 1. Stop Ch2

2 = 2. Stop Ch1 A = 2. Stop Ch2

3 = 3. Stop Ch1 B = 3. Stop Ch2

4 = 4. Stop Ch1 C = 4. Stop Ch2

6 = Cal1 Ch1

7 = Cal2 Ch1

ALU calculates Hit1 - Hit2

> For example:
>
> Reg1 = 0x01xxxx - 1st Stop Ch1-Start
>
> Reg1 = 0x2Bxxxx - 3rd Stop Ch2-2nd Stop Ch1
>
> Reg1 = 0x06xxxx - Cal1

If calibration operation is used, ALU would perform full calibration calculation (except when reading the calibration values. In this case, ALU would write the Cal1/Cal2 raw data into the output register).

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

Cal2-Cal1 = gradient

Time = RES_X × Tref × $2^{ClkHSDiv}$ = RES_X × Tref × N, N = 1, 2 or 4.
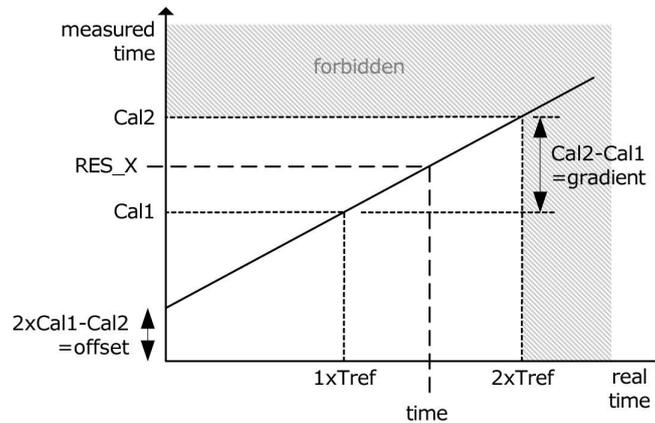
f. Select input trigger method

By setting Register2, bits 27 & 28 (REFDGE1 & FEDGE2), user can select whether the STOP inputs are sensitive to either rising or falling edges (RFEDGE = 0) or both rising and falling edges (RFEDGE = 1).

By setting Register 0, bits 8 to 10 (NEG_X), user can add an internal inverter on each input (Start, Stop1,Stop2). When RFEDGE = 0, rising edge triggers (NEG_X = 0) and falling edge triggers (NEG_X = 1).

g. Interrupt

The interrupt pin 8, INTN can have different sources. They are selected in Register 2, bits 29 to 31(EN_INT).

Reg 2 bit 29 = 1 ALU ready

Reg 2 bit 30 = 1 The set pulse number received

Reg 2 bit 31 = 1 Timeout of TDC measurement unit

The different options are wired by OR to enable more than one source. After the configuration, user must initialize the MS1022 by sending opcode "Init" so that the TDC can receive Start and Stop signals.

2.2 Measurement

After an initialization, TDC high-speed measurement unit receives Start pulse. It start to run until:

· The set sample number has been reached (maximum 4 times on each channel in the measurement range 1)

· A timeout occurs (about 2.4μs in the measurement range 1).

The time measurement raw data are internally stored in the TDC. The sample quality can be seen from the status register, bits 3 to 8. After measuring time interval, the TDC measures one and two periods of the internal reference clock (Tref × 1, 2 or 4). The calibration raw data (Cal1 and Cal2) are also stored internally .
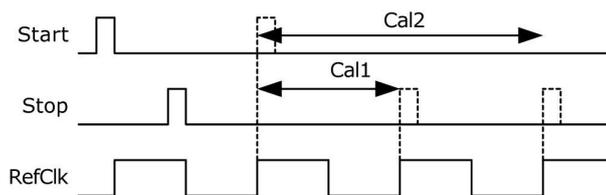
2.3 Data Process

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

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

The time taken by ALU operation depends on supply voltage and whether calibration is performed.

	Non-calibrated	Calibrated
3.3V	t. b. d.	t. b. d.
2.5V	t. b. d.	t. b. d.

As soon as the data is available in the result register, the interrupt fag will be reset, assumed that the ALU interrupt is enable (see Reg 2, EN_INT). Further the load pointer of the output register is increased by 1 and points to the next stored memory. The actual position of the load pointer can be seen in the status register, Bits 0 to 2.

2.4 Read Data

Now user can read data sending the opcode 10110ADR. With the next 16 cycles (non-calibrated data) or 32 cycles (calibrated data), the MS1022 will start to output result, beginning with the most significant Bit (MSB). The first rising edge of SCK resets the INTN pin (interrupt).

a. Non-calibrated data format

Non-calibrated data is 16bit signed integer in two's complement.

1BIN = Non-calibrated gate delay ≈90ps (at 3.3V and 25°C)

Time = RES_X × 90ps

For example:
Configuration
...
Write reg1='h014400 4 samples on channel 1, Calculate 1st Stop -Start
...

b. Calibrated data

Calibrated data is 32bit fixed-point number in two's complement and is in multiples of reference clock.

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

The measured time interval cannot exceed: $2 \times Tref \times ClkHSDiv$, Otherwise ALU will overflow and write the data hFFFFFFFF to result register.

ALU only allows to calculate one sample every time. If more Than one sample has been measured, it is necessary to write new commands to HIT1/HIT2 to instruct ALU for calculating other samples. After writing to HIT1/HIT2, it is necessary to wait for minimum t.b.d.µs (calibrated data) or t.b.d. ns(non-calibrated data) before reading or writing again to HIT1/HIT2.

> Initialize ...
> while(check interrupt flag)
> Write reg1='h024400 Calculate 2nd -Start
> Wait (4.6µs)
> Write reg1='h034400 Calculate3rd-Start
> Wait (4.6µs)
> Write reg1='h044400 Calculate4th-Start
> Wait(4.6µs)
> Now all sample data are stored in Register 0 to 3. Load pointer points to register address 4. At last, before next measurement, the MS1022 must be initialized again by sending code "Init" , so that TDC can receive new Start and Stop signals.

Measurement Range 2

1. Overview

· Only one Stop channel corresponding to Start channel

· Typical resolution 22ps /45ps /90ps

· 2xTref to 4ms @4MHz pulse pair resolution

· Measurement range: 2xTref to 4ms @ 4MHz

· Three times sampling capability, automatic result calculation

· Selectable rising/falling edge sensitivity

· A adjustable window for each single stop signal with 10ns precision and provide accurate stop enable

· Typical application: Ultrasonic heat meter, water meter

Digital TDC uses internal gate delay to measure high-precision time interval (can also see measurement range 1). In the measurement range 2, the maximum time interval is extended using a pre-divider. The resolution remains unchanged. In this mode, the high-speed unit of the TDC does not measure the whole time interval but only time interval from START or STOP signal to the rising edge of the adjacent reference clock (accurate counter). Between the two measurements, the TDC counts the period number of the reference clock (rough counter).
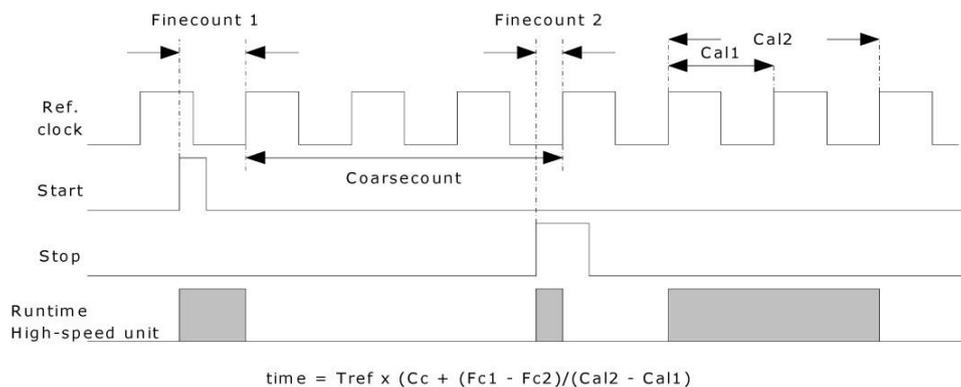
$$time = Tref \times (Cc + (Fc1 - Fc2)/(Cal2 - Cal1))$$

The minimum resolution of the MS1022 is 90ps at 3.3 V and 25°C. The RMS noise is about 60ps (0.7LSB). The gate propagation delay time is mainly decided by temperature and voltage. In the measurement range 2, measurement result is the sum of accurate value and rough value. Therefore, calibration must be performed in the measurement range 2. During calibration, TDC measures one and two periods of the reference clock.

Calibrated data is not effected by voltage and temperature.

The measurement range is limited by the size of rough counter.

$$tyy = Tref \times 2^{14} \approx 4.1ms @ 4MHz$$

The time interval between Start and Stop is calculated with 26bit measurement range.

	Time (Condition)	Description
tph	2.5 ns (min.)	Minimum pulse width
tpl	2.5 ns (min.)	Minimum pulse width
tss	2×Tref	Start to Stop @ Dis_Phasenoise=1
trr	2×Tref	Rising edge to rising edge
tff	2×Tref	Falling edge to Falling edge
tva	4.6μs(max)	ALU start to data valid
tyy	4ms (max)@ 4MHz	Maximum measurement range= $2^{14} \times Tref$
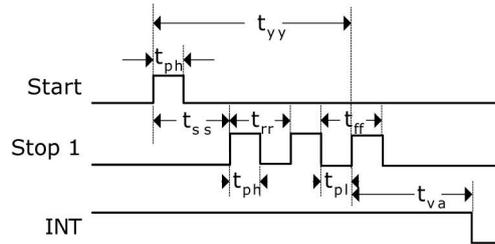
Each input terminal can separately be set to be sensitive to rising or falling edge. This is done in Register 0, Bits 0 to 2. (NEG_START, NEG_STOP1).

Further, all START/STOP inputs support active high.

Note: If the Start-Stop time interval is less than the lower limit t_{zz}, TDC will ignore all time-interval pulses that are less than t_{zz}. In no case, there will be fault results.

2. Measurement Process

2.1 Setting

Before the MS1022 is used, it must be configured.

Main setting of measurement range 2:

a. Select measurement range2

Set Register 0, Bit11, MRange2 = 1。

b. Select reference clock

In the measurement range 2, the MS1022 needs high-speed clock to perform time interval measurement. In the low power dissipation, the clock can be switched between two measurements, 32.768kHz clock is necessary on power-up timing control of high-speed oscillator.

Register 0, bits bit18&19, START_CLKHS is used to switch high-speed clock. If only high-speed clock is used, it is set to 1; If two oscillator clocks are all used for saving current, it should be set to 2 for ceramic oscillator and 3 for quartz oscillator.

Register 0, Bit 20&21, DIV_CLKHS is used to set internal divider number for the reference clock (1,2 or 4).

```
Configuration
    ↓
Clock calibration
    ↓
Initialization  ←─────────────────┐
    ↓                              │
Start cycle                        │
    ↓                              │
Fire pulses generated      Wait e.g. 1 s
    ↓                              ↑
TDC unit waits for                 │
-Start pulse               Read Data
-Stop pulse(s)                     ↑
    ↓                              │
Calibration                 Interrupt
measurement                        ↑
    ↓                              │
ALU postprocessing      Start temp measurem.
according                          ↑
    ↓                              │
Interrupt  ──────────→      Read Data
```

The choice has an influence on the minimum and maximum time intervals. The minimum time interval:

$$t_{min} = 2 \times Tref \times 2^{ClkHDiv}$$

The maximum time interval:

$$t_{max} = 2^{14} \times Tref \times 2^{ClkHDiv}$$

In addition, must ensure:

$$2 \times Tref \times 2^{ClkHDiv} < 2.4\mu s$$

Otherwise, during calibration, ALU will overflow and output 0xFFFFFFFF.

Note: In single-precision and dual-precision modes, the divided clock frequency must be in the range of 2MHz to 8MHz; in quad-precision mode, it must be in the range of 2MHz to 6MHz.

c. Set the pulse number

In Register 1, Bits 8-10(HITIN1), user can define the hits number of the MS1022. In the measurement range 2, channel 1 can be measured three times at most. Because Start is also seen as one sample, HITIN1 value is always higher by 1 than set sample number. The MS1022 measures until the set number of hits is reached or a timeout occurs. Register 0, Bits 11 to 13, HITIN2 must be set to 0.

For example, it is desired to receive two stop pulses, and HITIN1 = 3, HITIN2 = 0.
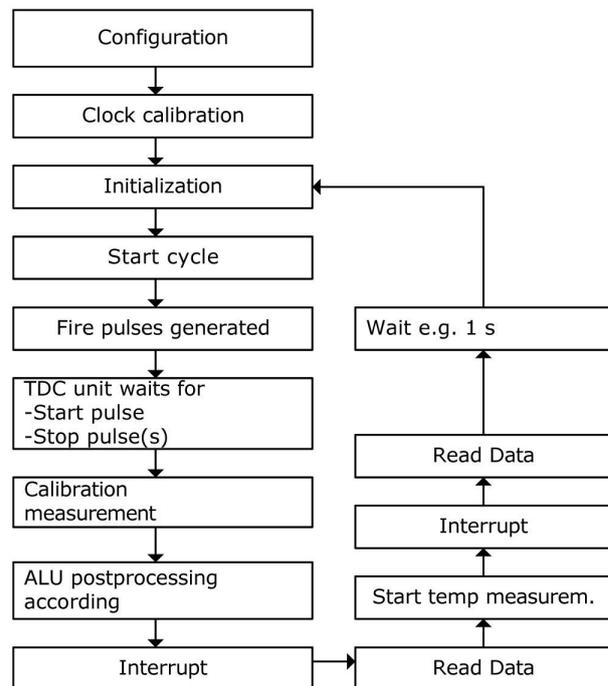
d. Select calibration

This option is switched on by setting Register 0, Bit13, CALIBRATE=1. In the measurement range 2, calibration must be performed. For the calibration, TDC measures one and two periods 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 command Start_Cal_TDC via SPI interface.

- Automatic update by setting Register 0, bit 12, NO_CAL_Auto = 0. In most applications, this will be the preferred setting.

e. Define ALU data process

With EN_AUTOCALC_MB2 = 1, the MS1022 calculates all received pulses and write to corresponding register automatically. Then the sum of the results is calculated and written into result register 3. This simplifies the communication between the MS1022 and the single-chip microcomputer, because it is not necessary to rewrite register 1.

With EN_AUTOCALC_MB2 is disabled, ALU only calculates one sample every time. ALU calculate the time interval between which two pulses by the settings in Register 1, Bits 24 to 27 (HIT1) and 28 to 31 (HIT2).

The Start pulse is internally handled like a Stop pulse because of the special measurement method in the measurement range 2.

Reg1 = 'h21xxxx = Calculate 1st Stop Ch1-Start

Reg1 = 'h31xxxx = Calculate 2nd Stop Ch1-Start

Reg1 = 'h41xxxx = Calculate 3rd Stop Ch1-Start

ALU calculates the time interval as follows:

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

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

f. Select input trigger method

By setting Register 2, bits 27&28 (RFEDGE1&RFEDGE2), user can select whether the STOP inputs are sensitive to either rising or falling edges (RFEDGE = 0) or both rising and falling edges (RFEDGE = 1). By setting Register 0, bits 8 to 10 (NEG_X), user can add an internal inverter on each input (Start, Stop1,Stop2).

When RFEDGE = 0, rising edge triggers (NEG_X = 0) and falling edge triggers (NEG_X = 1).

g. Interrupt

The interrupt pins (PIN8,INTN) can have different sources. They are selected in Register 2, bits 29 to 31(EN_INT).

EN_INT =   Not set No interrupt source

reg2 Bit29   ALU completes calculation

reg2 Bit30   Reach set sample number

reg2 Bit31   Timeout of TDC unit

The different options are wired by OR. The first rising edge of SCK would reset INTN pin (interrupt pin). After the configuration, user must initialize the MS1022 by sending opcode "Init" so that the TDC can receive Start and Stop signals.

2.2 Measurement

After an initialization, TDC unit receives the first pulse on Start channel. It start to run until:

‧ The set sample number has been reached (maximum 3 times on channel 1 in the measurement range 2)

‧ A timeout occurs. The timeout can be programmed to select differential reference clock factor by setting Reg 3, Bits 27&28 (SEL_TIMO_MB2). At 4 MHz, the values are:

SEL_TIMO_MR2 (@ 4 MHz, ClkHSDiv = 0)

$$= 0 \quad = 64 \ \mu s$$
$$= 1 \quad = 256 \ \mu s$$
$$= 2 \quad = 1024 \ \mu s$$
$$= 3 \quad = 4096 \ \mu s$$

At the end of the time measurement, TDC measures two periods of the reference clock for calibration.

2.3 Data Process

At the end of the measurement, ALU starts to process the data according to the HIT1, HIT2 settings and sends the result to the output register. ALU calculates and transfers the 32 bit fixed-point number to the output register.

The time taken by ALU calculation depends on supply voltage.

	One pulse
3.3 V	t.b.d. μs
2.5 V	t.b.d. μs

As soon as the data is valid in the result register, the interrupt bit will be reset (assumed that the ALU interrupt is enable, see Reg 2, EN_INT). Further the output result pointer is increased by 1 and points to the next empty address. The current result address pointer can be seen in the status register, Bits 0 to 2.

2.4 Read Data

Now user can read data sending the opcode 10110+ADDR. With the next 32 cycles (calibrated data), the MS1022 will start to output result, beginning with the most significant Bit (MSB).

Calibration result is 32bit fixed-point number in two's complement, representing the time interval which is minimum unit for reference clock period.

$$\text{Time} = \text{RES\_X} \times \text{Tref} \times 2^{\text{ClkHSDiv}}$$

Before the next measurement, the MS1022 must be initialized again by sending the opcode "Init", so that TDC can receive new Start and Stop signals.

Stop Masking

The MS1022 can set masking window for any of the 3 pulses on STOP1 input when no pulses are accepted. The masking window starts with START signal and has an accuracy of more than 10ns. The internal enable unit is connected to the external enable pin by logical AND. The external enable pin, START, STOP1, 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, DELVAL2 and DELVAL3 are fixed-point numbers with 14bit integer and 5bit decimals, multiplied by internal reference clock period:

$$Delay_{min} = DELVALX / 2^5 \times Tref \times 2^{ClkHSDiv}$$

· The minimum mask time is three clock periods.

· The mask values must have an ascending order. Each mask value must be three clock periods more than the previous value.

if not all masking windows are used, needless mask values must be forced to 0. When all DELVAL registers are set to 0, the unit will be disabled.

For example:

4 MHz reference, ClkHSDiv = 1

DELVAL1 = 'h3200 1st pulse not accepted before 200 μs after Start signal

(128000/32 × 250ns × 2^1 = 200 μs)

DELVAL2 = 'h3300 2nd pulse not accepted before 204 μs after Start signal

(13056/32 × 250ns × 2^1 = 204 μs)

DELVAL1 = 'h3400 3rd pulse not accepted before 208 μs after Start signal

(13312/32 × 250ns × 2^1 = 208 μs)

Analog Input Part

The MS1022 integrates an analog input part which can be used alternatively to the digital inputs. Especially the design of ultrasonic flow and heat meters is greatly simplified by this function. The external circuit of the ultrasonic part is reduced to just two resistors and capacitor connected to transducer. The ultrasonic signals will be packages of 10 to 200 sinusoidal oscillations with a several 100mV amplitude. The signals are coupled to the inputs by a high pass filter. Because the comparator can think zero-point as triggering, the triggering voltage of the comparator is set to 1/3 VCC. An analog multiplexer selects the input according to measurement direction. The comparator is chopper stabilized to guarantee low zero-point voltage drift (less than 2mV). This is precondition for a good measurement quality. The zero-point drift voltage of the comparator is frequently corrected by an internal chopper circuit. If temperature or supply voltage changes over time, the zero-point drift voltage will be automatically adjusted to less than 2mV.

All elements are controlled by the MS1022 control unit. They are only enabled during the measurement to reduce the whole measurement power dissipation.

A ultrasonic measurement of time interval is performed by command Start_TOF_Restart. The measurement sequence is as follows:

- The 4 MHz high-speed oscillator is switched on. The chips waits for the delay to give enough time for the oscillator to reach the full amplitude.

- The comparator, the reference voltage and the analog switch get powered.

- The capacitor of the transmitting channel (STOP1) is connected to GND.

- The transmitting buffer of down flow Fire (FIRE_DOWN) is connected to GND.

- The capacitor of the receiving channel (STOP2) is charged up to Vref. TDC waits the delay set in TW2.

- The analog switch selects STOP2 input as comparator input.

- FIRE_UP is selected as TDC START signal.

- The set pulse number is sent through the FIRE_UP pin.

- The analog signal at STOP2 transmits to the comparator and is converted to a digital signal that is connected to the STOP input of the TDC unit.

- When the time of STOP masking window (DELVAL) is reached, TDC is ready to measure. It can measure up to three STOP pulses.

- At the end of the measurement, control unit switches off the comparator, analog switch and the 4MHz oscillator. The current is reduced to close zero. And the interrupt fag is reset.

- The control unit waits a period, given in multiples of 50Hz/60Hz. During the processor, single-chip microcomputer must readout previous measurement results.

- After the delay, the same procedure is repeated but in the down flow measurement.
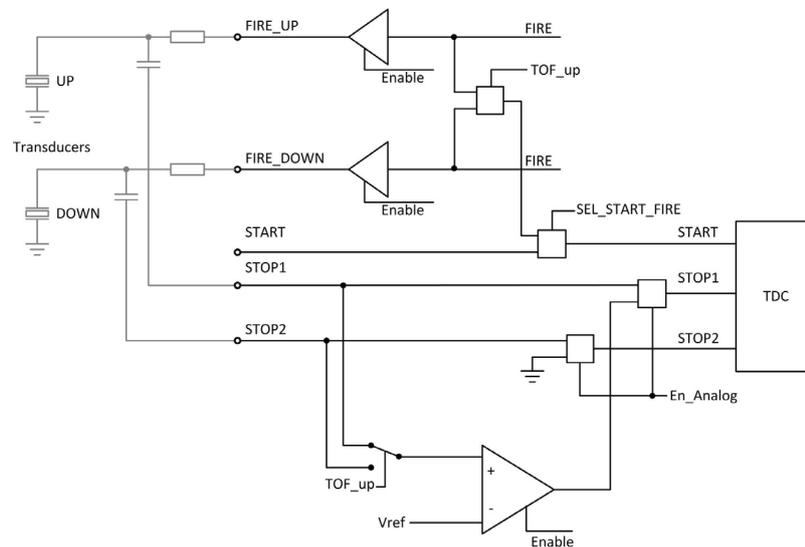
The offset voltage of the comparator can be set in steps of 1mV from -8mV to +7mV by means of parameter DA_korrt, bits 25 to 28 in Register 6. DA_korrt is set as two's complement.

In addition, when first wave mode is used, an additional offset of ±35mV can be set for the first wave detection.

First Wave Mode

The MS1022 integrates first wave mode. It is based on the measurement range 2 with the analog part being used. The offset voltage is controlled automatically to detect the first wave. Then according to the position of the first wave, the ToF time of return wave is measured, Additionally, the width of the first half wave is compared to the half wave of the first STOP. The ratio can be used as indicator for the signal strength. Due to the offset noise is very low and a definite indication is get that no water is in the tube.

The following summarizes the function:

• Save first wave detection allows high dynamic applications like water meter

• High-dynamic applications allow use high frequency, such as 1MHz to 4 MHz ultrasonic transducer

• Reverse flow can be recognized and handled (very helpful e.g. with water meter)

• Pulse width measurement allows to detect the received return signal and to track the trigger level to send an alarm.

• Offset voltage for low noise allows to indicate an empty tube.

The right figure illustrates the importance of first wave detection in the high-dynamic range measurement, such as ultrasonic water meter. With a fixed stop masking (fixed DALVAL values), it is not possible to recognize whether the time-of-fight changes is more than one period of one return signal. There are several factors that the change in ToF is more than a period. An important one is the influence of temperature which changes the ultrasonic speed.

For slow systems like heat meter, this might be corrected by intelligent software. But for high-dynamic systems like water meter, when the flow current is not certain, this method will no longer be appropriate.

The current trend is to use high-frequency transducer, such as 2MHz and 4MHz transducer so as to handle the condition when outside influence is more than a signal period.

Receive signal with no flow

Fixed DELVAL (stop masking)

TDC stops

Shift ToF ≥ Period

Receive signal with strong flow
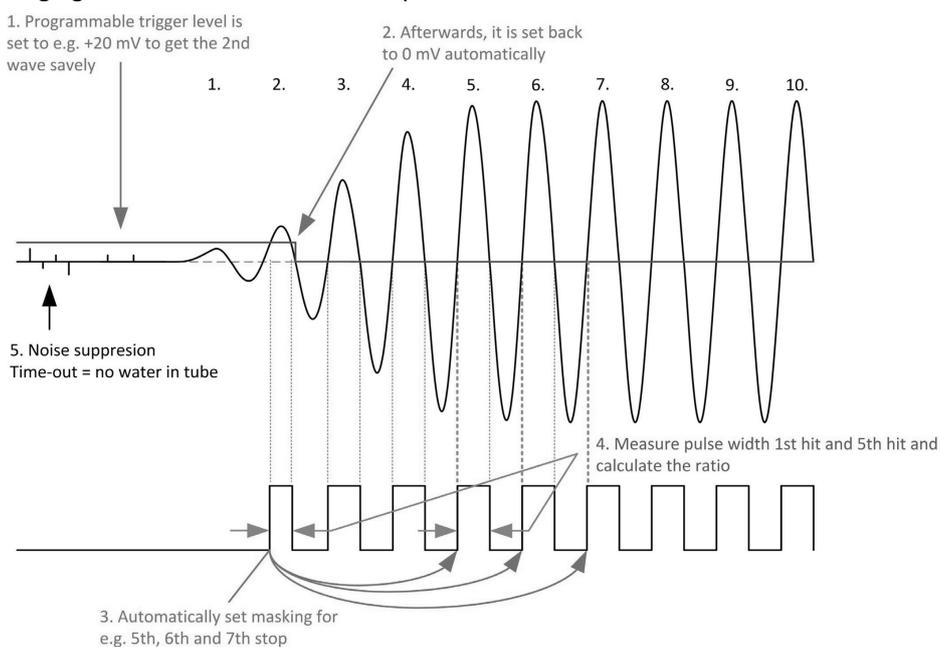
Fixed DELVAL (stop masking)

TDC stops
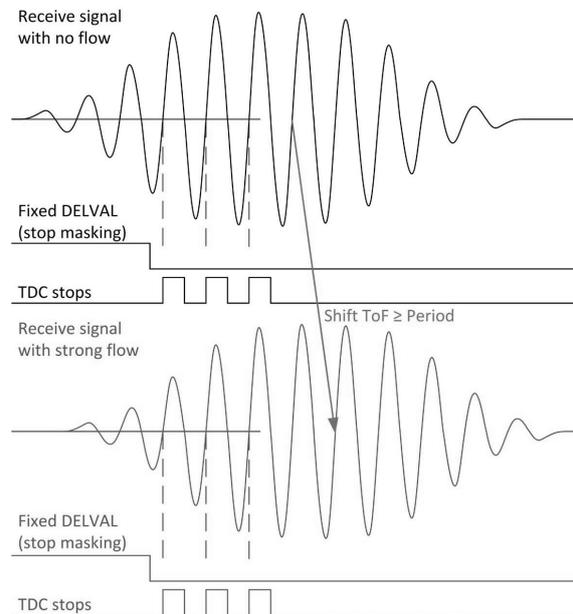
There is still another condition of getting wrong measurements. Coverings on the transducer, reflect mirror and shell will lead to signal attenuation from ±400mV to < ±80mV. The right figure shows how this will affect the first wave detection at a given, fixed offset for the first return wave detection. Once the amplitude of first wave is below the offset level, the measurement result will jump by one period.。

Receive signal with good signal quality

Receive signal with bad signal quality

Half the amplitude only
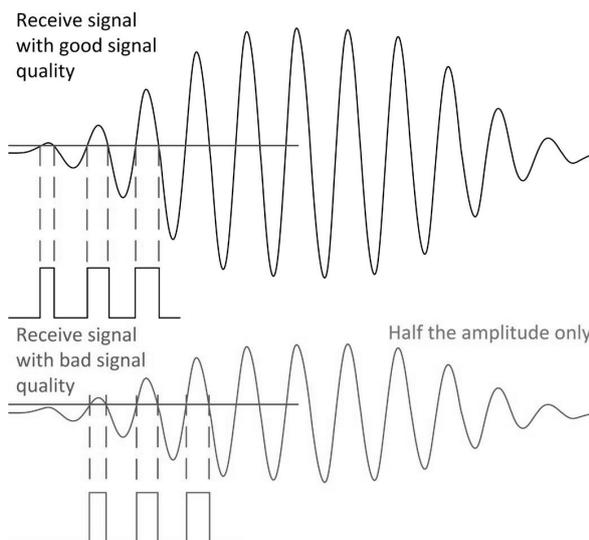
By the first wave detection of the MS1022, the pulse measurement time is related to the first wave and is independent from temperature and speed. Therefore, some fault zero-point detection and recognition would no longer occur.

In addition, the pulse width of first wave enables the user to monitor the signal quality. It is necessary to adjust wanted pulse according to ratio of pulse width, .

The following figure shows the measurement process for first wave mode of the MS1022 .

1. Programmable trigger level is set to e.g. +20 mV to get the 2nd wave savely

2. Afterwards, it is set back to 0 mV automatically

5. Noise suppresion
Time-out = no water in tube

4. Measure pulse width 1st hit and 5th hit and calculate the ratio

3. Automatically set masking for e.g. 5th, 6th and 7th stop

1. Pulse generator. The offset for the first wave detection is set to a programmable level. The DELVAL1 stop masking is used to suppress any noise and it is set just roughly close to the expected time-of-fight. Other noise will be further suppressed by the comparator offset until the received signal reaches the amplitude set by offset level.

2. The MS1022 measures the pulse width of first wave. Then, it automatically sets the offset to 0mV. Because offset temperature drift is less than 1mV, the measured drift is very low.

3. The masking window for three time measurements is set by parameters DELREL1 to DELREL3, relative to the first wave. For example, if set DELREL1 = 3, the 3rd wave is measured after the first wave.

4. The first half wave period (hwp) is measured as a reference for the width of first wave. In the above figure, this would be the width of the 5st wave. The ratio, $hwp_{first\ wave}/hwp_{firstToF}$, is in the range of 0 to 1. The smaller the value, the weaker received signal. The information can be used to monitor flow feature. If there are many deposits in tube or transducer over the years, signal ration may drop below 0.5. Therefore, the second wave can be used as reference in the future.

5. The MS1022 automatically calculates all three stop pulses and further calculates the sum of the three pulses, which will be read from Register 4. The communication with the microprocessor is greatly simplified by this way. As soon as the interrupt is reset, the microprocessor can immediately read measurement result. There is no need to send command to Register 1 like measurement range 1.

6. Once the tube is empty, there will be no stop signal. The offset value will remain at the level for the first wave detection. In this condition, noise can not trigger TDC and TDC will run into a timeout. In other words, the timeout is an indicator for an empty tube.

Register Configuration of First Wave Mode

Reg	Bit	Parameter	Description
3	30	EN_FIRST_WAVE	1= First wave mode, Register 3 and Register 4 would have new meaning
4	8-12	OFFS	Set comparator offset in two 's complement with 1mV unit 0 = 0 mV 1 = +1 mV ... 15 = +15 mV 16 = -1 mV 17 = -2 mV ... 31 = -16 mV
4	13	OFFSRNG1	Additional offset by +20mV
4	14	OFFSRNG2	Additional offset by - 20mV
3	8-25	DELREL1 DELREL2 DELREL3	Masking window, select the xth wave for time-of-fight measurement. Maximum is the 63rd wave. DELREL1 ≥ 3. DELREL1 to DELREL3 must be set in ascending order. Example: DELREL1 = 3, DELREL2 = 4, DELREL3 = 5 means to measure 3rd, 4th and 5th wave
4	16	DIS_PW	0 = On 1 = Off Pulse width measurement. The ratio can be read from address 8, register PW1ST is an 8 bit fixed-point number with one integer bit (range 0 to 1.99).
4	15	EDGE_FW	0 = Rising edge 1 = Falling edge Sets the edge sensitivity of the first wave. With a negative value, it is appropriate to trigger on the falling edge, negative amplitude trigger.
3	31	EN_AUTOCALC _MB2	1= Switch on the calculation of all received pulses. The sum of the results is written to Register 4.

Temperature Measurement

1. Overview

For heat meter applications, the MS1022 has a high-precision temperature measurement unit that offers high-precision and low power dissipation.

The measurement is based on the discharge time for resistor to capacitor. Therefore, capacitor would respectively discharge the reference resistor and temperature sensor resistor. The MS1022 integrates a Schmitt trigger.
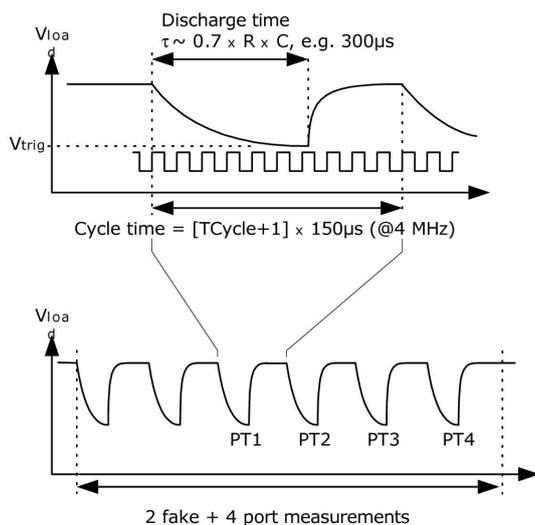

The temperature measurement unit has four resistor measurement ports, two of them to be used as the measurement ports of temperature sensors for hot water (up) and cold water (down). The other two ports are used for reference resistors. Basically, one reference resistor connected to both ports is enough.

The temperature sensor should have a minimum resistance of 500Ω. The cable length should not exceed 3m. The MS1022 only can measure 2-wire sensors. It is not possible to use 4-wire senors. The precision of the temperature measurement is fully satisfied with the requirements for heat meter when PT500 or PT1000 are used. In combination with PT500 or PT1000 temperature sensors, there is no need for two reference resistors. A typical application with one fixed reference is shown in right figure.
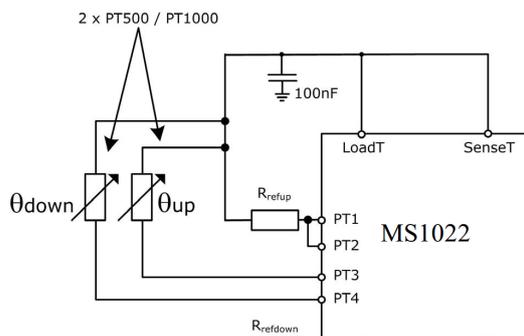
The MS1022 also supports temperature measurement with PT100 sensors, but the stability would be decreased. In this condition, we recommend to use two reference resistors instead of one, as shown in right figure. This helps to compensate gain drift of temperature sensor in total temperature range by means of two-point calibration .
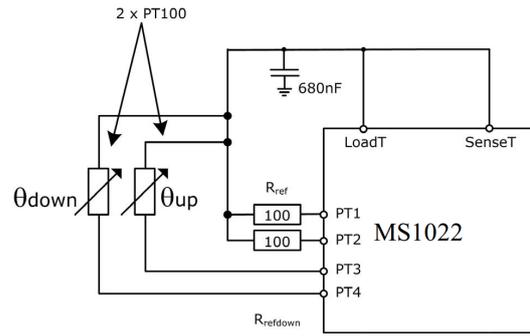
The temperature measurement is fully automatic sending the opcodes Start_Temp or Start_Temp_Restart according to microprocessor. Start_Temp or Start_Temp_Restart. With Start_Temp_Restart, the MS1022 would measure the temperature twice, with a delay given in multiples of the 50Hz/60Hz period. This will be helpful to reduce 50Hz/60Hz noise.

For a temperaure measurement, the MS1022 starts with 2 or 7 fake measurements on port PT1. Then, perform temperature measurement in the order PT1 > PT2 > PT3 > PT4. After the four measurements have finished, the interrupt fag is reset. The MS1022 also can inverse the order, making fake measurements from port PT4.

The four measurement results are found in result registers 0 to 3. Then, according to RES_2/RES_1 and RES_3/RES_4, the microprocessor can calculate the ratio Rtemp/Rref. At last, by means of a look-up table, it can achieve the current temperature value of sensor.

2. Description of Related Configuration Register

Register 0, bit 15, ANZ_FAKE sets the number of fake measurements at the beginning of temperature measurement. This is necessary to overcome mechanical effects of charge and discharge for capacitor.

ANZ_FAKE = 0   2 fake measurements

ANZ_FAKE = 1   7 fake measurements

Register 0, bit 16, 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, bit 17, ANZ_PORTS sets the number of ports that will be used.

ANZ_PORTS = 0 2 ports = 1 sensor

ANZ_PORTS = 1 4 ports = 2 sensors

Register 6, bit 11, TEMP_PORTDIR sets the order of the port measurements.

TEMP_PORTDIR = 0   PT1 > PT2 > PT3 > PT4

TEMP_PORTDIR = 1   PT4 > PT3 > PT2 > PT1

Register 6, bit 5, HZ60 sets the reference frequency for the delay between the up and down measurements for commands Start_TOF_Restart and Start_Temp_Restart.

HZ60   = 0   50Hz reference

HZ60   = 1   60Hz reference

Register 6, bits 18,19, CYCLE_TEMP, sets the factor timer for triggering the second temperature measurement in multiples of 50/60Hz.

CYCLE_TEMP = 0   0.5
                         = 1   0.75
                         = 2   1
                         = 3   1.25

Register 6, bit 30, NEG_STOP_TEMP set the path from input and SenseT signal. When internal Schmitt trigger is used, PIN17 and PIN18 are shorted; When external Schmitt trigger is used, PIN17 and PIN18 is externally connected (recommend 74HC14)

NEG_STOP_TEMP = 0 use external Schmitt trigger

                             = 1 use internal Schmitt trigger

3. Recommended Capacitor

To get accurate results, recommend capacitor type with very low dC/dU. Recommend to use C0G types or CfCap serie.

For heat meter application please do note use X7R or similar capacitors.

The discharge time should be about 150μs. Therefore, the capacitor should have the following values:

PT500:   220 nF
PT1000:   100 nF

Set Tcycle = 1 to avoid overflow error.

In heat meter application, please not use X7R or similar capacitance material.

4. Current Consumption

The temperature measurement needs an extremely low current for the MS1022, much less than an A/D converter does.

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

5. Error Detection

Additionally the temperature measurement unit checks the plausibility of the results. It is able to detect short-circuit or open-circuit of the sensor. Then, the MS1022 set status register, bit 11 or 12, to 1. And a error code is written to the corresponding result register.

·Short-circuit：equivalent to a very short time interval (< 8 x Tref = 2 μs @ 4 MHz). The MS1022 writes a 0x0 to the output register.

·Open-circuit：equivalent to no stop signal or timeout. The MS1022 writes a 0xFFFFFFFF into the output register.

Note: when 512μs (Tcycle = 1) cycle time is selected, it is necessary to have SEL_TIMO_MB2 at 2ms to avoid fault interrupt indication (INTN) .

6. Gain Error and Mathematical Compensation

The temperature measurement of the MS1022 is based that the resistance variation of temperature sensor is digitized by means of a high accurate time interval measurement. According to that, the Schmitt trigger' s delay time introduces a considerable gain error that results in a gain reduction compared to an ideal output value. This gain reduction can be mathematically described as a deviation from an ideal straight line. Hence, a simple mathematical correction by adding a correction factor compensates for this deviation from the ideal gain. It is calculated as follows:

$T_{corr} = T_{uncorr}/\text{gainfactor}$

T_{corr}: temperature result with gain corrected;

T_{uncorr}: temperature result with no gain corrected;

gainfactor: gain correction factor, compensates the deviation from an ideal gain of 1

By means of this compensation way, the effect of the Schmitt trigger's delay time can be reduced to a gain error of 0.05% of F. S. with the internal Schmitt trigger, or with an external 74AHC14 Schmitt trigger.

Three main parameters have to be considered, to select the gain correction factor:

· Base resistance of the temperature sensor (such as PT500, PT1000)

· Use Schmitt trigger (MS1022 internal, external 74AHC14)

· MS1022 supply voltage

The corresponding correction factors are provided in previous table.

Note:

The gain correction factors for the external Schmitt-trigger exclusively refer to the 74AHC14 Schmitt trigger. Other types (such as 74HC14) require different gain factors, in order to ensure a correct compensation. According to that, we strongly recommend to use a 74AHC14 as external Schmitt trigger.

Example 1:

Application with PT1000 sensor, the internal Schmitt trigger and 3V supply voltage. The gain factor is 0.9931. The gain corrected result is calculated by the following equation:

$$T_{corr} = T_{uncorr}/0.9931$$

Example 2：

Application with PT500 sensor, the external 74AHC14 Schmitt trigger and 3.6V supply voltage. The gain factor is 0.9980. The gain corrected result is calculated by the following equation:

$$T_{corr} = T_{uncorr}/ 0.9962$$

Oscillator

The MS1022 uses up to 2 clock signals depending on the operation mode:

• High-speed clock—used in calibration and as rough counter for the TDC measurement unit in the measurement range 2

• 32 kHz clock—used for internal timer

1. High-speed Oscillator

Generally, the MS1022 needs a high-speed clock for calibration. The recommend value is 4MHz, the frequency range is 2 to 8 MHz (2 to 6 MHz in quad-precision mode). When running in the measurement range mode 2 , the MS1022 needs the high-speed clock signal also as a part of the time measurement unit. And the other operations also need a high-speed clock.

The oscillator takes an average operation current of 260 μA when running all the time. But as it is needed only during the time measurement, the MS1022 has the capability to control the on-time by internal circuit. The settings are done with parameter START_CLKHS. With START_CLKHS > 1, the oscillator is switched on after sending commands Start_TOF, Start_TOF_Restart, Start_Temp or Start_Temp_Restart for the duration of the measurement. A delay between starting the oscillator and starting the measurement guarantees sufficient time for the oscillation to settle at full amplitude.

START_CLKHS = 0   Oscillator off

= 1   Oscillator on continuously

= 2   Delay 480 μs

= 3   Delay 1.46 ms

= 4   Delay 2.44 ms

= 5 to 7   Delay 5.14 ms
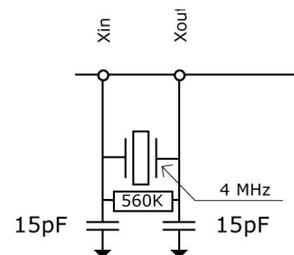
According to above set delay, t is guaranteed that the oscillator has settled before the measurement starts. For ceramic oscullator, 480 μs will be sufficient. By this measure, the average current consumption can be greatly reduced.

Example:

In ultrasonic flow meter (forth/back) per second, the high-speed oscillator is active only for about 2 ms. The average current consumption is 260μAs × 2 ms = 0.52μA.

2. 32.768kHz Oscillator

The MS1022 needs a 32.768kHz reference for the start-up control of the high-speed clock and the clock calibration. It is also as an integrated clock driver.

The 32.768kHz oscillator is permanently running and has a current consumption of only about 0.5μA at 3V. The start-up time of this oscillator is about 3s after power-up. The 32.768kHz oscillator cannot be switched off. Without using 32kHz clock, CLKIn pin must be connected to GND.
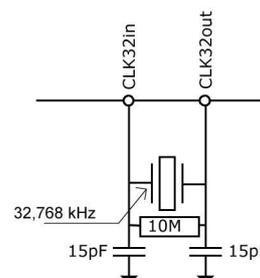
The low-power clock can be available for an external microprocessor by pin output.

The possible settings are:

SEL_TSTO1 = 7: 32 kHz output on FIRE_IN pin

SEL_TSTO2 = 7: 4 kHz (32kHz/8) output on EN_START pin

It is also possible to provide an external low-frequency square wave clock on the CLK32Out pin (3.6 Vmax.).

3. Calibrating High-speed Ceramic 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. However, it has larger error (0.3-0.5%) and obvious temperature drift. For this reason, the MS1022 allows to execute a calibration measurement to compensate this behavior. This measurement is based on the very precise 32.768 kHz clock. The MS1022 generates start/stop pulse from the 32.768 kHz clock and measures this time interval with its TDC unit. The result is stored in the result register and the interrupt fag is reset. Microprocessor can readout the result and calculate the frequency error of the ceramic oscillator.

The clock calibration is configured by setting Register 0, bit23-22, ANZ_PER_CALRES and is started with START_Cal_Resonator instruction by the microprocessor.

For example:

Use 4MHZ oscillator, CLKHSDIV=0, ANZ_PER_CALRES=1, and the theory result should be 22.0703125µs/250ns =488.28125 (RES_0 = 0x01E84800). If ceramic oscillator is 3.98MHz rather than accurate 4MHz, the calibration result would show 485,83984375 (RES_0 =1E5D700). According to this, microprocessor could calculate the calibration factor is 1.005.

Note: during the clock duration, EN_START must be high.

4. How to Use Clock Calibration
4.1 Application

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

4.2 Jitter of 32KHz Clock and Influence

The 32kHz clock is very precise in frequency with only a few ppm error. However, the phase jitter of peak-peak is about 3 to 5ns. For this reason, clock calibration measurement (Start_Cal_Resonator) has this error by itself. When multiplying a measurement result with the calibration result, the measurement result would generate jitter. The jitter amplitude of measurement result is the jitter amplitude of calibration multiplied by the ratio of calibration measurement time (ANZ_PER_CALRES) to measured time. If calibration is performed uninterruptedly, the calibration value would make the measurement result generate considerable jitter.

4.3 Calibration in Ultrasonic Flow Meter

A measurement result is always made of two single time-of-fight measurements in ultrasonic flow meter, with and against the flow direction. According to time difference between those measurements, flow is measured. To avoid the influence of the calibration jitter on this measurement result, it is necessary to use the same calibration value 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 calibrated must be performed between two measurements that are not subtracted from each other.

Pulse Generator

1. Overview

The fire-pulse generator generates a sequence of pulses which is highly programmable in frequency, phase and pulse number. The high-speed oscillator frequency is used as the basic frequency. This frequency is internally multiplied and can freely be divided by a factor of 2 to 15. It is possible to generate 1 to 127 pulses. If maximum 15 pulses are sent, the phase for each pulse can be adjusted by register configuration. The fire-pulse generator is activated by sending opcode Start_Cycle.

The fire-pulse generator provides two outputs, FIRE_UP and FIRE_DOWN. The driver capacity of each output is 96mA@3.3V. Furthermore, each output signal can be inverted to double the signal amplitude. The output can be set individually as high-Z. In addition, the default level of the inactive buffer can be set to GND.

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 the FIRE_IN input of the MS1022. Then it is digitally amplified and directly forwarded to the output buffer to perform synchronic clock output. When analog part is applied, "sing-around" method cannot be used.

2. Configuration of Relative Register

Pulse number:

ANZ_FIRE = 0   Pulse generator off

$\quad\quad\quad\quad$ = 1   1 pulse

$\quad\quad\quad\quad$ = 2   2 pulses

$\quad\quad\quad\quad$ … …

$\quad\quad\quad\quad$ = 127   127 pulses

SEL_START_FIRE = 1   Fire pulse directly to START signal of the TDC

FIREO_DEF   = 0   Default state High-Z

$\quad\quad\quad\quad\quad$ = 1   Default state GND. If internal analog part is used, must set like this. Apply recommended circuit with external R and C.

Pulse phase:

When not more than 15 pulses are sent, the phase of each pulse can be defined in Register 5, bits 0 to 15, PHFIRE. 0 presents LOW-HIGH and 1 for HIGH-LOW. The pulse sequence begins with the LSB and ends with the MSB.
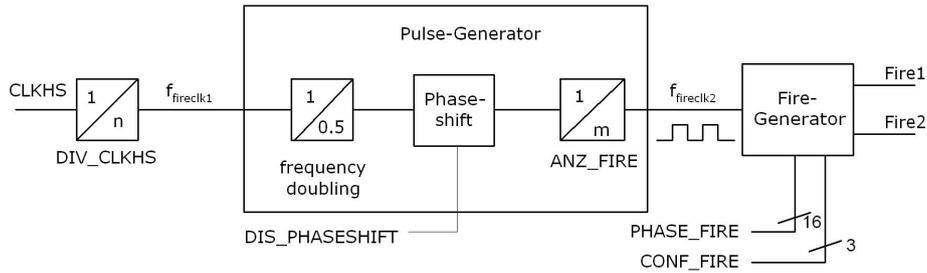
Example:

ANZ_FIRE = 7, PHFIRE = 0x0055

| 1 | 0 | 1 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
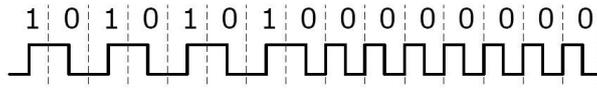
Fire-pulse frequency:

The input signal, fireclk1, for the fire-pulse generator is derived from the high-speed clock CLKHS and the selected division DIV_CLKHS.

The reference clock is first internally multiplied and divided by DIV_FIRE.

DIV_FIRE = 0   No allowed

     = 1   Divided by 2

     ... ...

     = 15   Divided by 16

Register 5, Bit 27 (DIS_PHASESHIFT) actives the phase shift, which introduces additional noise to reduce noise in following average.

DIS_PHASESHIFT = 0 Phase shift on

DIS_PHASESHIFT = 1 Phase shift off

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

$f_{fireclk2}$ is used as reference signal for the FIRE_UP / FIRE_DOWN signal, which is emitted by the output buffers of the fire pulse generator.
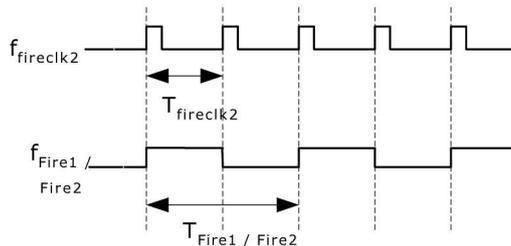
As shown above, at least two clock periods $T_{fireclk2}$ are required to send one Fire_Pulse. One for the high phase and one for the low phase of the FIRE_UP/FIRE_DOWN output signal.

Example:

CLKHS = 4 MHz, DIV_CLKHS = 1, DIV_FIRE = 1

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

FIRE_UP / FIRE_DOWN maximum frequency of output signal:

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

Output driver:

The output drivers are configured in Register 5, Bits 29 to 31 (CONF_FIRE):

Bit 31 = 1 FIRE_BOTH (Inverted on FIRE_DOWN)

Bit 30 = 1 FIRE_Up on

Bit 29 = 2 FIRE_Down on

Pulse-burst repetition (sing-around):

In Register 5, Bits 24 to 26 (REPEAT_FIRE), the repetitions number of the pulse sequence can be set.

REPEAT_FIRE = 0 No repetition

= 1 1 repetition

...   ...

= 7 7 repetitions

Only the pulse number set in ANZ_FIRE will be repeated. If no pulse is received with 5μs, the MS1022 detects the last pulse in the pulse sequence.

Note: This function can not be used with the internal analog part. It must be noted that the total time of 7 repetitions does not exceed the measurement range of the MS1022.

Fast Initiation

In the measurement range 1, the MS1022 offers the function of fast initialization. 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 only suitable for high-speed applications. It is specially appropriate for not-calibrated measurements with only one STOP signal.

Noise Unit

If user wants to improve the measurement results by averaging, it is not necessary to display the time difference synchronously. Instead, user should provide some noise so that different quantization steps of the characteristic curve of the TDC are involved. This can not happen with very constant time differences. Other wise the same LSB would be sampled repeatedly.

The noise unit enables the use of weighted averaging even for constant time differences. The noise unit adds a random offset to START. It is suitable for the application where the TDC gets a START signal and measures the time difference between STOP1 and STOP2 (such as laser ranging device).

The noise unit is switched on by setting Register 5, Bit 20, EN_STARTNOISE = 1.

ULTRASONIC HEAT METER APPLICATION

1. Overview

The MS1022 is perfectly suitable for low power dissipation ultrasonic heat meter designs. Due to the internal functions, including first wave auto-detection, high-precision temperature measurement, pulse generator, analog switches, comparator, STOP masking window and clock calibration, it only needs to add a simple microprocessor (without A/D converter) to perform high-precision measurement.

The final circuit can be very compact and has small size. The following diagram shows a typical ultrasonic heat meter with MS1022.
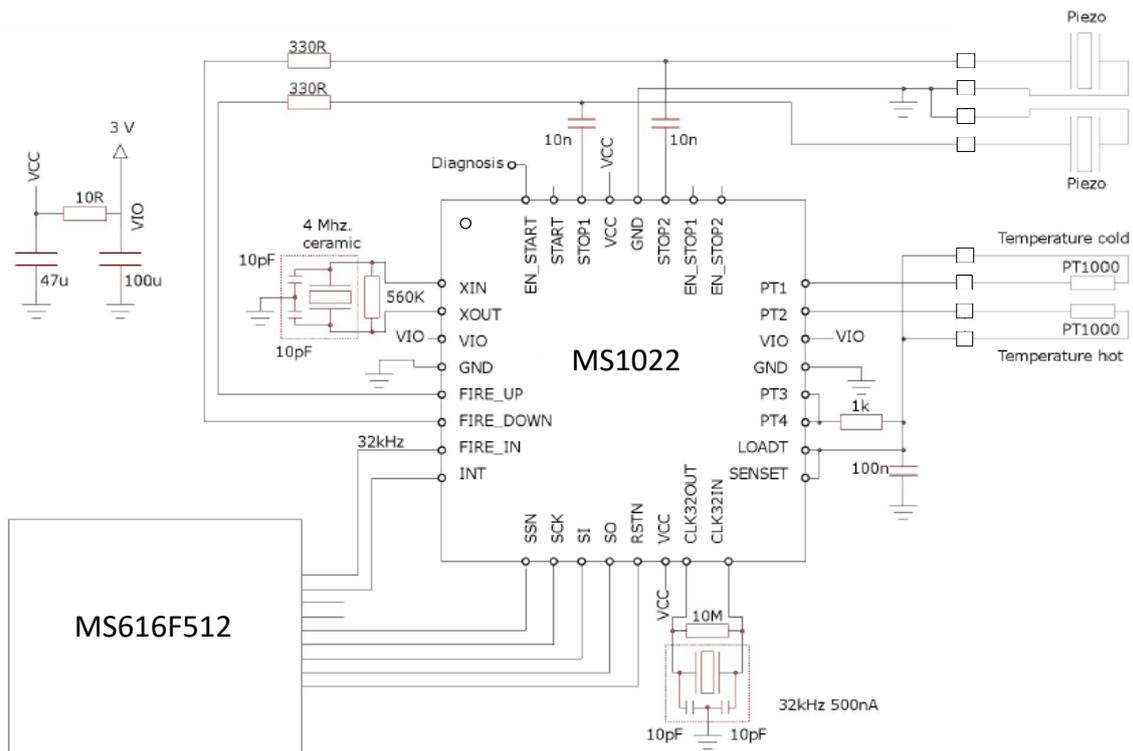
The red parts illustrate the external components. The number is reduced to a minimum:

· In the ultrasonic path, the piezo transducers are connected to a pair of R and C.

· In the temperature path, only need a temperature stable resistor and discharge capacitor.

· Oscillators take a 32.768 kHz quartz crystal and a 4 MHz ceramic oscillator. FIRE_IN pin can be used as output driver for the 32.768 kHz clock, so microprocessor does not need a low power-dissipation oscillator.

· For the power supply, use bypass capacitors to decouple VCC and VIO. Separate by a small resistor respectively. Only 11 low-cost elements are needed to compete all measurements.

2. Typical Configuration of Register

Reg	Value	Description
0	'hA30B6800	ANZ_FIRE = 10 (see Register 6). DIV_FIRE = 3, pulse frequency = 4 MHz/4 = 1.0 MHz. ANZ_PER_CALRES = 0, 4MHz is calibrated by a 61.035μs measurement. DIV_CLKHS = 0, 4 MHz ceramic oscillator is as internal clock without division. START_CLKHS = 2, the wait time for start-up is 480μs. ANZ_PORT = 1, apply all four temperature measurement ports. TCYCLE = 1, 512 μs as cycle time for temperature measurement. ANZ_FAKE = 0, 2 fake temperature measurements. SEL_ECLK_TMP = 1, apply 4MHzoscillator to define the cycle time of temperature measurement. CALIBRATE = 1, must be enabled in the measurement range 2. NO_CAL_AUTO = 0, must be set to auto-calibration in the measurement range 2. MESSB2 = 1, enable measurement range 2 for measuring > 2 μs. NEG_STOP/NEGSTART = 0, all channels are sensitive to rising edges. **Note: If use Start_TOF, recommend START_CLKHS=1 and off after test.**
1	'h21444000	HIT2 = 2, HIT1 = 1: calculate 1. Stop - Start in the measurement range 2. EN_FAST_Init = 0, off HITIN2 = 0。 HITIN1 = 4, measure 3 stop pulses (in the measurement range 2, start is regarded as 1 pulse, 4 pulses in total.) CURR32K = 0, use default. SEL_START_FIRE = 1, fire pulse drives the start signal directly. SEL_TSTO2 = 0, EN_START on. SEL_TSTO1 = 0, FIRE_IN pin is as pulse input. **Note: according to the setting, Fire_in and EN_Start cannot be floating.**
2	'hA0230000	EN_INT = b0101, interrupt is given by timeout, ALU calculation ends (see Register 6). RFEDGE1 = RFEDGE2 = 0, only use rising edge. DELVAL1 = 8960, the received time of first wave is after 70 μs. **Note: user can set DELVAL1 (masking time) by actual return signal.**
3	'hD0510300	EN_AUTOCALC = 1, automatically calculate all three pulses. EN_FIRST_WAVE = 1, enable the first wave detection.。 EN_ERR_VAL = 0, when it is timeout, 0xffffffff is written to result register. SEL_TIMO_MB2 = 2, after start pulse, if signal is not received within 1024 μs, it is timeout. DELREL1 = 3, DELREL2 = 4, DELREL3 = 5, after receiving the first wave, measure the 3rd, 4th and 5th stop pulse. **Note: user can set receive which stop pulse, according to the strongest wave after first wave.**
4	'h20004A00	DIS_PW = 0, pulse width measurement is enabled. EDGE_PW = 0, measure pulse width on the rising edge. OFFSRNG2 = 0, no negative offset OFFSRNG1 = 1, OFFS = 10: total offset = 20mV + 10mV = 30mV **Note: offset value can be adjusted according to strength of actual return signal.**

Reg	Value	Description
5	'h50000000	CON_FIRE = 2, disable FIRE_UP, FIRE_DOWN = enable. If Start_TOF_Restart opcode is used, FIRE_UP and FIRE_DOWN will be used in up and down flow measurements alternately. The register settings described here enable one cycle of down flow measurement (FIRE_DOWN = enable). EN_STARTNOISE = 0, enable. DIS_PHASESHIFT = 0, noise unit is enabled to reduce system error. REPEAT_FIRE = 0, no sing-around. PHASE_FIRE = 0, no phase change in fire pulses. **Note: if Start_TOF is used, it is necessary to set CON_FIRE=1 again to perform the second test.**
6	'hC0C06000	EN_ANALOG = 1, use internal analog comparator circuit. NEG_STOP_TEMP = 1, use internal Schmitter trigger as temperature measurement. DA_KORR=0, set comparator offset in the Register 4. TW2 = 3, 300µs delay to charge the high-pass capacitor. EN_INT = b1101, interrupt is given by time_out, ALU ready (see Register 6). START_CLKHS = 2, start-up time of ceramic oscillator is 480µs(see Register 0). CYCLE_TEMP = 2, use factor 1.0 for the delay between two measurements. CYCLE_TOF = 2, use delay factor 1.0 between the two TOF measurements. HZ60 = 0, 50 Hz base. FIREO_DEF = 1, when internal analog circuit is used, must enable QUAD_RES = 1, use 17ps resolution. DOUBLE_RES = 0 TEMP_PORTDIR = 0, standard temperature measurement sequence. ANZ_FIRE = 10 (see Register 0 at the same time). **Note: When Start_TOF_Restart opcode is used, CYCLE_TOF=0，HZ60=0. At this time, the minimum time interval between two flight time (up and down flow) is 8.3ms. Similarly, when Start_Temp_Restart opcode is used, CYCLE_TEMP=0，HZ60=0. And the minimum time interval between two temperature measurements is 8.3ms.**

3. Measurement Process

Power-on Reset:

Send SO = 'h50

Calibration clock:

Send SO = 'h03 Start_Cal_Resonator

Check-loop INTN = 0 ?

Send SO = 'hB0, Read SI = RES_0

Calibration factor = 61.035/RES_0

Measurement Cycle:

Temperature measurement every 30 seconds:

end SO = 'h02 Start_Temp

Check-loop INTN = 0 ?

Send SO = 'hB4, Read SI = STAT

STAT&'h1E00 > 0: -> Error routine

Send SO = 'hB0, Read SI = RES_0

Send SO = 'hB1, Read SI = RES_1

Send SO = 'hB2, Read SI = RES_2

Send SO = 'hB3, Read SI = RES_3

Rhot/Rref = RES_0/RES_1

Rcold/Rref = RES_3/RES_2

Lookup corresponding temperature in microprocessor data table.

One fight time interval every half second:

Send SO = 'h70 Initialize TDC

Send SO = 'h05 Start_TOF_Restart

Check-loop INTN = 0? (up flow TOF)

Send SO = 'hB4, Read SI = STAT

STAT&'h0600 > 0: -> Error routine,

timeout = empty tube.

Send SO = 'hB3, Read SI = RES_3

Send SO = 'h70 initialize TDC

Check-loop INTN = 0? (down flow TOF)

Send SO = 'hB4, Read SI = STAT

STAT& 'h0600 > 0: -> Error routine

Send SO = 'hB3, Read SI = RES_3

Now microprocessor can start to process data and then calculate the heat and flow values.

Detect signal strength by pulse width:

Send SO = ' hB8, Read SI = PW1ST

If PW1ST < 0.3 , signal is too weak and alarm signal is issued.

FAULT REPORT

1. TDC-CAL Data Read Error

When quad resolution is not set, the TDC-CAL value will give a wrong read value. The internal save value is correct, but the transfer value from output to the read register is not correct. Therefore, it has no effect on final measurement result. It only have problem in reading CAL calibration value.

Effect in the measurement range 2:

For the user using measurement range 2, CAL is only a mid-value without readout. And it is strongly recommended to use quad-precision mode.

Effect in the measurement range 1:

For all users, when auto-calibration is used for TDC, it has no any effect on final measurement result.

When in the measurement range 1, user uses not-calibrated measurement result and reads CAL value. However, in the manual TDC calibration, CAL value is unusable.(ultrasonic heat meter and water applications are not involved).

Solution:

For the fault, there are many differential solutions and the better way is as follows:

After user performs manual calibration, don't read the calibration result directly and only need to store the result in the TDC internal. Then in after measurements, ALU would automatically calculate by use previous calibration result. And this has no effect on final result.

### 2. Timeout Fault in Temperature Measurement

In order to avoid the fault, when cycle time of temperature measurement is 512µs (Register 0, bit 16, TCYCLE), the Register 3, bit 27 and 28, SEL_TIMO_MB2 is needed to set as 2ms. Otherwise the interrupt from INTN pin would have fault.

SIMILAR PRODUCTS COMPARISONS

|	MS1022	GP22	GP21	GP2
First Wave Mode	Yes	Yes	No	No
Pulse Width Measurement for First Wave	Yes	Yes	No	No
Set Comparator Offset	±42mV	±42mV	±7mV	No internal comparator
Masking Method for STOP Pulse	Set masking time relative to START and masking STOP number relative to first wave	Set masking time relative to START and masking STOP number relative to first wave	Only set masking time relative to START	Only set masking time relative to START
Auto-calculate All Measurement Results	Yes	Yes	No, calculate one result every writing one register	No, calculate one result every writing one register
Measurement Precision	90/45/22ps	90/45/22ps	90/45/22ps	65ps
Pulse Generator Phase Inverted Function	Normal Same as datasheet described	Abnormal Differential as datasheet described	Abnormal Differential as datasheet described	Abnormal Differential as datasheet described
Independence of Two STOP Channels	Two channels are independent with each other and can be used separately. The measurement results are not effected.	In the measurement range 1, if not use STOP1 channel, only use STOP2 channel, the result would be abnormal.	In the measurement range 1, if not use STOP1 channel, only use STOP2 channel, the result would be abnormal.	Two channels are independent with each other and can be used separately.
Wait Time for Continuous Two Measurements (Send opcode 0x05 or 0x06)	10/15/20/25/ms or 8.3/12.5/16.6/20.8ms	20/30/40/50ms or 16.67/25/33.3/41.7ms	20/30/40/50ms or 16.67/25/33.3/41.7ms	No function

PACKAGE OUTLINE DIMENSIONS

QFN32

TOP VIEW

SIDE VIEW

BOTTOM VIEW
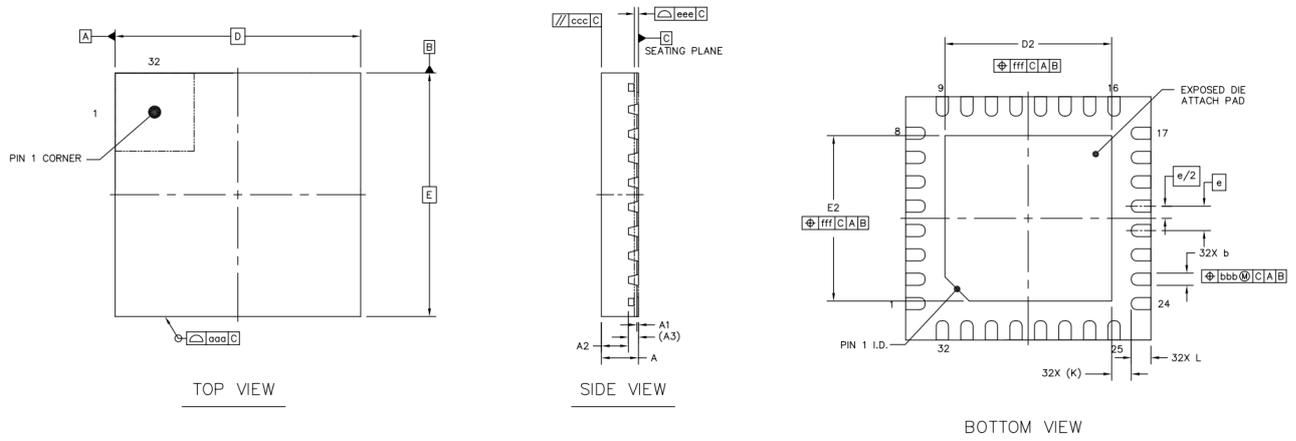
		Symbol	Dimensions in Millimeters		
			Min	Typ	Max
TOTAL THICKNESS		A	0.7	0.75	0.8
STAND OFF		A1	0	0.02	0.05
MOLD THICKNESS		A2		0.55	
L/F THICKNESS		A3	0.203 REF		
LEAD WIDTH		b	0.2	0.25	0.3
BODY SIZE	X	D	5 BSC		
	Y	E	5 BSC		
LEAD PITCH		e	0.5 BSC		
EP SIZE	X	D2	3.3	3.4	3.5
	Y	E2	3.3	3.4	3.5
LEAD LENGTH		L	0.3	0.4	0.5
LEAD TIP TO EXPOSED PAD EDGE		K	0.4 REF		
PACKAGE EDGE TOLERANCE		aaa	0.1		
MOLD FLATNESS		ccc	0.1		
COPLANARITY		eee	0.08		
LEAD OFFSET		bbb	0.1		
EXPOSED PAD OFFSET		fff	0.1		

MARKING and PACKAGING SPECIFICATIONS

1. Marking Drawing Description
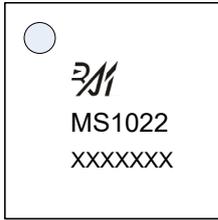
MS1022
XXXXXXX

Product Name : MS1022

Product Code : XXXXXXX

2. Marking Drawing Demand

Laser printing, contents in the middle, font type Arial.

3. Packaging Specifications

Device	Package	Piece/Reel	Reel/Box	Piece /Box	Box/Carton	Piece/Carton
MS1022	QFN32	4000	1	4000	8	32000

STATEMENT

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  product for customer.

MOS CIRCUIT OPERATION PRECAUTIONS

Static electricity can be generated in many places. The following precautions can be taken to effectively prevent the damage of MOS circuit caused by electrostatic discharge:

1. The operator shall ground through the anti-static wristband.

2. The equipment shell must be grounded.

3. The tools used in the assembly process must be grounded.

4. Must use conductor packaging or anti-static materials packaging or transportation.

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