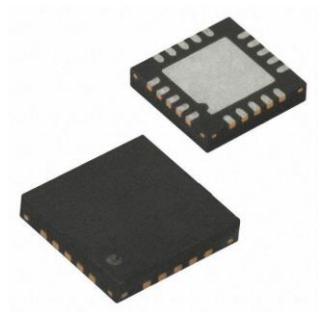


High-precision Time Measurement (TDC) Circuit for Laser Ranging

PRODUCT DESCRIPTION

The MS1003 is a high-precision time measurement (TDC) circuit. Compared with the MS1002, it has higher accuracy and smaller package, which is suitable for high-precision small package applications.

The MS1003 has dual-channel, multi-pulse sampling capability, high-speed SPI communication, multiple measurement modes, and is suitable for radar and laser ranging.



QFN20

FEATURES

- 46ps in Dual-channel Single-precision Mode
- 23ps in Single-channel Double Precision Mode
- Uncalibrated Single-precision Measurement Range 3.5ns to 16μs
- Uncalibrated Double Precision Measurement Range 3.5ns to 16μs
- Calibration Single Precision Measurement Range 3.5ns to 4μs
- Calibration Double precision Measurement Range 3.5ns to 2μs
- 10ns Minimum Pulse Interval, Dual channels can receive up to 20 pulses
- 4-wire SPI Communication Interface
- Operating Voltage 2.5V to 3.6V
- Working Temperature -40°C to +100°C
- QFN20 Package

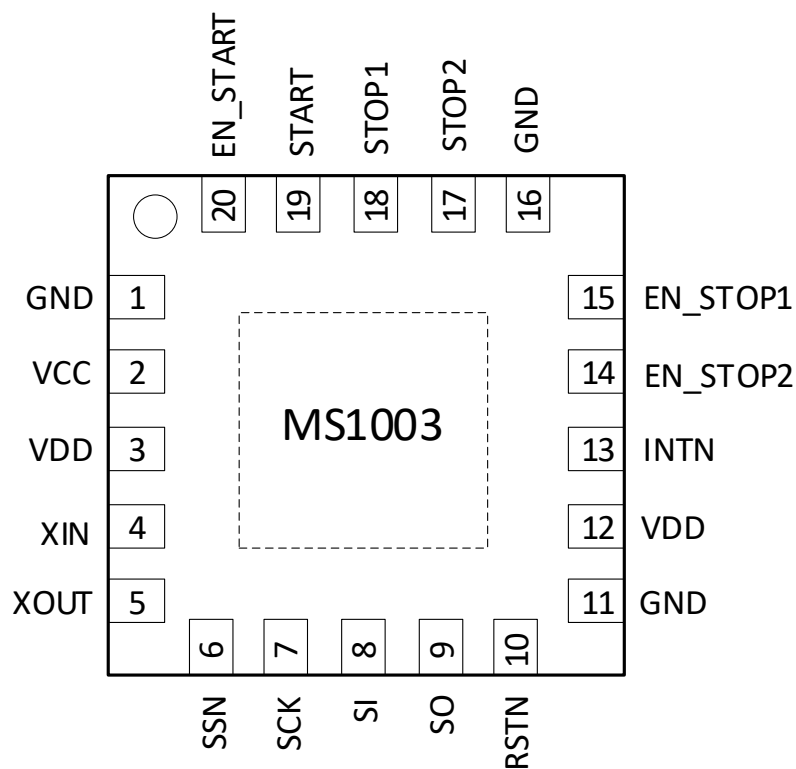
APPLICATIONS

- Radar
- Laser Ranging
- Pulse Measurement

PRODUCT SPECIFICATION

Part Number	Package	Marking
MS1003	QFN20	MS1003

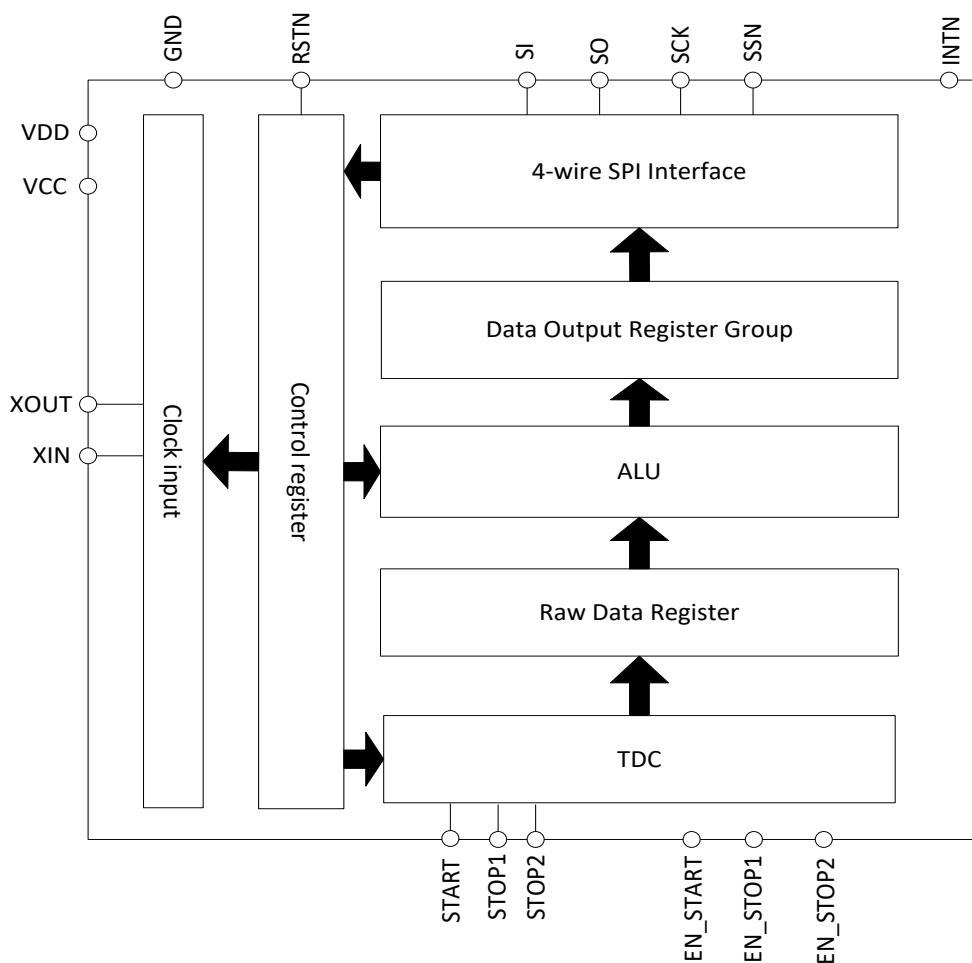
PIN CONFIGURATION



PIN DESCRIPTION

Pin	Name	Type	Description
1	GND	-	Ground
2	VCC	-	I/O Power Supply
3	VDD	-	Core Power Supply
4	XIN	I	High-speed Crystal Drive Input
5	XOUT	O	High-speed Crystal Drive Output
6	SSN	I	SPI interface Slave Selection, Active Low
7	SCK	I	SPI Interface Clock Input
8	SI	I	SPI Interface Data Input
9	SO	O	SPI Interface Data Output; High impedance when SPI is idle
10	RSTN	I	System Reset Input, Active Low
11	GND	-	Ground
12	VDD	-	Core Power Supply
13	INTN	O	Interrupt Flag, Active Low
14	EN_STOP2	I	Stop Channel 2 Enable Port, Active High
15	EN_STOP1	I	Stop Channel 1 Enable Port, Active High
16	GND	-	Ground
17	STOP2	I	Stop Channel 2
18	STOP1	I	Stop Channel 1
19	START	I	Start Channel
20	EN_START	I/O	The default output port, output START pulse, it is recommended not to directly connect to the power supply to avoid large current; EN_START internal pull-up Start enable, can be set to EN_START input by setting register, high level is effective

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_{DD}	-0.3 ~ 4	V
I/O Supply Voltage	V_{CC}	-0.3 ~ 4	V
Input Voltage	V_{IN}	-0.5 ~ $V_{CC}+0.5$	V
Storage Temperature Range	T_{STG}	-65 ~ 150	V
Operating Temperature Range	T_A	-40 ~ +100	V
Lead Temperature Range (10s)		260	°C
ESD(HBM)	V_{ESD}	>6	kV

RECOMMENDED OPERATING CONDITIONS

Unless otherwise noted, $T_A = 25^{\circ}\text{C} \pm 2^{\circ}\text{C}$.

Parameter	Symbol	Condition	Min	Typ	Max	Unit
Core Supply Voltage	V_{DD}	$V_{DD} = V_{CC}$	2.5		3.6	V
I/O Supply Voltage	V_{CC}		2.5		3.6	V
Input Rise Time	t_{RI}				200	ns
Input Fall Time	t_{FA}				200	ns
Operating Temperature Range	T_A		-40		100	°C

ELECTRICAL CHARACTERISTICS

DC Characteristics

$V_{CC} = V_{DD} = 3.0V$, $T_A = -40$ to $+85^{\circ}C$

Parameter	Symbol	Condition	Min	Typ	Max	Unit
4MHz Crystal Current	I_{HS}	$V_{DD} = V_{CC} = 3.6V$		200		μA
		$V_{DD} = V_{CC} = 3.0V$		130		μA
		When closed		<1		μA
Operating Current	I_O	TOF($V_{DD} = V_{CC} = 3.3V$)		4.1		mA
Output High Level	V_{OH}	$I_{OH} = tbd$ mA, $V_{CC} = Min$	0.8 V_{CC}			V
Output Low Level	V_{OL}	$I_{OL} = tbd$ mA, $V_{CC} = Min$			0.2 V_{CC}	V
Input High Level	V_{IH}	LVTTL, $V_{CC} = Max$	0.7 V_{CC}			V
Input Low Level	V_{IL}	LVTTL, $V_{CC} = Min$			0.3 V_{CC}	V

Terminal Equivalent Capacitance

Parameter	Symbol	Condition	Min	Typ	Max	Unit
Digital Input	C_{IN}	$V_{CC} = V_{DD}$, $f = 1MHz$, $T_A = 25^{\circ}C$		7		pF
Digital Output	C_O			3		pF
Bidirectional Input/Output	C_{IO}			9		pF

Time Measurement Unit

$V_{CC} = V_{DD} = 3.0V$, $T_A = 25^{\circ}C$

Parameter	Symbol	Condition	Min	Typ	Max	Unit
Measurement Resolution	LSB	DOUBLE_RES = 0		46		ps
		DOUBLE_RES = 1		23		
Standard Deviation	σ	DOUBLE_RES = 0	Measurement time 100ns	40		ps
			Measurement time 1000ns	48		
		DOUBLE_RES = 1	Measurement time 100ns	37		
			Measurement time 1000ns	46		
Measuring Range	t_M	Uncalibrated single precision		3.5ns		16 μs
		Uncalibrated double precision		3.5ns		16 μs
		Calibrated single precision		3.5ns		4 μs
		Calibrated double precision		3.5ns		2 μs

Clock Oscillator

Parameter	Symbol	Condition	Min	Typ	Max	Unit
High-speed Crystal Oscillator Reference Clock	Clk _{HS}		1	4	8	MHz
Ceramic Crystal Oscillator Start-up Time	t _{OSZST}			100		μs
Quartz Crystal Oscillator Start-up Time	t _{OSZST}			1		ms

APPLICATIONS INFORMATION

1. SPI Interface

The SPI interface of the MS1003 is compatible with 4-wire SPI, it needs a SerialSelectNot (SSN) signal, so it cannot work on 3-wire SPI interface.

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

The transmission starts from the most significant bit (MSB) and ends with the least significant bit (LSB). The transmission is done in bytes. Data transfer can Stop after each byte and send a LOW-HIGH-LOW level to SSN.

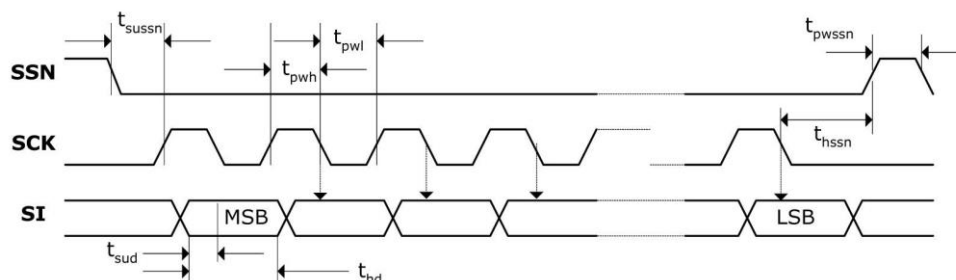


Figure 1. SPI Write Timing

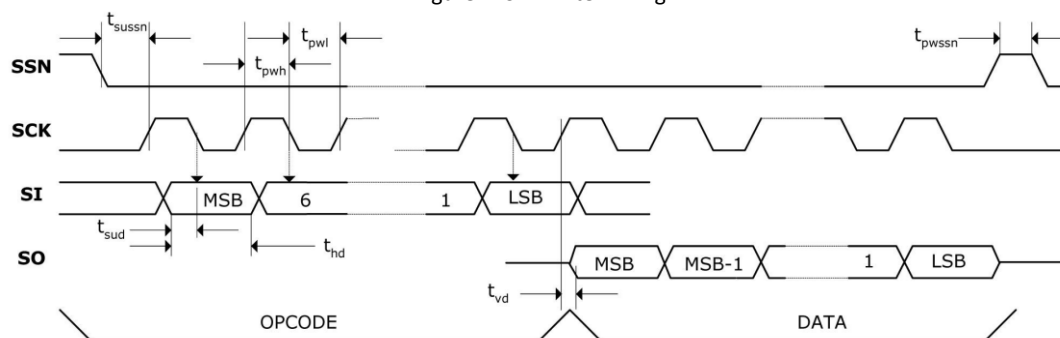


Figure 2. SPI Read Timing

Parameter	Symbol	Vdd=2.5V	Vdd=3.3V	Unit
Serial Clock Frequency	f_{clk}	25(Max)	40(Max)	MHz
Serial Clock, Pulse High	t_{pwh}	20(Min)	12(Min)	ns
Serial Clock, Pulse Low	t_{pwl}	20(Min)	13(Min)	ns
SSN is turned on until the clock edge is valid	t_{sussn}	20(Min)	20(Min)	ns
SSN Pulse Width between Write Cycles	t_{pwssn}	25(Min)	25(Min)	ns
SSN Hold Time after the Falling Edge of SCK	t_{hssn}	15(Min)	15(Min)	ns
Time from Valid Data to Falling Edge of SCK	t_{sud}	5(Min)	5(Min)	ns
Data Retention Time after the Falling Edge of SCLK	t_{hd}	5(Min)	5(Min)	ns
Time from Rising Edge of SCK to Valid Data	t_{vd}	15(Min)	10(Min)	ns

2. Timing of Closing the STOP Channel

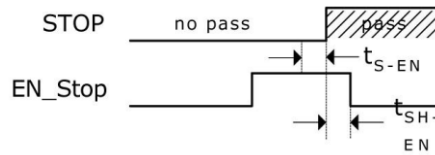


Figure 3. Timing of Closing the STOP Channel

Parameter	Symbol	Condition	Min	Typ	Max	Unit
Enable Setup Time	t_{S-EN}		3.5			ns
Enable Hold Time	t_{SH-EN}		15			ns

3. System Reset Sequence

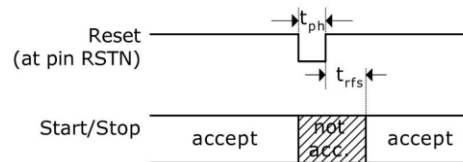


Figure 4. System Reset Sequence

Parameter	Symbol	Min	Max	Unit
Reset Pulse Width	t_{ph}	30		ns
The time interval from the rising edge of the reset pulse to when the pulse can be received	t_{rfs}	30		ns

4. Power Supply Voltage

In order to achieve the best measurement results, a good power supply is very important. The power supply should have high capacitance and low inductance.

The MS1003 provides two pairs of power supply ports: VCC-I/O supply voltage, VDD-core supply voltage.

All Ground pins should be connected to the ground plane of the printed circuit board. VCC and VDD should be given by a battery or a fixed linear voltage regulator. Do not use switching regulators to avoid interference caused by IO voltage.

The time-to-digital converter can have a good measurement effect, completely depends on a good power supply. Chip measurement is mainly pulse current, so a sufficient double-pass filter is very important: VCC 47 μ F (min 22 μ F), VDD 100 μ F (min 22 μ F).

The voltage should be given by an analog regulator. We recommend not to use switch-type voltage regulation.

5. Opcodes and Registers

5.1 Configuration Register

The MS1003 has a 32-bit configuration register.

Bit	Default	Parameter	Description	Set
31	0	HITIN2	Stop Expected pulse number of channel 2	0 = stop channel closed 2 = 1 pulse; 3 = 2 pulses; 4 = 3 pulses; 5 = 4 pulses; 6 = 5 pulses; 7 = 6 pulses; 8 = 7 pulses; 9 = 8 pulses A = 9 pulses; B = 10 pulses 1,C 到 F = Not allowed to set STOP1 cannot be set to 0
30	0			
29	1			
28	0			
27	0	HITIN1	Stop Expected pulse number of channel 1	
26	0			
25	1			
24	0			
23	0	SEL_TIMO	Overflow time selection (EN_SEL_TIMO=1 for this function to be effective); In addition, the overflow time is only related to the high-speed clock	0 = 1.5-2 main clock cycles @500ns 1 = 3.5-4 main clock cycles @1μs 2 = 7.5-8 main clock cycles @2μs 3 = 15.5-16 main clock cycles @4μs @ 4 MHz ClkHS
22	0			
21	0	DIV_CLKHS	Set the CLKHS high-speed reference clock Division factor	0 = No division 1 = Divide by 2 2 = Divide by 4 3 = Divide by 8
20	0			
19	0	START_CLKHS	Set the crystal oscillator on and off	0 = Crystal off 1 = Crystal on
18	1	DOUBLE_RES	Double precision measurement on	0 = off 1 = on
17	1	EN_ERR_VAL	Time overflow forces ALU to write 0xFFFFFFFF to the result register (Only the calibration mode is valid)	0 = off 1 = on
16	0	EN_FAST_INIT	Quick initialization function	0 = off 1 = on
15	0	SEL_TSTO2	EN_START pin function	0 = Input high level to turn on START 1 = START_TDC output 2 = STOP1 TDC output 3 = STOP2 TDC output
14	1			
13	1	CALIBRATE	Turn on/off calibration in ALU	0 = off 1 = on

Bit	Default	Parameter	Description	Set
12	0	NO_CAL_AUTO	Turn on/off to generate calibration value (If you need to turn on CALIBRATE, this bit must be set to 0)	0 = Automatically generate calibration value after measurement 1 = Turn off the function of automatically generating calibration values
11	0	K.D	Must be set as default	
10	0	NEG_STOP2	Reverse stop channel 2 input	0 = Trigger on rising edge 1 = Trigger on falling edge
9	0	NEG_STOP1	Reverse stop channel 1 input	0 = Trigger on rising edge 1 = Trigger on falling edge
8	0	NEG_START	Reverse start channel input	0 = Trigger on rising edge 1 = Trigger on falling edge
7	0	EN_SEL_TIMO	Overflow time function (Use with SEL_TIMO function)	0 = off 1 = on
6	0	EN_INT[2:0]	Interrupt source selection	Bit 6 = 1: Timeout interrupt trigger bit Bit 5 = 1: End Hits interrupt trigger bit Bit 4 = 1: ALU interrupt trigger bit
5	0			
4	0			
3	0	K.D	Must be set as default	
2	0	K.D	Must be set as default	
1	0	RFEDGE2	Edge sensitivity of STOP2	0 = Rising or falling edge 1 = Rising and falling edge
0	0	RFEDGE1	Edge sensitivity of STOP1	

5.2 Opcode

Opcode HEX	MSB LSB								Symbol	Operating
'h80	1	0	0	0	0	0	0	0	Write configuration register	Write 32bit
'hBx	1	0	1	1	A	A	A	A	Read STOP1 data A(0-9)	Read 24bit
'hCx	1	1	0	0	A	A	A	A	Read STOP2 data A(0-9)	Read 24bit
'hBB	1	0	1	1	1	0	1	1	Read calibration data (CAL)	Read 24bit
'hBC	1	0	1	1	1	1	0	0	Read the lower 8 bits of the configuration register	Read 8bit
'hBD	1	0	1	1	1	1	0	1	Read the status register (STAT)	Read 24bit
'h70	0	1	1	1	0	0	0	0	Init	Initialization
'h50	0	1	0	1	0	0	0	0	Power_On_Reset	Reset
'h04	0	0	0	0	0	1	0	0	Start_Cal_TDC	CAL measuring

5.3 Result Register

Opcode	Symbol	Number	Description
B0	RES1_0	24	STOP1 measurement result 1, Calibration mode: 24-bit fixed floating point number, high 8-bit integer, low 16-bit decimal; Non-calibration mode: 24-bit integer
B1	RES1_1	24	STOP1 measurement result 2, the format is the same as RES1_0
B2	RES1_2	24	STOP1 measurement result 3, the format is the same as RES1_0
B3	RES1_3	24	STOP1 measurement result 4, the format is the same as RES1_0
B4	RES1_4	24	STOP1 measurement result 5, the format is the same as RES1_0
B5	RES1_5	24	STOP1 measurement result 6, the format is the same as RES1_0
B6	RES1_6	24	STOP1 measurement result 7, the format is the same as RES1_0
B7	RES1_7	24	STOP1 measurement result 8, the format is the same as RES1_0
B8	RES1_8	24	STOP1 measurement result 9, the format is the same as RES1_0
B9	RES1_9	24	STOP1 measurement result 10, the format is the same as RES1_0
C0	RES2_0	24	STOP2 measurement result1, the format is the same as RES1_0
C1	RES2_1	24	STOP2 measurement result 2, the format is the same as RES1_0
C2	RES2_2	24	STOP2 measurement result 3, the format is the same as RES1_0
C3	RES2_3	24	STOP2 measurement result 4, the format is the same as RES1_0
C4	RES2_4	24	STOP2 measurement result 5, the format is the same as RES1_0
C5	RES2_5	24	STOP2 measurement result 6, the format is the same as RES1_0
C6	RES2_6	24	STOP2 measurement result 7, the format is the same as RES1_0
C7	RES2_7	24	STOP2 measurement result 8, the format is the same as RES1_0
C8	RES2_8	24	STOP2 measurement result 9, the format is the same as RES1_0
C9	RES2_9	24	STOP2 measurement result 10, the format is the same as RES1_0
BB	CAL	24	Calibration factor, integer, 24 bits

Calibration mode: $\text{Time} = \text{RES}_X \times \text{Tref} \times N$, when $N = 1, 2, 4$ or 8

Non-calibration mode: $\text{Time} = \text{RES}_X \times 46\text{ps}$ ($\text{VCC}=3.3\text{V}$, single precision)

5.4 Status Register (STAT)

Opcode	description								
BD	23-20	19-16	15	14	13	12-9	8-5	4	3-0
	0	STOP2 result address pointer	0	time overflow	TDC overflow	STOP2 pulse number	STOP1 pulse number	0	STOP1 result address pointer

6. Time Measurement

6.1 Overview

The measurement range of non-calibrated single-precision mode is from 3.5ns to 16μs (0-16μs is measured between two stop channels).

The non-calibrated double-precision mode measurement range is from 3.5ns to 16μs (0-16μs is measured between two stop channels).

The single-precision measurement range of the calibration mode is from 3.5ns to 4μs (0-4μs is measured between two stop channels).

The double-precision measurement range of the calibration mode is from 3.5ns to 2μs (0-2μs is measured between two stop channels).

The typical accuracy of single-precision mode is 46 ps, and the 2 stop channels are relative to the start channel.

The typical accuracy of the double-precision mode is 23 ps, and only the stop1 channel corresponds to the start channel.

Built-in special anti-shake technology to make the measurement time highly accurate.

The minimum interval between pulses of 10 ns.

Two stop channels can be collected at the same time, and each stop channel can have up to 10 pulses.

Each stop channel can select rising or falling edge capture, or select both rising and falling edges to capture at the same time.

Automatically measure the time interval between START and STOP pulses, no need for register settings.

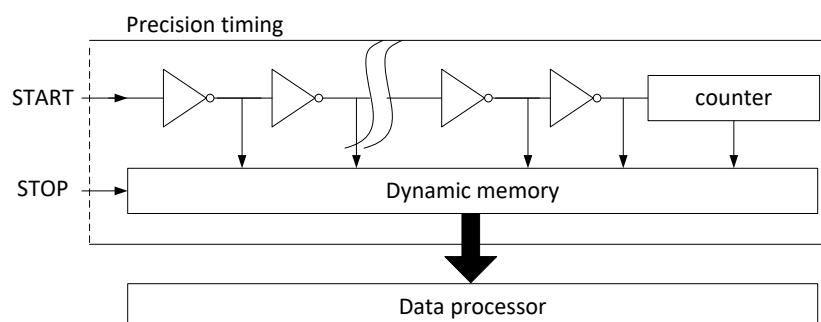
The overflow time can be set arbitrarily, thereby reducing the overflow time waiting during high-speed measurement.

In the non-calibration mode, you can arbitrarily measure pulses less than the expected number of pulses.

Typical applications: laser ranging, lidar, high-precision delay measurement.

6.2 Principle of High-precision Time Measurement

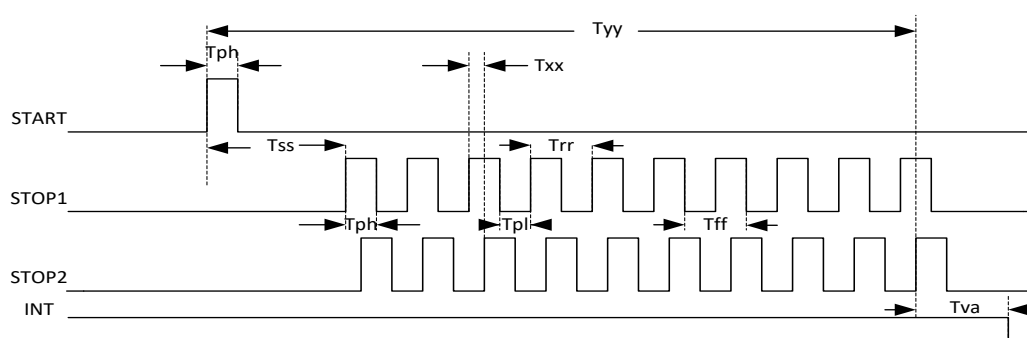
The digital TDC uses the internal logic gate delay to measure the time interval with high precision. The following figure illustrates the measurement principle structure of this absolute time TDC. This circuit structure ensures that the circuit uses a special measurement method to make the signal pass through the logic gate very accurate. The highest measurement accuracy depends entirely on the internal propagation time through the logic gate.



Time measurement is triggered by a start signal. After internal anti-shake processing, the TDC gate circuit starts high-speed counting until the stop signal generates the recording counting result, and stops counting when the expected number of STOP pulses is reached.

At 3.3V and 25°C, the single-precision minimum resolution of the MS1003 is 46ps. Temperature and voltage have a great influence on the propagation delay time of the gate circuit. Calibration is usually used to compensate for errors caused by temperature and voltage changes. In the calibration process, the TDC measures 0.5 and 1.5 clock cycles, and the TDC count result for one clock cycle is obtained after subtraction, which is the calibration value. The measurement range is limited by the size of the counter. The following is the maximum measurement range in non-calibration mode:

$$t_{yy} = 46 \text{ ps} \times 442368 \approx 20 \mu\text{s}$$



	Time (condition)	Description
Tph	2.5 ns (min.)	Minimum pulse width
Tpl	2.5 ns (min.)	Minimum pulse width
Tss	3.5 ns (min.) 20 μs (max.)	Between Start and Stop
Trr	10 ns (typ.)	Rising edge to rising edge
Tff	10 ns (typ.)	Falling edge to falling edge
Tva	t.b.d. Non-calibrated t.b.d. Calibration	Time from the last pulse to INIT output (See item 9 for details)
Txx	No time limit	Measurement time between channels
Tyy	20 μs (max)	Maximum measuring range

Each input terminal can be individually set to trigger on rising edge, falling edge, or both up and down edges at the same time. The trigger edge can be selected by setting bit8-10 (EG_START, NEG_STOP1, NEG_STOP2) of the register and bit0-1 (REFDGE) of the register.

After the time measurement is over, the MS1003 will automatically write the measurement results of each pulse to the corresponding result register in sequence, no need to set up the register operation. In the process of calculating the result, first calculate the pulse of the STOP1 channel, and then calculate the pulse of the STOP2 channel, so When using a single channel, STOP1 must be used.

6.3 Non-calibrated Time Measurement

6.3.1 Overview of Non-calibrated Time Measurement

Non-calibrated time measurement is actually the use of the logic gate delay inside the digital TDC to achieve high-precision time measurement. The maximum measurement range in non-calibrated mode is 3.5ns-16μs. In single-precision mode, two STOP channels can be measured at the same time. And each channel can measure up to 10 STOP pulses. In double-precision mode, only STOP1 channel can be used.

During the non-calibration time measurement process, the high-speed clock is not required, so the high-speed clock can be turned off by register setting (START_CLKHS=0). In this mode, the measurement speed is the fastest. The result register directly outputs the gate delay number. For the 20-bit effective bit of the result register in the mode, the measurement time is calculated as follows, and the measurement time is affected by temperature and voltage.

$$\text{Measurement time} = \text{RES_X} \times 46\text{ps} \quad (\text{DOUBLE_RES}=0)$$

$$\text{Measurement time} = \text{RES_X} \times 23\text{ps} \quad (\text{DOUBLE_RES}=1)$$

In the non-calibration mode, the time measurement and the CAL value can be measured at the same time. In this mode, you need to turn on the high-speed clock (START_CLKHS=1) and turn on the automatic calibration (NO_CAL_AUTO=0), so that the time will be measured and a Tref×N will be generated at the same time. The number of gate delays in N cycles, and then the CAL value RES_Tref is stored in the specified result register. The measurement time is calculated as follows. The measurement time has nothing to do with temperature and voltage, but only with high-speed clock jitter.

$$\text{Measurement time} = \text{RES_X} / \text{RES_Tref} \times \text{Tref} \times N, N = 1, 2, 4, 8;$$

When measuring overflow in non-calibration mode, when the overflow time function is turned off (EN_SEL_TIMO=0), the overflow time is equivalent to TDC overflow, that is, overflow occurs after 20μs, and the status register Bit13=1 (TDC overflow); when the overflow time function is enabled (EN_SEL_TIMO=1), the overflow time is set by the overflow time selection (SEL_TIMO). The overflow time is only related to the high-speed clock and is not affected by the clock division (DIV_CLKHS). For example, the high-speed clock is 8MHz, and SEL_TIMO=0. In the case of, the overflow time is 125ns, and the status register Bit14=1 (time overflow) when it overflows.

In non-calibration mode, when the number of measured pulses is less than the expected number of pulses, the value of the measured pulse can be output normally. Although the status register overflows at this time, the result of the measured pulse is correct. This application can be solved in the problem of multiple uncertain targets in the ranging process.

6.3.2 Register Settings

The main settings are:

- a. Select the number of expected pulses for measurement

Register bit 31-28 to set the expected number of STOP2 pulses HITIN2=0 or 2-B;

Register bit 27-24 sets the expected number of STOP1 pulses HITIN1=2-B, which cannot be set to 0; otherwise, the measurement cannot be started.

- b. Select measurement accuracy

Register bit 18, DOUBLE_RES = 1 selects double precision mode, the measurement accuracy is typically 23ps but only one stop channel is available. DOUBLE_RES = 0 Select single-precision mode, and the measurement accuracy is typically 46ps. At this time, both stop channels are available.

c. Calibration options

In non-calibration mode, calibration will be closed, register bit 13 CALIBRATE=0;

d. Generate CAL value

In non-calibration mode, you can choose to generate CAL value or not to generate CAL value. When register bit 12 NO_CAL_AUTO=0, CAL value is generated. When NO_CAL_AUTO=1, CAL value is not generated.

e. Overflow selection

In non-calibration mode, the overflow time of register bit 7 EN_SEL_TIMO=0 is turned off. At this time, the overflow time is TDC overflow. When EN_SEL_TIMO=1, the overflow time is turned on, and the overflow time is related to the setting of register bit 23-22 SEL_TIMO.

f. Select input trigger method

The edge trigger mode can be set on each input port (Start, Stop1, Stop2) by setting Bit 8-10 (NEG_X) of the register. When RFEDGE = 0, NEG_X = 0 is triggered on the rising edge, and NEG_X = 1 is triggered on the falling edge. You can also set Bit0&1 (REFDGE1 & FEDGE2) of the register to select whether STOP is triggered by a rising or falling edge alone (RFEDGE=0) or both rising and falling edges (RFEDGE=1). When RFEDGE=1, Bit 9 -10 selection is invalid.

g. Interrupt

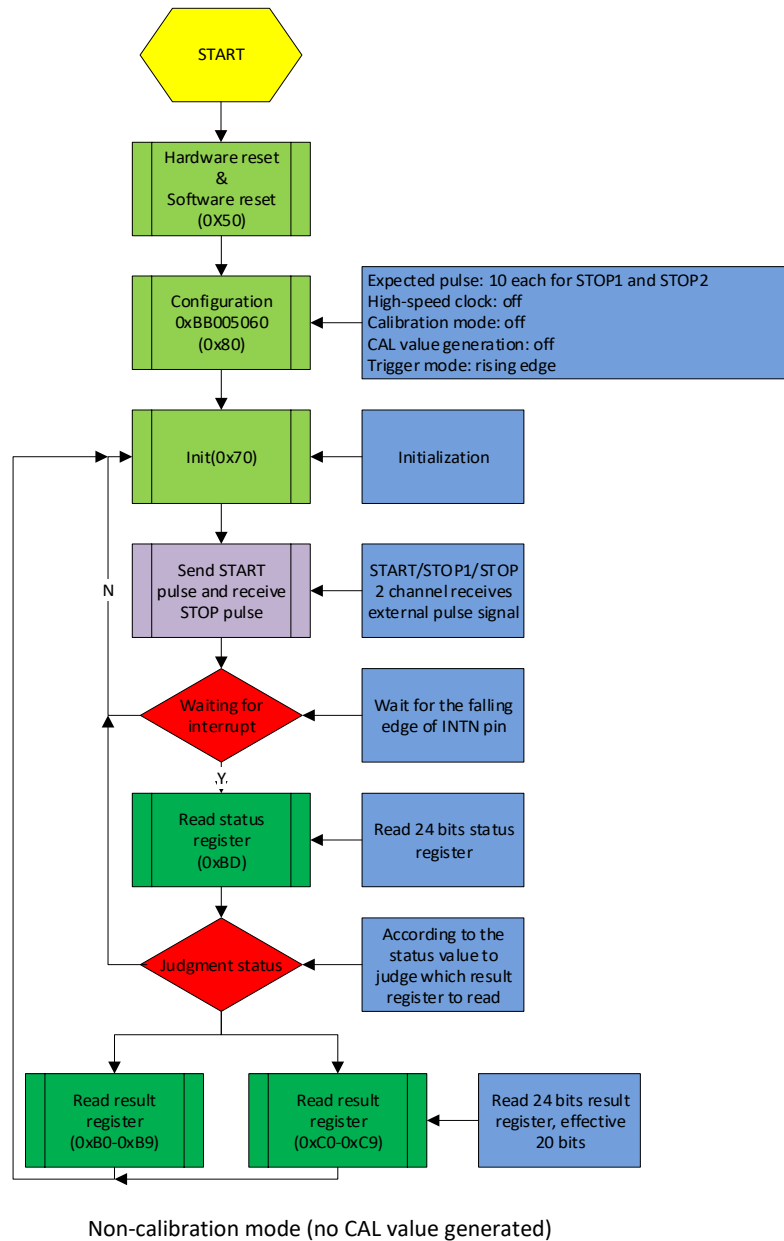
The interrupt pin INTN can have different interrupt sources, which can be selected in Bits4-6 (EN_INT) of the register, and the non-calibration mode selection bit 6 = 1 and bit 5 = 1;

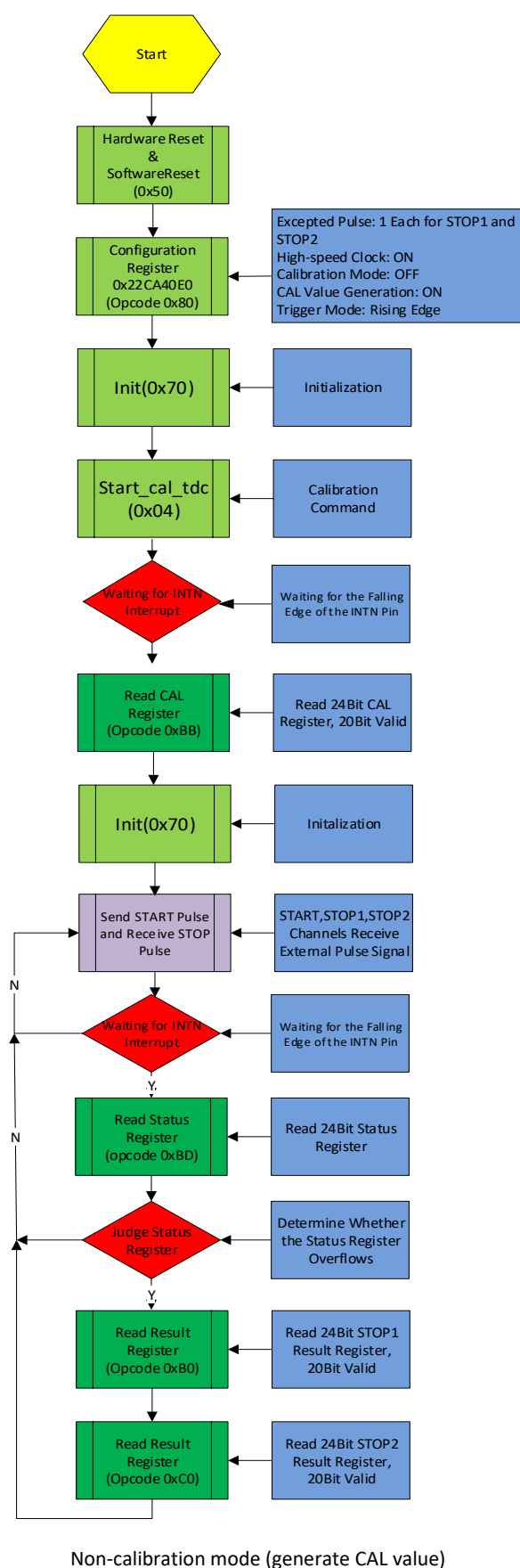
Reg bit 4 = 1 ALU is ready.

Reg bit 5 = 1 All expected pulses have been received.

Reg bit 6 = 1 The measurement time has overflowed.

6.3.3 Measurement Process





6.4 Calibration Time Measurement

Note: The maximum measurement range of single-precision calibration measurement is 4μs, and the maximum measurement range of double-precision measurement is 2μs.

6.4.1 Overview of Calibration Time Measurement

Calibration time measurement is performed when the high-speed oscillator is turned on. The measured gate delay number and Tref gate delay number are calculated by ALU and output to the result register. The output result is a 24-bit floating point number, the upper 8 bits are integer bits, and the lower 16 bits are decimal places. The maximum measurement range in calibration mode is 3.5ns-4μs. In single-precision mode, two STOP channels can be measured at the same time, and each channel can measure up to 10 STOP pulses. In double-precision mode, only STOP1 channel can be used.

During the calibration time measurement process, it is necessary to turn on the high-speed clock (START_CLKHS=1) and turn on the calibration (CALIBRATE=1). When the calibration value is generated, turn off (NO_CAL_AUTOCALIBRATE=1). The result register outputs the non-calibrated value (refer to the introduction of non-calibration). When the calibration value is generated (NO_CAL_AUTOCALIBRATE=0), the result register outputs the calibrated value RES_X. The measurement time is calculated as follows, and the measured time difference cannot exceed $2 \times T_{ref} \times DIV_CLKHS$.

$$\text{Measurement time} = \text{RES_X} \times T_{ref} \times N, N = 1, 2, 4, 8;$$

In the calibration time measurement, the overflow time function must be turned on (EN_SEL_TIMO=1). The overflow time is selected by the overflow time selection (SEL_TIMO). The time here is only related to the high-speed clock and is not affected by the clock division (DIV_CLKHS). For example, when the high-speed clock is 8MHz and SEL_TIMO=0, the overflow time is 250ns. At this time, the status register Bit14=1 (time overflow).

In calibration mode, the number of measured pulses must be greater than or equal to the number of expected pulses. When the number of measured pulses is less than the expected number of pulses, the ALU does not perform calculation. At this time, the status register Bit14=1 (time overflow). And when EN_ERR_VAL=1, the result register 0 outputs 0xFFFFFFFF.

6.4.2 Register Settings

The main settings are:

a. Select the number of expected pulses for measurement

Register bit 31-28 to set the expected number of STOP2 pulses HITIN2=0 or 2-B;

Register bit 27-24 sets the expected number of STOP1 pulses HITIN1=2-B, which cannot be set to 0; otherwise, the measurement cannot be started.

b. Select measurement accuracy

Register bit 18, DOUBLE_RES = 1 selects double precision mode, the measurement accuracy is typically 23ps but only one stop channel is available. DOUBLE_RES = 0 Select single-precision mode, and the measurement accuracy is typically 46ps. At this time, both stop channels are available.

c. Calibration options

In the calibration mode, both the high-speed crystal oscillator and calibration must be turned on. Register bit 13 CALIBRATE=1 and bit 19 START_CLKHS=1

d. Generate CAL value

In the calibration mode, you must choose to generate the CAL value. When the register bit 12 NO_CAL_AUTO=0, the CAL value is generated.

e. Overflow selection

In calibration mode, overflow must be turned on. Register bit 7 EN_SEL_TIMO=1 to turn on overflow time, and the overflow time is related to the setting of register bit 23-22 SEL_TIMO.

f. Select input trigger method

The edge trigger mode can be set on each input port (Start, Stop1, Stop2) by setting Bit 8-10 (NEG_X) of the register. When RFEDGE = 0, NEG_X = 0 is triggered on the rising edge, and NEG_X = 1 is triggered on the falling edge. You can also set the register Bit0&1 (REFEDGE1 & FEDGE2), you can select STOP falling edge trigger alone (RFEDGE=0) or rising edge and falling edge trigger at the same time (RFEDGE=1), when RFEDGE=1, Bit 9-10 selection invalid.

g. Interrupt

The interrupt pin INT can have different interrupt sources, which can be selected in Bits4-6 (EN_INT) of the register. Since Reg bit 5=1 interrupt output is the earliest, Reg bit 4=1 output is the latest, the user can choose according to the actual situation .

Reg bit 4 = 1 ALU is ready.

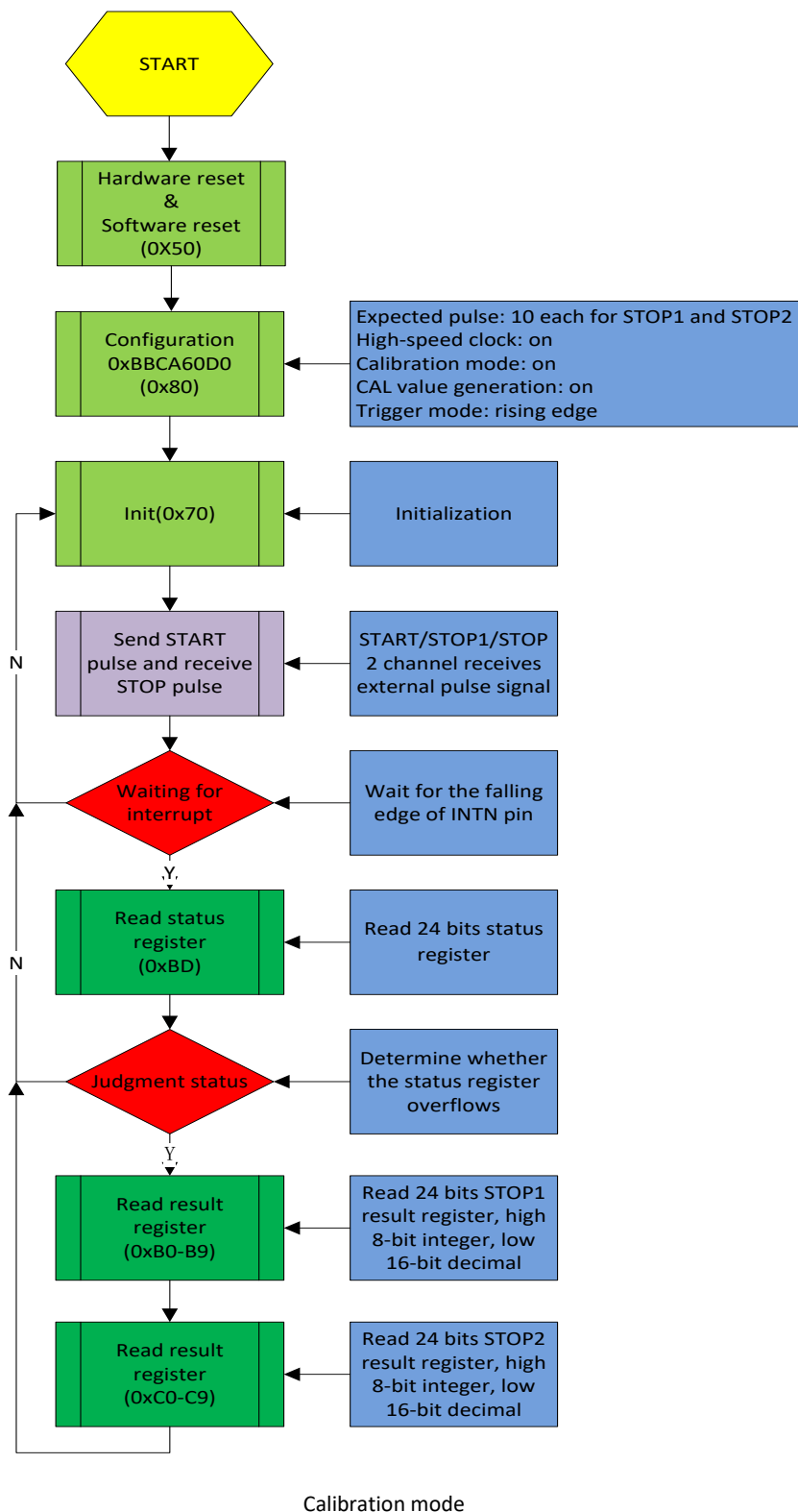
Reg bit 5 = 1 All expected pulses have been received.

Reg bit 6 = 1 Measurement time overflow & TDC overflow.

h. High-speed clock division

Since the calibration measurement time is less than $2 \times T_{ref}$, if you need to increase the measurement time, you need to set the high-speed clock divider. Set in Bits20-21 (DIV_CLKHS) of the register, but $2 \times T_{ref}$ cannot exceed the maximum measurement range of $4\mu s$.

6.4.3 Measurement Process



7. High Speed Oscillator

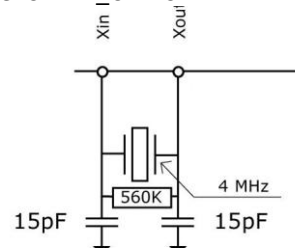
The MS1003 needs a high-speed clock for calibration sampling in calibration mode. Generally, the MS1003 needs a high-speed clock unit for calibration. The frequency range is 1-8MHz. The recommended high-speed clock frequency is 4Mhz.

When the crystal oscillator has been oscillating, the average operating current is 260 μ A. However, the crystal oscillator only needs to be turned on when measuring time. The MS1003 can control the on and off of the crystal oscillator through the internal circuit. The setting is realized by setting the parameter START_CLKHS.

START_CLKHS = 0 Crystal oscillator is off

= 1 The crystal oscillator keeps on

The current consumption can be greatly reduced by turning off the crystal oscillator in this way.

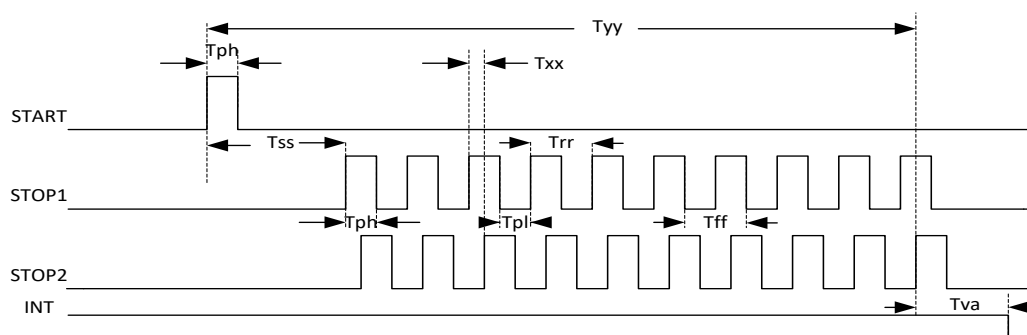


8. Quick Initialization

The MS1003 provides a quick initialization function. Set bit16 of the register (EN_FAST_INIT) = 1, the interrupt flag will automatically initialize the TDC. Therefore, the TDC is ready for the next measurement when the data is read. This mode is only suitable for high-speed applications. This is especially suitable for non-calibrated measurement mode with only one STOP signal. In the fast initialization mode, the value of the status register is always 0, so there is no need to read the status register.

9. Generation Time in Different Modes of INTN

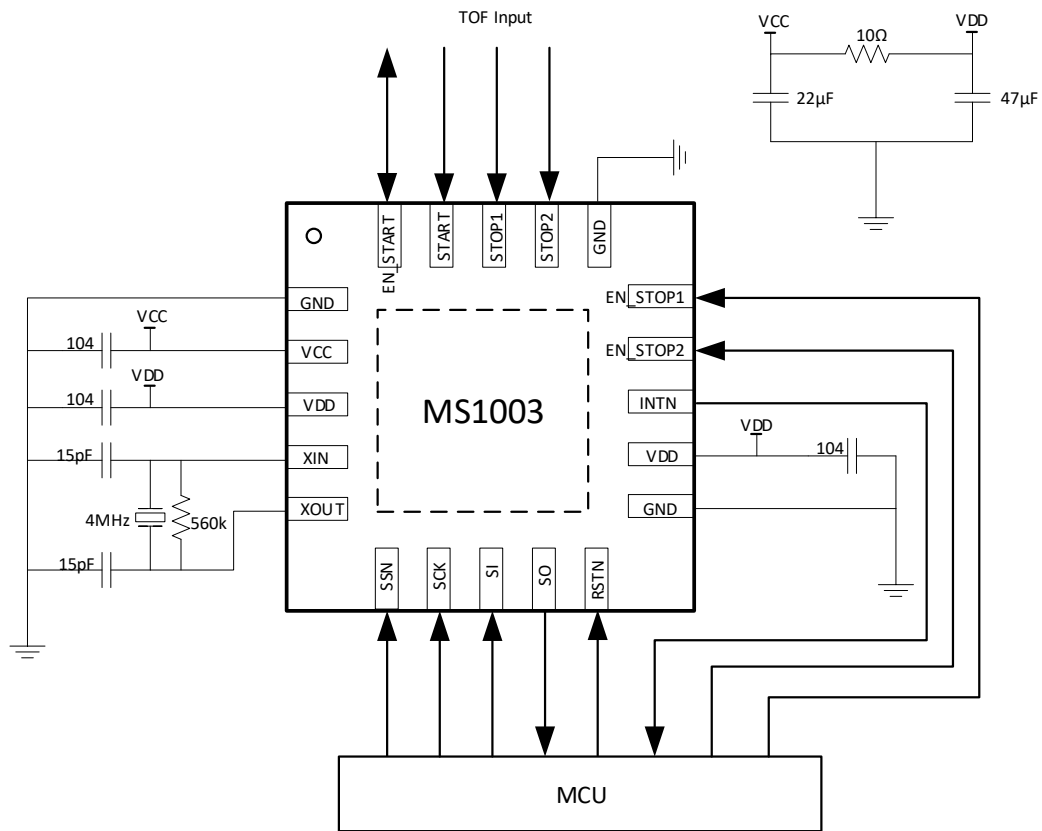
INIT is an important flag bit for the entire test process. INTN is used in conjunction with EN_INT[2:0]. Different interrupt sources have different output interrupt times. The time of Tva is the INTN generation time as shown in the figure below. The specific statistics are as follows:



Name	Conditions (High-speed clock 8MHZ)	Parameter	Unit
Tinit1	VCC=3.3V; EN_INT: End Hits=1; non-calibration mode; close CAL calibration; expect 1 STOP pulse and get one pulse.	16	ns
Tinit2	VCC=3.3V; EN_INT: ALU=1; non-calibration mode; close CAL calibration; expect 1 STOP pulse, and get one pulse.	104	ns

Name	Conditions (High-speed clock 8MHZ)	Parameter	Unit
Tinit3	VCC=3.3V; EN_INT: ALU=1; non-calibration mode; open CAL calibration; expect 1 STOP pulse, and get one pulse.	800	ns
Tinit4	VCC=3.3V; EN_INT: Timeout=1; non-calibration mode; overflow closed; 1 STOP pulse is expected, but no pulse is obtained.	20	μs
Tinit5	VCC=3.3V; EN_INT: Timeout=1; non-calibration mode; overflow is on, and SEL_TIMO_MB2=0; 1 STOP pulse is expected, but no pulse is obtained.	240	ns
Tinit6	VCC=3.3V; EN_INT: Timeout=1; non-calibration mode; overflow is on, and SEL_TIMO_MB2=1; 1 STOP pulse is expected, but no pulse is obtained.	500	ns
Tinit7	VCC=3.3V; EN_INT: Timeout=1; non-calibration mode; overflow is on, and SEL_TIMO_MB2=2; 1 STOP pulse is expected, but no pulse is obtained.	1000	ns
Tinit8	VCC=3.3V; EN_INT: Timeout=1; non-calibration mode; overflow is turned on, and SEL_TIMO_MB2=3; 1 STOP pulse is expected, but no pulse is obtained.	2000	ns
Tinit9	VCC=3.3V; EN_INT: ALU=1; calibration mode; open CAL calibration, overflow open; and SEL_TIMO_MB2=0; expect 1 STOP pulse, and get one pulse.	1300	ns
Tinit10	VCC=3.3V; EN_INT: Timeout=1; calibration mode; open CAL calibration; overflow open, and SEL_TIMO_MB2=0; 1 STOP pulse is expected, but no pulse is obtained.	240	ns
Tinit11	VCC=3.3V; EN_INT: Timeout=1; calibration mode; open CAL calibration; overflow open, and SEL_TIMO_MB2=1; 1 STOP pulse is expected, but no pulse is obtained.	500	ns
Tinit12	VCC=3.3V; EN_INT: Timeout=1; calibration mode; open CAL calibration; overflow open, and SEL_TIMO_MB2=2; 1 STOP pulse is expected, but no pulse is obtained.	1000	ns
Tinit13	VCC=3.3V; EN_INT: Timeout=1; calibration mode; open CAL calibration; overflow open, and SEL_TIMO_MB2=3; 1 STOP pulse is expected, but no pulse is obtained.	2000	ns

TYPICAL APPLICATION DIAGRAM

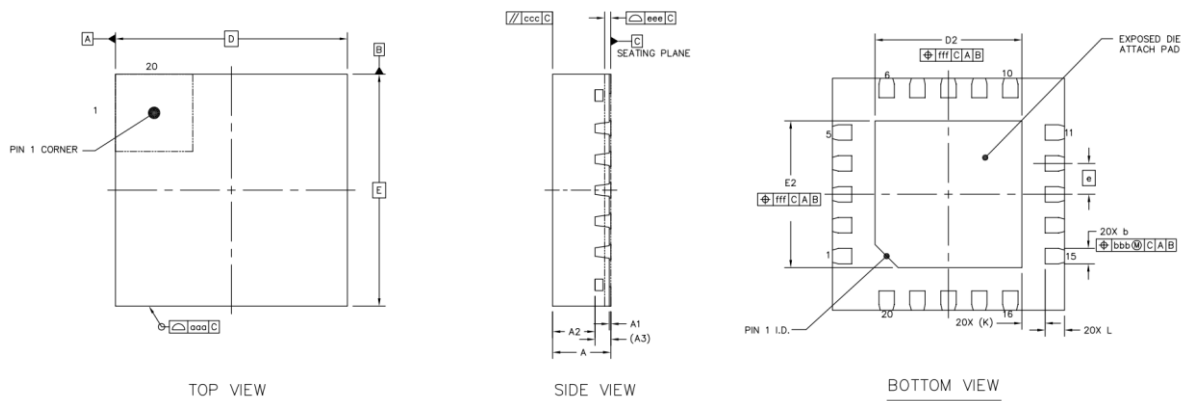


MAIN PERFORMANCE COMPARISON of MS1002&MS1022&MS1003

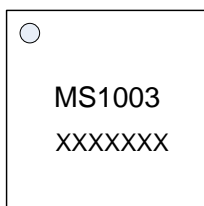
Parameters	Condition	MS1002	MS1022	MS1003	Unit
Measurement resolution 1	VCC=3.3, single precision	65	80	46	ps
Measurement resolution 2	VCC=3.3, double precision	/	40	23	ps
Measuring range	Non-calibrated	2	2.4	20	μs
	calibrated	4000	4000	4	μs
SPI speed	VCC=3.3	20	20	40	MHz
Number of STOP channels	single precision	2	2	2	/
	double precision	1	1	1	/
STOP channel capture pulse number	VCC=3.3	4	4	10	/
The measurement does not reach the expected number of pulses	Non-calibrated	no	no	yes	/
Output measurement results at one time	No overflow	no	no	yes	/

PACKAGE OUTLINE DIMENSIONS

QFN20



Symbol	Dimensions in Millimeters		
	Min	Typ	Max
A	0.7	0.75	0.8
A1	0	0.02	0.05
A2	-	0.55	-
A3	0.203 REF		
b	0.15	0.2	0.25
D	3 BSC		
E	3 BSC		
e	0.4 BSC		
D2	1.8	1.9	2
E2	1.8	1.9	2
L	0.15	0.25	0.35
K	0.3 REF		
aaa	0.1		
ccc	0.1		
eee	0.08		
bbb	0.07		
fff	0.1		

MARKING and PACKAGING SPECIFICATION**1. Marking Drawing Description**

Product Name : MS1003

Product Code : XXXXXXX

2. Marking Drawing Demand

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

3. Packaging Specification

Device	Package	Piece/Reel	Reel/Box	Piece/Box	Box/Carton	Piece/Carton
MS1003	QFN20	5000	1	5000	8	40000

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- The process of improving product is endless. And our company would sincerely provide more excellent 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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