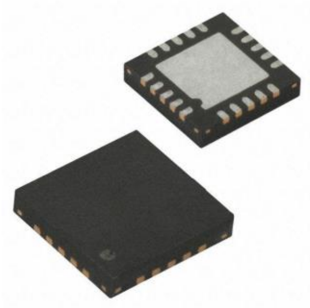
# High-precision Time Measurement (TDC) Circuit for Laser Ranging

## 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

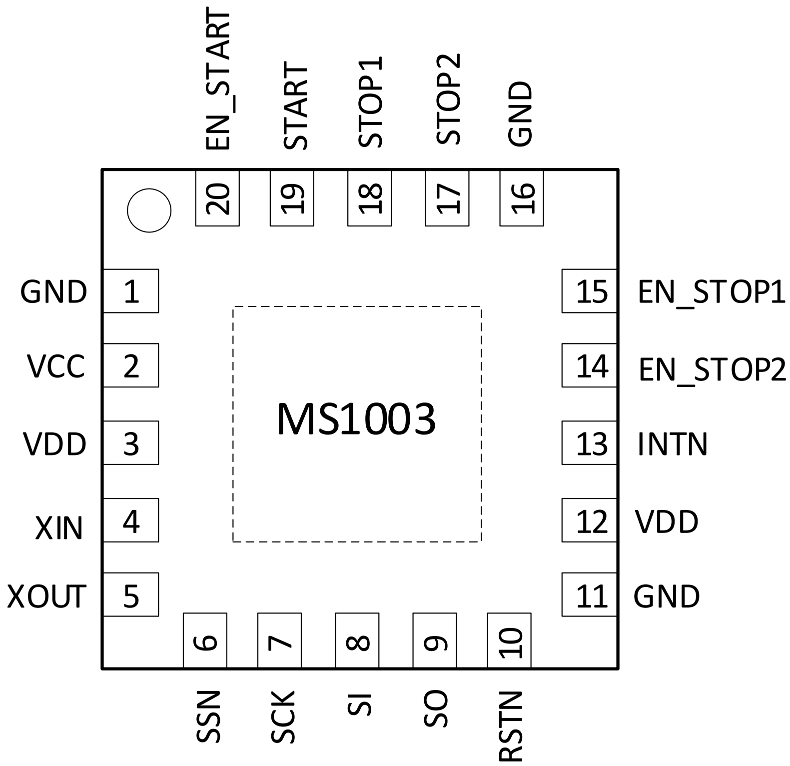
## APPLICATIONS

- Radar
- Laser Ranging
- Pulse Measurement

## PRODUCT SPECIFICATION

| Part Number | Package | Marking |
|---|---|---|
| MS1003 | QFN20 | MS1003 |

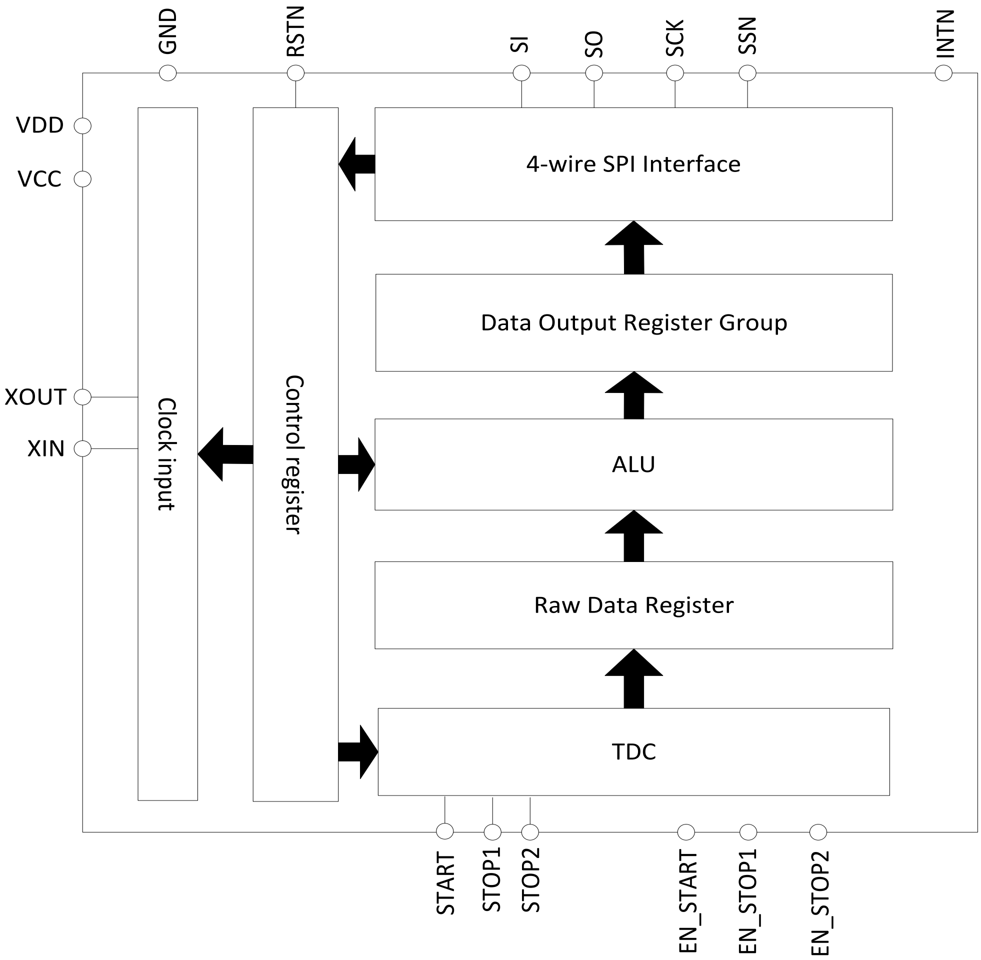
## PIN CONFIGURATION



## 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;<br>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 ~ Vcc+0.5 | V |
| Storage Temperature Range | $T_{STG}$ | -65 ~ 150 | V |
| Operating Temperature Range | $T_A$ | -40 ~ +100 | V |
| Soldering Temperature Range (10s) | $T_{SOLDER}$ | 260 | °C |
| ESD (HBM) | $V_{HBM}$ | >6000 | V |

## RECOMMENDED OPERATING CONDITIONS

Unless otherwise noted, $T_A$ = 25°C ±2°C.

| Parameter | Symbol | Condition | Min | Typ | Max | Unit |
|---|---|---|---|---|---|---|
| Core Supply Voltage[1] | $V_{DD}$ | $V_{DD}$= $V_{CC}$ | 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 |

Note 1: Include XIN, XOUT pins.

## ELECTRICAL CHARACTERISTICS

**DC Characteristics**

$V_{CC}$= $V_{DD}$= 3.0V, $T_A$= -40 to +85°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 Vcc | | | V |
| Output Low Level | $V_{OL}$ | $I_{OL}$=tbd mA, $V_{CC}$ =Min | | | 0.2 Vcc | V |
| Input High Level | $V_{IH}$ | LVTTL, $V_{CC}$= Max | 0.7 Vcc | | | V |
| Input Low Level | $V_{IL}$ | LVTTL, $V_{CC}$ = Min | | | 0.3 Vcc | V |

**Terminal Equivalent Capacitance**

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

**Time Measurement Unit**

$V_{CC}$= $V_{DD}$= 3.0 V, $T_A$ = 25°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 | | 16µs | |
| | | Uncalibrated double precision | | 3.5ns | | 16µs | |
| | | Calibrated single precision | | 3.5ns | | 4µs | |
| | | Calibrated double precision | | 3.5ns | | 2µs | |

**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.

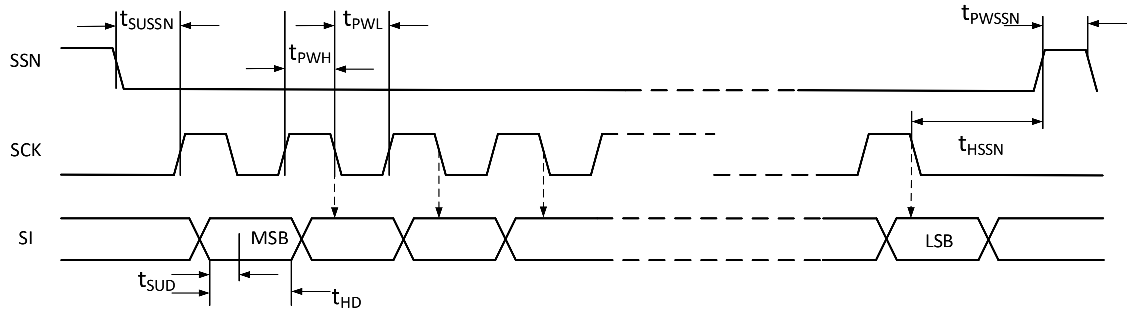



Figure 1. SPI Write Timing

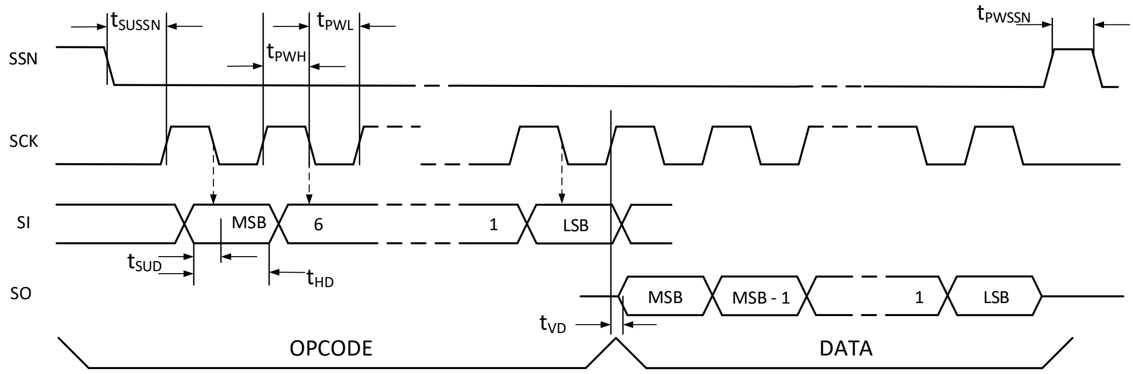



Figure 2. SPI Read Timing

| 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**

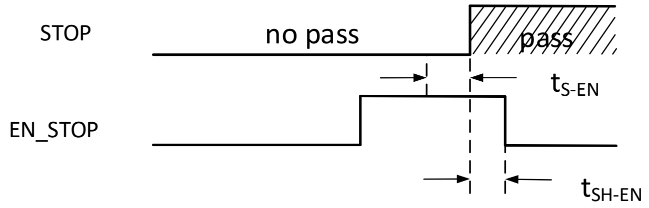



Figure 3. Timing of Closing the STOP Channel

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

**3. System Reset Sequence**

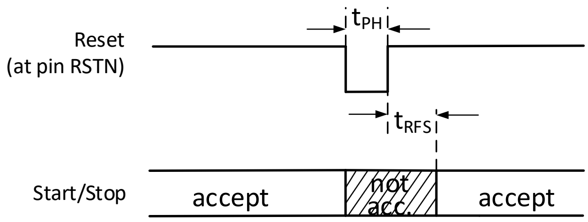



Figure 4. System Reset Sequence

| 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 µF (min 22µF), VDD 100 µF (min 22µF).

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<br>2 = 1 pulse; 3 = 2 pulses;<br>4 = 3 pulses; 5 = 4 pulses;<br>6 = 5 pulses; 7 = 6 pulses;<br>8 = 7 pulses; 9 = 8 pulses<br>A = 9 pulses; B = 10 pulses<br>1,C 到 F = Not allowed to set<br>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);<br>In addition, the overflow time is only related to the high-speed clock and independent of DIV_CLKHS. | 0 = 1.5-2 main clock cycles @500ns<br>1 = 3.5-4 main clock cycles @1µs<br>2 = 7.5-8 main clock cycles @2µs<br>3 = 15.5-16 main clock cycles @4µs<br>@ 4 MHz ClkHS |
| 22 | 0 | | | |
| 21 | 0 | DIV_CLKHS | Set the CLKHS high-speed reference clock Division factor | 0 = No division<br>1 = Divide by 2<br>2 = Divide by 4<br>3 = Divide by 8 |
| 20 | 0 | | | |
| 19 | 0 | START_CLKHS | Set the crystal oscillator on and off | 0 = Crystal off<br>1 = Crystal on |
| 18 | 1 | DOUBLE_RES | Double precision measurement on | 0 = off<br>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<br>1 = on |
| 16 | 0 | EN_FAST_INIT | Quick initialization function | 0 = off<br>1 = on |
| 15 | 0 | SEL_TSTO2 | EN_START pin function<br>(If SEL_TSTO2 > 0, EN_START is pulled to high internally) | 0 = Input high level to turn on START<br>1 = START_TDC output<br>2 = STOP1 TDC output<br>3 = STOP2 TDC output |
| 14 | 1 | | | |
| 13 | 1 | CALIBRATE | Turn on/off calibration in ALU | 0 = off<br>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<br>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<br>1 = Trigger on falling edge |
| 9 | 0 | NEG_STOP1 | Reverse stop channel 1 input | 0 = Trigger on rising edge<br>1 = Trigger on falling edge |
| 8 | 0 | NEG_START | Reverse start channel input | 0 = Trigger on rising edge<br>1 = Trigger on falling edge |
| 7 | 0 | EN_SEL_TIMO | Overflow time function (Use with SEL_TIMO function) | 0 = off<br>1 = on |
| 6 | 0 | EN_INT[2:0] | Interrupt source selection | Bit 6 = 1： Timeout interrupt trigger bit<br>Bit 5 = 1： End Hits interrupt trigger bit<br>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<br>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,<br>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: Time = RES_X × Tref × N, when N = 1, 2, 4 or 8

Non-calibration mode: Time = RES_X × 46ps (VCC=3.3V, 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.

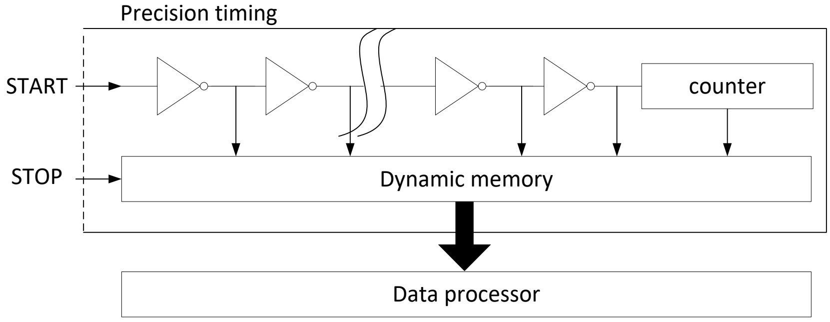
The overflow time can be set arbitrarily, thereby reducing the overflow time waiting during high-speed measurement.

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.

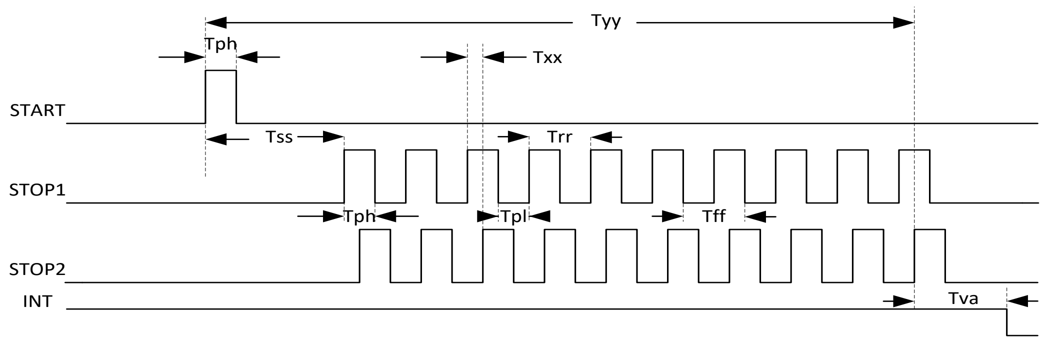
### 6.2 Principle of High-precision Time Measurement

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.




| | Time (condition) | Description |
|---|---|---|
| Tph | 2.5 ns (min.) | Minimum pulse width |
| Tpl | 2.5 ns (min.) | Minimum pulse width |
| Tss | 3.5 ns (min.)<br>16 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<br>t.b.d. Calibration | Time from the last pulse to INIT output<br>(See item 9 for details) |
| Txx | No time limit | Measurement time between channels |
| Tyy | 16 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 (REFDGEx) 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.

Measurement time=RES_X×46ps (DOUBLE_RES=0)

Measurement time=RES_X×23ps (DOUBLE_RES=1)

In the non-calibration mode, the time measurement and the CAL value can be measured at the same time. CAL value would be generated automatically when expected pulse is met. When it is not met, send Start_cal_tdc(0x04) to measure. In this mode, 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 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.

Measurement time=RES_X×(Tref× N/CAL), N = 1, 2,4,8

When received pulse does not meet expected pulse, overflow would occur. 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 16μs, and the status register Bit13=1 (TDC overflow); when the overflow time function When 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. The function can produce overflow interrupt in advance according to set overflow time.

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

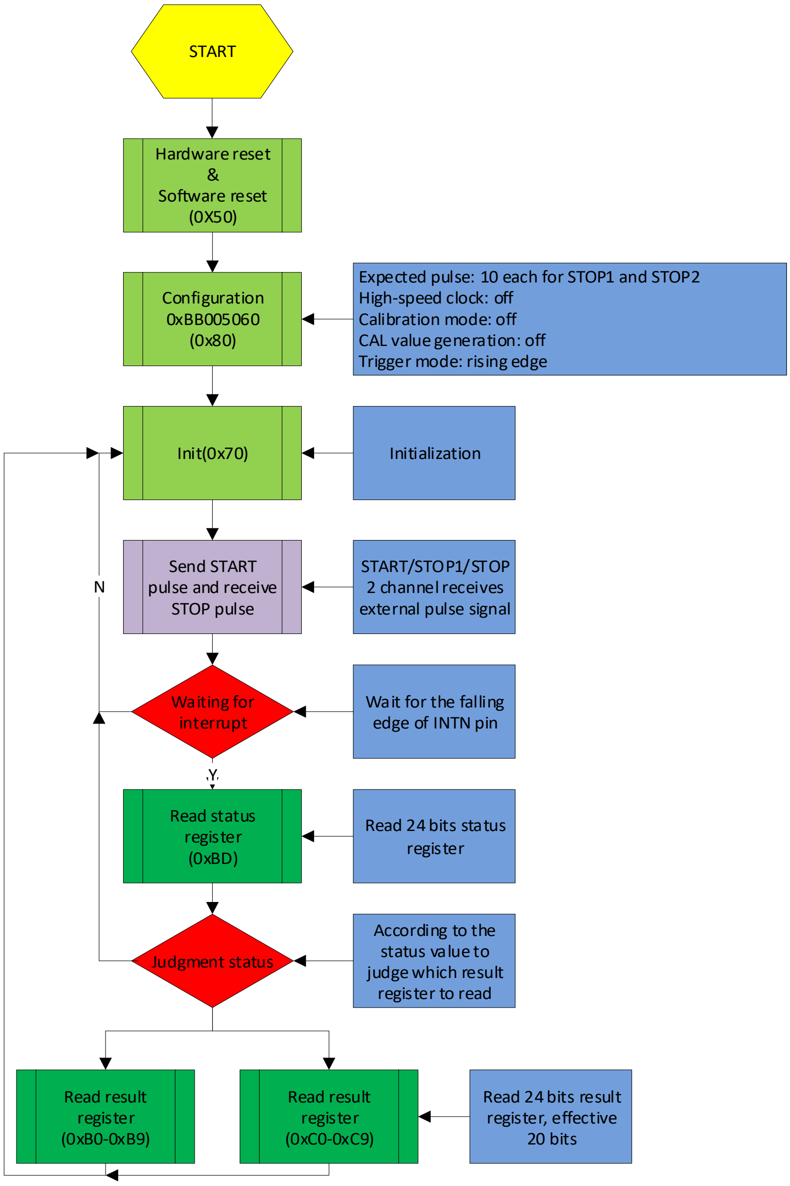
The interrupt pin INTN can have different interrupt sources, which can be selected in Bits4-6 (EN_INT) of the register, and the non-calibration mode selection bit 6 = 1 and bit 5 = 1;

Reg bit 4 = 1 ALU is ready.

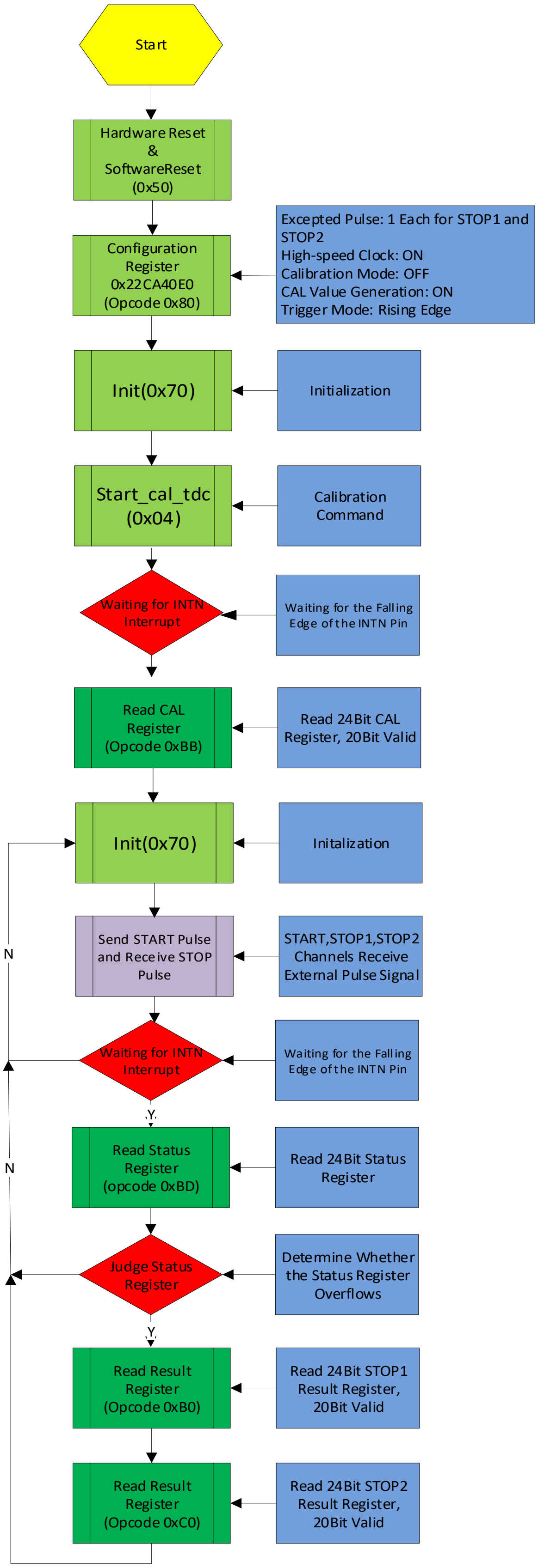
Reg bit 5 = 1 All expected pulses have been received.

Reg bit 6 = 1 The measurement time has overflowed.

### 6.3.3 Measurement Process




Non-calibration mode (no CAL value generated)




Non-calibration mode (generate CAL value)

### 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 × Tref × DIV_CLKHS.

$$\text{Measurement time} = RES\_X \times Tref \times N,\ N = 1, 2, 4, 8$$

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 0xFFFFFFFFFF.

#### 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 (REFDGE1 & 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.

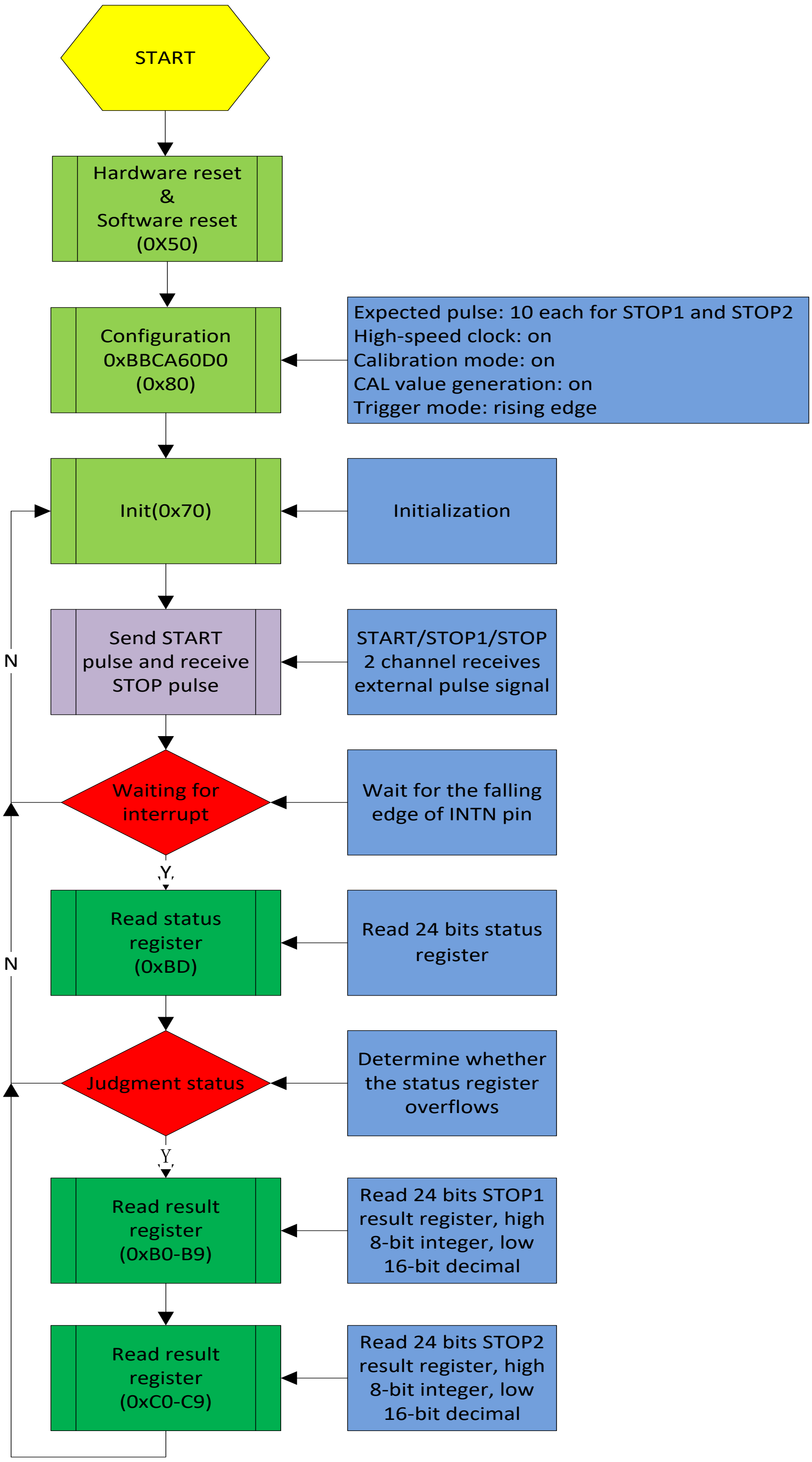
Reg bit 5 = 1 All expected pulses have been received.

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

h. High-speed clock division

Since the calibration measurement time is less than 2×Tref, 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×Tref cannot exceed the maximum measurement range of 4µs.

### 6.4.3 Measurement Process




Calibration mode

**7. High Speed Oscillator**

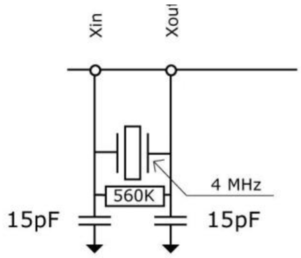
The MS1003 needs a high-speed clock for calibration sampling in calibration mode. Generally, the MS1003 needs a high-speed clock unit for calibration. The frequency range is 1-8MHZ. The recommended high-speed clock frequency is 4Mhz.

When the crystal oscillator has been oscillating, the average operating current is 260 μA. 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.

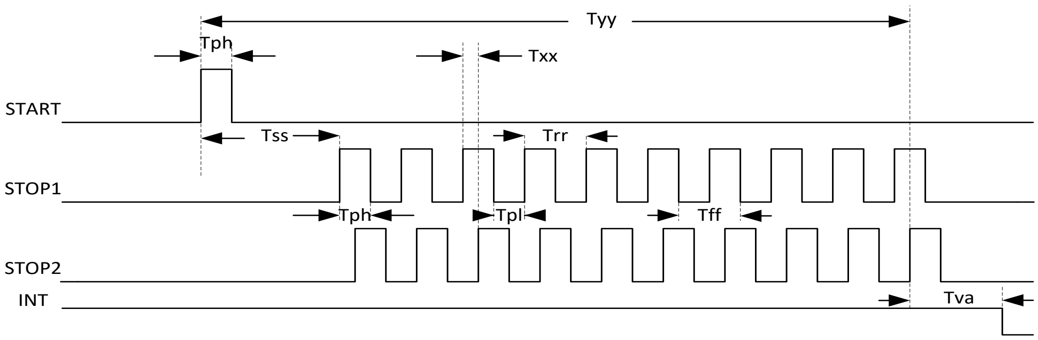



**8. Quick Initialization**

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**

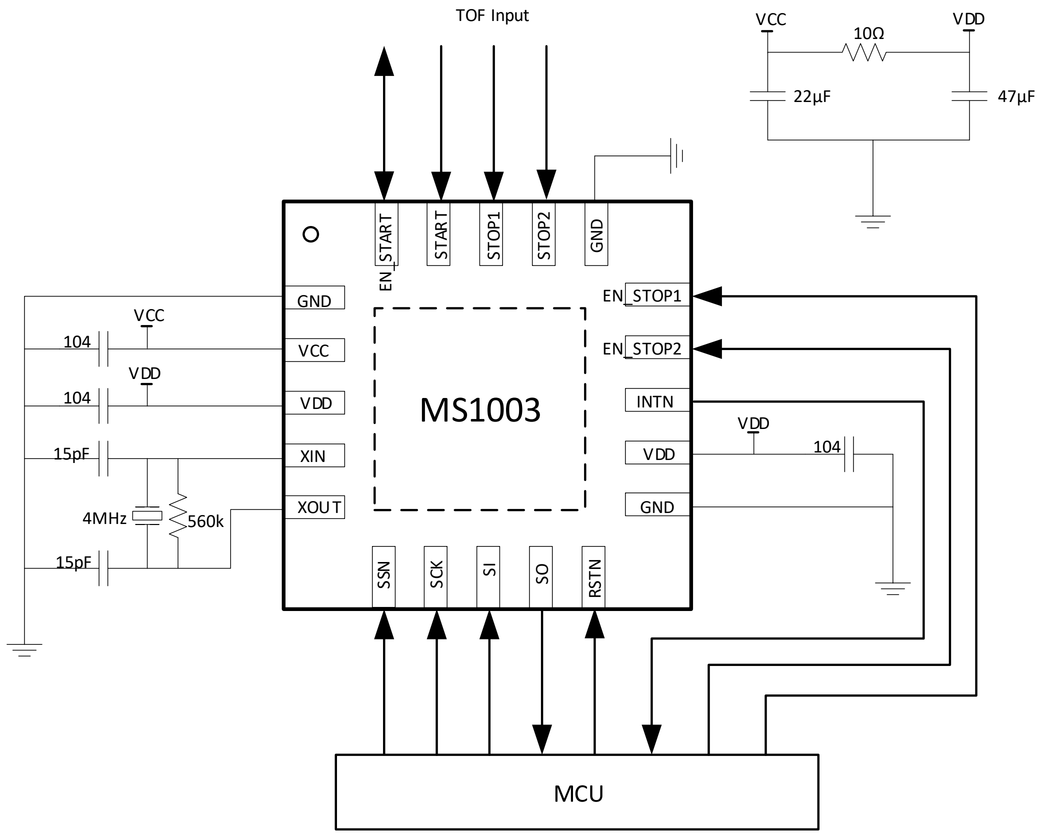
INIT is an important flag bit for the entire test process. INTN is used in conjunction with EN_INT[2:0]. Different interrupt sources have different output interrupt times. The time of Tva is the INTN generation time as shown in the figure below. The specific statistics are as follows:




| 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. | 16 | 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

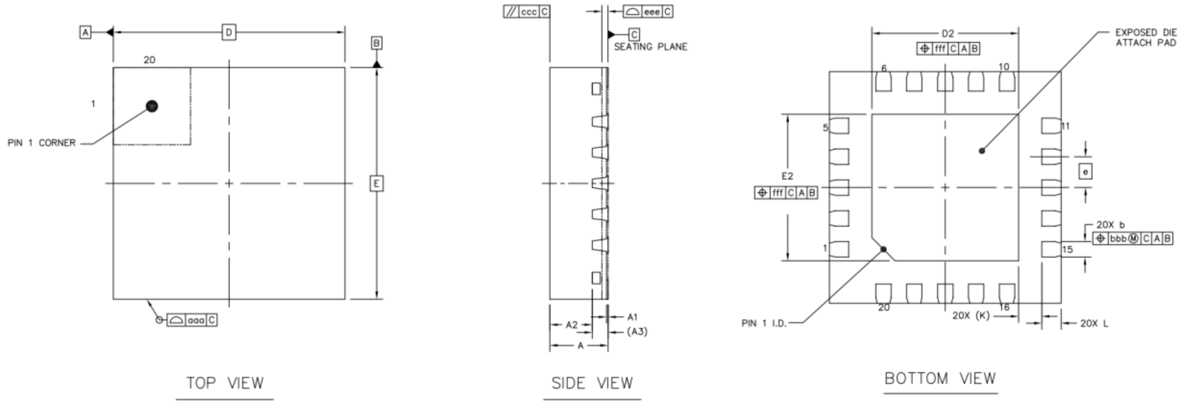


## MAIN PERFORMANCE COMPARISON of MS1002&MS1022&MS1003

| 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 | 16 | 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

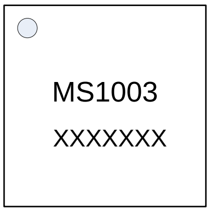
**QFN20**




| 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.

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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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