1. Hardware

The TDC evaluation kit comes with the Evaluation Base Board and the Evaluation TDC SOIC Board.

Product code	Name
MAG-TDC10002-S	TDC00002 EVK shield + EVK baseboard
MAG-TDC49002-S	TDC00002 EVK shield
MAG-EVK10001-x	EVK baseboard

1.1 Evaluation Base Board (MAG-EVK10001-x)

The Evaluation Base Board, illustrated in Figure 1, provides an interface between the Evaluation TDC SOIC Board and the PC. The Evaluation TDC SOIC Board fits on top of the base board via the socket headers, as illustrated in Figure 3 (left). A connection to the PC can be made using an USB Type-C cable.

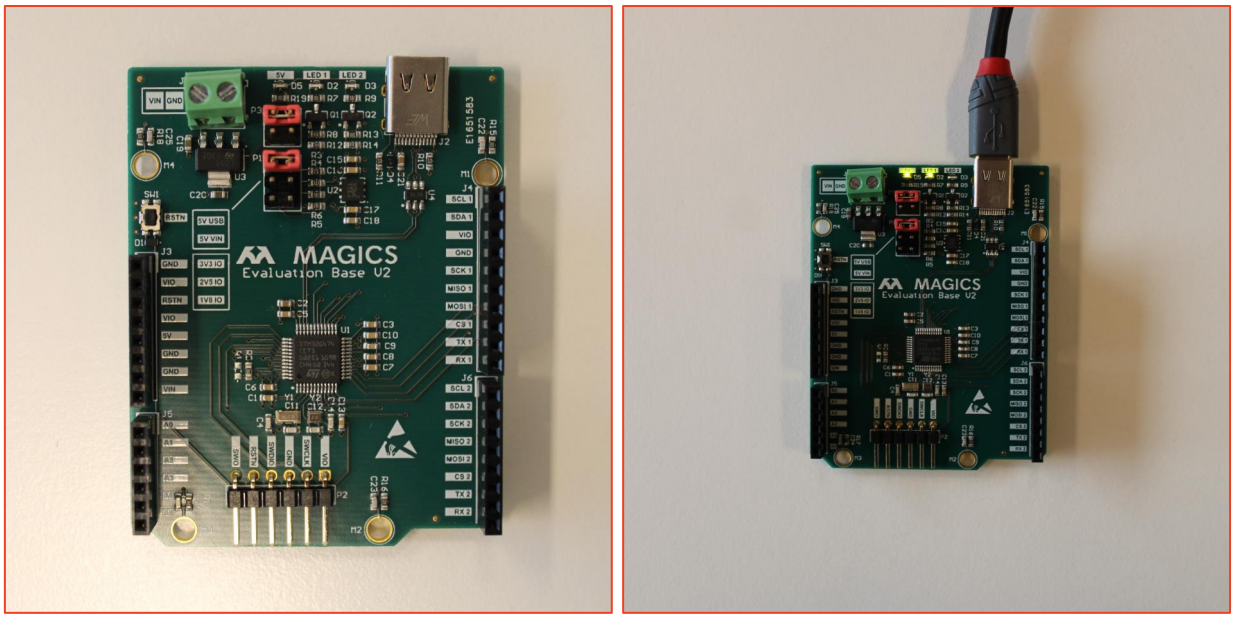

Figure 1: Evaluation Base Board (left), powered over USB (right)

The base board can be powered over USB, or by connecting an external supply to the provided screw terminals. When using the USB power, the red jumper of the upper connector must be placed horizontally at the top position. When powering the base board with an external supply, the jumper must be placed horizontally at the top position. The 5V LED indicates when the board is powered correctly. The 3V3IO should be used for the TDC Shield. The way the jumper should be placed, together with the way the external power supply should be connected, can be found on the base board itself. All other signals are marked on the board as well. Furthermore, there is a reset button at the left and two LEDs at the top. The absolute maximum ratings of the base board can be found in Table 1.

Table 1: Absolute Maximum Ratings Evaluation Base Board

Name	Description	Min	Max	Unit
Vin_ext	DC input voltage via screw terminals	6.2	15.0	V
Vin_usb	DC input voltage via USB Type-C connector		5	V
Top	Operating temperature	-40	80	°C

1.2 Evaluation TDC SOIC Board (MAG-TDC49002-S)

The Evaluation TDC SOIC Board is illustrated in Figure 2. This board holds the TDC itself and provides interconnectivity to the base board and the instrumentation.

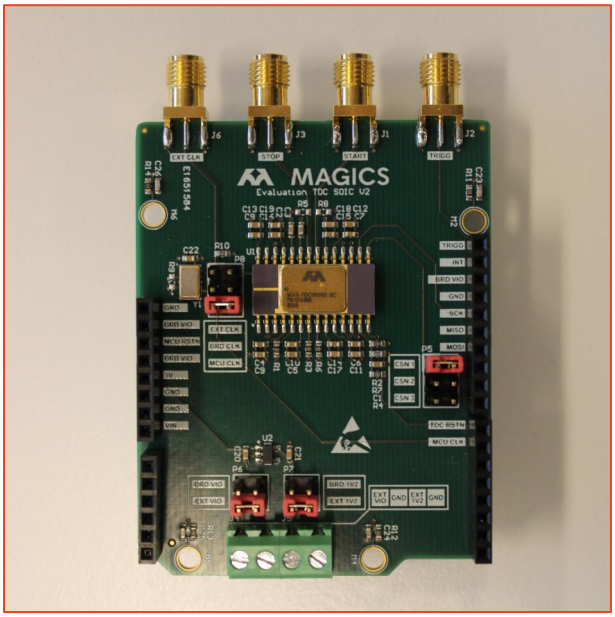

Figure 2: Evaluation TDC SOIC Board

At the top, there are the EXT CLK, STOP, START and TRIGG SMA connectors. At the bottom there is a power connector to power the TDC board separately from the base board. An example of how all these connectors should be connected to external measurement equipment can be found in the Section 2.3

Information about the TDC itself can be found in the datasheet (Technologies M. , 2024). The absolute maximum ratings of the TDC board can be found in Table 2.

Table 2: Absolute Maximum Ratings Evaluation TDC SOIC Board

Name	Description	Min	Max	Unit
Vext_3V3	External 3V3 voltage via screw terminals	-0.3	3.63	V
Vext_1V2	External 1V2 voltage via screw terminals	-0.3	1.32	V
Vext_clk	External clock input voltage via SMA connector	-0.3	3.63	V
Vstart	Start signal input voltage	-0.3	3.63	V
Vstop	Stop signal input voltage	-0.3	3.63	V
Vtrigg	Trigger signal output voltage	-0.3	3.63	V
Top	Operating temperature	-40	80	°C

1.3 Typical Application

To explore the main specifications of the TDC, the TDC evaluation kit can be connected to a two channel waveform generator with external trigger, as illustrated in Figure 3.

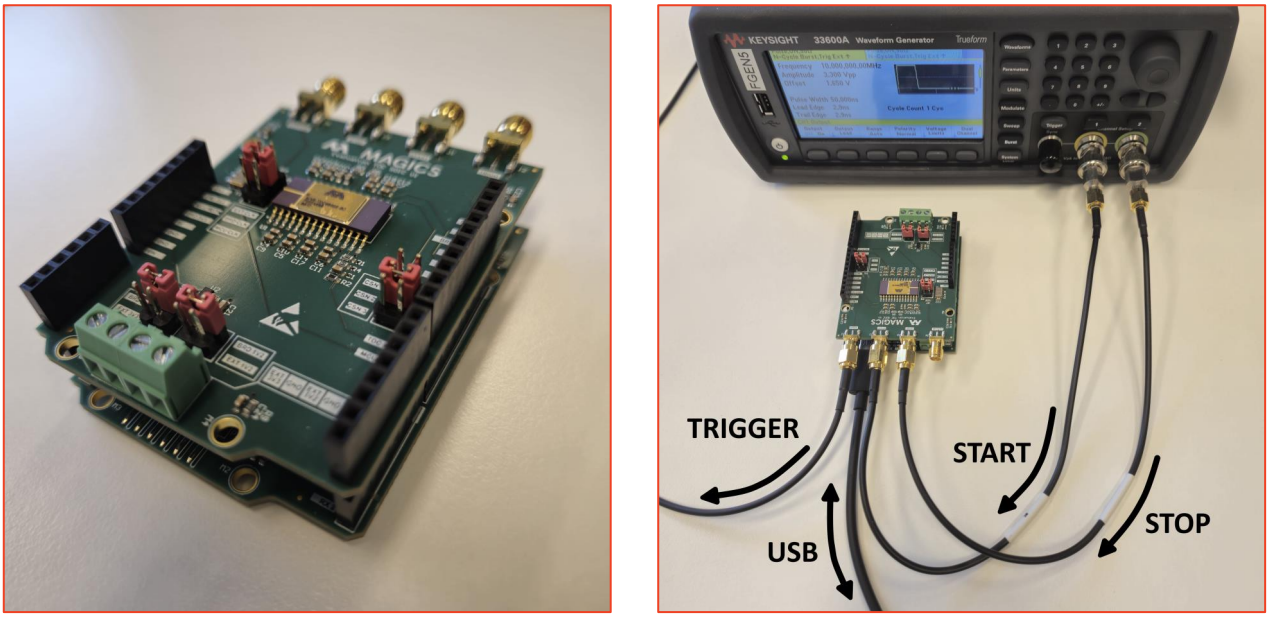

Figure 3: The complete stack (left) and the interconnections to a waveform generator (right)

Using SMA cables, the START signal is connected to CH1, STOP to CH2, and TRIGGER to the Ext Trig connector at the rear connector of the waveform generator. The stack itself is powered by and connected to the computer over USB.

The use of the Keysight 33600A or the Keysight 33500B (best performance) waveform generator is recommended. Each channel should have the settings applied listed in Table 3. Before applying these settings, a factory reset of the waveform generator should be performed.

Table 3: CH1 and CH2 waveform generator settings START and STOP signal

Group	Setting	Value
Waveforms	Pulse	
Parameters	Frequency	10MHz (adjustable)
	Amplitude	3.300Vpp
	Offset	1.650V
	Pulse Width	50ns
	Lead Edge	2.9ns
	Trail Edge	2.9ns
Trigger	Source	Ext
	Delay	CH1: 0s, CH2: 0s (adjustable)
	Slope	Rising
Burst	Burst	On
	N Cycle/Gated	N Cycle
	# Cycles/Infinite	# Cycles

Group	Setting	Value
	# of Cycles	CH1: 1, CH2: 1 (adjustable)
Output	Output	On
	Output Load	High-Z

Notes:

- To control the delay between the start and (first) stop pulse, the trigger delay of the second channel can be adjusted.
- The amount of stop pulses can be controlled by changing the amount of burst cycles of the second channel.
- The pulse frequency can be adjusted to control the delay between the multiple stop pulses.

In addition, an external reference clock can be applied to the EXT CLK SMA connector. For this, an extra waveform generator can be used. The settings for this waveform generator are listed in Table 4. To use the external reference clock, the upper left red jumper should be placed horizontally at the upper most position (EXT CLK). A legend is available on the board itself.

Table 4: CH1 or CH2 waveform generator settings REFCLK signal

Group	Setting	Value
Waveforms	Square	
Parameters	Frequency	10MHz
	Amplitude	3.300Vpp
	Offset	1.650V
	Duty cycle	50%
Output	Output	On
	Output Load	High-Z

There is an on board reference clock when no external reference clock is available. It can be selected using the upper left red jumper. There is the choice between the on board reference clock (BRD CLK), and the reference clock coming from the microcontroller on the base board (MCU CLK).

The on board reference clock has the next specifications:

- 10MHz frequency
- 50% duty cycle
- 3.3Vpp range
- 1.65V offset
- 100ppm stability

2. Software

The TDC Evaluation Kit comes with the TDC Evaluation Tool. This tool communicates to the Evaluation Kit via the SCPI command interface programmed on the Evaluation Base Board.

2.1 TDC Evaluation Tool

A General overview of the TDC Evaluation Tool is illustrated in Figure 4.

At the left there is the *HARDWARE CONFIGURATION* window. In this window, the connectivity to the Evaluation Base is monitored, together with SPI connectivity and locking of the reference clock of each TDC. TDC1 corresponds to the TDC Evaluation Board with the jumper at CS1, TDC2 with CS2 and TDC3 with CS3.

When selecting a TDC in the *HARDWARE CONFIGURATION* window, the *TDC CONFIGURATION* window will pop-up. In this window, the TDC itself can be configured, and a measurement can be performed.

When a measurement is executed, the *VISUALISATIONS* window will show up. Here it is decided how the measured data is plotted in the *MAIN PLOT* window. Also, the data can be exported to a csv file by pressing the EXPORT CAPTURED DATA button in this window.

In the *MAIN PLOT* window, different graph types can be selected. Simple data manipulation can be performed in this window. The figure can be exported here as well.

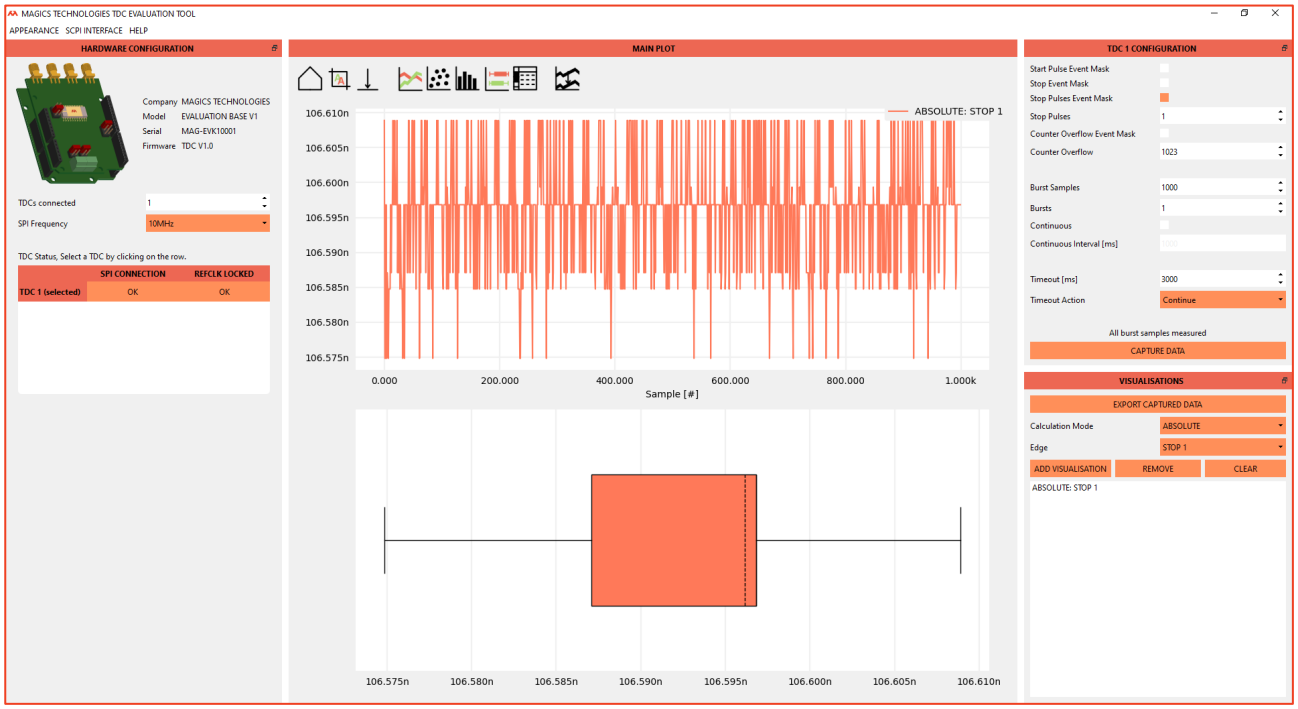

Figure 4: Overview of the TDC Evaluation Tool

The tool itself is fully self explaining. This means that one can hover its mouse over a setting to view extra explanation about it.

When selecting *HELP > TDC SHIELD,* an interactive window will open explaining the connectors of the TDC shield. This window is illustrated in Figure 5.

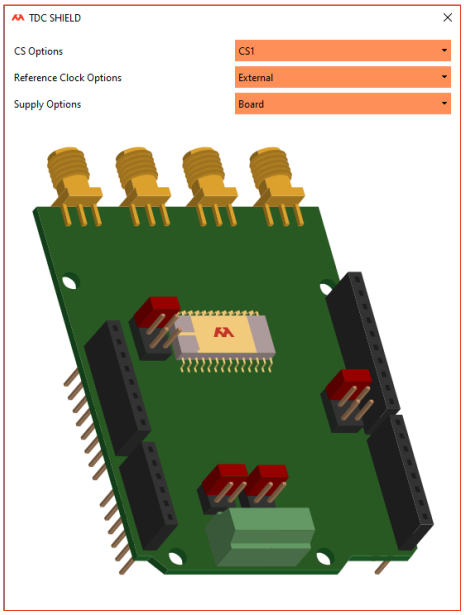

Figure 5: TDC shield window

The commands described in Section 3.2 can be executed in the SCPI COMMAND INTERFACE, which can be opened via the top menu button called SCPI INTERFACE. The window is illustrated in Figure 6.

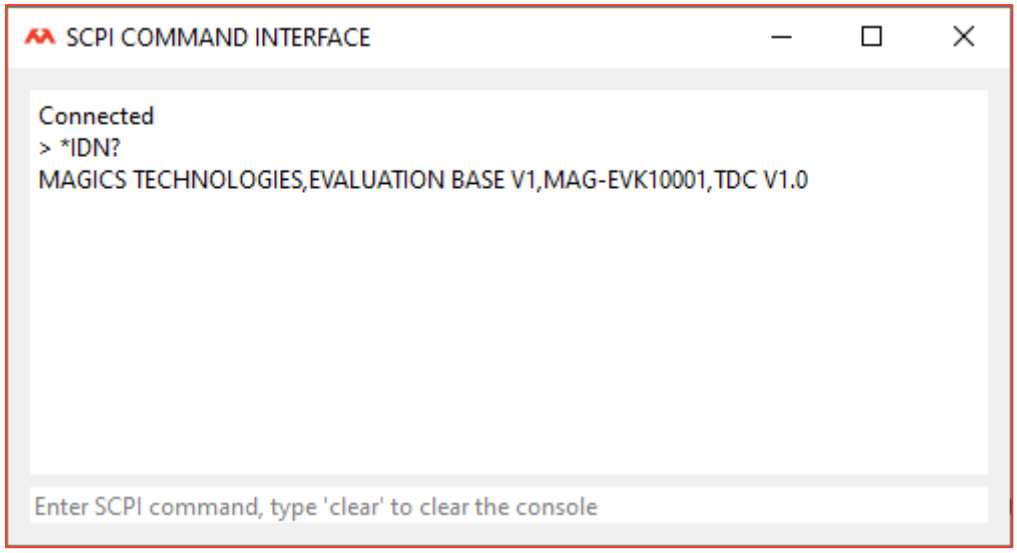

Figure 6: SCPI Command Interface

2.2 TDC SCPI Command Interface

The SCPI command interface is freely available and can be used to test the evaluation kit in other software environments.

SCPI stands for Standard Commands for Programmable Instruments, and is a standard for programming and controlling measurement devices, such as this evaluation kit. Also the recommended Keysight waveform generator uses this standard. More information about this standard can be found for example in the *Keysight Trueform Series Operating and Service Guide* (Technologies K. , 2023).

2.2.1 Serial USB connection

A serial connection to the Evaluation Base Board can be established via the TDC Evaluation Tool, as discussed above, or using commonly available software:

- Putty (Putty, n.d.) or RealTerm (Realterm, n.d.) is freely available software to communicate to the base board using a command line interface.
- Pyserial is a Python library to communicate to the base board using Python code.

The serial communication should be initiated with the next settings:

- Baud rate: 115200
- Parity: no
- Stop bits: 1
- Data bits: 8
- Flow control: no
- Termination: “\r\n”

2.2.2 Command overview

Table 5 summarizes all the commands implemented in the SCPI Command Interface. All commands are explained in the next sections.

Table 5: Command overview

IEEE-488.2	System	TDC
***CLS**	**SYSTem:ERRor[:NEXT]?**	**TDC:STATUS?**
***ESE**	**SYSTem:ERRor:COUNt?**	
***ESE?**	**SYSTem:ERRor:CLEAR**	**TDC:SPI:PRESCaler**
***ESR?**	**SYSTem:VERSion?**	**TDC:SPI:PRESCaler?**
***IDN?**	**SYSTem:RESet**	**TDC:SPI:REGister**
***OPC**		**TDC:SPI:REGister?**
***OPC?**		**TDC:SPI:PARAMeter**
***RST**		**TDC:SPI:PARAMeter?**
***SRE**		
***SRE?**		**TDC:MEASurement:INIT**
***STB?**		**TDC:MEASurement:STATUS?**
***TST?**		**TDC:MEASurement:CONTINUE**
***WAI**		**TDC:MEASurement:DATA?**
		TDC:MEASurement:RESET

2.2.3 IEEE-488.2 Common Commands

These commands are associated with the IEEE-488 standard. More information about these commands can be found in the *Keysight Trueform Series Operating and Service Guide* (Technologies K. , 2023).

***CLS** - Clear status command

***ESE** - Event status enable command

***ESE?** - Event status enable query

***ESR?** - Event status register query

***IDN?** - Instrument Identification: <Manufacturer>, <Model>, <Serial>, <Firmware>

***OPC** - Set operation complete bit command

***OPC?** - Operation complete bit query

***RST** - Reset Instrument to factory defaults command

***SRE** - Service request enable command

***SRE?** - Service request enable query

***STB?** - Read status byte query

***TST?** - Self-test query

***WAI** - Wait for all pending operations to complete command (no operation)

2.2.4 SYSTem Commands

The SYSTem commands are the extended commands associated with the IEEE standard. More information about these commands can be found in the *Keysight Trueform Series Operating and Service Guide* (Technologies K. , 2023).

SYSTem:ERRor[:NEXT]? - Read and clear one error from the error queue query

SYSTem:ERRor:COUNt? - Read the amount of errors in the error queue query

SYSTem:ERRor:CLEAR - Clear all the errors in the error queue command.

SYSTem:VERSion? - Return the version of the SCPI standard query.

SYSTem:RESet - Perform a system reset command.

2.2.5 TDC:STATUS and TDC:SPI Commands

TDC:STATUS? <CS>

Returns {<SPI OK>, <REFCLK OK>} | <ERR MSG>

Parameter	Description	Value
CS	Determines the CS pin to enable during the SPI transaction.	0, 1 or 2
SPI OK	Indicates whether SPI communication is possible.	“OK”	“NOK”
REFCLK OK	Indicates whether the reference clock of the TDC is locked. When there is no SPI communication this always will return “NA” since this check is done over SPI.	“OK”	“NOK”	“NA”
ERR MSG	Returns when a wrong CS value was provided or when the TDC is performing a measurement.	“NOK”

TDC:SPI:PRESCaler <PRESCALER>

Returns <OK MSG> | <ERR MSG>

Parameter	Description	Value
PRESCALER	Determines the SPI frequency prescaler. The prescaler scales the base frequency of 40MHz down with integer values. Possible SPI frequencies are 40MHz, 20MHz, 10MHz, 5MHz, 2.5MHz, 1.25MHz, 625kHz, 312.5kHz.	[1-8]
ERR MSG	Returns when an error occurred during the SPI initialisation or when the TDC is performing a measurement.	“NOK”

TDC:SPI:PRESCaler?

Returns <PRESCALER>

Parameter	Description	Value
PRESCALER	Determines the SPI frequency prescaler. The prescaler scales the base frequency of 40MHz down with integer values. Possible SPI frequencies are 40MHz, 20MHz, 10MHz, 5MHz, 2.5MHz, 1.25MHz, 625kHz, 312.5kHz.	[1-8]

TDC:SPI:REGister <CS>, <ADDR>, <DATA>

Returns <OK MSG> | <ERR MSG>

Parameter	Description	Value
CS	Determines the CS pin to enable during the SPI transaction.	0, 1 or 2
ADDR	The address of the register to program over SPI.	[24-53], 95
DATA	The value to program to the register.	[0-65535] (16bit)
ERR MSG	Returns when an error occurred during the SPI transaction or when the TDC is performing a measurement.	“NOK”

TDC:SPI:REGister? <CS>, <ADDR>

Returns <DATA> | <ERR MSG>

Parameter	Description	Value
CS	Determines the CS pin to enable during the SPI transaction.	0, 1 or 2
ADDR	The address of the register to read over SPI.	[24-53], 95
DATA	The register value red over SPI.	[0-65535] (16bit)
ERR MSG	Returns when an error occurred during the SPI transaction or when the TDC is performing a measurement.	"NOK"

TDC:SPI:PARAMeter <CS>, <ADDR>, <SHIFT>, <WIDTH>, <DATA>

Returns <OK MSG> | <ERR MSG>

Parameter	Description	Value
CS	Determines the CS pin to enable during the SPI transaction.	0, 1 or 2
ADDR	The address of the register parameter to write over SPI.	[24-53], 95
SHIFT	The position of the LSB of the register parameter in the register in bits.	[0-15]
WIDTH	The width of the register parameter in bits.	[0-15]
DATA	The value to program to the register parameter.	[0-65535] (16bit)
ERR MSG	Returns when an error occurred during the SPI transaction or when the TDC is performing a measurement.	"NOK"

TDC:SPI:PARAMeter? <CS>, <ADDR>, <SHIFT>, <WIDTH>

Returns <DATA> | <ERR MSG>

Parameter	Description	Value
CS	Determines the CS pin to enable during the SPI transaction.	0, 1 or 2
ADDR	The address of the register parameter to read over SPI.	[24-53], 95
SHIFT	The position of the LSB of the register parameter in the register in bits.	[0-15]
WIDTH	The width of the register parameter in bits.	[0-15]
DATA	The register parameter value red over SPI.	[0-65535] (16bit)
ERR MSG	Returns when an error occurred during the SPI transaction or when the TDC is performing a measurement.	"NOK"

2.2.6 TDC:MEASurement Commands

To optimize the interaction between the SCPI interface and multiple time measurements of the TDC, a state machine is implemented. The TDC:MEASurement command set provides interactions with this state machine. This state machine is illustrated in Figure 7.

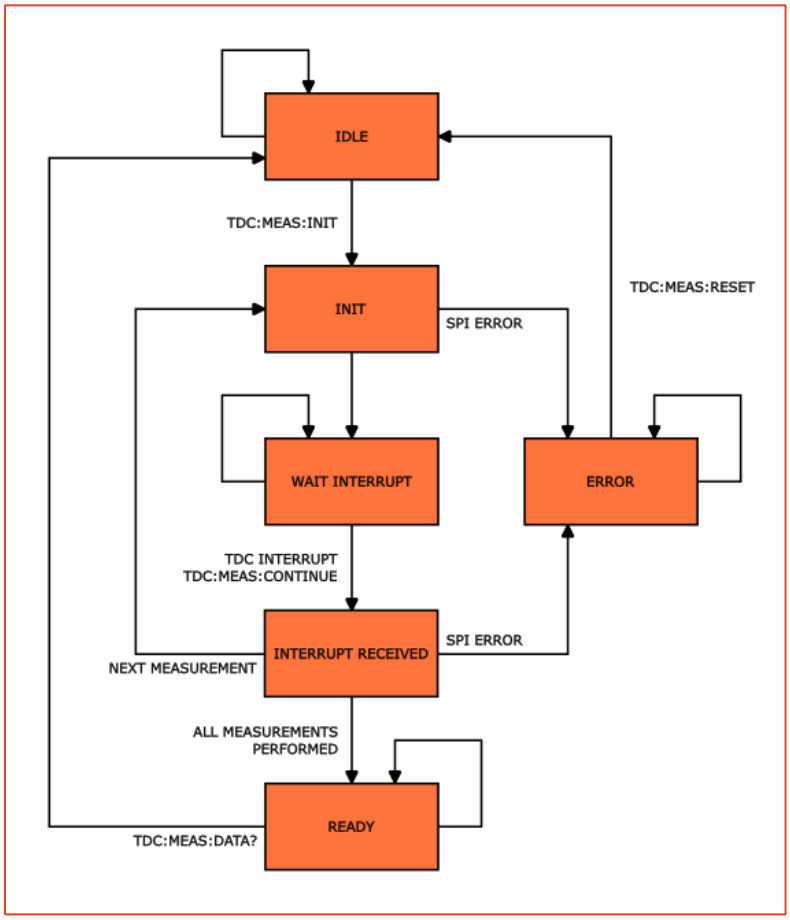

Figure 7: TDC measurement state machine

IDLE

In the IDLE state, configuration of the TDC is possible via the TDC:SPI command set. Also the TDC:STATUS command can be performed in the IDLE state. In all other states, these commands will return “NOK” to protect the measurement loop.

Using the TDC:MEAS:INIT command, the state machine can proceed from the IDLE state to the INIT state.

The IDLE state is indicated on the Evaluation Base Board with LED1 OFF and LED2 OFF.

INIT

During the INIT state, the TDC is prepared for a new conversion: the interrupt register is cleared and the TDC is armed. After this state, the state machine automatically proceeds to the WAIT INTERRUPT state.

The INIT state is indicated on the Evaluation Base Board with LED1 ON and LED2 OFF.

WAIT INTERRUPT

During the WAIT INTERRUPT state, the state machine waits on an interrupt coming from the TDC. When the interrupt is received, the state machine proceeds to the INTERRUPT RECEIVED state.

There is no timeout implemented since this depends on the time measurement expected. Another way to exit the WAIT INTERRUPT state is to execute the TDC:MEAS:CONTINUE command.

INTERRUPT RECEIVED

After receiving the interrupt, the counter values are collected in the INTERRUPT RECEIVED state.

Whether or not all measurements are performed, the state machine continues to the READY state. It proceeds to the INIT state to perform extra measurements.

READY

When all measurements are executed, the state machine stays in the READY state until the TDC:MEAS:DATA? command is performed. After a read-out the state machine goes back to the IDLE state.

The READY state is indicated on the Evaluation Base Board with LED1 OFF and LED2 ON.

ERROR

When an SPI error occurs, the state machine automatically goes to the ERROR state. With the TDC:MEAS:RESET command, the state machine can be reset to the IDLE state. This command can be performed in all states.

The ERROR state is indicated on the Evaluation Base Board with LED1 and LED2 blinking simultaneously.

TDC:MEASurement:INIT <CS>, <CYCLES>, <STOP PULSES>

Returns <OK MSG> | <ERR MSG>

Parameter	Description	Value
CS	Determines the CS pin to enable during the SPI transactions.	0, 1 or 2
CYCLES	The amount of time measurements to perform sequentially. The amount of cycles is limited to 1000/stop pulses.	[1, 1000/stop pulses]
STOP PULSES	The amount of stop pulses to read after the interrupt is received.	[1-5]
OK MSG	Returns when cycles < 1000/stop pulses.	"OK"
ERR MSG	Returns when cycles > 1000/stop pulses.	"NOK"

TDC:MEASurement:STATUS?

Returns <MEAS STATUS>, <CYCLES PERFORMED>

Parameter	Description	Value
MEAS STATUS	One of the states of the measurement state machine as an integer: 0. IDLE 1. INIT 2. WAIT INTERRUPT 3. INTERRUPT RECEIVED 4. READY 5. ERROR	[0, 5]
CYCLES PERFORMED	The amount of measurements already performed.	[0, 1000]

TDC:MEASurement:CONTINUE

Returns <OK MSG> | <ERR MSG>

Parameter	Description	Value
OK MSG	Returns when the state machine successfully proceeded from the WAIT INTERRUPT state to the INTERRUPT RECEIVED state	"OK"
ERR MSG	Returns when the state machine is not in the WAIT INTERRUPT STATE.	"NOK"

TDC:MEASurement:RESET

Returns <OK MSG>

Parameter	Description	Value
OK MSG	This command sets the state to IDLE and returns the OK MSG at all times.	"OK"

TDC:MEASurement:DATA?

Returns ..., <START BIN DEL N>, <START BIN CAL N>, <START COUNT LSB N>,

<START COUNT MSB N>, <STOP BIN DEL NM>, <STOP BIN CAL NM>,

<STOP COUNT LSB NM>, <STOP COUNT MSB NM>, ...

Parameter	Description	Value
START BIN DEL N	Start bin del value of the Nth start pulse.	[0, 255] (8bit)
START BIN CAL N	Start bin cal value of the Nth start pulse. The 8 MSBs are the start bin cal period. The 8 LSBs are the start bin cal offset.	[0, 65535] (16bit)
START COUNT LSB N	Start count LSB value of the Nth start pulse.	[0, 65535] (16bit)
START COUNT MSB N	Start count MSB value of the Nth start pulse.	[0, 65535] (16bit)
STOP BIN DEL NM	Stop bin del value of the Mth stop pulse of the Nth measurement.	[0, 255] (8bit)
STOP BIN CAL NM	Stop bin cal value of the Mth stop pulse of the Nth measurement. The 8 MSBs are the start bin cal period. The 8 LSBs are the start bin cal offset.	[0, 65535] (16bit)
STOP COUNT LSB NM	Stop count LSB value of the Mth stop pulse of the Nth measurement.	[0, 65535] (16bit)
STOP COUNT MSB NM	Stop count MSB value of the Mth stop pulse of the Nth measurement.	[0, 65535] (16bit)

How the delay between start and stop signals should be calculated starting from these counter values can be found in the datasheet (Technologies M. , 2024).

3. List of Acronyms

Acronym	Definition
BRD CLK	Board Clock
EXT CLK	External Clock
MCU	Microcontroller Unit
MCU CLK	Microcontroller Unit Clock
NOK	Not Oll Korrect
OK	Oll Korrect
PC	Personal Computer
RST	Reset
SPI	Serial Peripheral Interface
SMA	Sub-Miniature Version A
TDC	Time to Digital Converter
TRIGG	Trigger
USB	Universal Serial Bus

4. References

Putty. (n.d.). *Putty*. (Putty) Retrieved 07 12, 2024, from www.putty.org

Realterm. (n.d.). *Realterm*. Retrieved 07 12, 2024, from www.realterm.sourceforge.io

Technologies, K. (2023, December). *Keysight Trueform Series Operating and Service Guide.* Retrieved July 11, 2024, from https://www.keysight.com/be/en/assets/9018-03714/service-manuals/9018-03714.pdf

Technologies, M. (2024, 06). MAG-TDC00002-Sx - Time-to-Digital Converter. Geel: MAgics Technologies.

5. Revision information

Version number	Date	Change description
2025/05-rev1.0-1.2	2025-05-01	Initial versions.
2025/12-rev1.3	2025-12-08	Updated to the new template and nomenclature.

Disclaimer