Shanghai Siproin Microelectronics Co.,Ltd.

Time-to-Digital Converters(TDC)

SSP1922

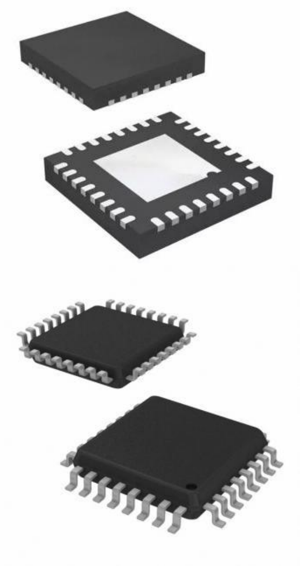
Date：2023/08/23
Version：1.1

Official Website：http://WWW.SIPROIN.COM

Catalog

1. General Description

SSP1922 is a high accurate time measurement (TDC) circuit. SSP1922 integrates analog comparator, analog switch, Schmidt flip-flop and other internal devices, thus greatly simplifying the peripheral circuit. At the same time, the first wave detection function is added inside, so that the anti-interference ability is greatly improved. The programmable offset range of the comparator is increased to ±35mV, the sampling accuracy can be improved.Measuring the relative pulse width of the first wave gives the user an indication of the strength of the received signal. Through this hint, we can judge the abnormal detection of ultrasonic transducer, the increase of wall covering, the presence of bubbles in water and so on. The Start-TOF-Restart command can complete a measurement of ultrasonic time difference (upstream and downstream) and data reading, so as to greatly reduce the software operation and power consumption. Compatible with TDC - GP22.



2. Features

Measurement mode 1:

- 2 channels with typ. 75 ps resolution
- channel double resolution with typ. 37 ps
- Range 3.5 ns (0ns) to 2.5 µs
- 20 ns pulse-pair resolution, 4-fold multihit

Measurement mode 2:

- 1 channel with typ. 75 ps resolution
- Double resolution mode with 37 ps, Quad resolution mode with 19 ps resolution
- Measurement range 500 ns to 4 ms (4M High speed clock)
- 3-fold multihit capability with automatic processing of all 3 data

Analog Input Circuit:

- Chopper-stabilized low-offset comparator, programmable, ±35mV
- First-wave detection
- First-wave pulse-width measurement
- Integrated analog switches for input selection
- External circuit is reduced to 2 resistors and 2 capacitors

Temperature Measurement Unit:

- 2 or 4 sensors, PT500/PT1000 or higher
- Schmitt trigger integrated
- 16-Bit eff. with external Schmitt trigger, 17.5-Bit eff. with integrated low noise Schmitt trigger
- Ultra low current (0.08 µA when measuring every 30 seconds)

Special Functions:

- Fire pulse generator, up to 127 pulses
- Trigger to rising and/or falling edge
- Precise stop enable by windowing
- Low-power 32 kHz oscillator (500nA)
- 7×32 Bit EEPROM

General:

- 4-wire SPI interface
- Operation voltage: 2.5V ~ 3.6V
- Operation temperature: -40℃~+125℃
- QFN32/LQFP32 Package

Applications

- Ultrasonic Heat meter， water meter
- Laser range finder
- velometer

3. Block Diagram and Pin Arrangement Diagram

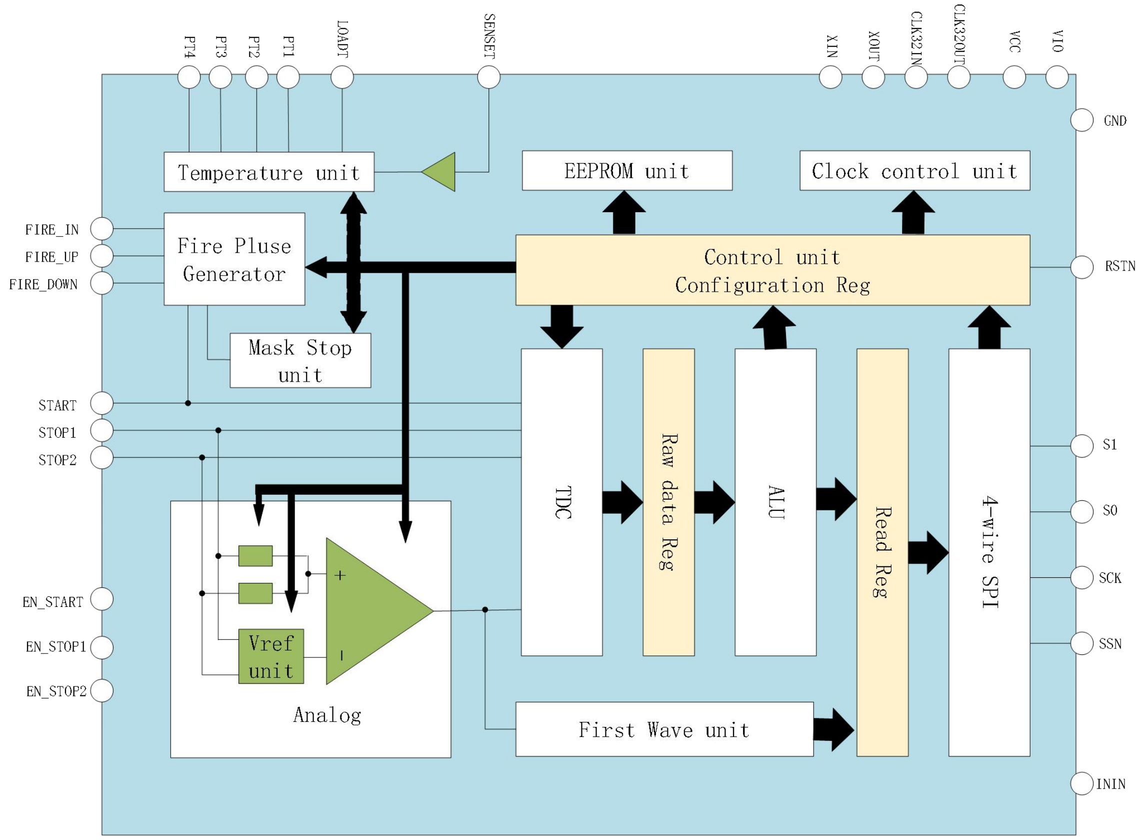


Figure 1 Block Diagram

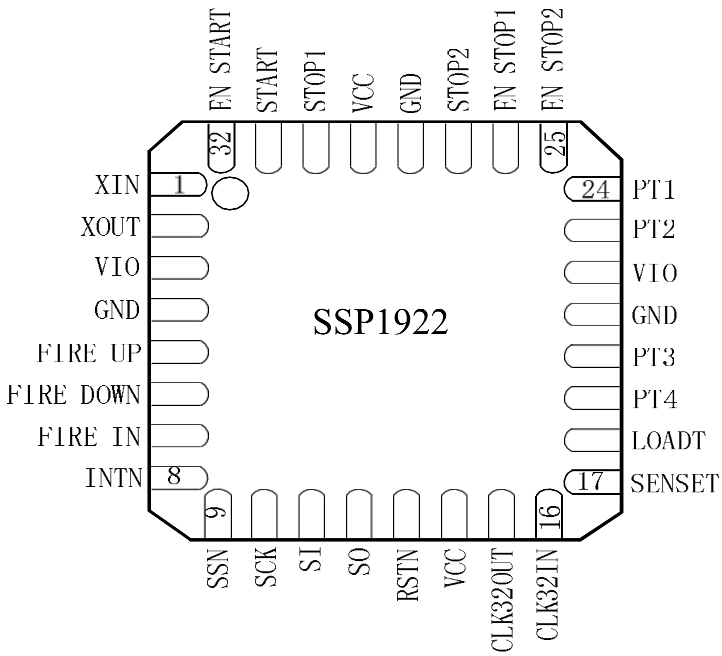


Figure 2 QFN32

4. Pin Assignment

No.	Name	I/O	Description	Remarks
1	XIN	I	Oscillator driver in	GND
2	XOUT	O	Oscillator driver out	
3	VIO	--	I/O – supply voltage	
4	GND	--	Ground	
5	FIRE_UP	O	Fire pulse generator output 1 (48mA)	
6	FIRE_DOWN	O	Fire pulse generator output 2 (48mA)	
7	FIRE_IN	I	“sing-around ” Signal input terminal	GND
8	INTN	O	Interrupt flag , LOW active (4mA)	
9	SSN	I	Slave select, LOW active	
10	SCK	I	Clock serial interface	
11	SI	I	Data input serial interface	
12	SO	O	Data output serial interface; Output low level when SPI is free	
13	RSTN	I	Reset input, LOW active	
14	VCC	--	Core supply voltage	
15	CLK32OUT	O	Output 32 kHz clock generator	n.c.
16	CLK32IN	I	Input 32 kHz clock generator	GND
17	SENSET	I	Sense input temperature measurement (Schmitt trigger)	GND
18	LOADT	O	Load output temperature measurement (24mA)	n.c.
19	PT4	O	Port 4 temperature measurement (>96mA open drain)	
20	PT3	O	Port 3 temperature measurement (>96mA open drain)	
21	GND	--	Ground	
22	VIO	--	I/O – supply voltage	
23	PT2	O	Port 2 temperature measurement (>96mA open drain)	
24	PT1	O	Port 1 temperature measurement (>96mA open drain)	
25	EN_STOP2	I	Enable pin stop input 2, HIGH active	Vio
26	EN_STOP1	I	Enable pin stop input 1, HIGH active	Vio
27	STOP2	I	Stop input 2	GND
28	GND	--	Ground	
29	VCC	--	Core supply voltage	
30	STOP1	I	Stop input 1	GND
31	START	I	Start input	GND
32	EN_START	I	Enable pin start input, HIGH active	Vio

Package specifications:

Part No	Package	Marking	Manner of Packing	Devices per bag/reel
SSP1922	QFN-32	SSP1922	REEL	2500
SSP1922P	LQFP32	SSP1922P		

Note: If the user does not use the pins, please follow the connection method in the "Remarks" column to set the pins that are not used.

5. Parameter Characteristic

5.1 Electrical Characteristics

5.1.1 Recommended Operating Conditions

Parameter	Symbol	Conditions	Min	Typ	Max	Unit
Core supply voltage*	V_{cc}	Vcc= Vio	2.5	-	3.6	V
I/O supply voltage	V_{io}		2.5	-	3.6	V
Normal input rising time	t_{ri}		-	-	200	ns
Normal input falling time	t_{fa}		-	-	200	ns
Schmitt trigger rising time	t_{ri}		-	-	5	ms
Schmitt trigger rising time	t_{fa}		-	-	5	ms
Ambient temperature	T_a	T_j must not exceed 125° C	-40	-	125	℃
Thermal resistance	$R_{th(j-)}$	junction-ambient	-	28	-	K/W

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

5.1.2 DC Characteristics (Vio=Vcc=3.0V, Tj=-40~+85° C)

Parameter	Symbol	Conditions	Min	Typ	Max	Unit
Current 32kHz oscillator	I_{32}	$I_{CC}+I_{IO}$,only 32 kHz oscillator running	-	1	-	µA
Current 4Mhz oscillator	I_{hs}	Vcc=Vio= 3.6V	-	200	-	µA
		Vcc=Vio=3.0V	-	130	-	µA
		off	-	<1	-	µA
Current time measuring unit	I_{tmu}	only during active time measurement	-	4	-	mA
Quiescent current	I_{ddq}	all clocks off, @85℃	-	<0.1	-	µA
Operating current	I_o	TOF-UP/DOWN, 1/s Temperature average, PT1000,1/30s	-	1.1 0.15	-	µA
Temperature measuring current	I_T	Every 30 seconds	-	0.085	-	µA
Analog current	I_{ana}	Turn on the Analog	-	0.8	-	mA
Total current	I_{total}	Two time measurements per second Temperature measurements are taken every 30 seconds	-	2.3	-	µA
High level output voltage	V_{oh}	I_{oh}= tbd mA Vio=Min.	0.8Vio	-		V
Low level output voltage	V_{ol}	I_{ol}=tbd mA, Vio=Min	-	-	0.2Vio	V
High level input voltage	V_{ih}	LVTTL, Vio = Max.	0.7Vio	-		V
Low level input voltage	V_{il}	LVTTL, Vio = Min.	-	-	0.3Vio	V
High level Schmitt trigger voltage	V_{th}		0.7Vio	-	-	V
Low level Schmitt trigger voltage	V_{tl}		-	-	0.3Vio	V
Schmitt trigger hysteresis	V_h		-	0.28	-	V

5.1.3 Terminal Capacitance

Parameter	Symbol	Conditions	Min	Typ	Max	Unit
Digital input	Cin	measured @ $V_{cc} = V_{io}$, f = 1 MHz,T=25°C	-	7	-	pF
Digital output	Co		-	-	-	
Bidirectional	Cio		-	9	-	
PT ports			-	t.b.d.	-	
Analog in			-	t.b.d.	-	

5.1.4 Analog Frontend

Parameter	Symbol	Conditions	Min	Typ	Max	Unit
Comparator input offset voltage (chopper stabilized)			-	<1	2	mV
Switch-on resistance of analog switches at STOP1/STOP2 inputs	$R_{dson(AS)}$		-	200	-	Ohm
Switch-on resistance of FIRE_UP, FIRE_DOWN output buffers	$R_{dson(FIRE)}$	Symmetrical outputs, $R_{dson}(HIGH)=R_{dson}(LOW)$	-	4	-	Ohm
Output current FIRE_UP, FIRE_DOWN output buffers	I_{FIRE}		-	96	-	mA

5.1.5 EEPROM

Parameter	Symbol	Conditions	Min	Typ	Max	Unit
Data retention @ 85°C		normal	10			years
		with Error correction	practically endless			

5.2 Converter Specification

5.2.1 Time Measuring Unit (Vio=Vcc=3.0V,Tj=25℃)

Parameter	Symbol	Conditions	Min	Typ	Max	Unit
Resolution of measurement	LSB	Measurement mode 1&2 DOUBLE_RES = 0	-	75	-	ps
		DOUBLE_RES = 1	-	37	-	
		Measurement mode 2: QUAD_RES = 1	-	19	-	
Standard deviation	σ	Measurement mode 1&2 DOUBLE_RES = 0 DOUBLE_RES = 1	-	t.b.d	-	ps
		Measurement mode 2: QUAD_RES = 1	-	t.b.d	-	
Measurement range	t_m	Measurement mode 1	3.5ns	-	2.4µs	
		Measurement mode 2(4M High-speed clock)	500ns	-	4ms	
Integral Non-linearity	INL		-	<0.1	-	LSB
Differential Non linearity	DNL		-	<0.1	-	LSB

5.2.2 Temperature Measuring Unit [1]

Terminal		Conditions				Unit
		Internal Schmitt trigger		external Schmitt trigger[2]		
		PT500	PT1000	PT500	PT1000	
Resolution RMS		17.5	17.5	16.0	16.0	Bit
SNR		105	105	96	96	dB
Absolute Gain[3]		0.9912	0.9931	0.9960	0.9979	
Absolute Gain vs.Vio	3.6V	0.9923	0.9940	0.9962	0.9980	
	3.0V	0.9912	0.9931	0.9960	0.9979	
	2.5V	0.9895	0.9915	0.9956	0.9979	
Gain-Drift vs.Vio [3]		0.25	0.23	0.06	0.04	%/V
max. Gain Error @ dΘ=100 K		0.05%	0.05%	0.02%	<0.01%	
Gain-Drift vs. Temp		0.022	0.017	0.012	0.0082	%/10K
Gain-Drift vs. Vio				0.08		%/V
Initial Zero Offset		<20	<10	<20	<10	mK
Offset Drift vs. Temp		<0.05	<0.03	<0.012	<0.082	mK/°C
PSRR			>100			dB

1. All values measured at Vio = Vcc = 3.0V, Cload = 100 nF for PT1000 and 200nF for PT500 (C0G-type).
2. measured with external 74AHC14 Schmitt trigger.
3. compared to an ideal gain of 1 .

5.3 Timings

At Vcc = 3.0 V±0.3 V, ambient temperature -40 °C to +85 °C unless otherwise specified.

5.3.1 Oscillator

Parameter	Symbol	Min	Typ	Max	Unit
32 kHz reference oscillator	Clk_{32}	-	32.768	-	kHz
32 kHz oscillator start-up time after power-up	t_{32st}	-	3	-	s
High-speed reference oscillator	Clk_{HS}	2	4	8	MHz
Oscillator start-up time with ceramic resonator	t_{oszst}	-	100	-	µs
Oscillator start-up time with crystal oscillator	t_{oszst}	-	1	-	ms

5.3.2 Serial Interface

Parameter	Symbol	Max		Unit
		Vio=2.5V	Vio=3.3V	
Serial clock frequency	f_{clk}	15	20	MHz
Serial clock, pulse width high	t_{pwh}	30	25	ns
Serial clock, pulse width low	t_{pwl}	30	25	ns
SSN enable to valid latch clock	t_{sussn}	40	10	ns
SSN pulse width between write cycles	t_{pwssn}	50	40	ns
SSN hold time after SCLK falling	t_{hssn}	40	25	ns
Data set-up time prior to SCLK falling	t_{sud}	5	5	ns
Data hold time before SCLK falling	t_{hd}	5	5	ns
Data valid after SCLK rising	t_{vd}	20	16	ns

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

The serial interface is compatible with 4-wire SPI and requires a SerialSelectNot (SSN) signal to not work on the 3-wire SPI interface.
The rising edge of the first SCK will reset the INTN pin (interrupt pin) state.

The transmission starts at the highest bit (MSB) and ends at the lowest bit (LSB). The transfer is done in bytes. Data transfer can be stopped after each byte by sending a LOW-HIGH-LOW level to the SSN.

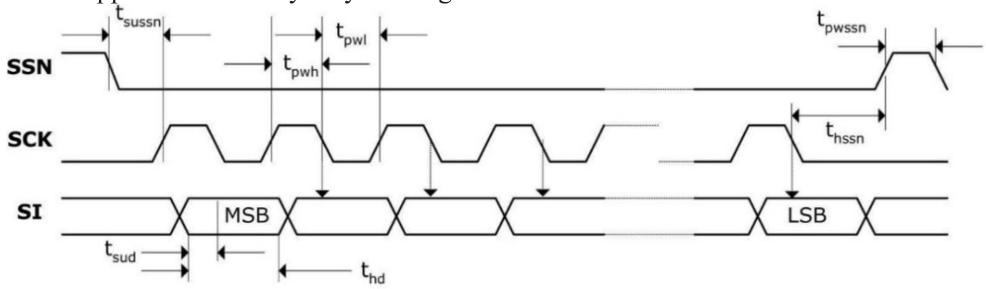


Figure 3 SPI Write

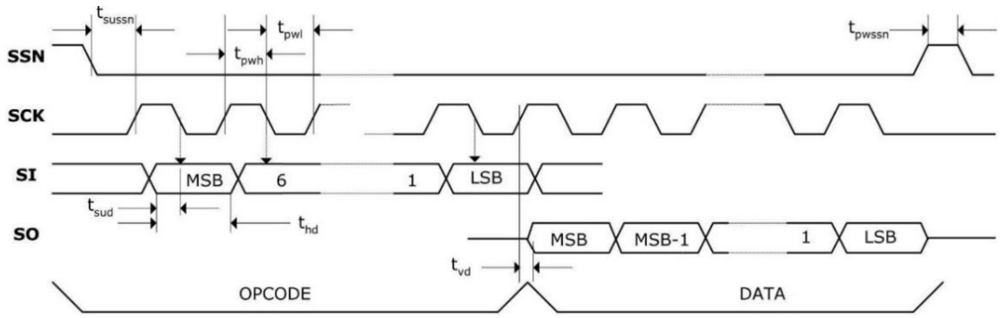


Figure 4 SPI Read

5.3.4 Disable Timings

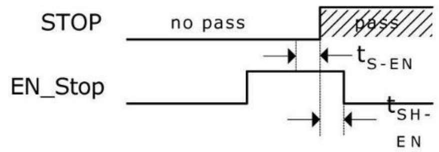


Figure 5 Disable Timings

5.3.5 Reset Timings

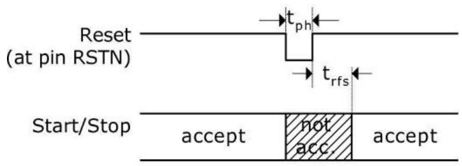


Figure 6 Reset Timings

Parameter	Symbol	Min	Max	Unit
Reset pulse width	tph	t.b.d.	-	ns
Time after rising edge of reset pulse before further communication	trfs	t.b.d.	-	ns

Note: After power-on reset, wait at least 500 us before starting the analog section.

5.4 Supply voltage

SSP1922 is a high end mixed analog/digital device. To reach full performance of the chip a good power supply is mandatory. It should be high capacitive and of low inductance. SSP1922 provides two pairs of power supply terminals:

Vio ----- I/O supply voltage

Vcc ---- Core supply voltage

All ground pins should be connected to a ground plane on the printed circuit board. Vio and Vcc should be provided by a battery or fixed linear vol tage regulator. Do not use switched regulators to avoid disturbances caused

by the I/O supply.
The measurement quality of a time-to-digital converter depends on a good power supply.
The chip sees mainly pulsed current and therefore a sufficient bypassing is mandatory:
Vcc 47 µF (minimum 22 µF)
Vio 100 µF (minimum 22 µF)
The supply voltage should be provided through analog regulators. We strongly recommend not to use switch mode power supplies.

5.5 Absolute Maximum Ratings（T=25℃）

Supply voltage V_{cc} vs. GND··········-0.3V～+4V
Supply voltage V_{io} vs. GND··········-0.3V～+4V
Vin voltage ··········-0.5V～V_{cc}+0.5V
ESD（HBM）··········>2000V
Junction temperature ·········· 125℃
Storage temperature ·········· -55℃～+150℃

6. Internal register Description

6.1 Configuration registers

SSP1922 has 7 configuration registers with 32 bit. The upper 24 bit are used for configuration and are write only. They are used to setup the SSP1922 operating mode. The lowest 8 bit can be used e.g. as an ID and can be read back.

Alphanumeric listing of configuration parameters:

Parameter	Register	Bits	Default value
ANZ_FAKE	0	15	0
ANZ_FIRE	6 0	28-31 8-10	2
ANZ_PER_CALRES	0	22,23	0
ANZ_PORT	0	17	1
CALIBRATE	0	13	1
Conf Fire	5	29-31	0
CURR32K	1	15	1
CYCLE_TEMP	6	18,19	0
CYCLE_TOF	6	16,17	0
DA_KORR	6	25-28	0
DELREL1	3	8-13	0
DELREL2	3	14-19	0
DELREL3	3	20-25	0
DELVAL1	2	8-26	0
DELVAL2	3	8-26	0
DELVAL3	4	8-26	0
DIS_PHASSHIFT	5	27	0
DIS_PW	4	16	0
DIV_CLKHS	0	20,21	0
DIV_FIRE	0	24-27	2
DOUBLE_RES	6	12	0
EDGE_FW	4	15	0
EN_ANALOG	6	31	0
EN_AUTOCALC_MB2	3	31	0
EN_ERR_VAL	3	29	0
EN_Fast_Init	1	23	0
EN_FIRST_WAVE	3	30	0

EN_INT	2 6	29-31 21	1
EN_STARTNOISE	5	28	0
FIREO_DEF	6	14	0
HIT1	1	24-27	5
HIT2	1	28-31	5
Hitin1	1	16-18	0
Hitin2	1	19-21	0
HZ60	6	15	0
ID0	0	0-7	0
ID1	1	0-7	0
ID2	2	0-7	0
ID3	3	0-7	0
ID4	4	0-7	0
ID5	5	0-7	0
ID6	6	0-7	0
MESSB2	0	11	1
NEG_START	0	8	1
NEG_STOP_TEMP	6	30	0
NEG_STOP1	0	9	1
NEG_STOP2	0	10	1
NO_CAL_AUTO	0	12	0
OFFS	4	8-12	0
OFFSRNG1	4	13	0
OFFSRNG2	4	14	0
PHFIRE	5	8-23	0
QUAD_RES	6	13	0
REPEAT_FIRE	5	24-26	0
RFEDGE1	2	27	0
RFEDGE2	2	28	0
SEL_ECLK_TMP	0	14	1
SEL_START_FIRE	1	14	0
SEL_TIMO_MB2	3	27,28	3
SEL_TSTO1	1	8-10	0
SEL_TSTO2	1	11-13	0
START_CLKHS	0 6	18,19 20	1
TCYCLE	0	16	0
TEMP_PORTDIR	6	11	0
TW2	6	22,23	0

6.2 Register 0（address 0）

Bits	Default value	Parameter	Description	Settings
31	0	ANZ_FIRE[3:0]	Sets number of pulses generated by fire pulse generator. Additional 3 bits are set in register 6. For values ANZ_FIRE > 15 the phase setting (PHFIRE) can not be used.	0 = off 1 = 1 pulse … 127 = 127 pulses
30	0			
29	1			
28	0			
27	0	DIV_FIRE	Sets predivider for internal clock signal of fire pulse generator	0 = not permitted 1 = divided by 2
26	0			
25	1			

24	0			… 15 = divided by 16
23	0	ANZ_PER_CALRES	Sets number of periods used for calibrating the ceramic resonator	0 = 2 periods= 61.035 µs 1 = 4 periods= 122.07 µs 2 = 8 periods= 244.14 µs 3 = 16 periods= 488.281µs
22	0			
21	0	DIV_CLKHS	Sets predivider for CLKHS	0 = not permitted, 1 =divided by 2, 2 = divided by 4, 3 = divided by 4
20	0			
19	0	START_CLKHS [1:0]	Defines the time interval the chip waits after switching on the oscillator before making a measurement. Note: The highest bit to adjust START_CLKS is located in register 6, bit 20. This has to be set to 1 for settling times of 2.44 ms and 5.14 ms.	0 = Oscillator off 1 = Oscillator continuously on 2 = settling time 480 µs 3 = settling time 1.46 ms 4 = settling time 2.44 ms 5 to 7 = settling time 5.14 ms
18	1			
17	1	ANZ_PORT	Sets number of ports used for temperature measurement	0 = 2 temperature ports (PT1 and PT2) 1 = 4 temperature ports
16	0	TCYCLE	Sets cycle time for temperature measurement	0 = 128 µs @ 4 MHz 1 = 512 µs @ 4 MHz (recommended)
15	0	ANZ_FAKE	Number of dummy cycles at the beginning of a temperature measurement	0 = 2 Fake measurements 1 = 7 Fake measurements
14	1	SEL_ECLK_TMP	Select reference signal for internal cycle clock for temperature measurement	0 = use 32.768 kHz as cycle clock 1 = use 128 * CLKHS as period for cycle clock (32 µs with 4 MHz high speed clock signal)
13	1	CALIBRATE	Enables/disables calibration calculation in the ALU	0 = calculation of calibrated results off (allowed only in measurement mode 1) 1 = calculation of calibrated results on (recommended)
12	0	NO_CAL_AUTO	Enables/disables auto-calibration run in the TDC	0 = auto-calibration after measurement 1 = auto-calibration disabled
11	1	MESSB2	Switch to measurement mode 2	0 = measurement mode 1 1 = measurement mode 2
10	0	NEG_STOP2	Negation stop 2 input	0 = non-inverted input signa (rising edge) 1 = inverted input signal (falling edge)
9	0	NEG_STOP1	Negation stop 1 input	0 = non-inverted input signa (rising edge) 1 = inverted input signal (falling edge)
8	0	NEG_START	Negation stop 1 input	0 = non-inverted input signa （rising edge) 1 = inverted inputsignal (falling edge)

7-0	0	ID0	Free bits, e.g. to be used as identification or version number	

6.3 Register 1（address1）

<table>
<tr><th>Bits</th><th>Default value</th><th>Parameter</th><th>Description</th><th colspan="2">Settings</th></tr>
<tr><td>31</td><td>0</td><td rowspan="4">HIT2</td><td rowspan="4">Defines operator for ALU data post-processing:
MRange1: HIT1 - HIT2
MRange2: HIT2 - HIT1</td><td rowspan="8">MRange1:
0 = Start
1 = 1. Stop Ch1
2 = 2. Stop Ch1
3 = 3. Stop Ch1
4 = 4. Stop Ch1
5 = no action
6 = Cal1 Ch1
7 = Cal2 Ch1
9 = 1. Stop Ch2
A = 2. Stop Ch2
B = 3. Stop Ch2
C = 4. Stop Ch2</td><td rowspan="4">MRange2:
2 =1.Stop Ch1
3 =2.Stop Ch1
4 =3.Stop Ch1</td></tr>
<tr><td>30</td><td>1</td></tr>
<tr><td>29</td><td>0</td></tr>
<tr><td>28</td><td>1</td></tr>
<tr><td>27</td><td>0</td><td rowspan="4">HIT1</td><td rowspan="4">Defines operator for ALU data post-processing:
MRange1: HIT1 - HIT2
MRange2: HIT2 - HIT1</td><td rowspan="4">MRange2:
1 = Start</td></tr>
<tr><td>26</td><td>1</td></tr>
<tr><td>25</td><td>0</td></tr>
<tr><td>24</td><td>1</td></tr>
<tr><td>23</td><td>0</td><td>EN_FAST_INIT</td><td>Enables fast init operation</td><td colspan="2">0 = Fast init mode disabled
1 = Fast init mode enabled</td></tr>
<tr><td>22</td><td>1</td><td></td><td>Keep the default values</td><td colspan="2"></td></tr>
<tr><td>21</td><td>0</td><td rowspan="3">HITIN2</td><td rowspan="3">Number of expected hits on channel 2</td><td colspan="2" rowspan="6">0 = stop channel disabled
1 = 1 hit
2 = 2 hits
3 = 3 hits
4 = 4 hits
5 to 7 = not permitted</td></tr>
<tr><td>20</td><td>0</td></tr>
<tr><td>19</td><td>0</td></tr>
<tr><td>18</td><td>0</td><td rowspan="3">HITIN1</td><td rowspan="3">Number of expected hits on channel 1</td></tr>
<tr><td>17</td><td>0</td></tr>
<tr><td>16</td><td>0</td></tr>
<tr><td>15</td><td>1</td><td>CURR32K</td><td>Low current option for 32 kHz oscillator. Basically there is no need to use high current option . Low current also guarantees oscillation.</td><td colspan="2">0 = low current
1 = high current</td></tr>
<tr><td>14</td><td>0</td><td>SEL_START_FIRE</td><td>Fire pulse is used as TDC start. The START input is disabled</td><td colspan="2">0 = GP2 behavior
1 = Use FIRE as Start</td></tr>
<tr><td>13</td><td>0</td><td rowspan="3">SEL_TSTO2</td><td rowspan="3">Defines functionality of EN_START pin. Besides the SSP1922 functionality this pin can act as output for various signals.
If SEL_TSTO2>0 then EN_STAR=HIGH internally.</td><td colspan="2" rowspan="3">0 = High level enables the START pin
1 = START_TDC output
2 = STOP1 TDC output
3 = STOP2 TDC output
4 = start Temperature measurement output
5 = DELVAL output by EN_STOP
6 = n.c.
7 = 4 kHz (32 kHz/8) clock</td></tr>
<tr><td>12</td><td>0</td></tr>
<tr><td>11</td><td>0</td></tr>
<tr><td>10</td><td>0</td><td rowspan="3">SEL_TSTO1</td><td rowspan="3">Defines functionality of FIRE_IN pin. Besides the SSP1922 functionality this pin can act as output for various signals. If SEL_TSTO1 >1 the FIRE_IN is connected to</td><td colspan="2" rowspan="3">0 =FIRE_IN input for sing-around
1 = START_TDC output
2 = STOP1 TDC output
3 = STOP2 TDC output
4 = Stop Temperature measurement output
5 = TOF=UP, =1 when TOF_UP</td></tr>
<tr><td>9</td><td>0</td></tr>
<tr><td>8</td><td>0</td></tr>
</table>

			GND internally.	measurement is turned on 6 =Comparator out 7 = 32 kHz clock
7~0	0	ID1	Free bits, e.g. to be used as identification or version number	

6.4 Register 2（address2）

Bits	Default value	Parameter	Description	Settings
31	0	EN_INT[2:0]	Activates interrupt sources wired by OR. Additional bit in register 6	Bit 31 = 1： Timeout interrupt enable
30	0			Bit 30 = 1： End Hits interrupt enable
29	1			Bit 29 = 1： ALU interrupt enable
28	0	RFEDGE2	Edge sensitivity channel 2	0 = rising or falling edge 1 = rising and falling edge
27	0	RFEDGE1	Edge sensitivity channel 1	
26~8	0	DELVAL1	Delay value for internal stop enable unit, hit 1 channel 1. Fixed point number with 14 integer and 5 fractional digits in multiples of Tref	DELVAL1 = 0 to 16383.96875
7-0	0	ID2	Free bits, e.g. to be used as identification or version number	

6.5 Register 3（address3）

Set EN_FIRST_WAVE = 0:

Bits	Default value	Parameter	Description	Settings
31	0	EN_AUTOCALC_ MB2	Only in measurement mode 2: automatic calculation of all enabled hits. The sum of the results is written to read register 4.	0 = disabled 1 = enabled
30	0	EN_FIRST_WAVE	Enables the automatic first hit detection. In case this bit is set registers 3 and 4 get a new meaning	0 = disabled 1 = enabled
29	0	EN_ERR_VAL	Timeout forces ALU to write 'hFFFFFFFF into the output register	0 = disabled 1 = enabled
28	1	SEL_TIMO_MB2	Select predivider for timeout in measurement mode 2	0 = 64 µs 1 = 256 µs 2 = 1024 µs 3 = 4096 µs @ 4 MHz ClkHS
27	1			
26~8	0	DELVAL2	Delay value for internal stop enable unit, The timing starts with the first pulse of the start channel.Fixed point number with 14 integer and 5 fractional digits in multiples of Tref	DELVAL2 = 0 to 16383.96875
7-0	0	ID3	Free bits, e.g. to be used as identification or version number	

Set EN_FIRST_WAVE =1:

Bits	Default value	Parameter	Description	Settings
31	0	EN_AUTOCALC_ MB2	Only in measurement mode 2: automatic calculation of all enabled hits. The sum of the results is written to read register 4.	0 = disabled 1 = enabled
30	0	EN_FIRST_WAVE	Enables the automatic first hit detection. In case this bit is set registers 3 and 4 get a new meaning	0 = disabled 1 = enabled
29	0	EN_ERR_VAL	Timeout forces ALU to write 'hFFFFFFFF into the output register	0 = disabled 1 = enabled
28	1	SEL_TIMO_MB2	Select predivider for timeout in measurement mode 2	0 = 64 µs 1 = 256 µs 2 = 1024 µs 3 = 4096 µs @ 4 MHz ClkHS
27	1			
26	0		Keep the default values	
25~20	0	DELREL3	Sets the number of the periods after the first hit for the 3rd stop	5 to 63 DELREL3 > DELREL2
19~14	0	DELREL2	Sets the number of the periods after the first hit for the 2nd stop	4 to 63 DELREL2 > DELREL1
13~8	0	DELREL1	Sets the number of the periods after the first hit for the 1st stop	3 to 63
7~0	0	ID3	Free bits, e.g. to be used as identification or version number	

6.6 Register 4（address4）

Set EN_FIRST_WAVE = 0:

Bits	Default value	Parameter	Description	Settings
31~27	4		Keep the default values	
26~8	0	DELVAL3	Delay value for internal stop enable unit, The timing starts with the first pulse of the start channel.Fixed point number with 14 integer and 5 fractional digits in multiples of Tref	DELVAL3 = 0 to 16383.96875
7~0	0	ID4	Free bits, e.g. to be used as identification or version number	

Set EN_FIRST_WAVE = 1:

Bits	Default value	Parameter	Description	Settings
31~27	4		Keep the default values	
26~17	0		Keep the default values	
16	0	DIS_PW	Disable pulse width measurement	0 = Enable pulse width measurement 1 = Disable pulse width measurement
15	0	EDGE_FW	Sets the edge sensitivity for the first wave. With a negative offset it is reasonable to trigger on the falling edge of the first wave.	0 = rising edge 1 = falling edge
14	0	OFFSRNG2	Additional offset shift by + 20 mV	0 = off

				1 = active
13	0	OFFSRNG1	Additional offset shift by - 20 mV	0 = off 1 = active
12~8	0	OFFS	2's complement number setting the offset shift in 1 mV steps	0 = 0 mV 1 = +1 mV ... 15 = +15 mV 16 = -16 mV 17 = -15 mV ... 31 = -1 mV
7~0	0	ID4	Free bits, e.g. to be used as identification or version number	

6.7 Register 5（address5）

Bits	Default value	Parameter	Description	Settings
31	0	CONF_FIRE	Output configuration for pulse generator 3'b 011 is not allowed	Bit 31 = 1: FIRE_BOTH (inverts FIRE_DOWN) Bit 30 = 1: enable output FIRE_UP Bit 29 = 1: enable output FIRE_DOWN
30	0			
29	0			
28	0	EN_STARTNOISE	Enables additional noise for start channel	1 = switch on noise unit
27	0	DIS_PHASESHIFT	Phase noise unit. Improves statistics and should be enabled if start pulse generation is derived from the SSP1922 reference clock (e.g. with fire pulse generator).	1 = disables phase noise， 0 = enables phase noise unit
26	0	REPEAT_FIRE	Number of pulse sequence repetition for "quasi-sing-around"	0 = no signal repetition 1 = 1 signal repetition ... 7 = 7 signal repetition
25	0			
24	0			
23~8	0	PHFIRE	Enables phase reversing for each pulse of a sequence of up to 15 possible pulses.	0 = no inversion 1 = inversion
7-0	0	ID5	Free bits, e.g. to be used as identification or version number	

6.8 Register 6（address6）

Bits	Default value	Parameter	Description	Settings
31	0	EN_ANALOG	Activates the analog part for the ultrasonic flow measurement is. If active, this section is powered only for the duration of the measurement to save current. STOP1 and STOP2 are analog inputs now and automatically selected by the internal multiplexer.	0 = STOP1 and STOP2 are digital inputs 1 = The analog section is used.
30	0	NEG_STOP_TEMP	Inverts the SenseT input signal. This is mandatory when the	0 = external 74HC14 is used 1 = internal Schmitt trigger

			internal comparator is used instead of the external one like in TDC-GP2	is used
29	0		Keep the default values	
28	0	DA_KORR	Sets comparator offset from -8mV to +7mV. 2's complement	15 = - 1mV 7 = 7mV 14 = - 2mV 6 = 6mV ... ... 9 = - 7mV 1 = 1mV 8 = - 8mV 0 = 0mV
27	0			
26	0			
25	0			
24	0		Keep the default values	
23	0	TW2	Timer to charge up the capacitor of the recommend RC network when the internal analog part is used.	Charge time: 0 = 90 µs 1 = 120 µs 2 = 150 µs 3 = 300 µs
22	0			
21	0	EN_INT[3]	Additional interrupt source. See also register 2 for the lower 3 bits of EN_INT. The various sources are wired by an OR. An EEPROM action, e.g.EEPROM_COMPARE, is managed by the SSP1922 and especially the EEPROM write may last up to 130ms. Indicating the end will be helpful.	1 = end of EEPROM action
20	0	START_CLKHS[2]	Highest bit to set the settling time for the high speed oscillator. The lower bits are set in register 0	0 = off 1 = continously on 2 = 480µs delay 3 = 1.46 ms 4 = 2.44 ms 5 to 7 = 5.14 ms
19	0	CYCLE_TEMP	Selects timer for triggering the second temperature measurement in multiples of 50/60 Hz	0 = 1 1 = 1.5 2 = 2 3 = 2.5
18	0			
17	0	CYCLE_TOF	Selects timer for triggering the second ToF measurement in multiples of 50/60 Hz	
16	0			
15	0	HZ60	SSP1922 can make complete up and down flow measurement and also two temperature measurements in series. The time interval between 2 measurements is based on 50 or 60 Hz.	0 = 50 Hz base, 20 ms 1 = 60 Hz base, 16.67ms
14	0	FIREO_DEF	Specifies the default level of the inactive fire buffer. Example: if FIRE_UP is active then the FIRE_DOWN buffer is connected to the default level. Setting 1 is mandatory when using the integrated analog section	0 = High-Z 1 = LOW
13	0	QUAD_RES	Option to improve the resolution by factor 4 from 75ps to 19ps. Can be used only in measurement mode 2.	0 = off 1 = on
12	0	DOUBLE_RES	Doubles the resolution from 75ps to 37ps. In measurement mode 1	0 = off 1 = on

			this option limits the number of stop inputs to one	
11		TEMP_PORTDIR	Ports for temperature measurement are measured in the opposite order.	0 = PT1 > PT2 > PT3 > PT4 1 = PT4 > PT3 > PT2 > PT1
10		ANZ_FIRE[6:4]	Highest 3 bits of the number of fire pulses. See also register 0. If ANZ_FIRE>15 then PHFIRE is no longer active.	0 = off 1 = 1 pulse 2 = 2 pulses … 127 = 127 pulses
9				
8				
7~0	0	ID6	Free bits, e.g. to be used as identification or version number	

6.9 Read registers

The result and status registers can be read by means of opcode 0xBx. The opcode is followed by 4, 2 or 1 bytes, depending on the address.
The ID register bits in the configuration registers can be read back by means of opcode 0xB7. This opcode is followed by 7 bytes in the order ID0, ID1 ... ID6, each byte with the MSB first.

<table>
<tr><th>ADR</th><th>Symbol</th><th>Bits</th><th colspan="10">Description</th></tr>
<tr><td>0</td><td>RES_0</td><td>32</td><td colspan="10">Measurement result 1,fixed-point number with16 integer and 16 fractional digits
2^{15} 2^{0}, 2^{-1} 2^{-16}</td></tr>
<tr><td>1</td><td>RES_1</td><td>32</td><td colspan="10">Measurement result 2,fixed-point number with 16 integer and 16 fractional digits</td></tr>
<tr><td>2</td><td>RES_2</td><td>32</td><td colspan="10">Measurement result 3,fixed-point number with 16 integer and 16 fractional digits</td></tr>
<tr><td>3</td><td>RES_3</td><td>32</td><td colspan="10">Measurement result 4,fixed-point number with 16 integer and 16 fractional digits</td></tr>
<tr><td rowspan="2">4</td><td rowspan="2">STAT</td><td rowspan="2">16</td><td>15</td><td>14</td><td>13</td><td>12</td><td>11</td><td>10</td><td>9</td><td>8-6</td><td>5-3</td><td>2-0</td></tr>
<tr><td>EEPROM_eq_CRE</td><td>EEPROM_DED</td><td>EEPROM_Error</td><td>Error short</td><td>Error open</td><td>Timeout Precounter</td><td>Timeout TDC</td><td># of hits Ch 2</td><td># of hits Ch 1</td><td>ALU_ OP_ PTR</td></tr>
<tr><td>5</td><td>REG_1</td><td>8</td><td colspan="10">Content of highest 8 bits of write register 1, to be used for testing the communication</td></tr>
<tr><td>8</td><td>PW1ST</td><td>8</td><td colspan="10">Pulse width 1st wave compared to measured hits, fixed point with 1 bit integer</td></tr>
</table>

6.10 Result Registers

The data structure and the occupancy of the result registers depend on the operation mode and whether calibrated or non-calibrated data are stored. Several cases must be distinguished:

- Only in measurement mode 1 negative results are possible.
- In measurement mode 2 only positive results are possible, given as unsigned numbers.
- A non-calibrated measure is possible only in measurement mode 1.
- In measurement mode 1 with calibrated data (ALU) the time intervals that have to be measured can not exceed twice the period of the calibration clock. When measuring bigger time intervals an ALU - overflow will occur and 0xFFFFFFFF is written in the appropriate result register.

Measurement mode 1 with calibrated data(Calibrate = 1)

The results are given in multiples of the internal reference clock (= external reference clock divided by 1, 2 or 4 (DIV_CLKHS)). Calibrated data are 32 bit fixed point numbers with 16 integer bits and 16 fractional bits. Any calibrated result covers therefore 1 result register. The serial output begins with the highest bit (2^{15}) and ends with the lowest one (2^{-16}). The numbers are available in complements of 2.

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

Measurement mode 1 without calibration(Calibrate = 0)

Non-calibrated data are of the type ‘Signed Integer’ and are stored as a 16 bit value in the high word of the result registers. The bits of the low word are set to zero. The result is represented as number of LSB and is available in complements of 2.

$$\text{Time} = \text{RES\_X} \times 75 \text{ ps}$$

Measurement mode 2

In measurement mode 2 the SSP1922 only supports calibrated measurement. The results are given in multiples of the internal reference clock (= external reference clock divided by 1, 2 or 4 (DIV_CLKHS)). Calibrated data are 32 bit fixed point numbers with 16 integer bits and 16 fractional bits. Any calibrated result covers therefore 1 result register. The serial output begins with the highest bit (2^{15}) and ends with the lowest one (2^{-16}). The numbers are available in complements of 2.

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

Temperature measurement

Discharge time in the same format as in c., measurement mode 2.The ratio of the discharge times equal the ratio of resistance:

$$R_T = R_{ref} \times \tau_T/\tau_{ref}$$

6.11 Status Register

Bits	Name	Description	Values
2-0	Pointer result register	Pointer to the result register.	
5-3	# of hits Ch 1	Number of hits registered on channel 1	
8-6	# of hits Ch 2	Number of hits registered on channel 2	
9	Timeout TDC	Indicates an overflow of the TDC unit	1 = overflow
10	Timeout Precounter	Indicates an overflow of the 14 bit precounter in MR 2	1 = overflow
11	Error open	Indicates an open sensor at temperature measurement	1 = open
12	Error short	Indicates a shorted sensor at temperature measurement	1 = short
13	EEPROM_Error	Single error in EEPROM which has been corrected	1 = error
14	EEPROM_DED	Double error detection. A multiple error has been detected which can not be corrected.	1 = multiple error
15	EEPROM_eq_CREG	Indicates whether the content of the configuration registers equals the EEPROM	1 = equal

6.12 PW1ST Register

This register holds a 8-bit fixed point number with 1 integer and 7 fractional digits. PW1ST gives the ratio of the width of the first half wave (at a given offset) compared to the half period of the received signal. Data range: 0 to 1.99219.

6.13 EEPROM

SSP1922 has a 7x32 bit EEPROM。This EEPROM can be used to store the configuration data together with the ID or version number. Only the following three actions are possible:

- Write configuration register content into the EEPROM
- Transfer the EEPROM content into the configuration registers
- Compare the configuration registers content with the EEPROM content

Besides the ID it is not possible to read back the EEPROM. This gives customers the possibility to program the chips by themselves and prohibit other to read back the configuration.

For verification it is possible to compare the configuration register may be compare with the EEPROM. Bit EEPROM_eq_CREG in the status register indicates whether the content is equal or not.

The EEPROM has an internal error correction (Hamming code). It is possible

- to detect and correct single bit errors,
- to detect multi-bit errors without correction

Errors are indicated in the status register, bits EEPROM_Error (single bit) and EEPROM_DED (double error detection).

With each read access/compare to the EEPROM the error bit is checked. In case a single bit error is detected a refresh cycle is started automatically and the data is restored.

The data retention of the EEPROM is > 10 years @ 85°C without single or multiple errors. With regular Compare_EEPROM commands (e.g. once per month) the data retention can be extended unlimited.

6.14 Opcodes

HEX	MSB							LSB	Description	Followed by
h8x	1	0	0	0	0	A	A	A	Write into address A	24 bit or 32 bit data
hBx	1	0	1	1	0	A	A	A	Read from address A	8, 16 or 32 bit data
hB7	1	0	1	1	0	1	1	1	Read ID bit	56 bit ID
hB8	1	0	1	1	1	0	0	0	Read PW1ST	8 bit
hC0	1	1	0	0	0	0	0	0	Write configuration registers into EEPROM	
hF0	1	1	1	1	0	0	0	0	Transfer EEPROM content into configuration registers	
hC6	1	1	0	0	0	1	1	0	Compare configuration registers with EEPROM	
h70	0	1	1	1	0	0	0	0	Init	
h50	0	1	0	1	0	0	0	0	Power_On_Reset	
h01	0	0	0	0	0	0	0	1	Start_TOF (primitive name: Start_Cycle)	
h02	0	0	0	0	0	0	1	0	Start_Temp	
’h03	0	0	0	0	0	0	1	1	Start_Cal_Resonator	
h04	0	0	0	0	0	1	0	0	Start_Cal_TDC	
h05	0	0	0	0	0	1	0	1	Start_TOF_Restart	
h06	0	0	0	0	0	1	1	0	Start_Temp_Restart	

SSP1922 is compatible with GP2 write register mode, for example:
h80 + 3 bytes will write configuration register 0 in the SSP1922 compatible mode.
h80 + 4 bytes will write configuration register 0 including IDO (SSP1922 only).
It is not possible to do incremental writing. Each register must be addressed separately.

Opcode Explanations:

- hC0, hF0, hC6 all refer to EEPROM operations. Those may last up 130 ms, especially the EEPROM write. Therefore, the EN_INT bit 3 in register 6 indicates the end of the EEPROM operation. This can be used to adjust microprocessor actions .
- h01, Start_TOF: triggers a sequence for a single time-of-flight measurement. First, the 4 MHz oscillator is switched on. After the delay set to settle the oscillator (START_CLKHS), the comparator and the reference voltage are switched on. The receiver capacitor is charged up the Vref while inactive fire buffer is pulled down to GND. After the delay set to charge up the capacitor (TW2), the fire buffer sends the fire pulses. After the delay set in DELVAL the TDC stop channel is open. At the end of the measurement the analog section and the 4 MHz are switched off and the current consumption drops down to near zero. The interrupt is set, pin INTN = LOW.
- h05, Start_TOF_Restart: This opcode runs the Start_TOF sequence twice, in up and down direction as it is typical in ultrasonic flow meters. The interrupt is set, pin INTN = LOW, when the time measurement for each direction is finished. So, for one Start_TOF_Restart command the microprocessor sees two interrupts and has to read twice. The time interval between the up and down measurement is set by configuration parameter

CYCLE_TOF in multiples of 50 Hz or 60 Hz. The right selection of the delay between the two measurements suppresses 50/60 Hz noise.

CYCLE_TOF	factor	HZ60 = 0(50Hz)	HZ60 = 1(60Hz)
0	1	20 ms	16.7 ms
1	1.5	30 ms	25 ms
2	2	40 ms	33.3 ms
3	2.5	50 ms	41.67 ms

- h02, Start_Temp: triggers a single temperature measurement sequence. It begins with the fake measurements (ANZ_FAKE) on port PT0. Then it measures ports PT0 > PT1 > PT2 > PT4. If TEMP_PORTDIR is set one then the sequence of ports is inverted, starting with the fake measurements at port PT4.
- h06, Start_Temp_Restart: This opcode runs the Start_Temp sequence twice. The time interval between the up and down measurement is set by configuration parameter CYCLE_TEMP in multiples of 50 Hz or 60 Hz. The right selection of the delay between the two measurements suppresses 50/60 Hz noise.

CYCLE_TEMP	factor	HZ60 = 0(50Hz)	HZ60 = 1(60Hz)
0	1	20 ms	16.7 ms
1	1.5	30 ms	25 ms
2	2	40 ms	33.3ms
3	2.5	50 ms	41.67 ms

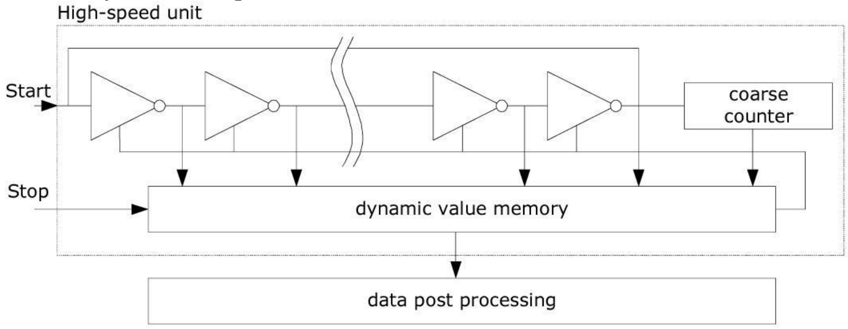
- h03, Start_Cal_Resonator: Triggers a calibration measurement of the high speed oscilator. The TDC measures a time interval between 61 µs and 488 µs, specified in ANZ_PER_CALRES. The end of the measurement is indicated by the interrupt. The result, in multiples or the high speed clock period, is stored in result register 0. Dividing this by the theoretical value gives the correction factor.
- h04, Start_Cal_TDC: This command starts a measurement of 2 periods of the reference clock. It is used to update the calibration raw data. Typically, the chip is configured for auto-calibration and this command is not necessary.

7. Measurement mode 1

7.1 General Description

- Measurement range from 3.5ns to2us(0 to 2us between stop channels)
- 2 stop channels referring to one start channel each of typ. 75ps resolution
- 1 stop channels referring to one start channel each of typ. 37ps resolution
- 20 ns pulse pair resolution
- 4-fold multihit capability for each stop channel
- Selectable rising/falling edge sensitivity for each channel
- Enable pins for windowing functionality
- The possibility to arbitrarily measure all events against each other
- Typical application: Laser ToF, RF ToF, ATE

Digital TDCs use internal propagation delays of signals through gates to measure time intervals with very high precision. The figure below clarifies the principal structure of such an absolute-time TDC. Intelligent circuit structures, redundant circuitry and special methods of layout on the chip make it possible to reconstruct the exact number of gates passed by the signal. The maximum possible resolution strongly depends on the maximum possible gate propagation delay on the chip.

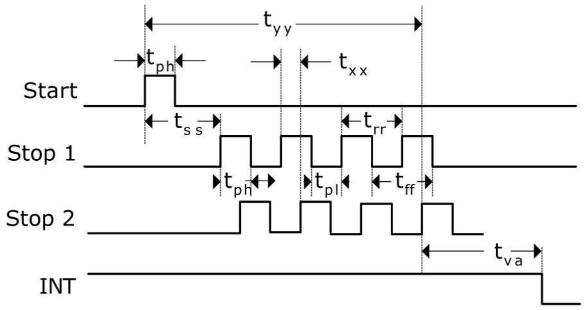


The measuring unit is triggered by a START signal and stopped by a STOP signal. Based on the position of the ring oscillator and the coarse counter the time interval between START and STOP is calculated with a 20 bit

measurement range.
The BIN size (LSB) is typically 75 ps at 3.3 V and 25 ℃ ambient temperature. The RMS noise is about 50 ps (0.7 LSB). The gate propagation delay times strongly depend on temperature and voltage. Usually this is solved doing a calibration. During such a calibration the TDC measures 1 and 2 periods of the reference clock. The measurement range is limited by size of the counter:

$$t_{yy} = BIN \times 26224 = 75ps \times 26224 \approx 2\ \mu s$$

	Time (Condition)	Description
tph	2.5ns (min.)	Minimum pulse width
tpl	2.5ns (min.)	Minimum pulse width
tss	3.5ns (min) 2 µs (max.)	Start to Stop
trr	20ns (typ.)	Rising edge to rising edge
tff	20ns (typ.)	
tva	t.b.d. uncalibrated t.b.d. calibrated	Last hit to data valid
txx	No timing limits	
tyy	2 µs (max)	Max. measurement range = 26224 × LSB



Each input separately can be set to be sensitive to rising or falling edge or both edges. This is done in register 0, bits 8 to 10. (NEG_START, NEG_STOP1, NEG_STOP2) and register 2, bit 27 & 28, RFEDGEx. Furthermore all Start/Stop-inputs support a high active enable pin.

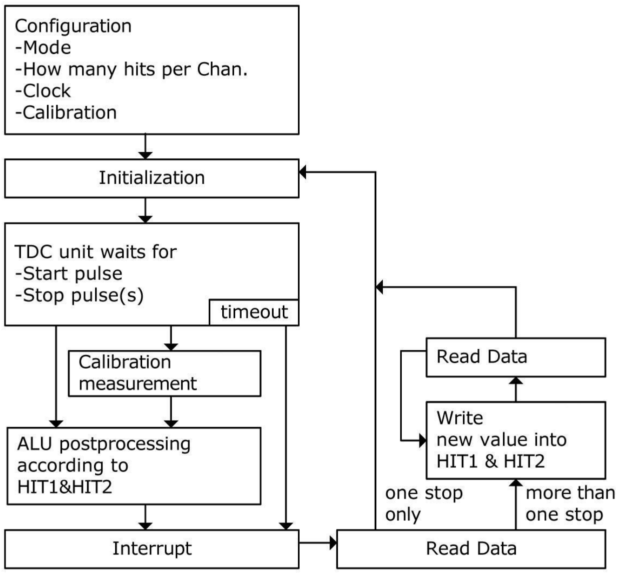
7.2 Measurement Flow

7.2.1 Configuration

At the beginning the SSP1922 has to be configured. The main settings for measurement mode 1 are:

a. Select measurement mode 1

Set register 0, bit 11, MESSB2 = 0.
Register 6, bit 12, DOUBLE_RES = 1 selects double resolution. With this bit set the resolution is typ. 37 ps instead of 75 ps, but only one STOP channel is available.



b. Select the reference clock

Register 0, bits 18 & 19 and register 6, bit 20, START_CLKHS defines the switch-on behavior of the high-speed clock. If only the 32 kHz is used it should be “0“. If only the high-speed clock is used it should be “1“ (continuously on).
Register 0, bits 20 & 21, DIV_CLKHS sets an additional internal divider for the reference clock (1, 2 or 4). This is important for calibrated measurements in measurement mode 1 because the ALU works correctly only if 2*T_{ref}(intern) is bigger than the maximum time interval to be measured. Otherwise the ALU output is 0xFFFFFFFF.
Make also sure that 2*T_{ref}(intern) < 2.4 µs to avoid a timeout during calibration.

c. Set the number of expected hits

In register 1, bits 16 to 18 and 19 to 21, HITIN1 and HITIN2 the user has to define the number of hits the SSP1922 has to wait for. A maximum of 4 on each channel is possible. The SSP1922 measures until the set number of hits is registered or a timeout occurs.

d. Select calibration

As the BIN size varies with temperature and voltage the SSP1922 ALU can internally calibrate the results. This option is switched on by setting register 0, bit13, CALIBRATE = “1“. It is recommended to do this.
For the calibration the TDC measures 1 and 2 cycles of the reference clock. The two data are stored as Cal1 and Cal2.
There are two ways to update the calibration data Cal1 and Cal2:
Separate calibration by sending opcode Start_Cal_TDC via the SPI interface.
Automatic update by setting register 0, bit 12, NO_CAL_AUTO = “0“. In most applications this will be the preferred setting.

e. Define ALU data processing

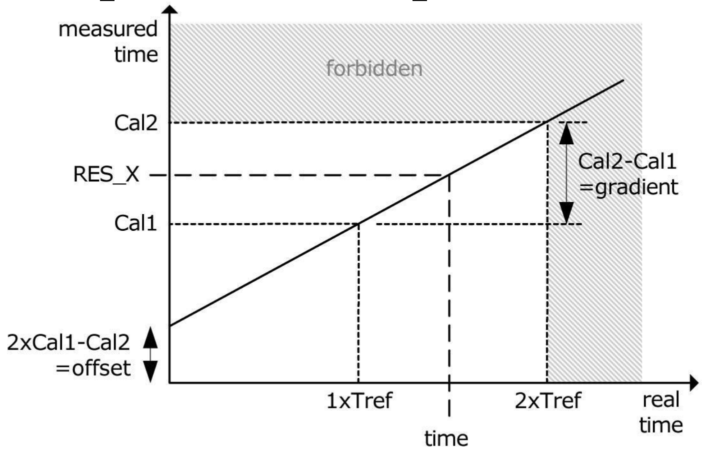
While the TDC unit can measure up to 4 hits on each channel the user is free in his definition what the ALU shall calculate. The settings are done in register 1, bits 16 to 19 and 20 to 23, HIT1 and HIT2. Both parameters can be set to:
0= Start
1= 1. Stop Ch1 9 = 1. Stop Ch2
2= 2. Stop Ch1 A = 2. Stop Ch2
3= 3. Stop Ch1 B = 3. Stop Ch2
4= 4. Stop Ch1 C = 4. Stop Ch2
6= Cal1 Ch1
7= Cal2 Ch1
The ALU calculates Hit1 - Hit2.

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

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

$$RES\_X = (HIT1-HIT2)/(Cal2-Cal1)$$
$$Cal2-Cal1 = gradient$$

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



f. Select input sensitivity

In register 2, bits 27 & 28, RFEDGE1 and RFEDGE2, the user can select whether the stop inputs are sensitive to either rising or falling edges (RFEDGE = "0") or to both rising and falling edges (RFEDGE = "1").
In register 0, bits 8 to 10 the user can add an internal inverter to ea ch input, Start, Stop1 and Stop2. With RFEDGE = "0" this is the same as rising edge (NEG_X = "0") or falling edge (NEG_X = "1").

g. Interrupt behavior

The interrupt pin 8, INT can have different sources. They are selected in register 2, bits 29 to 31, EN_INT and register 6, bit 21.

Reg 2 bit	29 = 1	ALU ready
Reg 2 bit	30 = 1	The set number of hits is there
Reg 2 bit	31 = 1	Timeout of the TDC unit
Reg 6 bit	21 = 1	End of EEPROM action

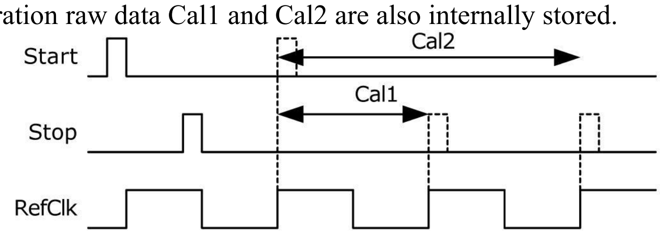
If two or more interrupt sources are required, the different options can be connected through the OR gate. This setup will be described further later.
After the configuration the user has to initialize the SSP1922 by sending opcode "Init" so that the TDC accepts Start and Stop hits.

7.2.2 Measurement

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

- the set number of hits has been seen (maximum 4 on both stop channels in mode 1)
- or until a timeout occurs at the end of the measurement range (at about 2 µs in mode 1).

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



7.2.3 Data Processing

At the end of the measurement the ALU starts to process the data according to the HIT1, HIT2 settings and transfers the result to the output register. In case calibration is off the ALU transfers the 16 bit raw data to the output register. With calibration the ALU calculates according to 3.1.1.d and transfers the 32 bit fixed point number to the output register.

The ALU can be switched off configuring HIT1 = HIT2 = 5.
The time it takes the ALU depends on whether calibration is on or not and the supply voltage.

	un-calibrated	calibrated
3.3V	t. b.d.	t. b.d.
2.5V	t. b.d.	t. b.d.

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

7.2.4 Reading Data

Now the user can read the data sending the opcode 10110ADR. With the next 16 clock cycles (un-calibrated data) or 32 clock cycles (calibrated data) the SSP1922 will send the result, beginning with the most significant bit (MSB). The first rising edge of SCK resets the INTN pin (interrupt).

a. Un-calibrated data format:

16 bit Signed integer in complements of 2.
1BIN = uncalibrated gate delay is about 75 ps at 3.3 V and 25℃.
Time = RES_X × 75 ps

b. Calibrated data format:

32 bit fixed-point number in complements of 2. Given in multiples of the reference clock.
Time = RES_X × T_{ref} × N, N = 1, 2 or 4

Example:
configuration
...
write reg1=’h014400 4 hits on channel 1
calculate 1st Stop -Start
...
Initialize
...
while(Check interrupt flag)
write reg1=’h024400 wait(4.6µs)
calculate 2nd -Start
Write reg1=’h034400 wait(4.6µs)
calculate 3rd-Start
write reg1=’h044400 wait(4.6µs)
calculate 4th-Start

Now all Hit data are available from registers 0 to 3. The load pointervalue is 4. .At the end the SSP1922 has to be initialized again to be ready for the next measurement. This is done by sending the opcode“Init“ so that the TDC accepts new Start and Stop hits.

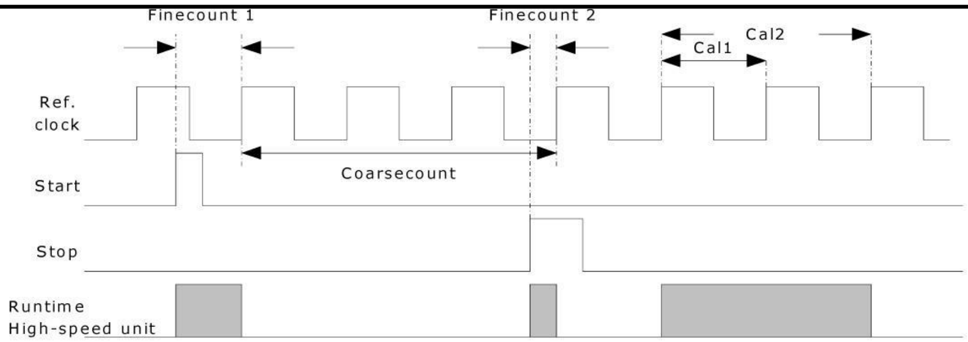
The measured time interval may not exceed：2 ×Tref× ClkHSDiv,
otherwise the ALU will go into overflow and will write the data hFFFFFFFF to the output register.
The configuration of the ALU allows only one hit calculation at the time. In case more than one hit has been measured it is necessary to write new commands to HIT1/HIT2 to instruct the ALU for calculating the other hits. After writing to HIT1/HIT2 it is necessary to wait for minimum t.b.d. µs (calibrated data) or t.b.d. ns (un-calibrated data) before reading or writing again to HIT1/HIT2.

8. Measurement mode 2

8.1 General Description

- 1 stop channels referring to one start channel
- Typical 19ps / 37ps / 75ps resolution
- Resolution of the interval pulse pair: 2 × Tref 到 4 ms @ 4MHz
- Measurement range from 2×T_{ref} to 4 ms @ 4 MHz
- 3-fold multihit capability, full-automated calculation
- Selectable rising/falling edge sensitivity
- Integrated programmable windowing for each single stop with 10 ns precision
- Typical application: Ultrasonic flow & heat meter

Digital TDCs use internal propagation delays of signals through gates to measure time intervals with very high precision (see also measurement mode 1, section 4). In measurement mode 2 the maximum time interval is extended using a pre-divider. The resolution in LSB remains unchanged by that. In this mode the high-speed unit of the TDC does not measure the whole time interval but only time intervals from START and STOP to the next rising edge of the reference clock (fine-counts). In between the fine-counts the TDC counts the number of periods of the reference clock (coarse-count).



time = Tref x (Cc + (Fc1 - Fc2)/(Cal2 - Cal1)

The SSP1922 converter front end section achieves a quantization BIN of 75 ps (LSB) where Vcc = 3.6 V and the ambient temperature is at 25 °C. RMS noise accounts for 50 ps (0.7 LSB) of this same result. As gate propagation delay is used for precision interval measurement it is important to consider that this delay time is directly affected by both Vcc and temperature. In Measurement mode 2 the measurement result is the sum of the exact measurement and the rough measurement.Therefore, using Measurement Mode 2, a calibration is required and is done automatically with the right configuration. During calibration the TDC measures one and two periods of the 4 MHz reference clock.

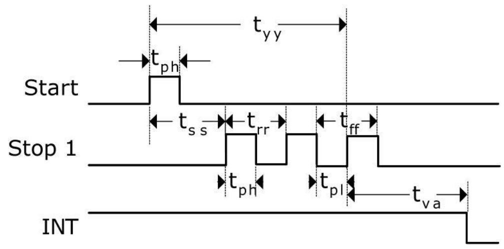
The calibrated result does not depend on temperature or supply voltage.

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

$$t_{yy} = T_{ref} \times 2^{14} \approx 4.1\text{ms} \ @\ 4\text{MHz}$$

The time interval between START and STOP is calculated with a 26 bit measurement range.

	Time (Condition)	Description
t_{ph}	2.5 ns (min.)	Minimum pulse width
t_{pl}	2.5 ns (min.)	Minimum pulse width
t_{ss}	$2\times T_{ref}$	Start to Stop @ Dis_Phasenoise=1
t_{rr}	$2\times T_{ref}$	Rising edge to rising edge
t_{ff}	$2\times T_{ref}$	Falling edge to falling edge
t_{va}	4.6µs(max)	ALU start to data valid
t_{yy}	4ms (max) @ 4MHz	Max. measurement range = $2^{14}\times$Tref

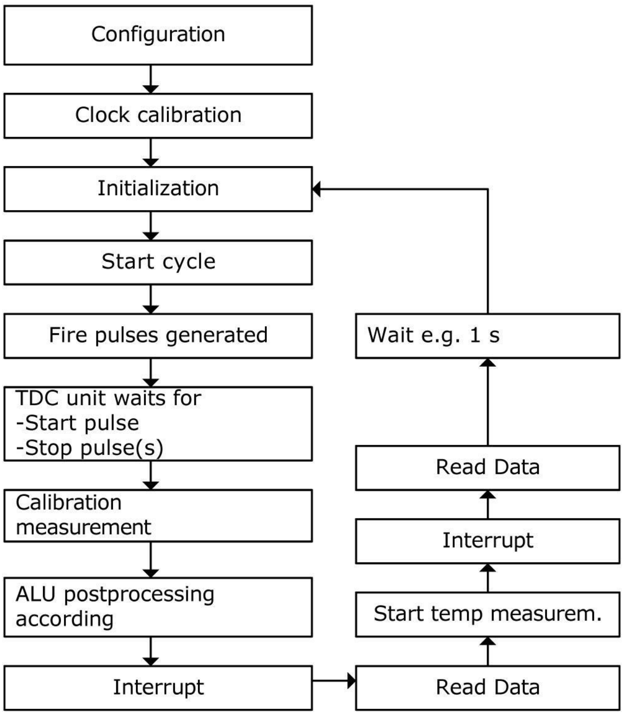


Each input separately can be set to be sensitive to rising or falling edge. This is done in register 0, bits 0 to 2. (NEG_START, NEG_STOP1). Further all Start/Stop-inputs support a high active enable pin.

Note:

In case the Start-Stop interval is less than the lower limit tzz the TDC will ignore more and more events the smaller it is. In no case there will be wrong results.

8.2 Measurement Flow



8.2.1 Configuration

At the beginning the SSP1922 has to be configured. The main settings for measurement mode 2 are:

a. Select measurement mode 2

Setting register 0, Bit11, MESSB2= 1。

b. Select the reference clock

In measurement mode 2 the SSP1922 needs the high-speed clock for the time measurement. In case of low-power applications this clock can be switched of in between measurements. The a 32.768 kHz clock is necessary for the timing control during the oscillator power-on.

Register 0, bits 18 & 19, START_CLKHS defines the switch-on behavior of the high-speed clock. If only the high-speed clock is used this is be set to “1“(continuously on). In case both oscillators are used for current saving reasons this should be set to “2“ for ceramic oscillators and to “3“ for quartz oscillators.

Register 0, Bits 20&21,DIV_CLKHS sets an additional internal divider for the reference clock (1, 2 or 4). The choice has an influence on the minimum time interval

the minimum time interval: $t = 2 \times T_{ref} \times 2^{ClkHDiv}$

the maximum time interval: $t = 2^{14} \times T_{ref} \times 2^{ClkHDiv}$

Further, it is necessary that: $2 \times Tref \times 2^{ClkHDiv} < 2.4\ \mu s$

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

Note:

The resulting clock after the predivider has to be in the allowed range of 2 MHz to 8 MHz in single and double resolution and from 2 MHz ... 6 MHz in quad resolution.

c. Set the number of expected hits

In register 1, bits 16 to 18, HITIN1 the user has to define the number of hits the SSP1922 has to wait for. A maximum of 3 on channel 1 is possible. The number HITIN1 always has to be higher by 1 than the number of expected hits. The reason is that the Start is also counted as a hit. The SSP1922 measures until the set number of hits is registered or a timeout occurs. register 0, bits 19 to 21, HITIN2 have to be set to “0“.

Example: 2 stop pulses are expected: HITIN1 = 3, HITIN2 = 0.

d. Select calibration

The calibration is switched on by setting register 0, bit13, CALIBRATE = “1“. It is mandatory to do this. For the calibration the TDC measures 1 and 2 cycles of the reference clock. The two data are stored as Cal1 and Cal2.

There are two ways to update the calibration data Cal1 and Cal2:

Separate calibration by sending opcode Start_Cal_TDC via the SPI interface

Automatic update by setting register 0, bit 12, NO_CAL_AUTO =0 In most applications this will be the preferred setting.

e. Define ALU data processing

With EN_AUTOCALC_MB2 = 1,the SSP1922 calculates all set hits automatically. In addition, the sum of the results is calculated, too, and written into read register RES_3. This simplifies the communication ,it is no longer necessary to re-write register 1.

With EN_AUTOCALC_MB2 disabled the ALU calculates only one hit at once. The settings are done in register 1, bits 24 to 27 and 28 to 31, HIT1 and HIT2. The Start pulse is internally handled like a Stop pulse because of the special measuring method in measurement mode 2.

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

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

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

The ALU calculates the time interval as:

$$RES\_X = CoarseCount + (HIT1-HIT2)/(Cal2-Cal1)$$

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

f. Select input sensitivity

In register 2, bits 27 & 28, RFEDGE1 and RFEDGE2, the user can select whether the stop inputs are sensitive to either rising or falling edges (RFEDGE = "0") or to both rising and falling edges (RFEDGE = "1"). In register 0, bits 8 to 10 the user can add an internal inverter to each input, Start, Stop1 and Stop2. With RFEDGE = "0" this is the same as rising edge (NEG_X = "0") or falling edge (NEG_X = "1").

g. Interrupt behavior

The INT pin（PIN8，INTN）can have various sources, to be selected in regi ster 2, bits 21 to 23, EN_INT, and register 6 bit 21 EN_INT.

EN_INT = no bits set no Interrupt source
reg2 Bit29 ALU ready
reg2 Bit30 The set number of hits is there
reg2 Bit31 Timeout of the TDC unit
reg6 Bit21 EEPROM action has finished

The different options are wired by OR. The first rising edge of SCK resets the INTN pin (interrupt).After the configuration the user has to initialize the SSP1922 by sending opcode "Init" so that the TDC accepts Start and Stop hits.

8.2.2 Measurement

After an initialization the TDC unit will start with the first pulse on the Start input. It will run until:
the set number of hits has been seen (maximum 3 on channel 1 in measurement mode 2)
or until a timeout occurs. The timeout can be programmed in multiples of the reference clock setting reg. 3, bits 27 & 28, SEL_TIMO_MB2. At 4 MHz the values are:

SEL_TIMO_MR2 (@ 4 MHz, ClkHSDiv = 0)
= 0 = 64 µs
= 1 = 256 µs
= 2 = 1024 µs
= 3 = 4096 µs

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

8.2.3 Data processing

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

The time it takes the ALU depends on the supply voltage to be calculated:

	1 pulse	2 pulse	3 pulse
3.3 V	t.b.d. µs		
2.5 V	t.b.d. µs		

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

8.2.4 Reading Data

Now the user can read the data sending the opcode 10110ADR. With the next 32 cycles (calibrated data) the SSP1922 will send the result, beginning with the main significant bit (MSB).

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

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

At the end the SSP1922 has to be initialized again to be ready for the next measurement. This is done by sending the opcode "Init" so that the TDC accepts new Start and Stop hits.

9. Functional Description

9.1 Stop Masking

The SSP1922 can set time-based masking windows for each of the 3 hits on Stop1 input when no hits are accepted. The masking refers to the start event and has an accuracy of less than 10 ns. The internal enable unit is connected to the external enable pin by a logical AND. The external enable pin must be set to "1" to use the internal masking unit.

The configuration settings are made in registers 4, DELVAL1, DELVAL2 and DELVAL3:

- DELVAL1,DELVAL2 and DELVAL3are fixed point numbers with 14 bit integer and 5 bit fractional digits, in multiples of the internal reference clock：

$$\text{Delay} = \text{DELVALX} / 2^5 \times \text{Tref} \times 2^{\text{ClkHSDiv}}$$

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

Example:
4 Mhz reference, ClkHSDiv = 1

DELVAL1 = 'h3200	1st Stop not accepted before 200 µs after Start ($128000/32 \times 250\text{ns} \times 2^1 = 200$ µs)
DELVAL2 = 'h3300	2nd Stop not accepted before 204 µs after Start ($13056/32 \times 250\text{ns} \times 2^1 = 204$ µs)
DELVAL1 = 'h3400	3rd Stop not accepted before 208 µs after Start ($13312/32 \times 250\text{ns} \times 2^1 = 208$ µs)

9.2 Analog Input Section

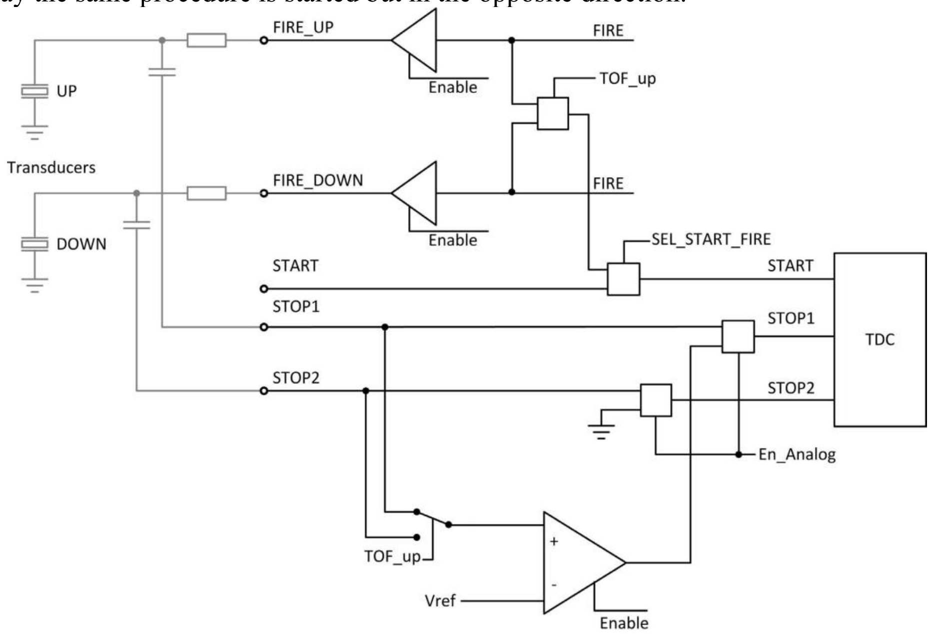
Relative to GP2, SSP1922 has an additional analog input section which can be used alternatively to the pure digital inputs. Especially the design of ultrasonic flow and heat meters is greatly simplified by this option. The external circuit of the ultrasonic part is reduced to just two resistors and capacitors additional to the piezo transducers.The ultrasonic signals will be 10-200 packages of sinusoidal oscillations with several 100mV amplitude. The signals are coupled to the inputs by means of a high pass filter as the comparator can not handle GND as threshold. The threshold of the comparator is set to 1/3 Vcc. An analog multiplexer selects the input according to the active measurement direction. The comparator is chopper stabilized to guarantee a low offset voltage in the range of < 2mV. This is mandatory for a good measurement quality. The input offset voltage of the comparator is frequently corrected by an internal chopper circuit. If temperature or supply voltage changes over time, the offset voltage is automatically adapted and holds at < 2mV.

All elements are controlled by the SSP1922 control unit. They are powered only during the measurement to keep down the power consumption.

A measurement sequence, triggered by command Start_TOF_Restart looks like the following procedure, starting with the up flow measurement:

- The 4 MHz oscillator is switched on. The chip waits for the programmed delay to give enough time for the oscillator to reach the full amplitude.
- The comparator, the reference voltage and the analog switches get powered.
- The capacitor of the transmitting path (STOP1) is connected to GND.
- The fire down buffer (FIRE_DOWN) is connected to GND.
- The capacitor of the receiving path (STOP2) is charged up to Vref. The TDC waits the delay set in TW2.
- The analog switch selects STOP2 input as input to the comparator.
- FIRE_UP is selected as TDC START signal.
- The set number of pulses is sent through the fire up buffer, pin FIRE_UP.
- The analog signal at STOP2 passes the comparator converted to a digital signal that is connected to the STOP input of the TDC unit.
- When the delay of the stop masking unit (DELVAL) expired the TDC is ready to measure. It can measure up to 3 stops.
- At the end of the measurement the control unit switches off the comparator, the reference the analog switches and the 4 MHz. The current is reduced to close zero. The interrupt flag is set.

- The control unit waits a period, given in multiples of 50Hz/60Hz. During this the processor has to read the results.
- After the delay the same procedure is started but in the opposite direction.



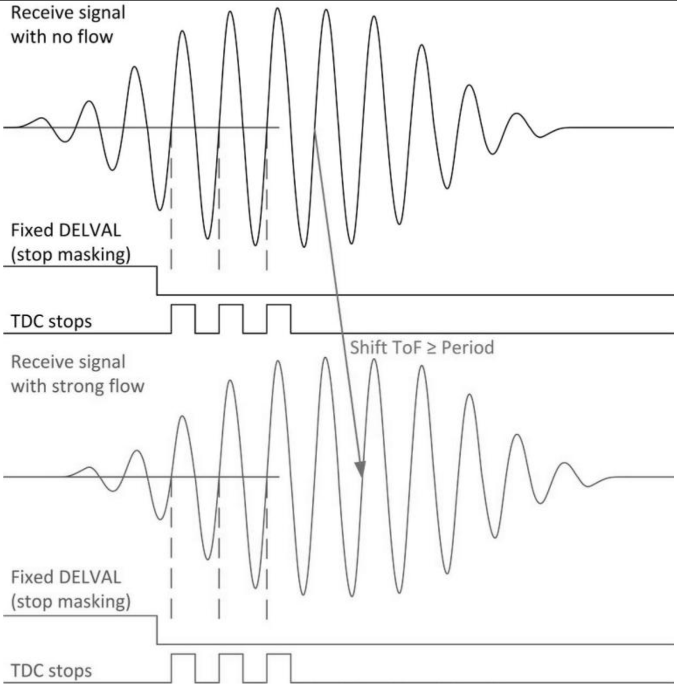
The offset of the comparator can be set in steps of 1mV from -8mV to +7mV by means of parameter DA_KORR, bits 25 to 28 in register 6. DA_KORR is set as 2‘s complement.
Additionally, with First Wave Mode an additional offset of ±35mV can be set for the first wave detection.

9.3 First Wave Mode

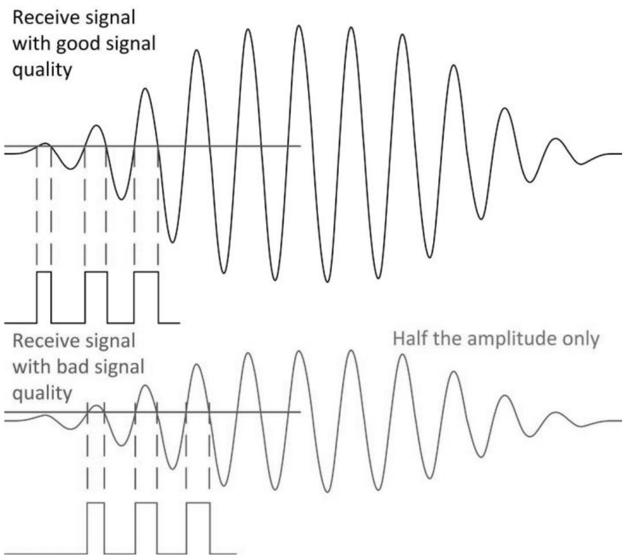
The major improvement of SSP1922 is the implementation of the First Wave Mode. It is based on measurement mode 2 with the analog section being used. The offset is controlled automatically to detect the first wave safely and to refer the final ToF measurement relative to the first wave. Additionally, the width of the first half wave is compared to the half wave of the first ToF measurement. The ratio can be used as indicator for the signal strength. Thanks to the offset noise are suppressed and a time out indicates no water in the tube. The following list summarizes the options :

- Save first wave detection, allows high dynamic applications like water meters
- Higher dynamics allow use of 2 MHz or 4 MHz transducers
- Even reverse flow can be handled (very helpful e.g. with water meters)
- Pulse width measurement, allows to analyze the strength of the receive signal and to track the trigger level or to send an alarm.
- Offset for noise suppression, allows to indicate an empty tube

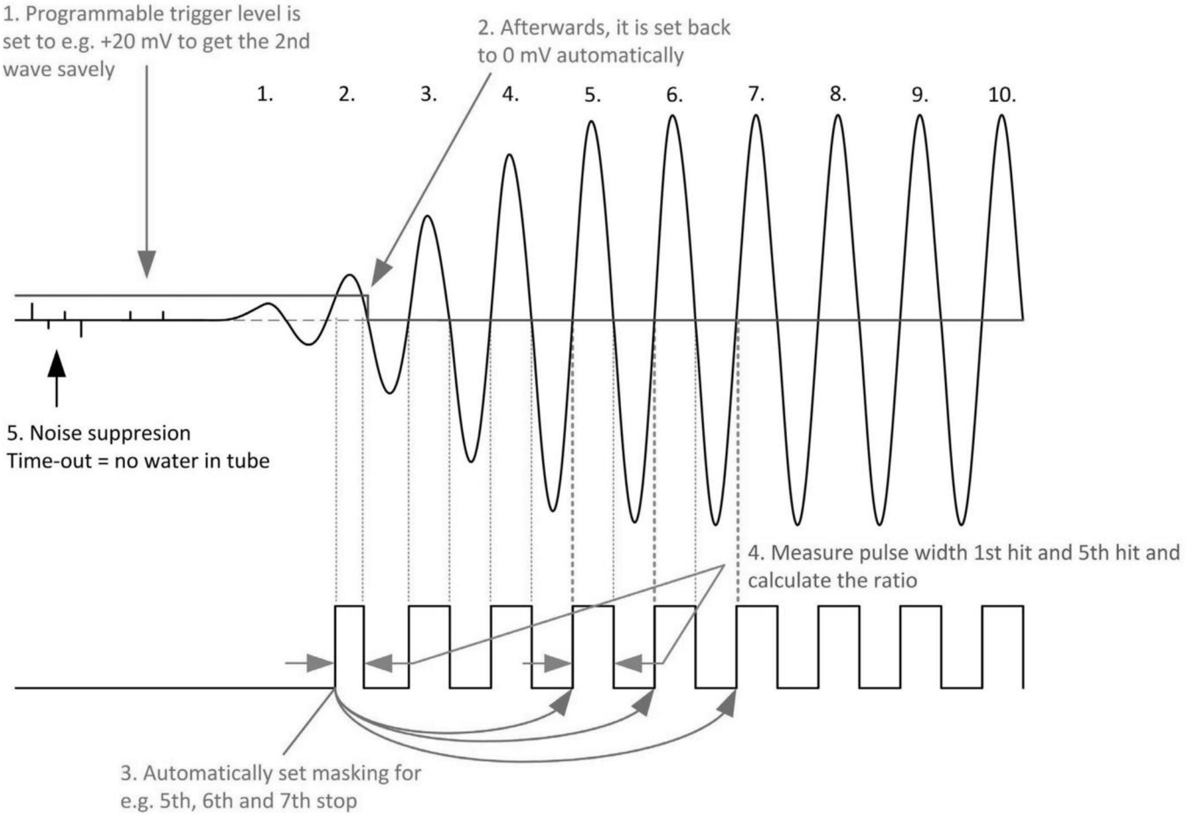
The figure below illustrates the importance of save first hit detection in flow meters with high dynamic range like water meters. With a fixed stop masking (fixed DELVAL values) it is not possible to recognize if the time-offlight changes more than the period of the sound signal. There are several reasons that the change in ToF is more than a period. An important one is the influence of temperature which changes the speed of ultrasound. For slow systems like heat meters this might be corrected by intelligent software. But for high dynamic systems like water meters with flow also in the opposite direction this method will no longer be appropriate.
The trend towards higher transducer frequencies like 2 MHz and 4 MHz is another reason for having a system that can handle intrinsically changes bigger than a signal period.



There is still another source of getting wrong measurements. Dirt deposition on the transducers, spool piece mirrors and housing will lead to signal damping e.g. from ±400mV to < ±80mV. The figure below shows how this will affect the first wave detection at a given, fixed offset for the first wave detection. Once the first wave amplitude is below the offset level the measurement result will jump by one period.



With the SSP1922's first wave detection the time-of-flight measurement is related to the first wave and gets independent from temperature and flow. Miscalculations due to wrong zero crossing assignment are no longer possible.
Additionally, the measurement of the width of the first half wave gives the user a chance to monitor the signal quality and to adjust the first wave offset trigger level if necessary.
The following figure shows the measurement flow in SSP1922 first wave mode.：



1. With the fire pulse generator the offset for the first wave detection is set to a programmable level. The DELVAL1 stop masking is used for surprising any noise and it is set just roughly close to the minimum expected time-of-flight. Further noise will be suppressed by the comparator offset until the receive signal reaches the amplitude above this offset level.
2. The SSP1922 measure the time interval between rising and falling edge of the first wave. Then, it automatically sets back the offset to 0mV. With < 1mV offset the offset drift of the flow measurement over temperature is minimized.
3. The stop masking for the three time measurements is set by parameters DELREL1 to DELREL3, relative to the first wave. E.g. DELREL1 = 3 says the 3rd wave after the first wave is measured.
4. The half wave period (hwp) of the first true time measurement is measured as a reference for the first wave. In the example from figure 4-12 this would be the width of the 5st wave.
5. The ratio hwpfirst wave/hwpfirstToF is in the range of “0” to “1”, typically less than “1”. The smaller the value the weaker is the receive signal. The information can be used to monitor the flow meter. If there are too many deposits over the years of operation and the signal ration drops e.g. below “0.5” then the second wave can be used as reference in the future.
6. SSP1922 automatically calculates all three stop event and further calculates the average of the three which will be available from register 4. This way, the communication with the microprocessor is simplified a lot. As soon as the interrupt is set the processor can immediately read all three results or just the average value. There is no need to rewrite register 1 like it was with GP2.
7. In case the spool piece is empty then there will be no stop signal. The offset w ill stay at the level for the first wave detection. This way, noise can not trigger the TDC and the TDC will run into a time-out. In other words: the timeout is an indicator for an empty tube.

First Wave Mode Configuration:

Reg	Bits	Parameter	Description
3	30	EN_FIRST_WAVE	1=Switches on the First Wave Mode, Reg3, DELVAL2 and Reg4, DELVAL3 get a new meaning.
4	8-12	OFFS	2’s complement number setting the offset shift in 1 mV steps 0 = 0 mV

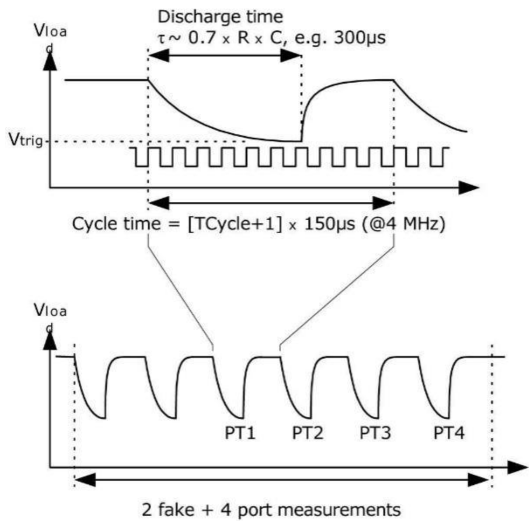
			1 = +1 mV ... 15 = +15 mV 16 = -16 mV 17 = -15 mV ... 31 = -1 mV
4	13	OFFSRNG1	1 = Additional offset shift by -20 mV
4	14	OFFSRNG2	1 = Additional offset shift by + 20 mV
3	8-25	DELREL1 DELREL2 DELREL3	Stop masking, select the xth wave for time-of-flight measurement. Maximum is the 63rd wave. DELREL1 ⩾3. DELREL1 to DELREL3 have to be set in ascending order. Example: DELREL1 = 3, DELREL2 = 4, DELREL3 = 5 means to measure 3rd, 4th and 5th wave after the first wave
4	16	DIS_PW	0 = switch on 1 = switch off pulse width measurement， The ratio can be read from address 8, register PW1ST as an 8 bit fixed point number with one integer bit (range 0 to 1.99)
4	15	EDGE_FW	0 = rising edge 1 = falling edge Sets the edge sensitivity for the first wave. With a negative offset it is reasonable to trigger on the falling edge of the first wave.
3	31	EN_AUTOCALC_MB2	1=switch on the automatic calculation of all enabled hits. The sum of the results is written to read measurement result 4 at read register address 3 (=RES_3).

9.4 Temperature Measurement

9.4.1 overview

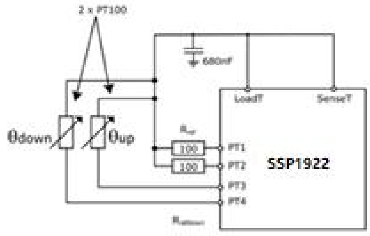
Especially for heat meter applications the SSP1922 has a PICOSTRAIN based temperature measuring unit that offers high resolution and very low current consumption.

The measurement is based on measuring discharge times. Therefore, a capacitor is discharged alternately through the sense resistors and the reference resistors. As an improvement compared to GP2, the SSP1922 has the comparator already integrated.

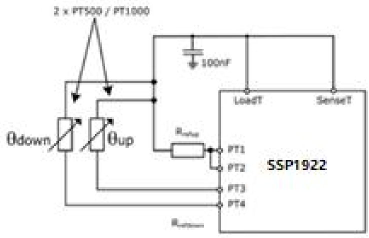


The unit has 4 resistor ports, two of them to be used for the temperature sensors for hot water (up) and cold water (down). The other two ports are used for reference resistors. Basically, on reference resistor connected to both ports is sufficient.

The temperature sensors should have a minimum resistance of 500 Ohm. The cable length should not exceed 3 m. SSP1922 can measure 2-wire sensors only. It is not possible to use 4-wire sensors. The precision of the temperature measurement is far within the limits of the standard for heat meters when PT500 or PT1000 are used. In combination with PT500 or PT1000 temperature sensors there is no need for two reference resistors. A typical setup with one fixed reference is shown in the right figure.



SSP1922 also supports the measurement of PT100 sensor, but the measurement stability will be reduced. In THIS CASE, WE RECOMMEND CONNECTING BOTH REFERENCE resist ORS RATHER THAN JUST ONE. As shown on the right. This will help to compensate the gain offset of the temperature sensor in the whole temperature range by the two point temperature accuracy.



The temperature measurement is fully automated. It is triggered by the µC sending the opcodes Start_Temp or Start_Temp_Restart. With Start_Temp_Restart the SSP1922 measures the temperature twice, with a delay given in multiples of the 50 Hz/60 Hz period. This will be of help to reduce 50Hz/60Hz noise.
For a measurement, the SSP1922 starts with 2 or 8 dummy measurements at port PT1 before it makes the real four measurements in the order PT1 > PT2 > PT3 > PT4. After the 4 measurements have finished the interrupt flag is set. SSP1922 has the possibility to inverse the order, making the dummy measurements at port PT4.
The four data are found in registers 0 to 3. From Res_2/RES_1 and RES_3/RES_4 the micro-controller can calculate the ratio Rtemp/Rref. By means of a look-up table it can calculate the temperature for the special type of sensor in use.

9.4.2 Related Configuration Registers Description

- Register 0, bit 15, ANZ_FAKE sets the number of dummy measurements at the beginning of a temperature measurement. This is necessary to overcome mechanical effects of the load capacitor.
  ANZ_FAKE = 0 2 dummy measurements
  ANZ_FAKE = 1 8 dummy measurements
  Register 0, bit 16, TCYCLE sets the cycle time for the temperature measurement.
  TCYCLE = 0 128 µs cycle time @ 4MHz
  TCYCLE = 1 512 µs cycle time @ 4MHz
- Register 0, bit 17, ANZ_PORT sets the number of ports that will be used.
  ANZ_PORT = 0 2 ports = 1 sensor
  ANZ_PORT = 1 4 ports = 2 sensors
- Register 6, bit 11, TEMP_PORTDIR sets the order of the port measurements
  TEMP_PORTDIR = 0 PT1 > PT2 > PT3 > PT4
  TEMP_PORTDIR = 1 PT4 > PT3 > PT2 > PT1
- Register 6, bit 5, HZ60 sets the base frequency for the delay between the up and down measurements for commands Start_TOF_Restart and Start_Temp_Restart.
  HZ60 = 0 50 Hz base
  HZ60 = 1 60 Hz base
- Register 6, bits 18, 19, CYCLE_TEMP, selects the factor timer for triggering the second temperature measurement in multiples of 50/60Hz.
  CYCLE_TEMP = 0 1
  = 1 1.5

= 2   2
= 3   2.5

- Register 6, bit 30, NEG_STOP_TEMP inverts this signal at the SenseT path. This is mandatory when the internal comparator is used. Without inversion the unit is compatible to GP2 operation with an external Schmitt trigger
  NEG_STOP_TEMP = 0   No inversion, GP2 compatible
  = 1   Inversion, mandatory when the internal comparator is used

9.4.3 Recommended Capacitor Values

To get accurate results we recommend capacitor types with very low dC/dU. We recommend:C0G types.
The discharge time should be about 150 µs. Therefore the capacitor should have the following value:
PT500: 220 nF
PT1000: 100 nF
Please set TCYCLE = 1 to avoid timeout error.
In the application of heat meter, please do not use X7R or similar capacitors.

9.4.4 Current consumption

By means of the TDC technology the temperature measurement needs an extremely low current, much less than an A/D converter does.
A full temperature measurement with 2 sensors, 2 references am PT1000 sensor type, including all calculations takes less than 2.5 µAs. With one temperature measurement in 30 seconds (typical for heat meters) the average current consumption is 0.08 µA only. This is about 50 times less than other solutions. A PT500 sensor doubles the current.

9.4.5 Error detection

Additionally the temperature unit checks the plausibility of the results. It is able to detect a short circuit of the sensor or an open sensor. SSP1922 then places the status register at position 1, 11 or 12, and writes an error code to the corresponding result register.

- Short circuit between lines: equivalent to a very short time interval (< 8×Tref = 2 µs @ 4 MHz). The SSP1922 writes a 0x0 to the output register of the shorted sensor.
- Broken sensor/Short circuit against GND: equivalent to no stop signal or timeout. The SSP1922 writes a 0xFFFFFFFF into the output register of the open sensor.

Note: Due to a bug it is necessary to have SEL_TIMO_MB2 at 2ms to get a correct interrupt indication when 512 µs cycle time is selected.

9.4.6 Gain error and its mathematical correction

The SSP1922 temperature measurement is based on the resistance variation of an RTD is digitized by means of a high accurate time interval measurement. According to that, the Schmitt trigger's delay time introduces a considerable gain error that results in a gain reduction compared to an ideal output value. This gain reduction can be mathematically described as a deviation from an ideal straight line. Hence, a simple mathematical correction by adding a correction factor compensates for this deviation from the ideal gain. It is calculated as follows:
$T_{corr} = T_{uncorr}/gainfactor$
T_{corr}:gain corrected temperature result；
T_{uncorr}:uncorrected temperature result；
gainfactor:gain correction factor, compensates the deviation from an ideal gain of 1
By means of this compensation, the effect of the Schmitt trigger’s delay time can be reduced to a residual gain error of 0.05 % of F. S. with the internal Schmitt trigger, or even less in combination with an external 74AHC14 Schmitt trigger.
Three main parameters have to be considered, to select the correct gain factor:

- base resistance of the temperature sensor (e.g. PT500, PT1000)
- used Schmitt trigger (SSP1922 -internal, external 74AHC14)
- SSP1922 supply voltage

Corresponding correction factors are provided in the previous table. Note：
The gain correction factors for the external Schmitt trigger exclusively refer to the 74AHC14 Schmitt trigger.

Other types (e.g. 74HC14) require different gain factors, in order to ensure a correct compensation. According to that, we strongly recommend to use a 74AHC14 as external Schmitt trigger.

Example 1：

Application with PT1000 Sensor, SSP1922 internal Schmitt trigger and 3.0 V supply voltage. According to the front table a gain factor of 0.9931 has to be selected. The gain corrected result is calculated then by the following equation：

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

Example 2：

Application with PT500 Sensor, external 74AHC14 Schmitt trigger and 3.6 V supply voltage. A gain factor of 0.9962. The gain corrected result is calculated as follows：

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

9.5 oscillator

The SSP1922 uses up to 2 clock signals depending on the operating mode：

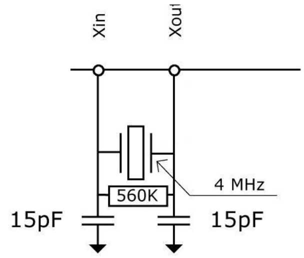
- High-speed clock, for calibration and as a predivider for the TDC measuring unit in measurement mode 2and for the EEPROM
- 32 kHz clock signal used for internal timer functions.

9.5.1 High-Speed Oscillator

Generally, the SSP1922 needs a high-speed clock for calibration. The recommend value is 4 MHz, the possible range is 2 to 8 MHz (2 to 6 MHz in QUAD_RES mode). When running in measurement mode 2 the SSP1922 needs the high-speed clock signal also as a part of the time measuring unit. Finally the operations need the high speed clock, too.

The oscillator takes an average current of 260 µA when running all the time. But as it is needed only during the time measurement, the SSP1922 has the capability to control the on-time by itself. The settings are done with parameter START_CLKHS. With START_CLKHS > 1 the oscillator is switched on after sending opcodes Start_TOF, Start_TOF_Restart, Start_Temp and Start_Temp_Restart for the duration of the measurement. A delay between starting the oscillator and starting the measurement guarantees sufficient time for the oscillation to settle at full amplitude.

START_CLKHS = 0 Oscillator off
= 1 Oscillator continuously on
= 2 The measurement is started with 480 µs delay.
= 3 The measurement is started with 1.46 ms delay.
= 4 The measurement is started with 2.44 ms delay.
= 5 to 7 The measurement is started with 5.14 ms delay.



The programmable delay guarantees that the oscillator has settled before the measurement starts. For ceramic resonators 480 µs will be sufficient. By this measure the average current consumption can be drastically reduced.

Example:

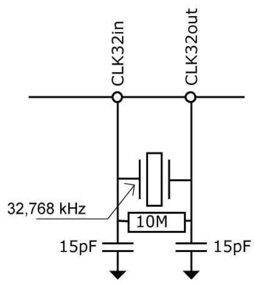
At one ToF measurement in an ultrasonic flow meter (forth/back) per second the highspeed oscillator is active only for about 2 ms.

The average current consumption is 260 µA/s × 2 ms = 0.52 µA。

9.5.2 32.768KHz Oscillator

The SSP1922 needs a 32.768 kHz reference for the start-up control of the high-speed clock and the clock calibration. It therefore offers an integrated low-power driver.

The 32.768 kHz oscillator is permanently running and has a current consumption of only about 0.5 µA at 3.0 V.



The settling time of this oscillator is about 3 s after power-up. The 32.768 kHz oscillator cannot be switched off.

With an external 32 kHz clock from the microprocessor pin CLK32in has to be connected to GND.
The low-power clock can be internally forwarded to an output pin to be available for an external microprocessor.
The possible settings are：
SEL_TSTO1 = 7: 32 kHz output at pin FIRE_IN
SEL_TSTO2 = 7: 4 kHz (32kHz/8) output at pin EN_START
It is also possible to provide an external low-frequency rectangular clock at the CLK32Out pin (3.6 V max.).

9.5.3 Calibrating a Ceramic High-speed Oscillator

Using a ceramic oscillator for the 2 to 8 MHz clock will be attractive because it is of low cost and has a fast settling time. Unfortunately it has a poor tolerance of 0.3 to 0.5 % and shows a temperature drift. For this reason the SSP1922 allows to execute a calibration measurement that allows to compensate this behavior. This measurement is based on the very precise 32.768 kHz clock. The SSP1922 generates start/stop pulses from the 32.768 kHz and measures this time interval with its TDC unit. The result is stored in the result register and the interrupt flag is set. The frequency error of the ceramic resonator can be calculated by the microprocessor.
The calibration is configured by setting register 0,bit 23 and 22, ANZ_PER_CALRES and is started with “START_Cal_Resonator“ - instruction by the microprocessor.
Example：
The system shall work with a 4 MHz resonator. With CLKHSDIV = 0 and ANZ_PER_CALRES = 1 the theoretical result is 122.0703125µs/250ns = 488.28125 (RES_0 = ’h01E84800). If the ceramic resonator in use is not exactly at 4 MHz but only 3.98 MHz the calibration measurement will show 485,83984375 (RES_0 = 1E5D700). The correction factor for the microcontroller is 1.005.
Note: During clock calibration the start input has to be enabled.

9.5.4 How to use Clock Calibration

- Application

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

- Jitter of the 32 kHz clock and consequences

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

- Application of this option in ultrasonic flow meters

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

9.6 Fire Pulse Generator

9.6.1 General Description

The fire pulse generator generates a sequence of pulses which is highly programmable in frequency, phase and number of pulses. The high-speed oscillator frequency divided by the factor selected for DIV_CLKHS is used as the basic frequency. This frequency is internally doubled and can freely be divided by a factor of 2 to 15. It is possible to generate 1 to 127 pulses. If maximum 15 pulses are sent the phase for each pulse can be adjusted per register configuration. The fire pulse generator is activated by sending opcode Start_Cycle. The fire pulse maybe used directly for the START of the TDC.
The fire pulse generator provides 2 outputs, FIRE_UP and FIRE_DOWN. The driver strength of each output is 96mA @ 3.3 V. Furthermore, FIRE_DOWN output signal can be inverted to double the signal amplitude. The outputs can be set individually High-Z. Alternately, the default level of the inactive buffer can be set to GND.

The trigger pulse generator can also be used in a similar way to the sing-around to generate and transmit pulse trains several times. With this feature, the received pulse train is sent to the FIRE_IN input port of SSP1922 and then digitally amplified and directly sent to the output buffer for clock synchronization output. You cannot use the sing-around method when applying the simulation part.

9.6.2 Configuration of relevant registers

Number of pulses：

ANZ_FIRE =0 Switch off fire pulse generator
=1 1 pulse
=2 2 pulses
… …
=127 127 pulses

SEL_START_FIRE = 1 Fire pulse is used as TDC START

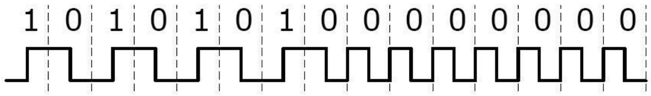
FIREO_DEF = 0 Default level High_Z
= 1 Default level GND. Mandatory if the internal analog circuit and the recommended circuit with external R and C is used.

Phase：

The phase of each pulse can be defined in register 5, PHFIRE[0..14], (Mandatory: PHFIRE[15] = 0), if not more than 15 pulses are sent. “0“ stands for HIGH-LOW and “1“ for LOW-HIGH. The pulse sequence begins with the LSB and ends with the MSB .

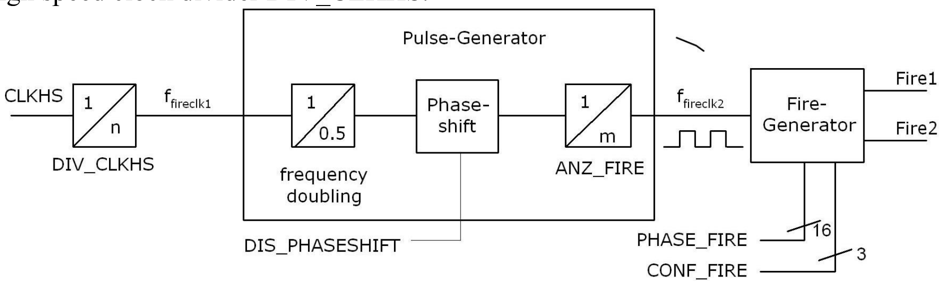
Example：

ANZ_FIRE = 7, PHFIRE = 0x0055



Fire pulse frequency:

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



This Signal is internally doubled and divided by DIV_FIRE.

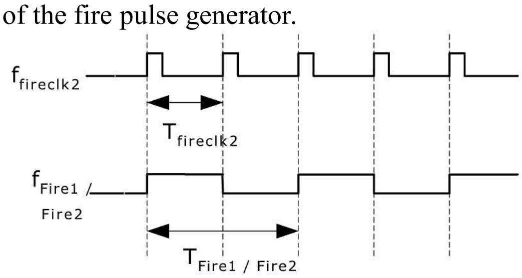
DIV_FIRE = 0 not permitted
=1 divided by 2
... ...
=15 divided by 16

Register 5, bit 27（DIS_PHASESHIFT）actives the phase shift, which introduces additional noise to improve statistical behavior when averaging.

DIS_PHASESHIFT = 0 Phase shift on
DIS_PHASESHIFT = 1 Phase shift off

$$f_{fireclk2} = f_{fireclk1} \times 2/(DIV\_FIRE+1)$$

ffireclk2 is used as reference signal for the FIRE_UP / FIRE_DOWN - signal which is emitted by the output buffers FIRE_UP / FIRE_DOWN of the fire pulse generator.



As shown in Figure above at least 2 clock periods $T_{fireclk2}$ are required to send one fire pulse. One for the high

phase and one for the low phase of the FIRE_UP/FIRE_DOWN output signal.
Example：
CLKHS = 4 MHz, DIV_CLKHS = 1, DIV_FIRE = 1

$$f_{fireclk2} = f_{fireclk1} \times 2/(DIV\_FIRE+1) = 2MHz$$

Max. frequency of the FIRE_UP / FIRE_DOWN output signa:

$$f_{fire/fire2} = 1/2 \times f_{fireclk2} = 1MHz$$

Driver outputs：
The output drivers are configured by setting CONF_FIRE in register 5, bits 29 to 31：

Bit 31 = 1 FIRE_BOTH (the FIRE_DOWN output is an inverted representation of FIRE_UP.)
Bit 30 = 1 Enable FIRE_UP output only
Bit 29 = 2 Enable FIRE_DOWN output only

Pulse group cycle（Sing-around）:
register 5 , Bits 24－26（REPEAT_FIRE）can set the number of cycles of the pulse train ：

REPEAT_FIRE	=	0	no cycle
	=	1	1 cycle
	...	...	
	=	7	7 cycles

SSP1922 repeats only the number of pulses set in ANZ_FIRE. If no pulse is received within 5µs, SSP1922 detects the last pulse in the pulse train.
Note：
This feature cannot be used when the internal simulation section is applied. It must be noted that the total time of 7 cycles does not exceed the measurement range of SSP1922.

9.7 Fast Initialization

In measurement mode 1 the SSP1922 offers the possibility of a fast initialization. Activated by setting register 1, bit 23, EN_FAST_INIT = “1“ the interrupt flag automatically initializes the TDC. So the TDC is already prepared for the next measurement while the data can be read out. This mode is for highest speed applications only. It is most reasonable for un-calibrated measurements with only one stop.

9.8 Noise Unit

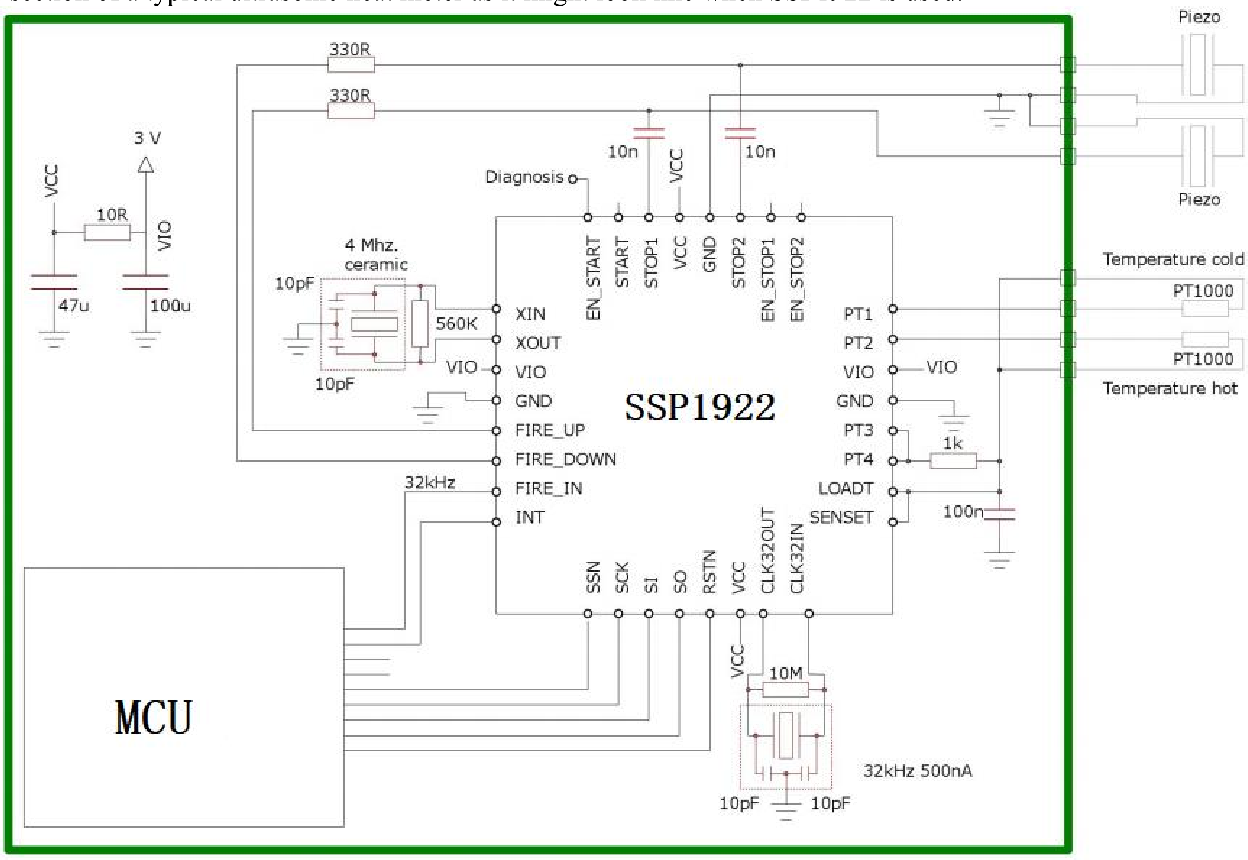
In case the user wants to improve the measuring results by averaging it is necessary that the values do not always display exactly the same time difference. Instead the user should provide some “noise” so that different quantization steps of the characteristic curve of the TDC are involved. This can not happen with very constant time differences. One would constantly hit the same LSB.
The noise unit enables the use of weighted averaging even for constant time differences. The noise unit adds a random offset to the start. It is dedicated to applications where the TDC gets a dummy start and measures the time difference between STOP1 and STOP2 (e.g. laser range finders).
The noise unit is switched on by setting register 5, bit 20, EN_STARTNOISE = “1“

10. Typical application of Ultrasonic Heat meter

10.1 summary

The SSP1922 is perfectly suited for low-cost ultrasonic heat meter designs. Thanks to the implemented functionality, including precision temperature measurement, fire pulse generator, analog switches, comparator, windowing and clock calibration, it is sufficient to add a simple microprocessor (without A/D converter).

The final circuit reaches a unknown level in compactness and small size. The following diagram shows the front end section of a typical ultrasonic heat meter as it might look like when SSP1922 is used.



The number is reduced to a minimum:

- In the ultrasonic path, the piezo transducers are connected through pairs of R and C.
- In the temperature path only a temperature stable reference resistor and a capacitor
- As oscillators take a 32.768 kHz and a ceramic 4 MHz oscillator. The FIRE_IN pin can be used as output driver for the 32.768 kHz clock, so the µP does not need a low power oscillator
- For the power supply use separate bypass capacitors of sufficient size to block Vcc and Vio. Separate both by a small resistor.

In total 11 low-cost elements only are needed for the measurement.

10.2 Typical configuration of registers

Register	Value	Typical example configuration
0	hA30B6800	ANZ_FIRE = 10 (see register 6, too)。 DIV_FIRE = 3, fire pulse frequency = 4 MHz/4 = 1.0 MHz。 ANZ_PER_CALRES = 0, the 4MHz is calibrated by a 61.035 µs measurement DIV_CLKHS = 0, the 4 MHz ceramic oscillator is internally used as it is START_CLKHS = 2, the ceramic oscillator has 480 µs to settle ANZ_PORT = 1, use all 4 ports for the temperature measurement TCYCLE = 1, 512 µs cycle time for the temperature measurement ANZ_FAKE = 0, 2 fake measurements SEL_ECLK_TMP = 1, use 4 MHz for the temperature measurement cycle definition CALIBRATE = 1, mandatory in measurement mode 2 to be on NO_CAL_AUTO = 0, mandatory in measurement mode 2 to have autocalibration MESSB2 = 1, switch on measurement mode 2 for measuring > 2 µs. NEG_STOP/NEGSTART = 0, all set to rising edges Note: If Start_TOF is used, advised to set START_CLKHS=1 and close the test after the test is complete
1	h21444000	HIT2 = 2, HIT1 = 1: calculate 1. Stop - Start in measurement mode 2 EN_FAST_Init = 0, off HITIN2 = 0 HITIN1 = 4, measure 3 stops (in measurement mode 2 this includes the start, too, giving 4 hits) CURR32K = 0, use default SEL_START_FIRE = 1, use the internal direct wiring from the fire pulse buffer to the TDC start SEL_TSTO2 = 0, EN_START active SEL_TSTO1 = 0, FIRE_IN pin is used as fire in Note: With this setting, the Fire_in and EN_Start pins cannot be un-connected.
2	hA0230000	EN_INT = b0101,Interrupts are given when an ALU calculation ends or an EEPROM action ends (see also Register 6). RFEDGE1 = RFEDGE2 = 0, use only rising edges DELVAL1 = 8960, the first stop is accepted after 70 µs Note: Users can set DELVAL1 value (i.e. shielding time) according to the actual echo signal.
3	hD0510300	EN_AUTOCALC = 1, All 3 pulses are calculated automatically. EN_FIRST_WAVE = 1, Enable the first wave detection mechanism. EN_ERR_VAL = 0, When time overflows, write 0xffffffff to the result register SEL_TIMO_MB2 = 2 , Overflow if no signal is received at 1024 µs after START pulse. DELREL1 = 3, DELREL2 = 4, DELREL3 = 5, measure the 3rd, 4th and 5th stop after the first hit Note: Users can set the number of STOP pulses to be received according to the strongest wave after the first wave.
4	h20004A00	DIS_PW = 0, pulse width measurement is not disabled EDGE_PW = 0, pulse width measured on rising edge OFFSRNG2 = 0, no negative offset OFFSRNG1 = 0, OFFS = 10: total offset = 20mV + 10mV = 30mV Note: The offset value can be adjusted according to the strength of the echo signal
5	h50000000	CON_FIRE = 2, close FIRE_UP, FIRE_DOWN = enable 。 If opcode Start_TOF_Restart is used FIRE_UP and FIRE_DOWN are used alternately for up and down flow measurements.The register setup described here starts a downstream measurement loop (FIRE_DOWN = switch on)。 EN_STARTNOISE = 0, Switch off. DIS_PHASESHIFT = 0, phase noise unit is active to improve the statistical behavior REPEAT_FIRE = 0, no sing-around

		PHASE_FIRE = 0, no phase change in the fire pulse sequence Note: If Start_TOF is used, you need to set CON_FIRE=1 again for the second test
6	hC0C06000	EN_ANALOG = 1, use the internal analog circuit NEG_STOP_TEMP = 1, use the internal Schmitt trigger for the temperature measurement DA_KORR=0, offset is set in register 4 TW2 = 3, 300 µs delay to charge up the capacitors of the highpass EN_INT = b0101, Interrupts are given by time_out, ALU ready or end of EEPROM action (see also Register 6). START_CLKHS = 2, the ceramic oscillator has 480 µs to settle (see also register 0) CYCLE_TEMP = 2, use factor 1.0 for the Start_Temp_Restart CYCLE_TOF = 2, use factor 1.0 for the delay between two ToF measurements HZ60 = 0, 50 Hz base FIREO_DEF = 1,When using internal analog circuits, QUAD_RES = 1 must be turned on and 17 ps resolution applied. DOUBLE_RES = 0 TEMP_PORTDIR = 0, standard order for T measurement ANZ_FIRE = 10 (see register 0, too) Note: CYCLE_TOF=0, HZ60=0 when the Start_TOF_Restart opcode is used; At this time, the interval between the two flights (upstream and downstream) was the shortest 16.67ms; When the Start_Temp_Restart opcode is used, CYCLE_TEMP=0, HZ60=0, and the interval between two temperature measurements is at least16.67ms.

10.3 Measurement flow

Power-on reset：
Send SO = ’ h50
Calibrate Clock:
Send SO = ’ h03 Start_Cal_Resonator
Check-loop INTN = 0 ?
Send SO = ’ hB0,Read SI = RES_0
Correction factor = 61.035/RES_0
Measurement loop：
Temperature measurement, every 30 seconds:
Send SO = ’ h02 Start_Temp
Check-loop INTN = 0 ?
Send SO = ’ hB4, Read SI = STAT
STAT&’ h1E00 > 0: -> Error routine
Send SO = ’ hB0, Read SI = RES_0
Send SO = ’ hB1, Read SI = RES_1
Send SO = ’ hB2, Read SI = RES_2
Send SO = ’ hB3, Read SI = RES_3
Rhot/Rref = RES_0/RES_1
Rcold/Rref = RES_3/RES_2
Go to look-up table to get the temperature.
Time-of-flight measurement every half second:
Send SO = ’ h70 Initialize TDC
Send SO = ’ h05 Start_TOF_Restart
Check-loop INTN = 0? (TOF_UP)
Send SO = ’ hB4, Read SI = STAT
STAT&’ h0600 > 0: -> Error routine,
timeout = empty tube
Send SO = ’ hB3, Read SI = RES_3
Send SO = ’ h70 Initialize TDC

Check-loop INTN = 0? (TOF_DOWN)
Send SO = ’hB4, Read SI = STAT
STAT&’h0600 > 0: -> Error routine
Send SO = ’hB3, Read SI = RES_3
µP can now start the data post-processing and calculate the flow and the heat.
Check signal strength via pulse width:
Send SO = ’hB8, Read SI = PW1ST
If PW1ST < 0.3 signal is too weak, alarm

10.4 Bug Report

TDC-CAL read error without Quad resolution

In case quad resolution is not set then reading separately the TDC-CAL value will give a wrong read value. The internal calibration value is correct, but the transfer to the read register is not correct. Therefore, measurement data are not affected. The problem is only when the CAL calibration value is read.

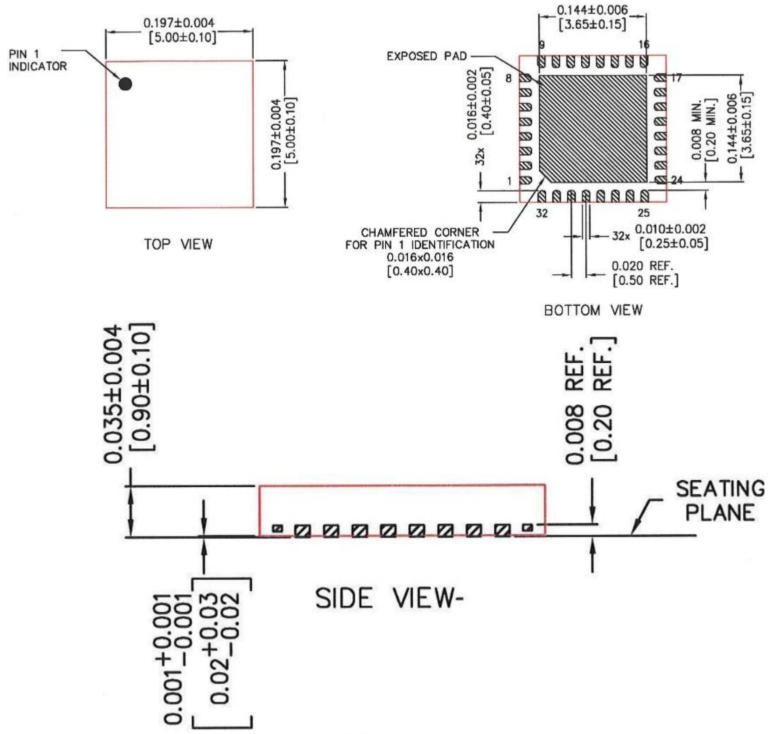
Effect in Measurement mode 2：
In this mode the cal value is for information only. Further, quad resolution is recommended anyway.
Effect in Measurement mode 1：
Customers using auto calibration are not affected.
This CAL value is not available only if the user applies uncalibrated measurements in the case of Measurement mode 1, and the CAL number is read out externally, whereas manual TDC calibration is performed. (Ultrasonic heat meter, water meter and other applications are not involved).

Workaround：
There are different solutions to this error, among which the best method is:
After manual calibration, the user can not read the calibration result directly. Instead, the calibration result can be stored in the TDC, and the ALU will automatically use the previous calibration result for calculation when future measurement is performed. In this way, it has no effect on the final result.

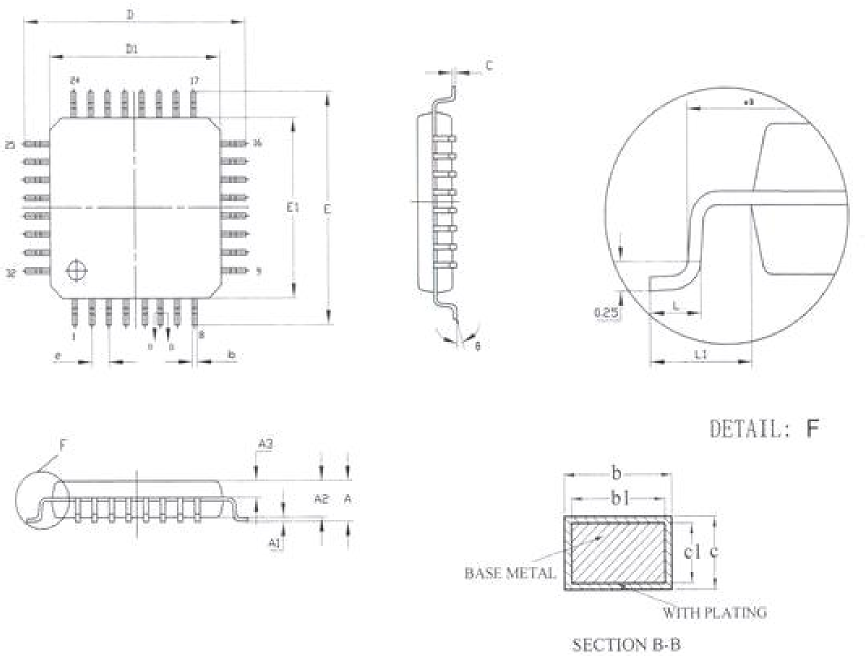
Timeout Temperature Measurement
To avoid this error, SEL_TIMO_MB2 in bits 27 and 28 of register 3 needs to be set to 2ms when the cycle time of temperature measurement is 512µs (16-bit TCYCLE of register 0), otherwise the interrupt coming out of the INTN pin may have an error.

11. Package Information

11.1 QFN32



11.2 LQFP32



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

11.3 Note

QFN-32 package outline, 5× 5 × 0.9 mm^3 , 0.5 mm lead pitch

Caution:

Center pad, 3.65 * 3.65 mm^2, is internally connected to GND. No wires other than GND are allowed underneath. It is not necessary to connect the center pad to GND.

Suitable Socket: Plastronics 32QN50S15050D

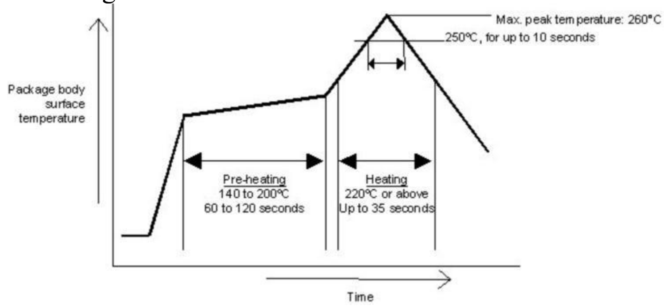
Thermal resistance: Roughly 28 K/W (value just for reference)。

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

Moisture Sensitive Level (MSL)：Based on JEDEC 020 Moisture Sensitivity Level definition the SSP1922 is classified as MSL 3.

Soldering Temperature Profile

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



Maximum temperature

The maximum temperature requirement for the resin surface, given 260ºC as the peak temperature of the package body's surface, is that the resin surface temperature must not exceed 250ºC for more than 10 seconds. This temperature should be kept as low as possible to reduce the load caused by thermal stress on the package, which is why soldering for short periods only is recommended. In addition to using a suitable temperature profile, we also recommend that you check carefully to confirm good soldering results.

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

MOS circuit operation precautions：

Static electricity will be generated in many places. Taking the following precautions can effectively prevent MOS circuit damage caused by electrostatic discharge：

- Operators shall be grounded through anti-static wrist strap.
- The device shell must be grounded.
- Tools used in the assembly process must be grounded.
- It must be packed or transported in conductor packing or antistatic material.

Version Change Description

Version：V1.0 Author：Xinchun Li Time：2021.09.09

Modify the record：

1. Re-typesetting the manual
2. Modify some data

Version：V1.1 Author：Xinchun Li Time：2023.08.23

Modify the record：

1. Modify some data

Statement

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