High-precision time-distance measurement (TDC) circuits

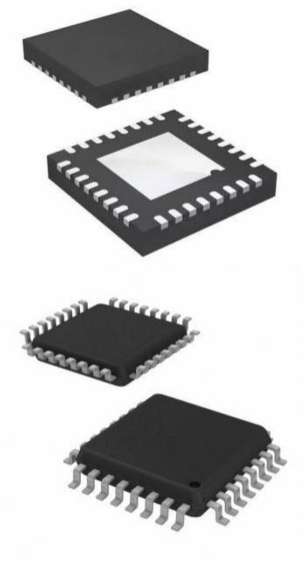
Description

- SL1922 is a high-precision Time-to-Digital Converter (TDC) circuit. Internally, it integrates analog comparators, analog switches, Schmitt triggers, and other devices, thereby significantly simplifying external circuitry.

- Additionally, it includes a first wave detection function internally, greatly enhancing its anti-interference capability. The programmable offset range of the internal comparator is ±35mV, which improves sampling accuracy. Users can assess the relative width of the first echo pulse to determine indications of received signal strength. This indication helps in detecting anomalies such as ultrasound transducer abnormalities, increased pipe wall coatings, or the presence of bubbles in water.

- By issuing the command Start TOFRestart, SL1922 can complete a measurement of ultrasound time-of-flight (both upstream and downstream) and read data, thereby reducing software operations and power consumption significantly. It is compatible with TDC-GP22.

Features



Measurement range 1:

- Dual channel single precision mode 75ps
- Single channel double precision mode 37ps
- Measurement range 3.5ns (0ns) to 2.5μs
- 20ns minimum pulse interval, receives up to 4 pulses

Measurement range 2:

- Single channel single precision mode 75ps resolution
- Double precision mode 37ps, quad precision mode 19ps resolution
- Measurement range 500ns to 4ms(at4m high-speed clock)
- Measurement of 3 pulses and automatic processing of 3 data

Analogue input circuit:

- Chopper-stabilised low-drift comparator with programmable offset voltage, ±35 mv
- First wave detection
- Measures the pulse width of the first wave
- Analogue switches for input selection integrated inside
- External circuitry requires only 2 resistors and 2 capacitors

Temperature measurement unit:

- 2 or 4 temperature sensors, pt500/pt1000 or higher
- Has an internal integrated schmitt trigger
- 16-bit rms progress with external schmitt trigger, 17.5-bit rms precision with internal low-noise trigger
- Ultra-low power consumption (0.08μa at measurements every 30 seconds)

Special features:

- Pulse generator for up to 127 pulses
- Rising or/and falling edge triggered measurements
- High-precision stop shield window
- Low power 32k oscillator (500na)
- 7 x 32-bit EEPROM

Overview:

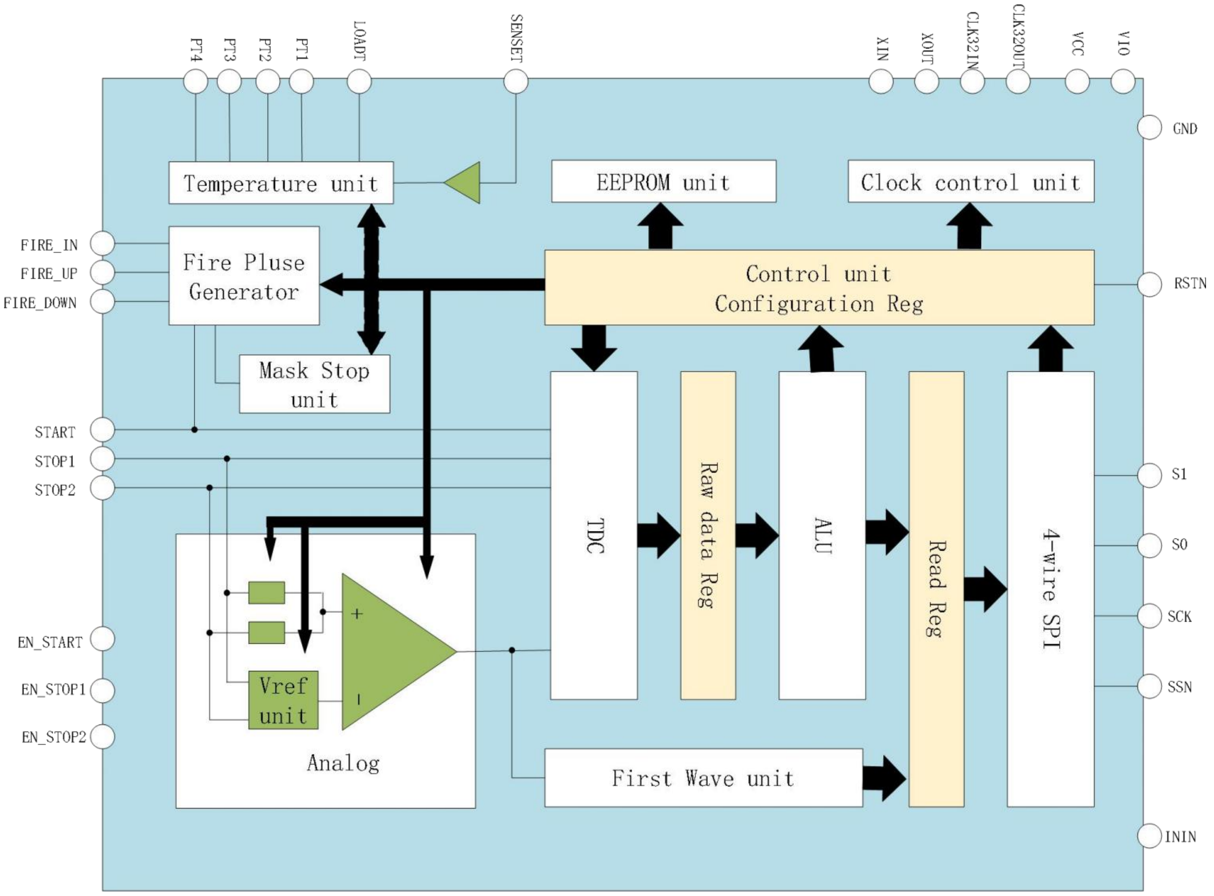
- 4 line spi communication interface
- Operating voltage 2.5v to 3.6v
- Operating temperature -40°c to +125°c
- Qfn32/lqfp32 package

Application

- ultrasonic heat meter, water meter
- laser distance measurement

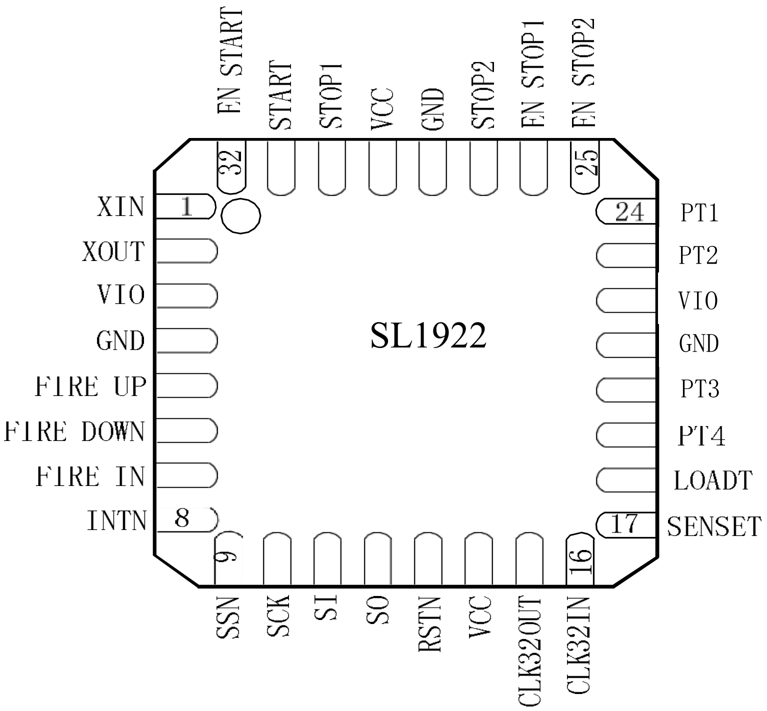
System block diagram

Fig. 1 Internal Block Diagram



Pin configuration and function

Figure 2 QFN32



Pin function

Pin Number	Pin Name	I/O	function	Note
1	XIN	I	high-speed crystal drive input	GND
2	X_{OUT}	O	crystal drive output	
3	VIO	--	port power	
4	GND	--	ground	
5	FIRE_UP	O	pulse generation port 1 (48mA) PT1	
6	FIRE_DOWN	O	pulse generation port 2 (48mA) PT2	
7	FIRE_IN	I	"acoustic loop" signal input port VIO	GND
8	INTN	O	interrupt flag, active low (4mA)	
9	SSN	I	serial interface slave select, active low GND	
10	SCK	I	serial interface clock input PT3	
11	SI	I	serial interface data input	
12	SO	O	serial interface data output; SPI output low when idle	
13	RSTN	I	system reset input, active low	
14	V_{CC}	--	kernel power supply	
15	CLK32OUT	O	32 kHz clock output	vacant
16	CLK32IN	I	32 kHz clock input	GND
17	SENSET	I	temperature measurement input (schmidt)	GND
18	LOADT	O	temperature measurement output (24mA)	vacant
19	PT4	O	temperature measurement port 4 (>96mA open leakage current)	
20	PT3	O	temperature measurement port 3 (>96mA open leakage current)	
21	GND	--	ground	
22	VIO	--	port power	
23	PT2	O	temperature measurement port 2 (>96mA open leakage current)	
24	PT1	O	temperature measurement port 1 (>96mA open leakage current)	
25	EN_STOP2	I	stop channel 2 enable port, active high	V_{io}
26	EN_STOP1	I	stop channel 1 enable port, active high	V_{io}
27	STOP2	I	stop channel 2	GND
28	GND	--	ground	
29	V_{CC}	--	kernel power supply	
30	STOP1	I	stop channel 1	GND
31	START	I	start channel	GND
32	EN_START	I	start channel enable, active high	V_{io}

Package:

PN	Package	PN	Packaging Form	Quantities
SL1922	QFN-32	SL1922	reel	2500
SL1922P	LQFP32	SL1922P		

Note:Please follow the instructions in the "Notes" column to configure any unused pins accordingly, if applicable.

Electrical characteristics

Recommended operating conditions

Parameters	Symbol	Test Conditions	Min	Typ	Max	Units
kernel supply voltage*	V_{cc}	$V_{cc}= V_{io}$	2.5	-	3.6	V
IO supply voltage	V_{io}		2.5	-	3.6	V
general input rising edge time	t_{ri}		-	-	200	ns
general input falling edge time	t_{fa}		-	-	200	ns
schmitt trigger rising edge time	t_{ri}		-	-	5	ms
schmitt trigger falling edge time	t_{fa}		-	-	5	ms
environmental temperature	T_a	T_j must not exceed 125°C	-40	-	125	℃
thermistor	$R_{th(j-)}$	Knot-Environment	-	28	-	K/W

Includes crystal pins X_{IN}, X_{OUT}, Clk32In, Clk32Out

DC Characteristics ($V_{io}=V_{cc}=3.0V$, $T_j=-40\sim+85°C$)

Parameters	Symbol	Test Conditions	Min	Typ	Max	Units
32kHz crystal current	I_{32}	$I_{CC}+I_{IO}$, 32kHz crystal operation only	-	1	-	μA
4 MHz crystal current	I_{hs}	$V_{cc}=V_{io}= 3.6V$	-	200	-	μA
		$V_{cc}=V_{io}=3.0V$	-	130	-	μA
		close	-	<1	-	μA
time measurement unit current	I_{tmu}	only when time measurement is on	-	4	-	mA
quiescent current	I_{ddq}	all clocks off, @85°C	-	<0.1	-	μA
operating current	Io	TOF-UP/DOWN, 1/s normal temperature, PT1000,1/30s	-	1.1 0.15	-	μA
temperature measurement current	I_T	every 30 seconds	-	0.085	-	μA
analogue partial current	I_{ana}	turn on the analogue section	-	0.8	-	mA
total current	I_{total}	2 time measurements per second temperature measurement every 30 seconds	-	2.3	-	μA
output high voltage	V_{oh}	$I_{oh}= t_{bd}$ mA V_{io}=Min.	$0.8V_{io}$	-		V
output low voltage	V_{ol}	$I_{ol}=t_{bd}$ mA, V_{io}=Min	-	-	$0.2V_{io}$	V
input high voltage	V_{ih}	LVTTL, V_{io} = Max.	$0.7V_{io}$	-		V
input low voltage	V_{il}	LVTTL, V_{io} = Min.	-	-	$0.3V_{io}$	V
schmitt trigger high voltage	V_{th}		$0.7V_{io}$	-	-	V

Terminal equivalent capacitance

Parameters	Symbol	Test Conditions	Min	Typ	Max	Units
digital input	C_{in}		-	7	-	
digital output	C_o	At @ V_{cc} = V_{io}, f = 1 MHz, T=25°C	-	-	-	pF
bi-directionality	C_{io}	f = 1 MHz, T=25°C	-	9	-	
PT ports			-	t.b.d.	-	
analogue input			-	t.b.d.	-	

Analogue circuit front-end

Parameters	Symbol	Test Conditions	Min	Typ	Max	Units
comparator input voltage drift (chopper stabilisation)			-	<1	2	mV
impedance with analogue switch on for STOP1/STOP2 inputs	R_{dson}(AS)		-	200	-	Ohm
FIRE_UP, FIRE_DOWN outputs	R_{dson}(FIRE)	symmetrical output, R_{dson}(HIGH)= R_{dson}(LOW)	-	4	-	Ohm
turn-on impedance when the cache is turned on						

EEPROM

Parameters	Symbol	Test Conditions	Min	Typ	Max	Units
data retention time @ 85°C		normal operation	10			year
		with error correction	generally unlimited			

Converter parameters

Time measurement unit (V_{io}=V_{cc}=3.0V, T_j=25℃)

Parameters	Symbol	Test Conditions	Min	Typ	Max	Units
measurement resolution	LSB	measurement range 1&2 DOUBLE_RES = 0	-	75	-	
		DOUBLE_RES = 1	-	37	-	ps
		measurement mode 2: QUAD_RES = 1	-	19	-	
		measurement range 1&2 DOUBLE_RES = 0				
standard deviation	σ	DOUBLE_RES = 1	-	t.b.d	-	ps
		measurement mode 2: QUAD_RES = 1	-	t.b.d	-	
	tm	measurement range 1	3.5ns	-	2.4μs	
measurement range		measurement range 2(4M high speed clock)	500ns	-	4ms	
integral nonlinearity	INL		-	<0.1	-	LSB

Temperature measurement unit 1

Parameters		Test Conditions				Units
		internal Schmitt Trigger		external Schmitt Trigger [2]		
		PT500	PT1000	PT500	PT1000	
resolution RMS		17.5	17.5	16	16	Bit
SNR		105	105	96	96	dB
absolute gain 3		0.9912	0.9931	0.996	0.9979	
absolute gainvs.V_{io}	3.6V	0.9923	0.994	0.9962	0.998	
	3.0V	0.9912	0.9931	0.996	0.9979	
	2.5V	0.9895	0.9915	0.9956	0.9979	
gain driftvs.V_{io} 3		0.25	0.23	0.06	0.04	%/V
maximum gain error @ dΘ=100 K		0.05%	0.05%	0.02%	<0.01%	
gain drift vs.		0.022	0.017	0.012	0.0082	%/10K
gain drift vs. V_{io}				0.08		%/V
initial zero drift		<20	<10	<20	<10	mK
zero drift vs.		<0.05	<0.03	<0.012	<0.082	mK/℃
PSRR			>100			dB

1. All measurements are conducted with V_{io} = V_{cc} = 3.0V, and Cload = 100nF for PT1000, while 200nF is used for PT500 (C0G type).
2. Using external 74AHC14 Schmitt triggers.
3. Compared with an ideal gain of 1 scenario.

Timing

If not specified otherwise, the following characteristics are measured under the conditions of V_{cc} = 3.3V ± 0.3V and an ambient temperature range of -40°C to +85°C.

Clock oscillator

Parameters	Symbol	Min	Typ	Max	Units
32 kHz reference crystal clock	Clk_{32}	-	32.768	-	kHz
32 kHz crystal start-up time after power-up	t_{32st}	-	3	-	s
high speed crystal reference clock	Clk_{HS}	2	4	8	MHz
ceramic crystal start-up time	t_{oszst}	-	100	-	µs
quartz crystal start-up time	t_{oszst}	-	1	-	ms

Serial interface

Parameters	Symbol	Max		Units
		V_{io}=2.5V	V_{io}=3.3V	
serial clock frequency	f_{clk}	15	20	MHz
serial clock, pulse high	t_{pwh}	30	25	ns
serial clock, pulse low	t_{pwl}	30	25	ns
SSN enable valid until clock edge	t_{sussn}	40	10	ns
SSN pulse width between write cycles	t_{pwssn}	50	40	ns
SSN hold time after SCK falling edge	t_{hssn}	40	25	ns
time from valid data to falling edge of SCK	t_{sud}	5	5	ns
data hold time after SCLK falling edge	t_{hd}	5	5	ns
time from rising edge of SCK to data validity	t_{vd}	20	16	ns

Serial interface (SPI compatible, clock phase =1, clock polarity =0).

The serial interface is compatible with 4-wire SPI, requiring a Serial Select Not (SSN) signal, and therefore cannot operate in 3-wire SPI mode.

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

Data transmission starts from the most significant bit (MSB) and ends at the least significant bit (LSB). Transmission occurs on a byte-by-byte basis. Transmission can be halted after each byte by sending a LOW-HIGH-LOW level to SSN (Serial Select Not)

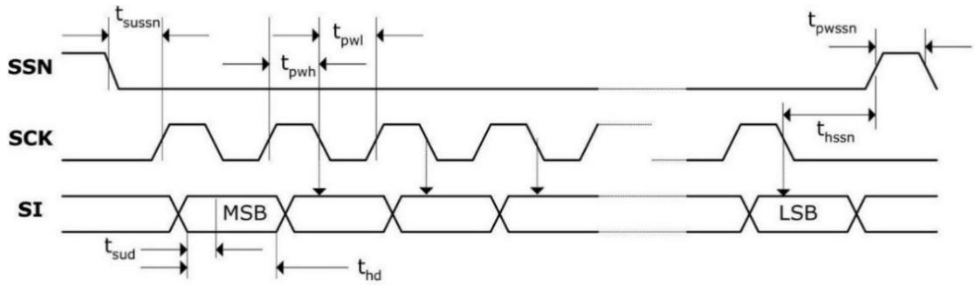


Figure 3 SPI Write Timing

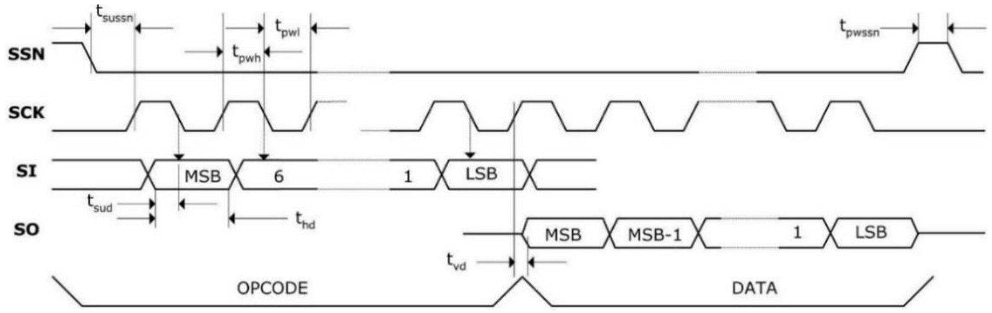


Fig. 4 SPI Read Timing

Timing for closing the STOP channel

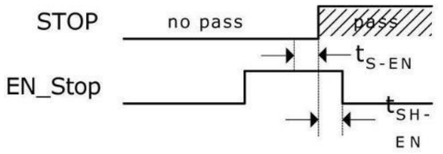


Figure 5 Closing STOP channel timing

System Reset Timing

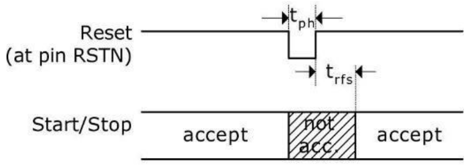


Figure 6 System reset timing

Parameters	Symbol	Min	Max	Units
reset pulse width	t_{ph}	t.b.d.	-	ns
time interval after the rising edge of the reset pulse until the pulse can be accepted	t_{rfs}	t.b.d.	-	ns

Note: After power-on reset, it is necessary to wait at least 500 microseconds before starting the analog circuitry section.

Supply voltage

SL1922 is a high-end mixed-signal device. For optimal measurement performance, a good power supply is crucial. The power supply should feature high capacitance and low inductance. SL1922 provides two pairs of power supply ports:

V_{io} ----- I/O supply voltage
V_{cc} ----- kernel supply voltage

All ground pins should be connected to the ground plane of the printed circuit board (PCB). V_{io} and V_{cc} should be supplied through either a battery or a stable linear voltage regulator. Avoid using switch-mode regulators to prevent interference caused by IO voltage fluctuations.

The performance of a time-to-digital converter depends entirely on a good power supply. Since the chip measurements mainly involve pulsed currents, adequate dual-band filtering is crucial.

V_{cc} 47 µF (Min 22 µF)
V_{io} 100 µF (Min 22 µF)

Voltage is supplied through an analog regulator, and we recommend avoiding the use of switch-mode voltage regulators.

Limiting parameters（T=25℃）

V_{cc} equivalent to GND voltage.. -0.3V～+4V
V_{io} supply voltage .... -0.3V～+4V
V_{in} Pin Voltage .... -0.5V～V_{cc}+0.5V
ESD（HBM） .... >2000V
Maximum junction temperature.. 125℃
storage temperature range .... -55℃～+150℃

Internal register description

Configuration registers

SL1922 has 7 sets of 32-bit configuration registers. The upper 24 bits are reserved for register configuration and are write-only, used to configure the operation of the SL1922. The lower 8 bits can be used, for instance, to store product IDs that can be read back.

Alphabetical listing of register configuration parameters:

Parameter	Register	Bit	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	28-31	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	8-23	0
DELVAL2	3	8-23	0
DELVAL3	4	8-23	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

Register 0 (address 0)

Bit	Default Value	Parameters (In Parentheses GP22 Name)	Description	Setting
31	0	ANZ_FIRE[3:0] (FIRE#)	Sets the number of pulses emitted by the fire port, the remaining 3 bits are set in register 6.The remaining 3 bits are set in register 6.If the number of emitted pulses ANZ_FIRE >15, the phase setting PHFIRE cannot be applied. the phase setting PHFIRE cannot be applied.	0 = off 1 = 1 pulse ... 127 = 127 pulses
30	0			
29	1			
28	0			
27	0	DIV_FIRE	setting the crossover factor of the pulse generated by the internal clock signal	0 = no crossover 1 = 2 crossover frequencies ... 15 = 16 divisions
26	0			
25	1			
24	0			

23	0	ANZ_PER_CAL RES (CALRES#)	set the number of 32k clock cycles to apply to the calibrated ceramic crystal	0 = 2 cycles = 61.035 µs 1 = 4 cycles = 122.07 µs 2 = 8 cycles = 244.14 µs 3 = 16 cycles = 488.281 µs
22	0			
21	0	DIV_CLKHS (Clk$_{HSDiv}$)	setting the crossover factor of the CLKHS high-speed reference clock	0 = no crossover, 1 = 2 crossover 2 = 4 divisions, 3 = 4 divisions
20	0			
19	0	START_CLKHS [1:0]	defines the crystal start-up interval after the crystal is switched on and before the measurement starts. Note: The highest bit to adjust START_CLKS is bit 20 in register 6. This bit must be set to 1 when setting the start time to 2.44 ms and 5.14 ms.	0 = crystal off 1 = crystal on all the time 2 = Start-up delay 480 µs 3 = Start-up delay 1.46 ms 4 = Start-up delay 2.44 ms 5 to 7 = start-up delay 5.14 ms
18	1			
17	1	ANZ_PORT (PORT#)	setting the number of ports to apply temperature measurement	0 = 2 temperature measurement ports (PT1 and PT2) 1 = 4 temperature measurement ports
16	0	TCYCLE	setting the cycle time for temperature measurement	0 = 128 µs @ 4 MHz 1 = 512 µs @ 4 MHz (recommended)
15	0	ANZ_FAKE(FAKE#)	warm-up pseudo-measurement before temperature measurement	0 = 2 warm-up pseudo-measurements 1 = 7 warm-up pseudo-measurements
14	1	SEL_ECLK_TM P (SelClkT)	selecting the reference signal for the internal cycle clock for temperature measurement	0 = Apply 32.768 kHz as clock 1 = apply 128 * CLKHS as clock period (32µs with 4MHz crystal)
13	1	CALIBRATE	enable/disable calibration in the ALU	0 = Calibration off (only permitted in measuring range 1) 1 = calibration on (recommended)
12	0	NO_CAL_AUT O (DisAutoCal)	Enable/disable running auto-calibration in the TDC	0 = Automatic calibration after measurement 1 = Disable auto-calibration
11	1	MESSB2 (MRange2)	selection of the measuring range 2	0 = Measuring range 1 1 = Measuring range 2
10	0	NEG_STOP2	inverted stop Channel 2 input	0 = Non-inverted input signal - rising edge 1 = Inverted input signal - falling edge
9	0	NEG_STOP1	reverse stop Channel 1 input	0 = Non-inverted input signal - rising edge 1 = Inverted input signal - falling edge
8	0	NEG_START	reverse start channel 1 input	0 = Non-inverted input signal - rising edge 1 = Inverted input signal - falling edge
7-0	0	ID0	free bits, e.g. for storing version numbers, etc.	

Register 1 (address 1)

Bit	Default Value	Parameters (In Parentheses GP22 Name)	Description	Setting	
31	0	HIT2	used to define how the ALU calculates results: MRange1: HIT1 - HIT2 MRange2: HIT2 - HIT1	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	MRange2: 2 =1.Stop Ch1 3 =2.Stop Ch1 4 =3.Stop Ch1
30	1				
29	0				
28	1				
27	0	HIT1	used to define how the ALU calculates results: MRange1: HIT1 - HIT2 MRange2: HIT2 - HIT1		MRange2: 1 = Start
26	1				
25	0				
24	1				
23	0	EN_FAST_INIT	launching the Quick Initialisation Function	0 = switch off function 1 = Activate function	
22	1		keep the default value		
21	0	HITIN2	expected number of pulses in stop channel 2	0 = stop Channel off 1 = 1 pulse	
20	0				
19	0				

18	0	HITIN1	expected number of pulses on stop channel 1	2 = 2 pulses 3 = 3 pulses 4 = 4 pulses 5 to 7 = setting not allowed
17	0			
16	0			
15	1	CURR32K	Low power option for 32kHz crystals. Generally speaking, it is not necessary to apply the high current option. It is not necessary to apply the high current option, as the low current can be used to ensure proper operation of the crystal.	0 = low current 1 = high current (original GP2 mode)
14	0	SEL_START_FIRE	The fire pulse is used to trigger TDC start.	0 = same as GP2 1 = apply fire internal trigger Start
13	0	SEL_TSTO2	Defines the function of the EN_START pin. In addition to the function of the function in the SL1922, this pin can be used for the output of different signals.pin can be used for the output of different signals.	0 = GP2 Same function, high level will turn on the START pin. 1 = START_TDC output 2 = STOP1 TDC output 3 = STOP2 TDC output 4 = Switch on temperature measurement output 5 = Switch on DELVAL output via EN_STOP 6 = n.c. not connected 7 = 4 kHz (32 kHz/8) clock
12	0		SEL_TSTOP2 > 0 then EN_START will be = high internally.	
11	0			
10	0	SEL_TSTO1	Defines the function of the FIRE_IN pin. This pin can be used as an output signal in addition to the function of the SL1922. If SEL_TSTO1 > 1 then FIRE_IN will be internally connected to GND.	0 = Fire_in input with the same function as in GP2, acoustic loop method 1 = START_TDC output 2 = STOP1 TDC output 3 = STOP2 TDC output 4 = Enable Stop temperature measurement output 5 = TOF=UP, =1 when TOF_UP measurement is on 6 = RUN_HA, =1 when hardmacro is on 7 = 32 kHz clock
9	0			
8	0			
7~0	0	ID1	Free bits, e.g. for storing version numbers, etc.	

Register 2 (address 2)

Bit	**Default Value**	**Parameters (In Parentheses GP22 Name)**	**Description**	**Setting**
31	0	EN_INT[2:0]	The or gates are used to initiate different interrupt triggers, and a bit in register 6 is used to trigger the interrupt.	Bit 31 = 1: Timeout interrupt trigger bit Bit 30 = 1: End Hits interrupt trigger bit Bit 29 = 1: ALU interrupt trigger bit
30	0			
29	1			
28	0	RFEDGE2	edge sensitivity of channel 2	0 = rising or falling edge 1 = rising and falling edge
27	0	RFEDGE1	channel 1 edge sensitivity	
26~8	0	DELVAL1	The delay time set to enable the stop pulse starts from the first pulse of the start channel. 14-bit integer part, 5-bit decimal part, multiple of T_{ref}.14-digit integer part, 5-digit decimal part, multiple of T_{ref}.	DELVAL1 = 0 to 16383.96875
7-0	0	ID2	free bits, e.g. for storing version numbers, etc.	

Register 3 (address 3)

Set EN_FIRST_WAVE = 0.

Bit	Default Value	Parameters (In Parentheses GP22 Name)	Description	Setting
31	0	EN_AUTOCAL C_ MB2	Only in measuring range 2: All pulses obtained by switching on are automatically counted. The sum of these results is written into register 4.The sum of these results is written into register 4.	0 = Off 1 = On
30	0	EN_FIRST_WA VE	Enables automatic first wave detection. If turned on, a new meaning will be generated in Register 3 and Register 4.	0 = Off 1 = On
29	0	EN_ERR_VAL	Forcing ALU to write 0xFFFFFFFF to result register due to time overflow	0 = off 1 = on
28	1	SEL_TIMO_MB 2	selection of time limit for overflow in measuring range 2	0 = 64 µs 1 = 256 µs 2 = 1024 µs 3 = 4096 µs @ 4 MHz ClkHS
27	1			
26~8	0	DELVAL2	The delay time set to enable the stop pulse starts from the first pulse of the start channel. 14-bit integer portion, 5-bit decimal portion, multiple of Tref。	DELVAL2 = 0 to 16383.96875
7-0	0	ID3	free bits, e.g. for storing version numbers, etc.	

Set EN_FIRST_WAVE =1.

Bit	Default Value	Parameters (In Parentheses GP22 Name)	Description	Setting
31	0	EN_AUTOCALC_ MB2	Only in measuring range 2: All pulses obtained by switching on are calculated automatically. The sum of these results is written into register 4.	0 = off 1 = on
30	0	EN_FIRST_WAVE	Enables automatic first wave detection. If turned on, a new meaning will be generated in Register 3 and Register 4.	0 = off 1 = on
29	0	EN_ERR_VAL	Forcing ALU to write 0xFFFFFFFF to result register due to time overflow	0 = off 1 = on
28	1	SEL_TIMO_MB2	Selection of time limit for overflow in measuring range 2	0 = 64 µs 1 = 256 µs 2 = 1024 µs 3 = 4096 µs @ 4 MHz ClkHS
27	1			
26	0		Keep the default value	
25~20	0	DELREL3	Sets how many echo cycles are received when the third stop is detected in the first wave.	5 to 63 DELREL3 > DELREL2
19~14	0	DELREL2	Sets how many echo cycles are received from the first wave detection to the second stop.	4 to 63 DELREL2 > DELREL1
13~8	0	DELREL1	Sets how many echo cycles are received when the first stop is detected on the first wave.	3 to 63
7~0	0	ID3	free bits, e.g. for storing version numbers, etc.	

Register 4 (address 4)

Set EN_FIRST_WAVE = 0:

Bit	Default Value	Parameters (In Parentheses GP22 Name)	Description	Setting
31~27	2		keep the default value	
26~8	0	DELVAL3	The delay time set to enable the stop pulse starts from the first pulse of the start channel. 14-digit integer portion, 5-digit decimal portion, multiple of T_{ref}.	DELVAL3 = 0 to 16383.96875
7~0	0	ID4	free bits, e.g. for storing version numbers, etc.	

Set EN_FIRST_WAVE = 1:

Bit	Default Value	Parameters (In Parentheses GP22 Name)	Description	Setting
31~27	2		keep the default value	
26~17	0		keep the default value	
16	0	DIS_PW	disable pulse width measurement	0 = switch on pulse width measurement 1 = switch off pulse width measurement

15	0	EDGE_FW	Set the edge sensitivity for first wave identification. Setting it to falling edge sensitive makes more sense for negative amplitudes.	0 = rising edge 1 = falling edge
14	0	OFFSRNG2	add additional offset + 20 mV	0 = off 1 = on
13	0	OFFSRNG1	add additional offset - 20 mV	0 = off 1 = on
12~8	0	OFFS	Sets comparator offset, 2's complement in units of1 mV	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. for storing version numbers, etc.	

Register 5 (address 5)

Bit	Default Value	Parameters (In Parentheses GP22 Name)	Description	Setting
31	0	CONF_FIRE	Pulse trigger output setting 3'b 011 Not settable	Bit 31 = 1: both on (reverse FIRE_DOWN) Bit 30 = 1: switch off output FIRE_UP Bit 29 = 1: switch off output FIRE_DOWN
30	0			
29	0			
28	0	EN_STARTNOISE	adding noise to the start channel signal	1 = switch on the noise unit
27	0	DIS_PHASESHIFT (DIS_PHASENOIS E)	Noise unit. When applying the SL1922 reference clock to generate the start pulse (e.g. connecting fire to start), turn on this unit to reduce the system error by averaging.	1 = disable the phase noise shift unit. GP2 must be set to 10 = on
26	0	REPEAT_FIRE	Number of repetitions of the pulse sequence used for the acoustic loop method	0 = no repetition 1 = 1 repetition ... 7 = 7 repetitions
25	0			
24	0			
23~8	0	PHFIRE （PHASE_FIRE）	phase setting for each pulse in a pulse train of up to 15 pulses	0 = not reversed 1 = Reverse
7-0	0	ID5	free bits, e.g. for storing version numbers, etc.	

Register 6 (address 6)

Bit	Default Value	Parameters (In Parentheses GP22 Name)	Description	Setting
31	0	EN_ANALOG	Switch on the analogue measuring section required for ultrasonic flow measurement. If switched on, this section will be energised during the measurement to save current. STOP1 and STOP2 will automatically be selected as analogue inputs internally.	0 = STOP1 and STOP2 are digital inputs 1 = analogue section on
30	0	NEG_STOP_TEMP	Inverts the SenseT input signal. This must be turned on when the internal comparator is applied, not when the GP2 applies an external comparator.	0 = External 74HC14 applied (GP2 compatible) 1 = Apply internal Schmitt trigger
29	0		Keep the default value	
28	0	DA_KORR	Sets the comparator offset from -8 mV to +7 mV. 2's complement	15 =1 mV ,7 = 7 mV 14 =2 mV ,6 = 6 mV ... 9 =... ,8 =7 mV 1 = 1 mV ,8 mV 0 = 0 mV
27	0			
26	0			
25	0			
24	0		Keep the default value	

23	0	TW2	Time to charge the capacitance of the recommended RC when applying the internal analogue part.	Charging time: 0 = 90 µs 1 = 120 µs 2 = 150 µs 3 = 300 µs
22	0			
21	0	EN_INT[3]	For other bits, see the lower three bits of register 2, EN_INT. The different interrupt sources are internally connected via a gate. EEPROM actions, such as EEPROM_COMPARE, will be run through the SL1922. In particular, EEPROM write operations can last up to 130ms. Therefore, it is necessary to indicate the end of the operation.	1 = End of EEPROM action
20	0	START_CLKHS[2]	The highest bit sets the start-up time of the high-speed crystal. The low bit is set in register 0.	0 = Off 1 = Continuously on 2 = 480 µs delay 3 = 1.46 ms 4 = 2.44 ms 5 to 7 = 5.14 ms
19	0	CYCLE_TEMP	Selection of the timer for triggering the second temperature measurement, given in multiples of 50/60 Hz.	0 = 0.5 1 = 0.75 2 = 1 3 = 1.25
18	0			
17	0	CYCLE_TOF	Selects the timer that triggers the second time measurement, given in multiples of 50/60 Hz.	
16	0			
15	0	HZ60	The SL1922 can perform a complete upstream time-of-flight and downstream time-of-flight, as well as two temperature measurements. The delay between measurements is based on a 50 or 60 Hz clock.	0 = 50 Hz basis, 20 ms 1 = 60 Hz basis, 16.67 ms
14	0	FIREO_DEF	Defines the default level of the inactive fire channel. E.g. if FIRE_UP is active, then the FIRE_DOWN buffer is connected to the default level. Must be set to 1 when applying the internally integrated analogue section.	0 = High-Z 1 = Low
13	0	QUAD_RES	4-fold increase in measurement accuracy from 75 ps to 19 ps in measurement range 2	0 = off 1 = on
12	0	DOUBLE_RES	Doubling of the measuring accuracy from 75 ps to 37 ps in measuring range 2	0 = off 1 = on
11		TEMP_PORTDIR	Temperature measurement port measurement sequence reversed	0 = PT1 > PT2 > PT3 > PT4 1 = PT4 > PT3 > PT2 > PT1
10		ANZ_FIRE[6:4]	The high 3 bits set the number of pulses to be sent. See also register 0. If ANZ_FIRE > 15 then PHFIRE is not valid for pulse phase setting.	0 = off 1 = 1 pulse 2 = 2 pulses ... 127 = 127 pulses
9				
8				
7~0	0	ID6	Free bits, e.g. for storing version numbers, etc.	

Reading registers

The result register and status register can both be read by sending the operation code 0xBX. Depending on the address, the operation code can be either 4, 2, or 1 byte long.

The ID register bits in the configuration registers can be read by sending the operation code 0xB7. This operation code will provide 7 bytes of information in the order of ID0, ID1, ..., ID6. Transmission starts from the highest bit.

<table>
<tr><th>Address</th><th>Sign</th><th>Bit number</th><th colspan="10">Description</th></tr>
<tr><td>0</td><td>RES_0</td><td>32</td><td colspan="10">Measurement Results 1,Fixed Floating Point, 16-Bit Integer Part, 16-Bit Decimal Part
15 0 -1 -16
2 2 , 2 2</td></tr>
<tr><td>1</td><td>RES_1</td><td>32</td><td colspan="10">measurement Result 2, Fixed Floating Point, 16-bit Integer Part, 16-bit Decimal Part</td></tr>
<tr><td>2</td><td>RES_2</td><td>32</td><td colspan="10">measurement Result 3, Fixed Floating Point, 16-bit Integer Part, 16-bit Decimal Part</td></tr>
<tr><td>3</td><td>RES_3</td><td>32</td><td colspan="10">measurement Result 4, Fixed Floating Point, 16-bit Integer Part, 16-bit Decimal Part</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月6日</td><td>5月3日</td><td>2-0</td></tr>
<tr><td>EEPROM_eq_CRE</td><td>EEPROM_DED</td><td>EEPROM_Error</td><td>temperature measurement short circuit</td><td>temperature measurement open circuit</td><td>coarse value count overflow</td><td>TDC unit overflow</td><td>number of pulses received on channel 2</td><td>number of pulses received on channel 1</td><td>result address pointer</td></tr>
<tr><td>5</td><td>REG_1</td><td>8</td><td colspan="10">displays the upper 8 bits of Write Register 1, which is used to test communication.</td></tr>
<tr><td>8</td><td>PW1ST</td><td>8</td><td colspan="10">Measurement ratio of pulse width, fixed floating-point number, where 1 bit is an integer</td></tr>
</table>

Result registers

The allocation of data structures and result registers is determined by the operating mode and whether the stored data is calibrated. Please note the following points:

- negative values are only possible in measuring range 1.
- only positive values are available in measuring range 2 as unsigned numbers.
- only in measurement range 1 can non-calibrated measurements be performed.
- in measurement range 1, during calibrated measurements, the tested time interval must not exceed two calibration clock cycles. If the measured time difference exceeds two calibration clock cycles, the ALU will overflow and write 0xFFFFFFFF to the corresponding result register.

Measurement range 1, when calibrated (Calibrate = 1), results in multiples of the internal reference clock cycles. The internal reference clock equals the external reference clock divided by DIV_CLKHS (DIV_CLKHS = 1, 2, 4). The calibration value is a 32-bit fixed-point number, consisting of a 16-bit integer and a 16-bit fractional part. Therefore, one calibration value occupies one result register. Serial output starts from the most significant bit (215) and ends at the least significant bit (2-16), with data presented in two's complement form.

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

Measuring range 1 without calibration (Calibrate = 0)

Uncalibrated values are typically signed integers and are stored as 16-bit values in the upper 16 bits of the result register, with the lower 16 bits of the result register set to 0. The result represents the number of least significant bits in 2's complement form. The lower 16 bits of the result register are set to 0. The result represents the number of least significant bits in 2's complement form. time = RES_X × 75ps

Measuring range 2

In measurement range 2, the SL1922 only supports calibration measurements. The measurement result is a multiple of the internal reference clock period, which is equal to the external reference clock divided by DIV_CLKHS (DIV_CLKHS = 1, 2, 4). The calibration value is a 32-bit fixed point number consisting of a 16-bit integer and a 16-bit decimal. Therefore one calibration value occupies one result register. The serial output starts with the highest bit (215) and ends with the lowest bit (2-16) in 2's complement

Time = RES_X × Tref × N , with N = 1, 2 or 4

Temperature measurement

The measurement of the discharge time has the same structure as for measuring range 2. The ratio for the discharge time is the same as for the resistance.

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

Status registers

Bit	Name	Description	Value
2-0	Pointer result register	pointer to next empty result register address	
3 May	# of hits Ch 1	displays the number of pulses recorded on channel 1.	
6 August	# of hits Ch 2	displays the number of pulses recorded on channel 2.	
9	Timeout TDC	display TDC measuring unit overflow	1 = overflow
10	Timeout Precounter	displays the overflow of the 14-bit coarse value counter in measuring range 2	1 = overflow
11	Error open	indicates that the measured temperature sensor is disconnected	1 = open
12	Error short	indicates that the measured temperature sensor is short-circuited	1 = short circuit
13	EEPROM_Error	There was an error in the EEPROM and it was corrected.	1 = error
14	EEPROM_DED	Multiple error checks. There are 2 uncorrectable errors generated in the EEPROM.	1 = 2 errors
15	EEPROM_eq_CREG	Displays whether the contents of the configuration register are the same as those in the EEPROM.	1 = same

PW1ST registers

This register is an 8-bit fixed-point register, with 1 bit allocated for the integer part and 7 bits for the fractional part. PW1ST provides the ratio of the width of the first echo half-wave (under a given offset voltage condition) to the desired received echo half-wave. Data range: 0 to 1.99219.

EEPROM

SL1922 has a 7x32-bit EEPROM. This EEPROM can be used to store configuration data, ID version numbers, and other information. Only the following three operations are permissible:

- writes the contents of the configuration register to the EEPROM
- transfers the contents of the EEPROM to the configuration register.
- compares the contents of the configuration register with the contents of the EEPROM

It is not possible to read back the contents of the EEPROM except for the ID. This makes it impossible for others to read the configuration data after the customer has programmed the chip. You can compare the contents of the comparison configuration register (CREG) with the EEPROM.

The status register will indicate whether the contents are identical with the EEPROM_eq_CREG bit.

The EEPROM has an internal error calibration (hamming checksum). Individual bit errors can be detected and corrected:

- errors in two bits can be detected but not corrected.
- detects single-bit errors and corrects them.

Errors will be indicated in the status register with the EEPROM_Error (single-bit detection) and EEPROM_DED (double-bit error detection) bits

During each read operation and comparison with the EEPROM, error bits are checked. Upon detection of a single-bit error, a new cycle will automatically commence, and the data will be re-stored.

The data in EEPROM can remain intact for over 10 years at 85° C without encountering any single or multiple errors. By regularly using the Compare_EEPROM command (e.g., monthly), the data retention can be indefinitely extended.

Opcode

Opcode HEX	MSB LSB								Sign	ReadOut
h8x	1	0	0	0	0	A	A	A	write address A	24-bit or 32-bit data
hBx	1	0	1	1	0	A	A	A	retrieve 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 bt
hC0	1	1	0	0	0	0	0	0	write configuration registers to EEPROM	
hF0	1	1	1	1	0	0	0	0	transfer EEPROM contents back into configuration registers	
hC6	1	1	0	0	0	1	1	0	comparing EEPROM and Configuration Register Contents	
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 (formerly: 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	

The SL1922 is compatible with the GP2 Write Register mode, for example.

- h80 + 3 bytes will be written to configuration register 0 in GP2 compatibility mode.
- h80 + 4 bytes will be written to Configuration Register 0 including IDO (only in SL1922 mode). Write operations cannot be performed consecutively.
- Each register must be addressed separately.

Opcode description:

- hC0, hF0, and hC6 are all operation codes related to EEPROM. These operations typically require approximately 130ms to complete, especially when performing EEPROM write operations. Therefore, bit 3 in register 6, EN_INT, indicates the completion of EEPROM operations. This bit can be used to prompt the microcontroller to proceed with the next action.

- h01, Start_TOF: Triggers a time-of-flight measurement. Initially, the 4 MHz crystal oscillator is activated. After aspecified delay (START_CLKHS), the comparator and reference voltage are enabled. The receiving capacitor ischarged to Vref, while the inactive fire buffer is pulled down to GND. After a delay set by the charging time(TW2), the fire buffer emits a fire pulse. Following the delay window set by DELVAL, the stop channel opens toreceive the pulse. At the end of the measurement, the analog section and 4 MHz crystal oscillator are deactivated, reducing the overall current to approximately 0. An interrupt is triggered with INTN set to low.

- h05, Start_TOF_Restart: This new operation code executes Start_TOF twice, performing one time-of-flight measurement each for upstream and downstream in a flow meter. After both measurements are completed, the interrupt flag is set once. Therefore, after issuing a Start_TOF_Restart command, the micro controller will encounter two interrupts and must read the data twice. The interval between the upstream and downstream time-of-flight measurements can be specified using the CYCLE_TOF configuration parameter, which is a multiple of 50 Hz or 60 Hz. Choosing the correct delay between the two measurements helps to suppress 50/60 Hz noise effectively.

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

- h02, Start_Temp: will trigger a temperature measurement. It will first perform several warm-up measurements on port PT0 (ANZ_FAKE). Then start measuring ports PT0 > PT1 > PT2 > PT4 in that order. if TEMP_PORTDIR is set to 1, then the order of port measurements will be reversed. Warm-up measurements will start at port PT4.

- h06, Start_Temp_Restart: This opcode will run the temperature measurement Start_Temp twice. The time delay between the upstream and downstream temperature measurement is given by the parameter configuration CYCLE_TEMP in multiples of 50 Hz or 60 Hz. Correct selection of the delay between the two measurements will suppress 50/60 Hz noise.

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

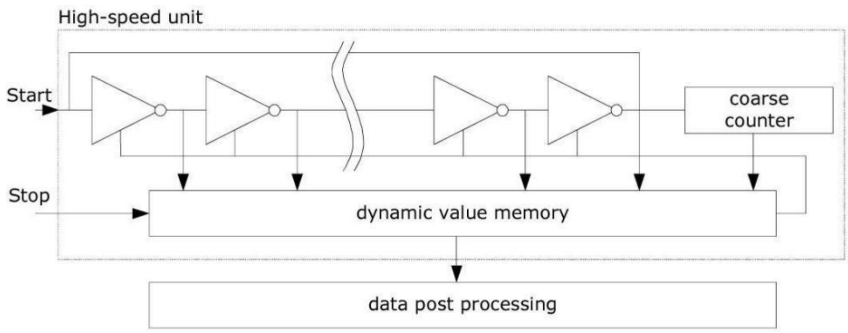
- h03, Start_Cal_Resonator: Initiates a calibration measurement for the high-speed oscillator. The TDC measures a time interval ranging from 61 μs to 488 μs, as defined by ANZ_PER_CALRES.Upon completion of the measurement, an interrupt is signaled through the interrupt pin. The resulting value, expressed as multiples of the high-speed clock cycles, is stored in Result Register 0. This value is then compared against the theoretical value to derive the calibration coefficient.

- h04, Start_Cal_TDC: This command will start the measurement of 2 reference clock cycles. It is mainly used to update the data of calibration TDC. If the chip is set to auto-calibration, this command is not needed.

Measuring range

Introduction

- Measurement range from 3.5ns to 2us (0-2us between different stop channels)
- 2 stop channels relative to a start channel, typical accuracy 75 ps.
- 1 one stop channel corresponds to one start channel with a typical accuracy of 37 ps.
- 20 ns minimum interval between pulses
- Up to 4 pulses per stop channel
- Selectable rising/falling edge sensitivity per channel
- Startup pin for powerful windowing features
- Can measure the time interval between any two pulses
- Typical applications for : Laser time measurement, RF, TOF, ATE
- The digital TDC applies internal logic gate delays to measure time intervals with high accuracy. The following diagram illustrates the principle structure of this absolute time TDC measurement. Intelligent circuitry, ensuring that the circuitry and special measurement methods allow the signal to pass through the logic gates very accurately. The maximum measurement accuracy depends entirely on the propagation time of the internal signals through the logic gates.

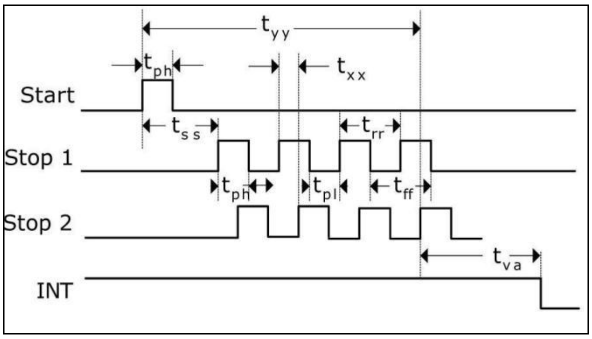


The measurement unit is triggered by a start signal and stopped by a stop signal. The time interval between the start and stop signals can be calculated using the position of the ring oscillator and the coarse count value. This allows for a measurement range of up to 20 bits.

At 3.3V and 25°C, the SL1922 has a minimum resolution of 75ps. The RMS noise is approximately 50ps (0.7 LSB). Temperature and voltage variations significantly impact the propagation delay of the gate circuitry. Typically, errors caused by these variations are compensated through calibration. During calibration, the TDC measures one or two calibration clock cycles. The measurement range is limited by the size of the counter.

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

	Length	Description
tph	2.5 ns (min.)	minimum pulse width
tpl	2.5 ns (min.)	minimum pulse width
tss	3.5 ns ns (min) 2 µs (max.)	Start to Stop
trr	20 ns (typ.)	rising edge to rising edge
tff	20 ns (typ.)	
	t.b.d. non-calibrated	valid time from the appearance of the last pulse to the measurement result
tva	t.b.d. post-calibration	
txx	no time limit	



Measurement process

Setting

Before using the SL1922, it must be configured.

The primary settings for Measurement Range 1 are:

a. Selection of the measuring range 1

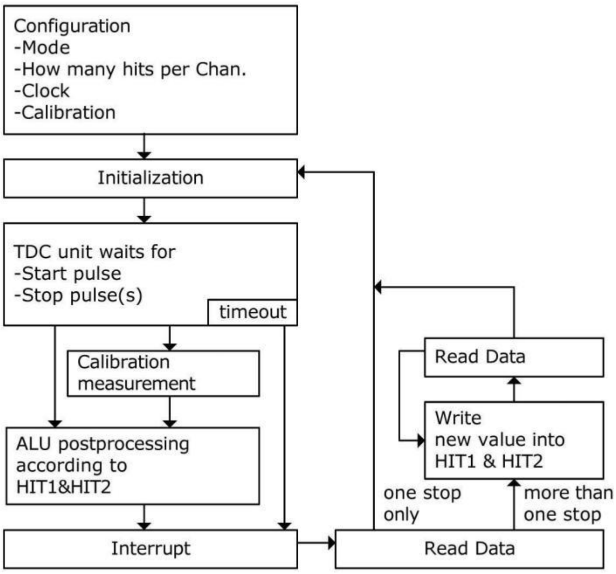
Setting register 0, bit 11, MESSB2 = 0.

Register 6, bit 12, DOUBLE_RES = 1 selects double precision mode. With this selection, the measurement accuracy is typically 37ps instead of 75ps, but only one stop channel is available.

b. Selecting the reference Clock

Register 0 bits 18 & 19 and register 6, bit 20 , START_CLKHS are used to switch the high speed clock. Set to 0 if only 32kHZ clock is used, or 1 if only high speed clock is used (continuous mode).

Registers 0,bits 20 & 21,DIV_CLKHS are used to set the value of the internal divider of the reference clock (1, 2 or 4).



This is important for calibration measurements in measurement range 1, because the ALU will only work properly if 2Tref (internal clock) is greater than the maximum time interval to be measured. Otherwise the ALU outputs a value of 0xFFFFFFFF.

Also make sure that the 2Tref (internal clock) is <2us to avoid time overflow during calibration.

c. Setting the number of pulses accepted

The number of pulses to be measured by the SL1922 can be set by the user in registers 1,bits 16-18 (HITIN1) and bits 19-21 (HITIN2). Up to 4 measurements per channel are possible. The SL1922 will continue to measure until the set number of hits is completed or until an overflow occurs.

d. Calibration options

The ALU of the SL1922 needs to internally calibrate the measurements since the resolution of the measurements changes with temperature and voltage. The calibration measurement can be selected by setting Bit13 (Calibrate) of register 0 to ‘1’. It is recommended to use the calibration measurement.

For calibration, the TDC measures one and two reference clock cycles, which are stored as Cal1 and Cal2. There are two ways to update the calibration data Cal1 and Cal2:

Individual calibration by sending the Start_Cal_TDC command via the SPI interface;

Automatic update by setting Bit12 (NO_CAL_Auto) = ‘0’ in register 0. Automatic updating is preferred in most applications.

e. Define ALU data processing

Although each channel of the TDC unit can measure four times, users have the freedom to define which two signals' time difference the ALU calculates. This can be configured in registers 1, with bits 16-19 (HIT1) and 20-23 (HIT2). Specifically set as:

0= Start

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

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

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

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

6= Cal1 Ch1

7= Cal2 Ch1

ALU calculated Hit1 - Hit2.

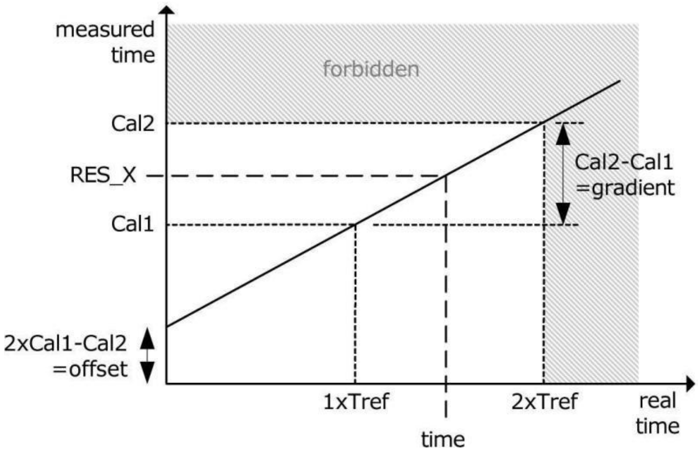
e.g.
Reg1 = 0x01xxxx - 1st Stop Ch1-Start
Reg1 = 0x2Bxxxx - 3rd Stop Ch2-2nd Stop Ch1
Reg1 = 0x06xxxx - Cal1

If calibration is performed, the ALU will conduct a full calibration calculation (excluding the ongoing calibration value reading). In this scenario, the ALU will write the raw data Cal1/Cal2 into the output register.

$$\mathbf{RES\_X = (HIT1 - HIT2) / (Cal2 - Cal1)}$$

$$Cal2-Cal1 = gradient$$

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



f. Selection of input trigger method

By setting register 2, Bit 27 & 28 (REFDGE1 & FEDGE2), users can choose whether to trigger STOP on the falling edge only (RFEDGE="0") or on both the rising and falling edges simultaneously (RFEDGE="1").

Additionally, users can utilize register 0, Bit 8-10 (NEG_X) to add an internal inverter to each input port (Start, Stop1, Stop2). When RFEDGE = 0, NEG_X = 0 triggers on the rising edge, while NEG_X = 1 triggers on the falling edge.

g. Disruptions

The interrupt pin Pin8,INT can have different interrupt sources, selected in Bits 29-31 (EN_INT) of Register 2 and bit 21 of Register 6.

Reg 2 bit 29 = 1 The ALU is ready.
Reg 2 bit 30 = 1 The set number of pulses is received in full.
Reg 2 bit 31 = 1 TDC measurement unit overflowed
Reg 6 bit 21 = 1 End of EEPROM action

If two or more interrupt sources are required, different options can be connected via the ‘or’ gate. This setting will be further described later.

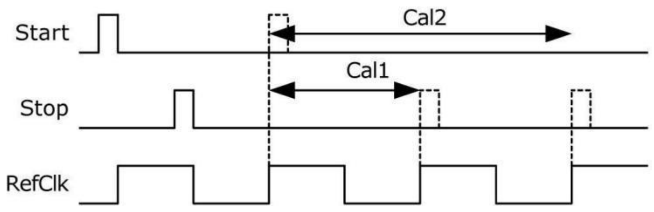
After the setup, the user must initialise the SL1922 by sending the code ‘Init’ in order for the TDC to be able to accept the Start and Stop signals.

Measurement

After initialisation, the TDC high-speed measuring unit receives the Start pulse and operates until.

- Set number of samples reached (max. 4 samples per channel in measuring range 1)
- Or after a measurement overflow (approx. 2µs in measurement range 1)

The time measurement raw data is stored inside the TDC. Bits 3-8 of the status register show the number of samples. If calibration is performed,after measuring the time difference, the TDC starts to measure one and two internal reference clock cycles (Tref *1,2 or 4). The calibration raw data (Cal1 and Cal2) are also stored inside the TDC.



Data processing

At the end of measurement, the ALU begins processing data according to HIT1 and HIT2 settings and sends the results to the output register. If no calibration is performed, the ALU transfers 16-bit raw data to the output register. If calibration is performed, the ALU performs preconfigured calculations and transfers a 32-bit fixed-point number to the output register.

Set HIT1 = HIT2 = 5 to cut off the ALU.

The time taken for the ALU to operate is determined by whether or not calibration is performed and the supply voltage.

	Not calibrated	**Calibrated**
3.3V	t. b. d.	t. b. d.
2.5V	t. b. d.	t. b. d.

Assuming that ALU idle is selected as the interrupt source (set in REG2, EN_INT), the interrupt flag bit is set whenever there is readable data in the result register. The load pointer of the output register is then incremented by 1 and points to the next cell to be stored. Bits 0-2 of the status register show the actual position of the load pointer.

Reading data

Now, when the user sends the code "10110ADR", data reading begins. Following this, SL1922 proceeds with either 16 cycles (for uncalibrated data) or 32 cycles (for calibrated data). The SL1922 outputs the results starting from the Most Significant Bit (MSB). The rising edge of the first SCK (Serial Clock) pulse will reset the INTN pin (interrupt).

a. Uncalibrated data format

Uncalibrated data is a 16-bit signed integer in the form of the complement of the binary. 1BIN = Uncalibrated gate delay time ≈ 75 ps at 3.3V and 25 ° C.

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

b. Calibration data

Calibration data is a 32-bit fixed floating point number in 2's complement form. It is a multiple of the reference clock.

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

The measured time difference must not exceed: 2 × Tref × ClkHSDiv, otherwise the ALU will overflow and write to the reference clock. Otherwise the ALU overflows and writes to the result register hFFFFFFFF.

The ALU is only allowed to calculate one sample at a time. If more than one sample is taken If more than one sample is computed, a new command must be written to HIT1/HIT2 to instruct the ALU to compute additional samples. After writing a command to HIT1/HIT2 t.b.d.μs (calibration value) or t.b.d.μs (calibration value) is written to HIT1/HIT2. (calibrated value) or t.b.d.ns (non-calibrated value) after a command is written to HIT1/HIT2, another read/write operation to HIT1/HIT2 cannot be performed.

```
e.g.:
Configure
...
Write reg1='h014400 4 samples on
channel 1
Calculate 1st Stop -Start
Initialise ...
while(check interrupt flag)

Write reg1='h024400 wait (4.6μs)          count
2nd-Start
Write reg1='h034400 wait(4.6μs)
3rd-Start                                 count
Write reg1='h044400 wait  (4.6μs)
4th-Start
```

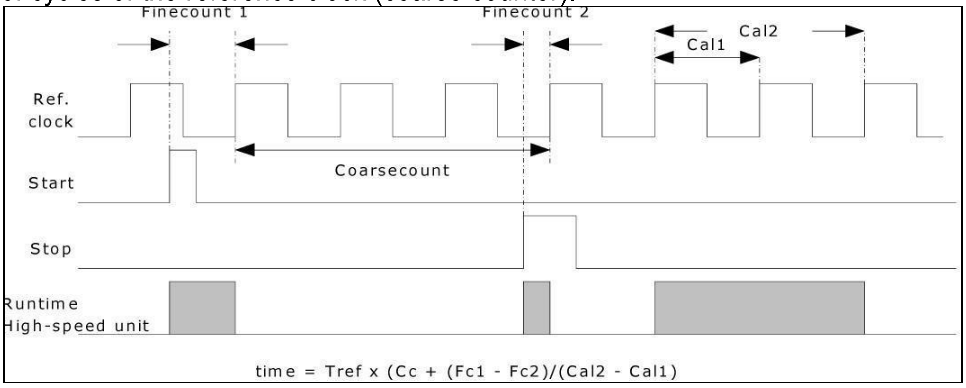
All samples are now stored in registers 0 to 3 and the load pointer now points to register address 4. Finally the SSP1922 has to be initialised again before the next measurement by sending the code 'Init' so that the TDC can receive the new Start and Stop signals.

Measurement range II

Introduction

- Has only one stop channel corresponding to the start channel
- Typical resolutions for are 19 ps / 37 ps / 75 ps
- Interval pulse pair resolution from 2 x tref to 4 ms @ 4mhz
- Measurement range: 2×tref～4ms @4mhz
- Has a 3-sampling capacity and automatically calculates the results.
- Optional rising/falling edge trigger
- Each individual stop signal has an adjustable window of 10ns accuracy to provide accurate stop enable
- Typical applications:Ultrasonic heat meter, water meter

The Time-to-Digital Converter (TDC) measures high-precision time intervals based on the propagation delay of signals through internal gates (referenced also in Section 1 of the measurement range). In Measurement Range 2, a pre-scaler is used to extend the maximum measurable time interval while maintaining the resolution. In this mode, the TDC's high-speed unit does not measure the entire time interval; instead, it measures the interval time from the START or STOP signal to the nearest rising edge of a reference clock (accurate counter). Between two precise measurements, the TDC counts the number of cycles of the reference clock (coarse counter).



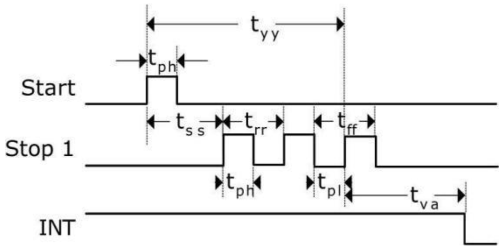
At 3.6V and 25°C, the SL1922 achieves a minimum resolution of 75ps. The RMS noise level is approximately 50ps (0.7LSB). The propagation delay of gates primarily depends on temperature and voltage. In Measurement Range 2, the measurement result comprises the sum of precise and coarse measurements. Therefore, calibration is necessary in Measurement Range 2. During calibration, the TDC measures one or two cycles of the reference clock separately.

Calibrated data is unaffected by voltage and temperature variations. The measurement range is limited by the size of the coarse counter:

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

The time difference between Start and Stop is calculated in the 26-bit measurement range.

	length	description
tph	2.5 ns (min.)	Minimum pulse width
tpl	2.5 ns (min.)	Minimum pulse width
tss	2×Tref	Between Start and Stop @ Dis_Phasenoise=1
trr	2×Tref	Rising edge to rising edg
tff	2×Tref	Falling edge to falling edge
tva	4.6µs(max)	ALU start to data validity
tyy	4ms (max)@ 4MHz	Maximum measuring range= 2^{14}×Tref



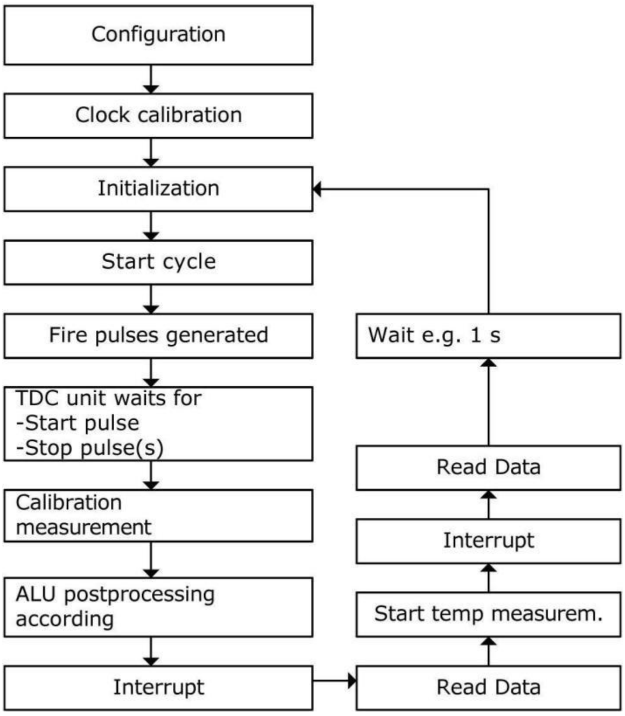
Each input can be individually configured for rising or falling edge triggering and the trigger edge can be selected by setting bit0-2 (NEG_START, NEG_STOP1) of register 0. In addition, all START/STOP input ports support high level activation.

Note: If the time difference between Start-Stop is less than the minimum time limit tzz, the TDC will ignore all time difference pulses less than tzz.In no case will an incorrect result occur.

Measurement process

Setting

The SL1922 must be set up before you can start using it.
The main settings for measuring range 2 are:



a. Selection of the measuring range 2

Set register 0, Bit11, MRange2 = 1.

b.Selection of reference clock

In measurement range 2 the SL1922 requires a high-speed clock for interval measurements. In low-power applications, the clock can be switched between measurements. A clock of 32.768 kHz is necessary for the power-up timing control of the high-speed oscillator.

Bits 18 & 19 of register 0, START_CLKHS, are used to switch the high speed clock. If only the high-speed clock is used, set to 1; if both oscillator clocks are used to save current, set to 2 for ceramic oscillator and 3 for quartz oscillator.

Register 0, Bits 20&21,DIV_CLKHS is used to set the internal divider value of the reference clock (1, 2 or 4). This selection has an effect on both the minimum time interval and the maximum time interval.

This selection has an effect on both the minimum time interval and the maximum time interval.

The minimum time interval is: t = 2×Tref ×2ClkHDiv

The maximum time interval is: t = 214 × Tref × 2ClkHDiv

It must also be ensured that 2 × Tref × 2ClkHDiv < 2.4 μs.

Otherwise the ALU overflows during calibration and outputs the value 0xFFFFFFFF.

Note: The divided clock frequency must be in the range of 2Mhz to 8Mhz in single and double precision modes, and 2MHz to 6Mhz in quad precision mode.

c. Setting the required number of pulses

The user can set the number of hits to be measured by the SL1922 in register 1,bits 8-10 (HITIN1). In measurement range 2, channel 1 can be measured up to 3 times. Since Start is also counted as a sample, the value of HITIN1 is always 1 more than the set number of samples, and the SL1922 will continue to measure until the preset number of hits is reached or an overflow occurs Register 0,bits 11 to 13 (HITIN2) must be set to 0. For example, if you want to receive 2 stop pulses, you can set the number of hits to be measured in registers 1,bits 8 to 10 (HITIN1).
Example: If you want to receive 2 stop pulses, set HITIN1 = 3, HITIN2 = 0.

d. Selection of calibration

The calibration measurement can be selected by setting Bit 13 (CALIBRATE) of register 0 to ‘1’. Calibration is required in measurement range 2.

The TDC measures one and two reference clock cycles for calibration, and these two data are stored as Cal1 and Cal2. There are two ways to update the calibration values Cal1 and Cal2.

Individual calibration by sending the Start_Cal_TDC command through the SPI interface.

Automatic calibration is preferred in most applications by setting Bit12 of register 0 with NO_CAL_AUTO =0.

e. Define ALU data processing

By setting EN_AUTOCALC_MB2 = 1, the SL1922 will automatically compute all received pulses and write them into the respective registers. Additionally, it calculates the sum of three results and writes this data into Result Register 3. This simplifies communication between the microcontroller and SL1922, as there is no need to rewrite the calculation operand into Register 1.

When EN_AUTOCALC_MB2 is set to 0 to disable automatic calculation, the ALU computes one sample per operation. You can specify which two pulses to calculate the time interval between by setting HIT1 (Bit24-27) and HIT2 (Bit28-31) in Register 1. Due to the specific measurement method of Measurement Range 2, the Start pulse is internally treated as the Stop pulse within the TDC. Examples of Register 1 settings include:

Reg1 = ’h21xxxx = Calculate 1st Stop Ch1-Start
Reg1 = ’h31xxxx = Calculate 2nd Stop Ch1-Start
Reg1 = ’h41xxxx = Calculate 3rd Stop Ch1-Start

ALU calculated the time interval as follows.

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

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

f. Select input trigger method

By setting Bit27&28 (RFEDGE1&RFEDGE2) of register 2, user can select whether the STOP input is triggered by the rising or falling edge alone (RFEDGE = 0) or both the rising and falling edges (RFEDGE = 1). The user can set Bit8-10 of register 0 (NEG_X) to trigger on every rising or falling edge.(NEG_X) to add an internal inverter to each input port (Start, Stop1 and Stop2).

When RFEDGE = 0, NEG_X = 0 triggers on the rising edge and NEG_X = 1 triggers on the falling edge.

g. Interruption

The interrupt pins (PIN8, INTN) can have different interrupt sources, which are selected in register 2 Bit 29-31 (EN_INT), register 6 Bit 21 (EN_IN).
EN_INT = not set No interrupt source
reg2 Bit29 ALU completed calculation
reg2 Bit30 Pre-set number of samples reached reg2 Bit31 TDC unit overflowed
reg6 Bit21 End of EEPROM action

Different options can be connected via a contingency gate. The first rising edge of SCK will reset the INTN pin (interrupt pin). After setting, the user must initialise the SL1922 by sending the code ‘Init’ so that the TDC can receive the Start and Stop signals.

Measurement

After initialisation, the TDC unit receives the first pulse on the Start channel and starts working until:

The preset number of samples is reached (up to 3 samples on channel 1 in measurement range 2) or a measurement overflow is encountered. The overflow time can be limited by selecting a different reference lock factor by setting Bits 27 & 28 of register 3 (SEL_TIMO_MB2). At 4 MHZ, the corresponding values are as follows:

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 two reference clock cycles for calibration.

Data processing

At the end of the measurement, the ALU starts to process the data according to the HIT1 and HIT2 settings and sends the results to the output registers.The ALU calculates according to the pre-set settings and transfers a 32-bit fixed floating-point number to the output registers.

The time taken by the ALU to perform the calculations is determined by the supply voltage.

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

As long as the output result register data is valid, the interrupt bit will be set (assuming the ALU interrupt is on, see register 2, EN_INT). In addition the result pointer will be incremented by 1 and will point to the next empty address. The current result address pointer can be seen in the status registers, Bit0-2.

Reading data

Now the user sends the code 10110+ADDR to be able to read the data. The SL1922 then performs 32 cycles (calibration data) and outputs the result from the most significant bit (MSB).

The calibration results are displayed as 2's complement 32 bit fixed floating point numbers representing the time interval in minimum units of the reference clock period.

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

Finally the SL1922 must be initialised again before the next measurement by sending the code ‘Init’ so that the TDC can receive the new Start and Stop signals.

Functionality

Stop Shielding

If you do not want to receive any samples, the SL1922 can be set up with a blocking window to block any of the three pulses on channel STOP1. The masking window starts with the START signal and has an accuracy of more than 10 ns. The internal enable unit is connected to the external enable pin through a logic gate. The external START and STOP1 enable pins must be set to 1 when the internal mask is used.

The following settings can be made in DELVAL1, DELVAL2 and DELVAL3 of register 4:

- DELVAL1,DELVAL2 and DELVAL3 are fixed floating point numbers consisting of a 14-bit integer part and a 5-bit decimal part to be multiplied by the internal reference clock period:

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

- The minimum blocking time for the is 3 clock cycles
- mask values must be in ascending order and each mask value must be 3 clock cycles greater than the previous value
- If not all mask windows are applied, then the unwanted mask values must be forced to 0. When all DEVAL registers are set to 0, then this unit will be closed.

e.g.:

4 Mhz reference, ClkHSDiv = 1

DELVAL1 = ‘h3200 is allowed to receive the first pulse 200 μs after the start signal (128000/32 × 250ns × 21 = 200 μs) DELVAL2 = “h3300 is allowed to receive the second pulse 204 μs after the start signal (13056/32 × 250ns × 21 = 204 μs) DELVAL1 = ”h3400 is allowed to receive the second pulse 208 μs after the start signal (13056/32 × 250ns × 21 = 204 μs) DELVAL1 = ‘h3400 The third pulse is only allowed after 208 μs of the start signal (13312/32 × 250ns × 21 = 208 μs).

Analogue input section

Compared to the GP2, the SL1922 integrates an additional analog circuit input section which serves as an alternative input to the digital input section. This feature significantly simplifies circuit design, particularly in ultrasonic heat flow measurement applications, reducing the peripheral circuitry design for ultrasonic circuits to just two resistors and a capacitor connected to one end of the transducer.

The input ultrasonic signal typically consists of 10-200 sinusoidal oscillations with amplitudes in the range of several hundred millivolts. This signal is high-pass filtered and coupled to the input. Due to the internal comparator's inability to trigger at zero crossing, its trigger voltage is set at 1/3 VCC. An analog selector chooses different measurement inputs based on the measurement direction. A chopper-stabilized comparator ensures low voltage zero drift (less than 2mV), which is essential for high-quality measurements. The comparator's zero drift is frequently calibrated internally through chopper circuits to adjust automatically to less than 2mV in case of temperature or voltage fluctuations over time.

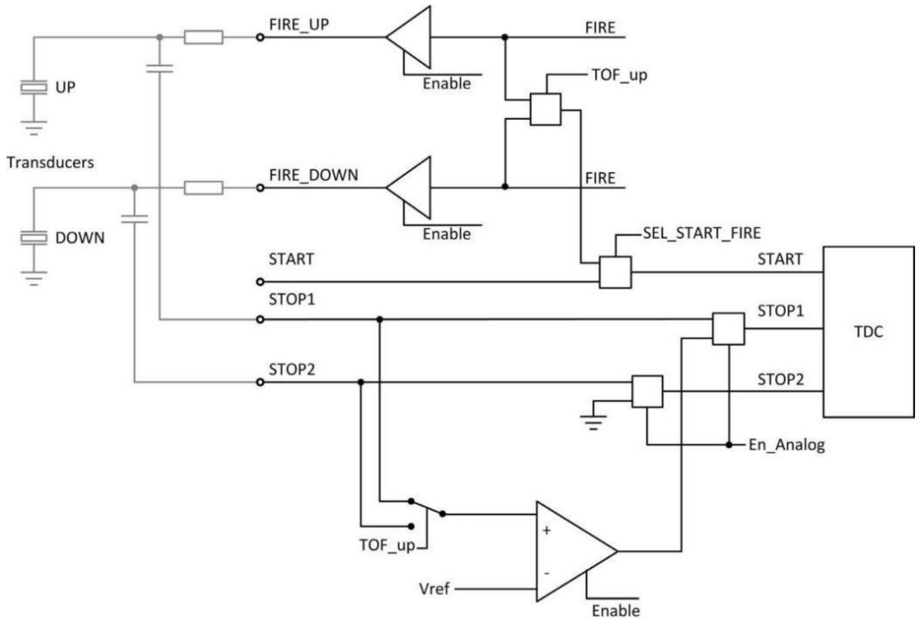
All components are controlled via the control unit of the SL1922. They are switched on only during the measurement process, thus reducing the overall measurement power consumption.

The command Start_TOF_Restart will start an ultrasonic time difference measurement in the following order.

- MHz high-speed oscillation will be switched on. The chip waits for a delay until the oscillator reaches full amplitude;
- The reference voltage of the comparator and the analogue switches will be powered;
- The capacitor for the transmit signal channel (STOP1) will be connected to GND;
- The downstream Fire transmit buffer (FIRE_Down) is also connected to GND;
- The receive signal channel (STOP2) capacitor will be charged to Vref and TDC waits for the delay set in TW2;
- The analogue switch will select the STOP2 input as the input to the comparator side;
- FIRE_UP selects the input to the TDC as the START signal;
- The set number of fire pulses will be sent at pin FIRE_UP;
- The analogue signal is transferred to the comparator via the STOP2 pin and converted into a digital signal for the STOP input of the connected TDC unit;
- When the time of the STOP blocking window has been reached (DELVAL), the TDC is ready to start the measurement. It can measure up to 3 STOP pulses;
- At the end of the measurement the control unit switches off the comparator, as well as the analogue switches and the 4Mhz crystal, and the current is lowered close to zero, at which point the interrupt is set;
- The control unit will wait for a time given in multiples of 50Hz/60Hz; during this time the microcontroller has to read out the previous.

Measurement results

After a time delay, the same process will be repeated in a downstream measurement.



The offset voltage of the comparator can be set on a 1mV basis from - 8mV to +7 mV. This setting is made via the parameter DA_korrt, Bit 25-28 in register 6 and is given in 2's complement.

In addition, when applying the first wave mode, the comparator offset for the first wave recognition can be additionally set to ±35mV.

First-wave mode

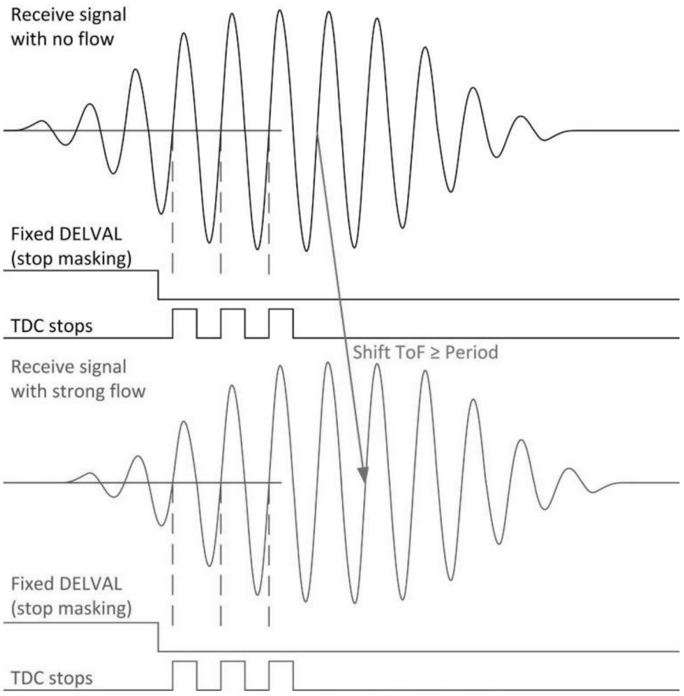
The main enhancement of the SL1922 chip is the integration of a first wave recognition mode, which is based on the internal analogue part of the Measurement Range 2 application. As a new feature, this offset voltage offset is automatically controlled to safely detect the first wave pulse and then measure the ToF flight time of the desired echo based on the position of the first wave.

In addition, the width of the half cycle of the first echo is compared to the width of the half wave of the true time-of-flight measurement and the ratio is used as an indication of the signal strength. Since the offset noise is very reduced, a clear indication can be given when there is no water in the tube section. The new features are summarised below:

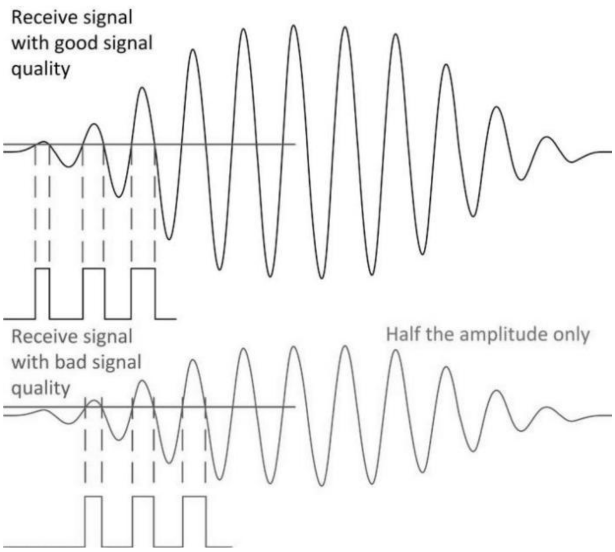
- Safe first wave detection allows for highly dynamic applications such as ultrasonic water meters
- Highly dynamic applications allow the application of high frequency ultrasonic transducers such as 2MHz or 4MHz.
- Water backflow can also be recognised and processed (e.g. very useful in water metering).
- Pulse width measurements can help detect received echo signals and can signal alarms based on triggered amplitude levels
- Offset voltage offset Low noise and can give a signal for empty tube sections.

The figure below depicts the importance of the first wave detection in high dynamic range measurements such as ultrasonic water meters. Because of the fixed stop shielding window (fixed DALVAL value) it is not possible to determine if the time of flight varies by more than one drive cycle. There are many factors that can cause the time-of-flight to vary by more than one cycle. One very important factor is the effect of temperature which will change the speed of sound of the ultrasound. For relatively slow systems such as ultrasonic heat meters, this effect can be corrected by intelligent software. However, for highly dynamic systems such as water meters, where the direction of flow is uncertain, this approach cannot be applied.

The current trend is to use high-frequency transducers such as 2MHz and 4MHz transducers, which can handle the situation when external influences are greater than one ultrasonic cycle.



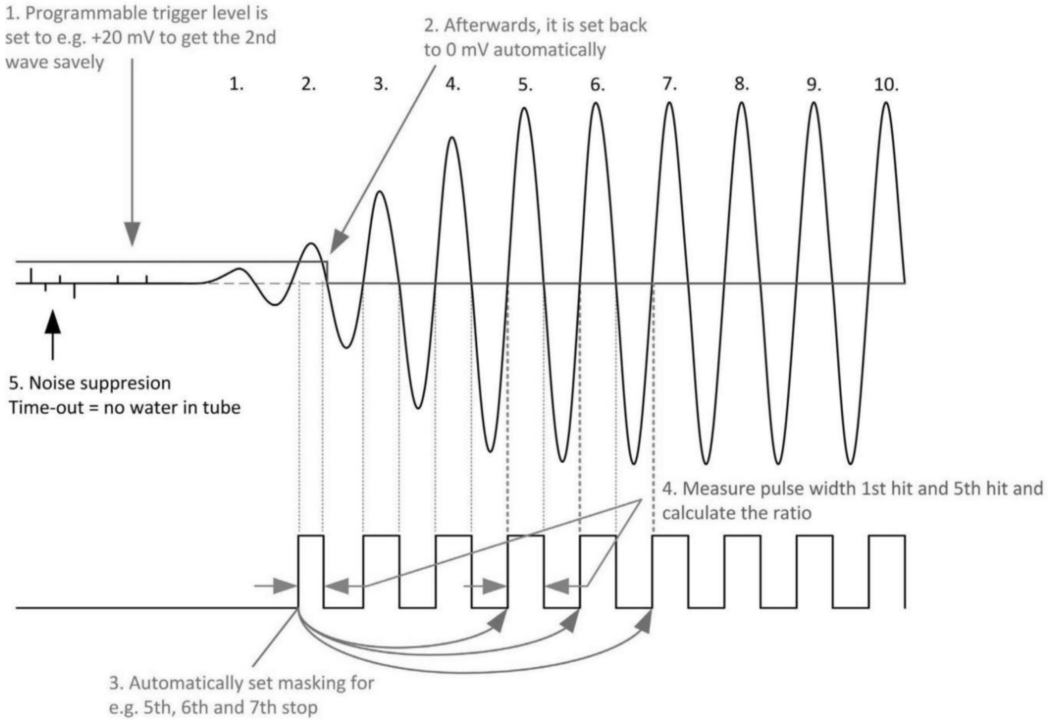
There is also the possibility of obtaining incorrect measurements. These are coverings on the measuring transducer, on the measuring mirror or on the measuring housing. These coverings will cause an attenuation of the measured signal from ±400 mV to < ±80 mV. The figure on the right shows how this problem affects the identification of the first wave when only a fixed offset is applied to detect the first echo. As soon as the amplitude of the first wave is below the offset value, the measurement will jump by one cycle.



With the SL1922's first-wave detection function, the chip measures pulses in relation to the time of the first echo, independent of the fluid temperature and fluid velocity. As a result, incorrect zero detection and identification of the zero point no longer occurs.

In addition, the measurement of the pulse width of the first wave allows the user to monitor the quality of the measured signal and, if necessary, to adjust the desired pulse according to this pulse width ratio.

The following figure shows the measurement flow of the SL1922 in first wave mode:



1. Pulse generator that sets the offset voltage offset of the comparator required for the first wave detection to a programmable level.

The stop blocking window of DELVAL1 is used to suppress noise in the period before the stop pulse, and can be set roughly to the time of flight before the stop reaches the channel. Other noise will be further suppressed by the offset of the comparator until the received signal reaches the amplitude level set by the offset.

2. The SL1922 measures the pulse width of the first wave. It will then automatically set the offset back to 0mV. Since the temperature drift of the chip's offset is less than 1mV, the drift of the measurement is very small.

3. The shielding window for the three time measurements is set in the parameters DELREL1 to DELREL3, which are set relative to the pulse of the first wave. For example, if you set DELREL1 = 3, then after the first wave is measured, the echo time of the third wave will be measured.

4. The half-wave period (hwp) of the first true time is also measured and recorded, and will be used as a reference for comparing with the width of the first wave. In the figure above, it is the width of the 5th pulse. The ratio hwpfirst wave/hwpfirstToF is generally in the range 0-1. The smaller the ratio, the weaker the received signal. This information can be used to monitor fluid properties. If there is too much sediment in the tube section or on the transducer over a long period of time, the ratio may drop below 0.5 and the second pulse can be used as a reference for future measurements.

5. The SL1922 will automatically calculate all 3 stop pulses and then calculate the average value of these 3 pulses, which can be read out in register 4. In this way, communication with the microcontroller is greatly simplified. As soon as the interrupt is set, the microcontroller can read out the measurement result and the average value. There is no need to resend commands to register 1 as in GP2.

6. Once the tube section is empty, no stop signal will be generated. The value of offset will remain at the value set for detecting the first wave. In this case, the noise will not trigger the TDC and the TDC will give an overflow.

In other words: the measurement of overflow is a very important judgement condition for the empty tube section.

Configuration of registers in first wave mode:

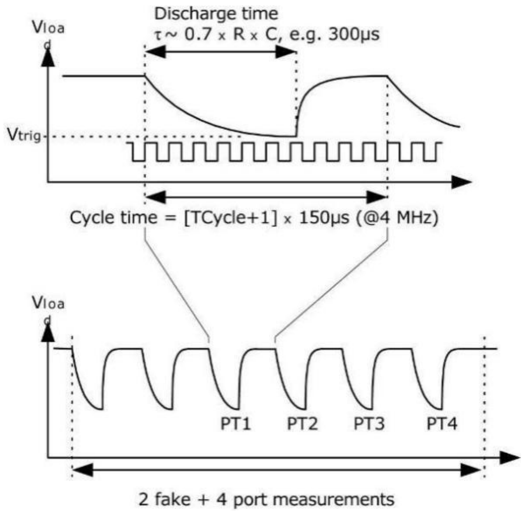
Processor Register	Bit	Parametric	Description
3	30	EN_FIRST_WAVE	1 = mode of the first wave, registers 3 and 4 will have new meanings
4	8-12	OFFS	Set the offset of the comparator in 2's complement, in 1mV steps. 0 = 0 mV 1 = +1 mV ... 15 = +15 mV 16 = -1 mV 17 = -2 mV ... 31 = -16 mV
4	13	OFFSRNG1	Additional offset magnitude of +20 mV added
4	14	OFFSRNG2	Additional offset amplitude of -20 mV is added.
3	8-25	DELREL1 DELREL2 DELREL3	Mask window to select the time of flight for which you wish to measure the first echo. The maximum number of pulses that can be selected is the 63rd. . DELREL1 ≥ 3. DELREL1 to DELREL3 must be set in an increasing trend. Example: DELREL1 = 3, DELREL3 DELREL1 = 3, DELREL2 = 4, DELREL3 = 5 means that the echo times of the 3rd, 4th and 5th waves are measured.
4	16	DIS_PW	0 = On 1 = off Pulse width measurement function, the ratio can be read from address 8. Register PW1ST is an 8-bit fixed floating point number with 1 integer bit (range 0 to 1.99).
4	15	EDGE_FW	0 = rising edge 1 = falling edge Sets the first wave edge sensitivity. When set to a negative value, the Suitable for triggering by falling edge, i.e. negative amplitude triggering.
3	31	EN_AUTOCALC_MB2	1=On to count all received pulses. The measured sum is stored in register 4.

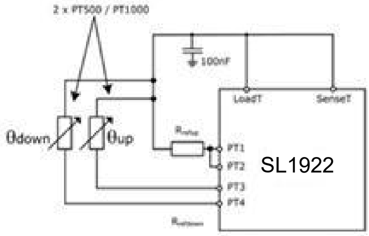
Temperature measurement

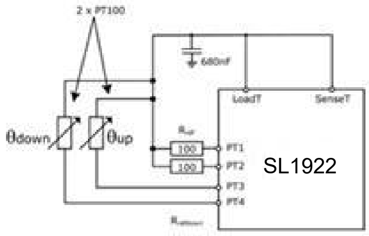
Overview

For heat meter applications, the SL1922 has a high accuracy temperature measurement unit that provides high accuracy and low power consumption. The measurement is based on the discharge time of the resistor to the capacitor. Therefore the capacitor will be discharged separately for the reference resistor and the temperature sensor resistor.

In contrast to the GP2, the SL1922 integrates a comparative Schmitt gate inside the chip.







The Temperature Measurement Unit has 4 resistance measurement ports, 2 of which are used as temperature sensor measurement ports for hot water (upstream) and cold water (downstream) measurements, and the other two are used to connect a reference resistor. Normally only one reference resistor needs to be connected to both ports.

The minimum resistance of the temperature sensor must not be less than 500 ohms. The length of the wires must not exceed 3 m. The SL1922 can only measure 2-wire sensors, it is not possible to apply 4-wire sensors. The accuracy of the temperature measurement with PT500 or PT1000 is perfectly suited to the requirements of the heat meter. When using PT500 or PT1000 sensors, two reference resistors can be dispensed with. Typical applications with one reference fixed resistor can be seen in the diagram below.

The SL1922 also supports the measurement of PT100 sensors, but the stability of the measurement will be reduced. In this case, it is recommended to connect both reference resistors instead of only one. This will help the measurement to pass the temperature difference between the two points. This will help to compensate for the gain shift of the temperature sensor over the entire temperature range with a two-point temperature comparison.

The temperature measurement is fully automatic. By sending the opcode Start_Temp or Start_Temp_Restart through the microcontroller. by sending Start_Temp_Restart, the SL1922 will measure the temperature twice, with a time delay between the two times that is a multiple of 50 Hz/60Hz. This will help to reduce the 50 Hz/60 Hz noise. For a single temperature measurement, the SL1922 first takes 2 or 8 warm-up pseudo measurements on the PT1 port and then takes temperature measurements in the order PT1 > PT2 > PT3 > PT4 ports. The interrupt flag bit will be set at the end of the 4-port measurement. The SL1922 can also perform temperature measurements in reverse port order, in which case the warm-up measurement will start at port PT4.

The 4 measurement results will be found in the result registers 0-3. The microcontroller can then calculate the ratio R_{temp}/R_{ref} from RES_2/RES_1 and RES_3/RES_4. By consulting the temperature table, the current measured temperature of the sensor can be obtained.

Related Configuration Register Descriptions

- Bit 15 of memory 0, ANZ_FAKE sets the number of temperature measurement warm-up measurements at the start. This setting is necessary to overcome the mechanical effects of capacitor charging and discharging.
  ANZ_FAKE = 0 2 warm-up measurements
  ANZ_FAKE = 1 8 warm-up measurements
  Bit 16 of register 0, TCYCLE, sets the cycle time of the temperature measurement.
  TCYCLE = 0 128 μs cycle time @ 4MHz
  TCYCLE = 1 512 μs cycle time @ 4MHz
- Bit 17 of register 0 of , ANZ_PORTS how many temperature measurement ports will be used.
  ANZ_PORTS = 0 2 ports = 1 sensor
  ANZ_PORTS = 1 4 ports = 2 sensors
- Bit 11 of register 6, TEMP_PORTDIR Order of measurement ports
  TEMP_PORTDIR = 0 PT1 > PT2 > PT3 > PT4
  TEMP_PORTDIR = 1 PT4 > PT3 > PT2 > PT1
- Bit 5 of register 6 of , HZ60 sets the time reference for the delay of the Start_TOF_Restart and Start_Temp_Restart commands between upstream and downstream measurements.
  HZ60 = 0 50 Hz reference
  HZ60 = 1 60 Hz reference
- Bits 18 and 19 of register 6 of , CYCLE_TEMP, set the timer coefficient for triggering the second temperature measurement in 50/60Hz multiples.
  CYCLE_TEMP = 0 0.5
  = 1 0.75
  = 2 1
  = 3 1.25
- Bit 30 of register 6, NEG_STOP_TEMP will reverse the signal on the Sense T path. This setting is used within the application. It is mandatory to set the comparator. When not inverted, the temperature measurement unit is fully compatible with the external Schmitt trigger circuit of the GP2.
  NEG_STOP_TEMP = 0 not inverted, compatible with GP2
  = 1 inverted, must be set when applying the internal comparator

Recommended capacitance

For accurate measurements, we recommend capacitors with very low dC/dU. We recommend the C0G series type capacitors or the CfCap series from TAIYO YUDEN.

Since the discharge time is approximately 150 μs, the following capacitance values should be selected.
PT500: 220 nF
PT1000: 100 nF
Set Tcycle = 1 to avoid overflow errors.
Do not use X7R or similar capacitor materials in heat meter applications.

Current consumption

Temperature measurements with the SL1922 have a very low current consumption compared to temperature measurements with an A/D converter.
A complete temperature measurement (2 sensors, 2 references), including all calculations, consumes less than 2.5μA/s. If a temperature measurement is performed every 30 seconds (typical measurement frequency of a calorimeter), the average current consumption is 0.08μA, which is less than 1/50th of the power consumption of the other measurement methods. a PT500 sensor doubles the current.

Error monitoring

The temperature measurement unit also has a function to check the availability of the result. It detects whether the sensor is short-circuited or open-circuited, and then the SL1922 puts 11 or 12 of the status register in position 1 and writes an error code to the corresponding result register.

- Short-circuit: Equivalent to a time interval that is too short (< 8 x tref = 2 μs @ 4 mhz), the sl1922 will write 0x0 in the output register.
- Sensor break: Equivalent to no stop signal or time overflow, the ssp1922 writes 0xffffffff in the output register. Note: When selecting a cycle period of 512 μs (tcycle = 1) for temperature measurement, you must make sel_timo_mb2 2 ms, otherwise the interrupt flag (intn) obtained otherwise the interrupt flag (intn) obtained may be incorrect.

Gain Error and Mathematical Algorithm Compensation

The temperature measurement of the SL1922 is based on the conversion of the resistance change on the temperature sensor into a highly accurate time interval measurement. Due to the delay time of the Schmitt trigger a very significant gain error is introduced, which results in a gain reduction of the measurement result compared to the ideal result. This reduction can be described as an offset error in a straight line. Therefore, a simple arithmetic correction can be made to compensate for the offset from the ideal value by giving a gain compensation factor. The correction for this factor is as follows:

T_{corr} = tuncorr/gainfactor tcorr: Temperature result after gain correction;

T_{uncorr}: Temperature result without gain correction;

Gainfactor: Gain correction factor to compensate for the deviation from the ideal gain of 1.

By means of this compensation, the delay time of the schmitt trigger can be reduced to 0.05% of the amplitude of the gain error caused by applying the internal schmitt trigger or by applying an external 74ahc14 schmitt trigger.

Three main parameters must be taken into account to select the gain correction factor:

- Base resistance of temperature sensors (e.g. PT500,PT1000)
- Applying Schmitt Trigger (SL1922 internal or external 74AHC14)
- SL1922 Supply Voltage

The corresponding correction factors are provided in the previous table. Caution:

Our gain correction coefficients for external Schmitt triggers are based on measurements obtained with the 74AHC14. Other types (e.g. 74HC14) require different gain correction factors to ensure correct compensation of the gain. Therefore, if an external Schmitt is required, we strongly recommend applying the 74AHC14 as an external Schmitt trigger.

Example 1:

When applying a PT1000 temperature sensor, the SL1922 has an internal Schmitt trigger and a 3V supply voltage. According to the previous table the gain factor is 0.9931. The corrected result of the gain can be made using the following formula:

$$Tcorr = Tuncorr/0.9931$$

Example 2:

Application of a PT500 temperature sensor with external 74AHC14 Schmitt trigger and 3.6V supply voltage. The gain coefficient is 0.9980, so the gain-corrected result can be obtained using the following equation:

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

Oscillator

The SL1922 can be connected to up to 2 clock signals depending on the operating mode:

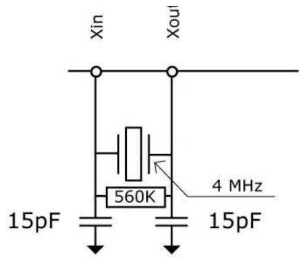
- High-speed clock - used for calibration and as coarse value counter for the TDC measurement unit in measurement range 2
- For EEPROM 32KHz clock - used as internal timer

High speed oscillator

Typically the SL1922 requires a high speed clock unit for calibration in the frequency range 2-8 MHz (2-6 MHz in quad precision mode), the recommended high speed clock frequency is 4 Mhz. The SL1922 also requires a high speed clock signal as part of the time measurement unit for measurement range 2, as well as a high speed clock for a number of other operations.

The average operating current of the crystal is 260 µA when it is always on, but the crystal only needs to be switched on for time measurements, and the SL1922 can control the switch-on time of the crystal via an internal circuit. The setting is done by setting the parameter START_CLKHS. Setting START_CLKHS > 1 turns the crystal on for measurements after the Start_TOF, Start_TOF_Restart, Start_Temp or Start_Temp_Restart commands have been sent. Set a delay between switching on the crystal and the measurement to ensure that the crystal has sufficient time to oscillate to full amplitude.

START_CLKHS = 0 The crystal is switched off.
= 1 Crystal on continuously
= 2 Delay 480 µs
= 3 Delay 1.46 ms
= 4 Delay 2.44 ms
= 5 to 7 Delay 5.14 ms



The delay set above ensures that the crystal has reached full amplitude between measurements. For ceramic crystals a delay of 480µs is sufficient for ceramic crystals. In this way the current consumption can be significantly reduced. Example.

In an ultrasonic flow measurement with one time measurement per second (to/from) the switch-on time of the high-speed crystal is only approx. 2 ms. the evaluated power consumption is 260 µA/s × 2 ms = 0.52 µA.

32.768KHz oscillator

The SL1922 requires a 32.768KHz reference clock to control the high-speed clock start and for clock calibration. It can also be used as a complete clock driver.

If the 32.768 kHz oscillator is always in operation, the current consumption is about 0.5 μA at 3 V. The start-up time of this oscillator after power-on is about 3 s. The 32.768 kHz oscillator cannot be switched off. The 32.768 kHz oscillator cannot be switched off. When the 32 kHz clock is not used, the CLKIn pin must be grounded. This low-power clock can be output to an external microcontroller as a clock source through the pin, the register setting is:

SEL_TSTO1 = 7: 32 kHz output on FIRE_IN pin.
SEL_TSTO2 = 7: 4 kHz (32kHz/8) at EN_START pin

An external low frequency square wave can also be supplied to the CLK32Out pin of the chip (3.6 V maximum).

Calibrating high-speed ceramic oscillators

The 2-8MHz ceramic oscillator is still attractive because of its low cost and fast start-up. However, it has a large error (0.3%-0.5 %) and has significant temperature drift. The SL1922 therefore compensates for this characteristic of ceramic oscillators by performing clock calibration calibration measurements. The measurements are based on an accurate 32.768kHz clock, the SL1922 takes a Star/Stop pulse from the 32.768kHz clock and starts the TDC unit to measure this differential. The result is stored in the result register and the interrupt flag bit is set. The microcontroller can read the result and calculate the frequency error of the ceramic oscillator.

The clock calibration can be set in bits 23 and 22 of register 0, ANZ_PER_CALRES, and is started when the system receives the START_CAL_RESONATOR command from the microcontroller.

Example:
Using a 4MHZ crystal, CLKHSDIV=0, ANZ_PER_CALRES=1, the theoretical result should be 122.0703125 μs/250ns = 488.28125 (RES_0 = 0x01E84800). If the ceramic oscillator is not exactly 4MHz but 3.98MHz, the calibration measurement will show 485,83984375 (RES_0 = 1E5D700). The microcontroller can calculate a correction factor of 1.005 from this.

Note: EN_START must be high during clock calibration.

How to use clock calibration

Application

This option is particularly suitable for ultrasonic flow/calorimetry. The use of ceramic oscillators in this field has two main advantages: low cost and low current consumption. Ceramic oscillators have a very short start-up time, so the current can be reduced by a few microamps. This saves several 100mAh batteries over 10 years of operation. This option has no effect on the accuracy of the chip, as long as it is operated correctly.

32KHZ Jitter in the clock and resulting effects

The frequency of the 32KHZ clock is very precise, with an error of only a few parts per million. However, the phase jitter between peak-to-peak is about 3-5 ns. The clock calibration measurement (Start_Cal_Resonator) is therefore inherently inaccurate. Therefore, when the measurement result is multiplied by the clock calibration result, the measurement result is also jittered. The jitter amplitude of the measurement result is the ratio of the jitter amplitude at the time of calibration multiplied by the calibration measurement time (ANZ_PER_CALRES) to the measured time. If the calibration is performed without interruption, the calibration value can cause considerable jitter in the measurement result.

Calibration in ultrasonic flow meters

In the ultrasonic flowmeter, the measurement result consists of ultrasonic wave propagation in the fluid downstream propagation and countercurrent propagation of the two one-way propagation time measurement. According to the ultrasonic countercurrent propagation and downstream propagation time difference, you can calculate the flow rate of the fluid. In order to avoid the influence of calibration clock jitter on the measurement results, the same calibration value must be used for the measurement of the downstream propagation time and the countercurrent propagation time. Only in this way will the time difference between the ultrasonic propagation downstream and against the flow be unaffected by jitter in the calibration clock. The clock calibration must be performed between the downstream and the countercurrent and before they are subtracted.

Pulse generator

Overview

The Trigger Pulse Generator generates a pulse train with adjustable frequency, phase and number of pulses. The high-speed oscillator frequency is used as the base clock. This frequency is internally multiplied and can be freely divided by a factor of 2-15. A pulse train of 1-127 pulses can be generated, and if up to 15 pulses are to be sent, the phase of each pulse train can be adjusted by setting a register. The trigger pulse generator is activated by sending the code Start_Cycle.

The pulse generator provides two outputs, FIRE_UP and FIRE_DOWN, each of which has a driving capacity of 96mA at 3.3V. In addition, each output signal can be inverted to double the amplitude of the signal. The output pins can be individually set to high resistance. In addition, the default inactive buffer can be set to GND.

The trigger pulse generator can also be used to generate and transmit a pulse train multiple times in a similar way to an acoustic loop. With this feature, the received pulse train is sent to the FIRE_IN input of the SL1922 and then digitally amplified and sent directly to the output buffer for clock synchronisation. This feature of the acoustic loop method cannot be used when applying the analogue section.

Configuration of the relevant registers

Number of pulses:

ANZ_FIRE =0 Turn off the pulse generator
=1 1 pulse
=2 2 pulses
... ...
=127 127 pulses

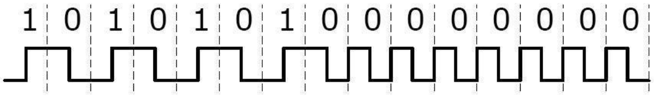
SEL_START_FIRE = 1 Fire pulses are given directly to the TDC's START signal
FIREO_DEF = 0 Default state High_Z (GP2 compatible)
= 1 Default state is GND. This setting is necessary if applying the internal analogue part, applying the recommended external circuit with R, C

Pulse phase:

The phase of the pulse can be defined in register 5, bits 0 to 15, PHFIRE, if the transmit pulse does not exceed 15 pulses. 0 means from low to high, 1 means from high to bottom. The pulse sequence starts with the lowest valid bit, LSB, and ends with the highest valid bit, MSB.

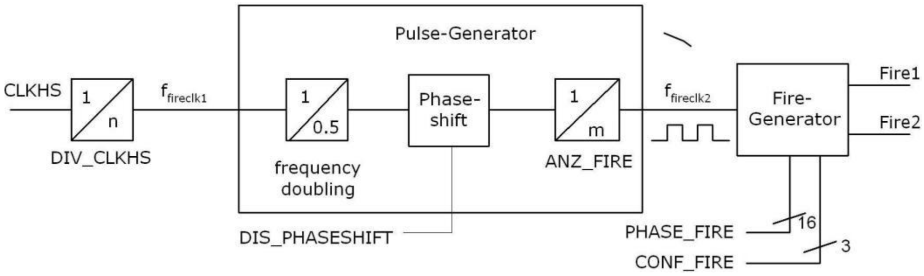
Example:

ANZ_FIRE = 7, PHFIRE = 0x0055



Frequency of pulse emission

The input signal fireclk1 of the pulse generator is derived from the high-speed clock CLKHS together with the selected crossover factor DIV_CLKHS.



The frequency of the base clock is internally multiplied and then divided by DIV_FIRE.

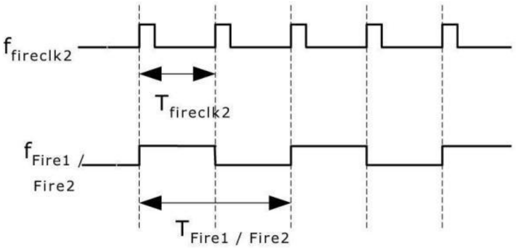
DIV_FIRE = 0 is not allowed.
1 divided by 2
... ...
15 divided by 16

Setting bit 27 of register 5 (DIS_PHASESHIFT) activates the phase shift function, which will add extra noise for better noise reduction in the subsequent averaging.

DIS_PHASESHIFT = 0 Shift is on.
DIS_PHASESHIFT = 1 shift off

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

ffireclk2 is used as a reference signal for the FIRE_UP/FIRE_DOWN signal in the output buffer from the pulse generator.



At least two Tfireclk2 clock cycles are required to send a pulse as shown above. One of them is used as the high phase of the FIRE_UP/FIRE_DOWN output and the other as the low phase.

Example:

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

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

FIRE_UP / FIRE_DOWN Maximum frequency of the output signal.

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

Output Driver:

The output drive can be set in Bits 29-31 of Register 5 (CONF_FIRE):

Bit 31 = 1 FIRE_BOTH (reverse on FIRE_DOWN signal)
Bit 30 = 1 FIRE_Up On
Bit 29 = 2 FIRE_Down

On Pulse group loop (acoustic loop method)

Bits 24-26 (REPEAT_FIRE) in register 5 set the number of cycles of the pulse train:

REPEAT_FIRE = 0 no loop
= ... 1 cycles 1 time
...
= ... 7 cycles 7 time

The S L1922 repeats only the number of pulses set in ANZ_FIRE. If no pulse is received within 5μs, the SL1922 detects the last pulse in the pulse train.

Caution:

This function cannot be used with the internal analogue section applied. Care must be taken that the total time of the 7 cycles does not exceed the measurement range of the SL1922.

Quick initialization

In measuring range 1, the SL1922 provides a fast initialisation. By setting register 1, 15 (EN_FAST_INIT) = 1, the interrupt flag automatically initialises the TDC.

1, the interrupt flag automatically initialises the TDC so that the TDC is ready for the next measurement as soon as the data is read out. This mode is only suitable for high-speed applications. This is particularly suitable for non-calibrated measurement modes with only one STOP signal.

Noise units

If the user wants to improve the results by averaging, it is not necessary to synchronise the results with the time difference. Instead, the user should provide some ‘noise’ so that the different quantisation steps of the TDC characteristic curve can be connected. This cannot be done for constant time difference, otherwise the same minimum RMS value will be sampled repeatedly.

The noise unit makes it possible to use a weighted average for constant time differences. The noise unit adds a random offset to the START. This applies to applications where the TDC receives a single START signal and then measures the time difference between STOP1 and STOP2 (e.g. laser rangefinders).

The noise unit can be switched on by setting bit 20 of register 5 (EN_STARTNOISE) = 1.

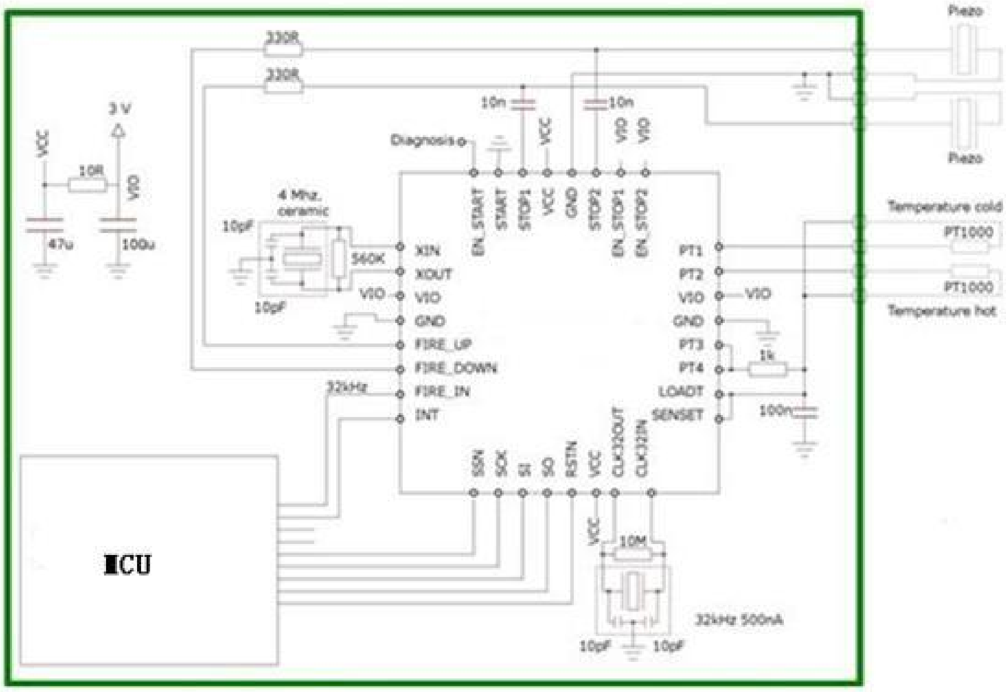
Typical applications of ultrasonic heat meters

Overview

The SL1922 is ideally suited to the design and application of low-power ultrasonic heat meters. Due to the internal functions of the chip, including the first wave auto-detection function, high-precision temperature measurement, pulse generator, analogue switches, comparator, STOP shielded window function, and clock calibration, only a simple external microcontroller (no AD required) is needed to carry out high-precision measurements.

The final circuit can be very compact and small in size. The following diagram shows a typical ultrasonic heat meter application SL1922

The following diagram shows the entire circuit of a typical ultrasonic heat meter design.



Minimization of the overall number of components.

- In the ultrasonic echo path, only the piezoelectric ceramic transducer is connected to a pair of resistors and capacitors.
- In the temperature measurement path, only an additional temperature stabilizing resistor and discharge capacitor are required.
- For the oscillator we chose a 32.768Khz quartz crystal and a 4M ceramic crystal. The FIRE_IN pin can be used to drive the output of the 32.768Khz crystal. Therefore the microcontroller does not need a low power oscillator.
- For the power section it is necessary to apply a bypass capacitor to decouple VCC and VIO. These are separated by a small resistor. In total, only 11 low-cost components are needed for all measurements.

Typical configuration of registers

Processor Register	Worth	Description
0	h A30B6800	ANZ_FIRE = 10 (see description of register 6). DIV_FIRE = 3, Pulse transmit frequency = 4 MHz/4 = 1.0 MHz. ANZ_PER_CALRES = 0, 4 MHz crystal is calibrated with a single 61.035μs measurement. div_clkhs = 0, 4 MHz ceramic crystal cycle is not divided as internal clock. start_clkhs = 2, Ceramic oscillator start-up wait time is 480μs. START_CLKHS = 2, ceramic oscillator start-up wait time is 480μs. ANZ_PORT = 1, apply all 4 temperature measurement ports. TCYCLE = 1, 512 μs as cycle time for temperature measurement. ANZ_FAKE = 0, 2 temperature warm-up measurements. SEL_ECLK_TMP = 1, 4 MHz crystal is applied to define the temperature measurement cycle time. CALIBRATE = 1, must be turned on for measurement range 2. NO_CAL_AUTO = 0, must be set to auto-calibrate in measurement range 2. MESSB2 = 1, turn on measurement range 2 to measure time differences > 2 μs. NEG_STOP/NEGSTART = 0, all channels are sensitive to rising edges. Note: If Start_TOF is used, it is recommended to set START_CLKHS = 1 and turn it off when the test is complete.
1	h 21444000	HIT2 = 2, HIT1 = 1: in measuring range 2 counts 1. Stop - Start. EN_FAST_Init = 0, closes HITIN2 = 0. HITIN1 = 4, measures 3 stop pulses (in measuring range 2, start also counts as one pulse) CURR32K = 0, applies. HITIN1 = 4, measure 3 stop pulses (in measuring range 2, start is counted as one pulse, total 4 pulses) CURR32K = 0, apply default. SEL_START_FIRE = 1, start signal is directly driven by fire pulse inside the chip. SEL_TSTO2 = 0, EN_START is on. SEL_TSTO1 = 0, FIRE_IN pin is used as pulse input. Note: According to this setting, the FIRE_IN and EN_START pins cannot be left idle.
2	h A0230000	EN_INT = b0101, the interrupt is given by a time overflow, the end of the ALU calculation or the end of the EEPROM action (see also register 6). RFEDGE1 = RFEDGE2 = 0, only the rising edge is applied. DELVAL1 = 8960, the first wave is received after 70 μs. Note: User can set the DELVAL1 value (i.e. blocking time) according to the actual echo signal.
3	h D0510300	EN_AUTOCALC = 1, automatically counts all 3 pulses. EN_FIRST_WAVE = 1, turn on the first wave detection mechanism. EN_ERR_VAL = 0, write 0xffffffff to result register when time overflow occurs SEL_TIMO_MB2 = 2 , overflow if no signal is received 1024 μs after start pulse. DELREL1 = 3, DELREL2 = 4, DELREL3 = 5, measure the 3rd, 4th and 5th stop pulses after receiving the first wave. Note: The user can set the number of stop pulses to be received according to the strongest wave after the first wave.
4	h 20004A00	DIS_PW = 0, pulse width measurement is enabled EDGE_PW = 0, pulse width measurement at rising edge OFFSRNG2 = 0, do not set negative offset value OFFSRNG1 = 1, OFFS = 10: total offset = 20 mV + 10 mV = 30 mV Note: The offset value can be adjusted according to the actual strength of the echo signal.
5	h 50000000	CON_FIRE = 2, FIRE_UP off, FIRE_DOWN = on. If the Start_TOF_Restart opcode is applied, then FIRE_UP and FIRE_DOWN will be used alternately for upstream and downstream measurements. The register setting described here turns on a downstream measurement cycle (FIRE_DOWN = on). EN_STARTNOISE = 0, on. DIS_PHASESHIFT = 0, the noise unit is turned on to better reduce the system error. REPEAT_FIRE = 0, no acoustic loop method required. PHASE_FIRE = 0, no phase change during the transmit pulse. Note: If Start_TOF is used, it is necessary to set CON_FIRE=1 again for a second test.
6	h C0C06000	EN_ANALOG = 1, Apply internal analog comparator circuit. NEG_STOP_TEMP = 1, Apply internal Schmitt trigger as temperature measurement DA_KORR = 0, Set comparator offset in register 4. TW2 = 3, 300 μs delay to charge the high pass capacitor. EN_INT = b1101, interrupt is given by time_out, ALU ready or end of EEPROM operation (see also register 6).
		START_CLKHS = 2, ceramic oscillator start-up time of 480 μs (see register 0) CYCLE_TEMP = 2, delay factor 1.0 applied between two measurements. CYCLE_TOF = 2, delay factor 1.0 between two ultrasonic time difference measurements HZ60 = 0, 50 Hz basis FIREO_DEF = 1, must be turned on when applying internal analog circuitry QUAD_RES = 1, applies 17 ps resolution DOUBLE_RES = 0 TEMP_PORTDIR = 0, standard temperature measurement sequence. ANZ_FIRE = 10 (see also description of register 0). Note: When using the Start_TOF_Restart opcode, CYCLE_TOF = 0, HZ60 = 0, the time between two flights (upstream and downstream) is a minimum of 8.3 MS; similarly when using the Start_Temp_Restart opcode, CYCLE_TEMP = 0, HZ60 = 0, the temperature measurement interval between two flights is a minimum of 8.3 MS. The minimum time between temperature measurements is 8.3MS.

Measurement process

Power-on reset:

Send SO = 'h50 Calibration Clock.
Send SO = 'h03 Start_Cal_Resonator Check-loop INTN = 0 ?
Send SO = 'hB0, read SI = RES_0
Calibration factor = 61.035/RES_0

Measurement 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 the microcontroller database table to find the appropriate temperature. Measure the time-of-flight interval every half a second:.
Send SO = 'h70 Initialize TDC Send SO = 'h05 Start_TOF_Restart Check-loop INTN = 0? (upstream TOF) Send SO = 'hB4, Read SI = STAT
STAT&'h0600 > 0: -> Error routine, timeout = empty pipe segment.
Send SO = 'hB3, read SI = RES_3 Send SO = 'h70 Initialize TDC Check-loop INTN = 0? (Downstream TOF) Send SO = 'hB4, read SI = STAT
STAT&'h0600 > 0: -> Error routine
Send SO = 'hB3, read SI = RES_3
The microcontroller can now start data processing and then calculate the values for heat and flow.

Check signal strength by pulse width: -> Error routine
Send SO = 'hB8, read SI = PW1ST
If PW1ST < 0.3 the signal is too weak, an alarm signal is sent.

Bug reports

TDC-CAL data readout data error

When the SL1922 is not turned on in 4-precision mode, the TDC-CAL values read out are incorrect. The main problem with this error is that the output to the result register is wrong, while the internally stored value is correct. Therefore it has no effect on the final measurement result. The problem only exists when reading the CAL calibration values.

Impact in measuring range 2:
For all users applying measurement range 2 this CAL is only an intermediate value and does not read out this intermediate value. And it is highly recommended to use
4 accuracy mode is highly recommended.

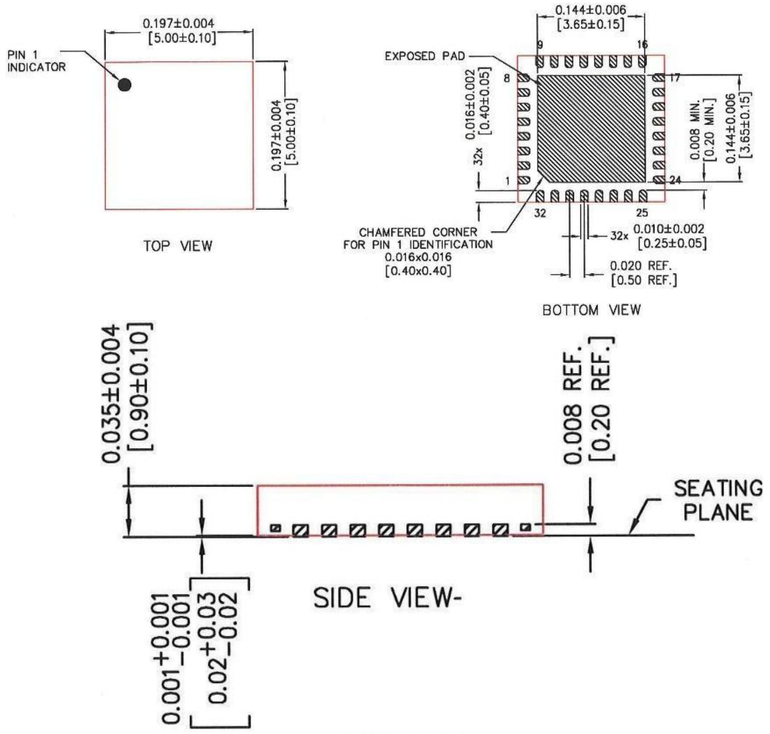
Impact in measuring range 1:
For all users, when applying the auto-calibration TDC, there is no effect on the final measurement result.
Only if the user applies a non-calibrated measurement in measuring range 1 and reads this CAL value externally, and performs a manual TDC calibration, this CAL value is not available. (This does not apply to applications such as ultrasonic heat meters, water meters, etc.).

Solution:
There are different solutions to this error, the better one being:
Instead of reading the calibration result after manual calibration, the user can store the calibration result in the TDC, and the ALU will automatically use the previous calibration result to calculate when measuring in the future. This has no effect on the final result.

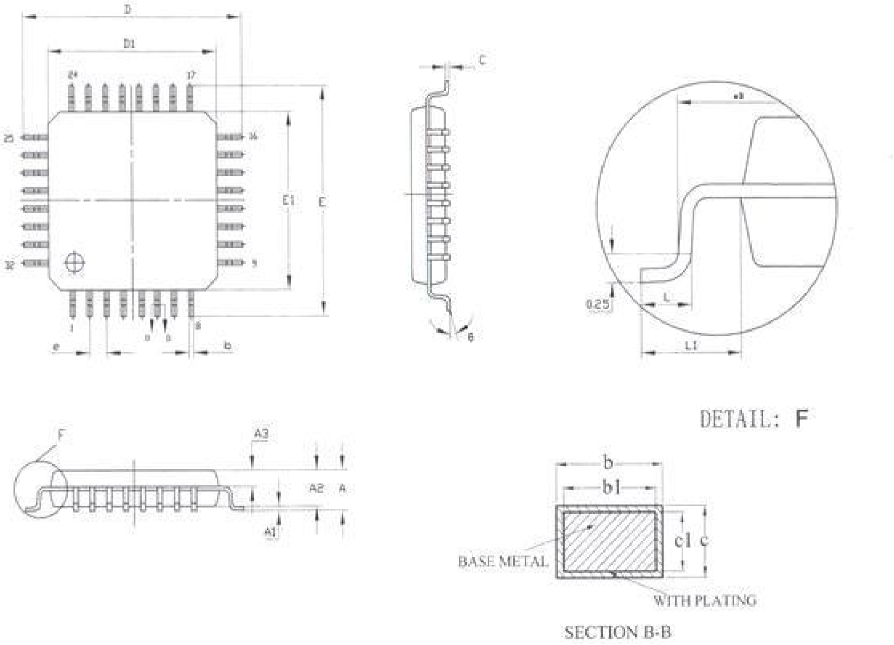
Time overflow error in temperature measurement
To avoid this error, when the cycle time of temperature measurement is 512 μs (TCYCLE in bit 16 of register 0), it is necessary to set SEL_TIMO_MB2 in bits 27 and 28 of register 3 to 2ms, otherwise the interrupt from the INTN pin may be incorrect.

Package Outline Diagram

QFN32



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		

Precautions

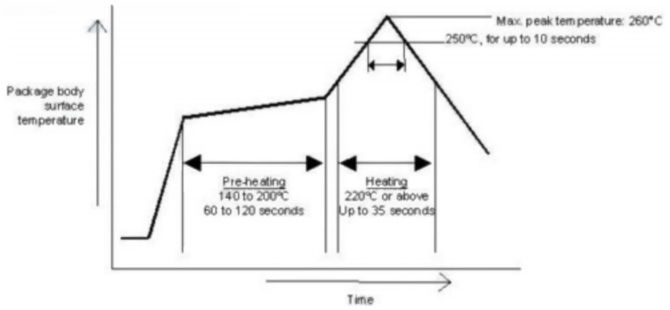
QFN-32 package size, 5 x 5 x 0.9 mm³, 0.5 mm lead spacing Notes.
Center pad, 3.65 * 3.65 mm3, internally connected to GND. In the following section, no connection other than GND can be made. It is not necessary to connect the center pad to ground GND.

Suitable socket type: Plastronics 32QN50S15050D

Thermistor: Approx. 28 K/W (values are for reference only). Environment: Package is RoHS certified and lead-free.

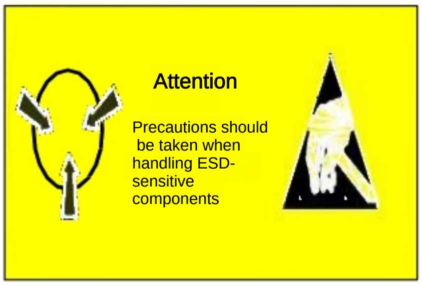
Moisture Sensitivity Classification (MSL): The SL1922 is classified as MSL 3 according to the definition of JEDEC 020 Moisture Sensitivity Classification Soldering Temperature Profile

The temperature profile of the IR reflow oven (temperature is the resin surface temperature) should be obtained within the temperature range described below as follows.



Highest temperature

The maximum temperature requirement for the resin surface is specified as 260° C as the peak temperature of the encapsulated chip surface, because the temperature on the resin surface should not exceed 250° C for 10 seconds. this temperature should be kept as low as possible to minimize the load caused by thermal interference during encapsulation, i.e., shorter soldering times are recommended. In addition to using the appropriate temperature profile, we also recommend that you carefully check to make sure that the solder pins are well soldered.



MOS circuit operation precautions:

Static electricity is generated in many places. Taking the following precautions can effectively prevent damage to MOS circuits caused by exposure to electrostatic discharge:

- The operator is grounded via an anti-static wrist strap.
- The equipment enclosure must be grounded.
- Tools used during assembly must be grounded.
- It must be packaged or shipped in conductor packaging or antistatic material.