

Ultrasonic Water & Heat Metering with TDC-GP22

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1 Overview

In 2012 acam launched the TDC-GP22 Time-to-Digital Converter. It comes with extended functionality and provides great benefit to designers that demand for ps resolution in time of flight applications, e. g. like ultrasonic water and heat meters.

Especially the integration of analog elements like a offset stabilized comparator and analog switches simplifies the hardware design and reduces the number of external components to a minimum.

This application note is intended as an add-on to the TDC-GP22 datasheet and describes the implementation of an ultrasonic heat meter front-end with the TDC-GP22. It provides additional information that helps to decrease design time and avoid circuit problems due to wrong component values or incorrect configuration of the device. We recommend to follow the layout guidelines and to copy the schematics of the demo board. This is well proven and shows best performance with respect to offset drift and noise. Finally, the application note contains a generic software example that shows a typical measurement flow.



2 Introduction

This application note describes the implementation of an ultrasonic heat meter front-end that is based on acam's TDC-GP22 Time-to-Digital Converter. The GP22 operates as a front-end device that provides fully automated control of the flow- and temperature measurement sequence. The amount of heat dissipated is calculated from the flow rate and the temperature difference of the incoming and outgoing fluid by an external microcontroller.



Figure 1.1: GP22 Front-end electronics for heat meters

Design Goals:

- Compact and cost saving hardware design that keeps external components to a minimum
- Low current consumption (down to 2 μA for a complete measurement cycle including the analog part, transducers and PT sensors)
- High resolution time-of-flight measurement that allows compact and small spool pieces with small diameters
- High resolution but low current temperature measurement
- Open system architecture offers a high degree of flexibility with an external microcontroller and a modular system design

2.1 Flow Measurement

The ultrasonic flow measurement is based on the transit-time principle. Two transducers are connected to the TDC-GP22. They can both operate as an ultrasonic transmitter or receiver.

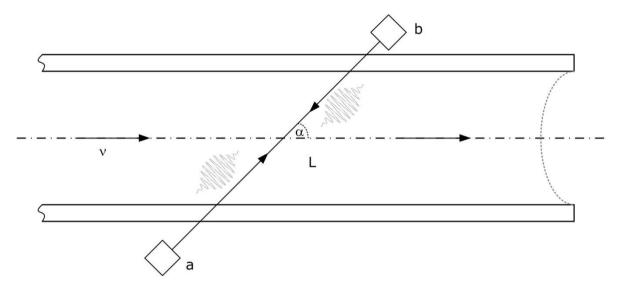


Figure 1.2 Basic principle of ultrasonic flow metering by means of transit time difference measurement

The GP22 alternately transmits a 1 MHz signal burst (20 pulses) between the two transducers and measures the transit time that a pulse burst takes for traveling from transducer a to b and the opposite direction from b to a. The transit time of the ultrasonic signal propagating in flow direction is shorter than the transit time of the signal propagating against flow direction.

For a given average fluid velocity v, a measurement path L and a sound velocity C_0 in the fluid, an acoustic signal needs the time t_{up} for the upstream path and t_{down} in downstream direction. They can be calculated as follows:

$$t_{up} = \frac{L}{c_0 + v * \cos \propto}$$

$$t_{down} = \frac{L}{c_0 - v * \cos \alpha}$$



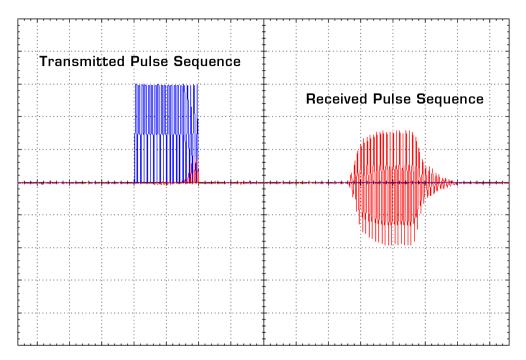


Figure 1.3: Send- / received pulse sequence (Sent pulse=1V/Div.; Received pulse=200mV/Div.; Timebase=10µs)

The computation of the result is then performed by an external microcontroller. In a first step it calculates the time difference of the delay times in up- and down direction and after that the velocity v.

$$\Delta t = t_{down} - t_{up} = \frac{2 * L * v * \cos \alpha}{c_0^2 - v^2 * \cos^2 \alpha} \approx \frac{2 * L * \cos \alpha}{c_0^2} * v$$

$$v \approx \frac{\Delta t * c_0^2}{2 * L * \cos \alpha}$$

2.2 Temperature Difference Measurement

For heat meters it is important to measure the temperature with very high resolution but low power consumption on the other hand. The TDC-GP22 uses the PICOSTRAIN method to measure the temperature difference of the incoming and outgoing water. It transfers the temperature dependent resistance variation of an RTD in an accurate time interval measurement. A capacitor is discharged alternately through the RTD sensor and a temperature stable reference resistor and the discharge times are measured with picosecond resolution. The Figure below shows a signal curve for a temperature measurement sequence with seven additional Fake measurements.

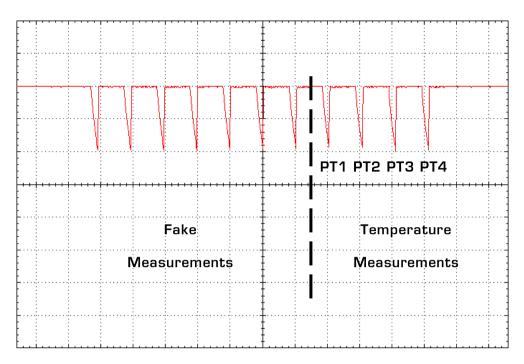


Figure 1.4: Oscillogram of the fake- and temperature measurement charging-/discharging cycles, measured at R9 (Cycles=1V/Div.; Timebase=500 μ s)

The result is then provided in the corresponding GP22 result register O to 3. The ratio of the discharge time shows the deviation of the sensor resistance relative to the reference resistor. From the given results T_{RTD} and T_{Ref} the external microcontroller calculates the temperature difference as follows:

$$R_{RTD} = \frac{\left(\frac{T_{RTD}}{T_{Ref}} - 1\right) * R_o}{gainfactor}$$

For the internal comparator at 3.0 V the gain correction factor is 0.9931. Now the temperature can be calculated by solving the RTD transfer function for the temperature:

$$\vartheta = \frac{-R_o * A + \sqrt{(R_0 * A)^2 - 4 * R_0 * B * (R_0 - R)}}{2 * R_0 * B}$$

Fake measurements improve stability of the temperature measurement by adding additional charging /discharging cycles before the actual temperature measurement starts

Finally, the temperature difference is calculated as follows:

$$\Delta \vartheta = \vartheta_{RTD} - \vartheta_{Ref}$$



3 Circuit Description

The complete schematics and the layout can be found in section 3 of this document. To get best results and to avoid circuit problems we recommend to use it as a reference for your design. The main considerable design items are now described in the following chapters.

3.1 Power Supply Considerations

The TDC-GP22 needs two supply voltages for chip internal power supply. The core supply voltage Vcc and the I/O supply voltages Vio. Both can be generated from one and the same source. Usually, a linear regulator. Here, the XC6206 from Torex Semiconductor is used. Because of its very low quiescent current of only $1\mu A$ in operation it is ideal for power critical applications, like battery driven heat or flow meters. Additionally, a good decoupling and bypassing is recommended for noise reduction. The below schematics gives a reference for your design:

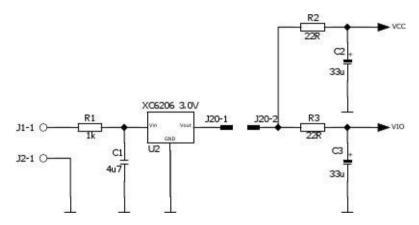


Figure 2.1 Power supply bypassing and decoupling Important Note:

Do not use switched regulators in your power supply design. They would introduce a lot of noise that significantly reduces the measurement quality.

3.2 External Clock Sources

Battery driven applications like heat meters demand for very low current consumption. According to that the GP22 operates with two LVCMOS or LVTTL compatible clock sources. A 32.768 kHz quartz and a 4 MHz ceramic oscillator. For power efficiency the 4 MHz clock is controlled by the 32 kHz quartz and only switched on during time measurement.

3.2.1 The 32,768 Hz Quartz

The 32.768 kHz quartz is responsible for start-up control of the 4 MHz clock and is used as reference for calibrating the 4 MHz ceramic oscillator, as explained in chapter 2.2.2. The 10 pF capacitors together with the paralleled 10M resistor guarantuees stable oscillation.

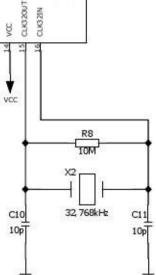


Figure 2.2: Connecting the 32.768 kHz quartz oscillator

3.2.2 The 4 MHz High Speed Clock Oscillator

As 4 MHz clock source a standard ceramic oscillator in combination with a 560 k parallel resistor can be used. The high speed clock circuit is shown below.

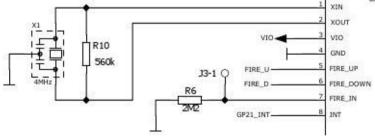


Figure 2.3 Circuit diagram for the 4 MHz ceramic resonator

Compared to a crystal oscillator it is more cost efficient and thanks to the short settling time it can be operated in a power saving switched mode. Then the active states are controlled by the GP22 internally.

The GP22 integrated clock calibration helps to overcome the poor accuracy and temperature drift behavior that is typical for a ceramic oscillator. This offers quartz accurate time measurement, even when a ceramic oscillator is used as high speed clock. For more details about how to use the clock calibration please have a look to section 5.1.4 of the TDC-GP22 datasheet.



3.2.3 Clock Option for external Microcontroller

To save external components the GP22 can provide a 4 kHz or a 32 kHz signal, e. g. as a system clock for the external microcontroller. The 32 kHz can be provided through EN_START pin and has to be configured by SEL_TSTO2 parameter in configuration register 1. A 4 kHz signal is available on FIRE_IN by appropriate configuration of the SEL_TSTO1 parameter in configuration register 1.

3.3 Transmitter / Receiver Circuit

Basically, the transmission circuit consists of two first order high pass filters. They are connected to Fire_Up and Fire_Down pins of the TDC-GP22 and their resistor outputs drive the piezo transducers. On the receiver side the capacitor outputs are connected to GP22 analog inputs. Here, COG capacitors should be used to achieve highest temperature stability. An integrated analog multiplexer operates the transducers alternatingly as transmitter / receiver. All elements are controlled by the TDC-GP22 and only powered up during measurement.

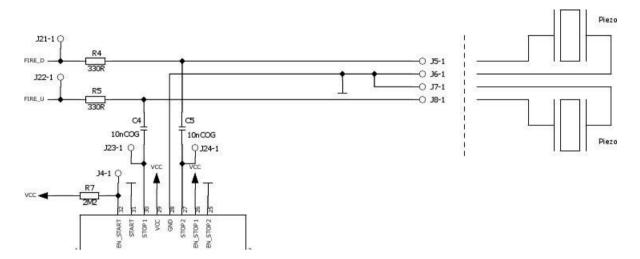


Figure 2.4 Circuit diagram of the transmitter / receiver signal path

As the integrated comparator cannot handle GND as threshold the LoadC capacitors (C4, C5) in the receiving path switch the signal to the comparator threshold of 1/3 Vcc. Then it is coupled to the TDC-GP2 analog inputs. Figure 2.5 shows the corresponding oscilloscope trace.

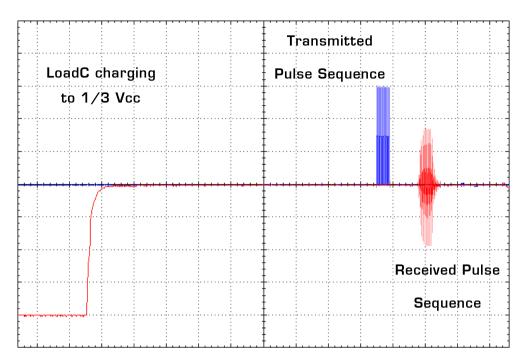


Figure 2.5: Signal curve on non-inverted comparator input (Sent pulse=1V/Div.; Received pulse=200mV/Div.; Timebase=50µs)

Finally, the integrated low noise comparator generates a square wave signal from the received pulse sequence that provides the stop pulses for the GP22 internal time measurement unit.

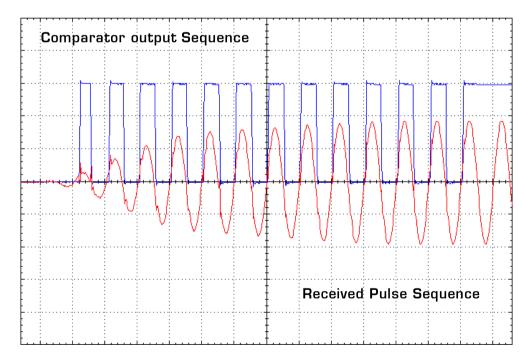


Figure 2.6: Received pulse sequence and corresponding comparator output signal (Comparator output signal=1V/Div.; Received pulse=200mV/Div.; Timebase=1.0µs)

More details about the GP22 analog unit and how it operates can be found in section 4.3 of the TDC-GP22 datasheet.



3.3.1 Time Windowing by Stop Masking

The major improvement of TDC-GP22 is the implementation of the First Wave Mode.

The DELVAL1 stop masking is used to suppress any noise in advance to the acoustic received signal. The noise come e.g. from the fire pulses. The Figure below shows a typical configuration with DELVAL1 = 5000. This applies a time window with a delay of 39062,50ns delay (@ 4 MHz high speed clock) before the stop 1 channel is activated to detect the incoming stops. DELVAL2 and DELVAL 3 are not required and set to 0. The DELVAL1 setting should cover at least the duration of the fire burst (e.g. 20µs at 20 pulses with 1MHz). More details are described in section 4.2.3 of the TDC-GP22 datasheet.

The stop masking for the three time measurements is set by parameters DELREL1 to DELREL3, relative to the first wave. DELREL1 = 8, DELREL2 = 9, DELREL3 = 10 measure the 8th, 9th and 10th stop after the first wave. More details are described in section 4.4 of the TDC-GP22 datasheet.

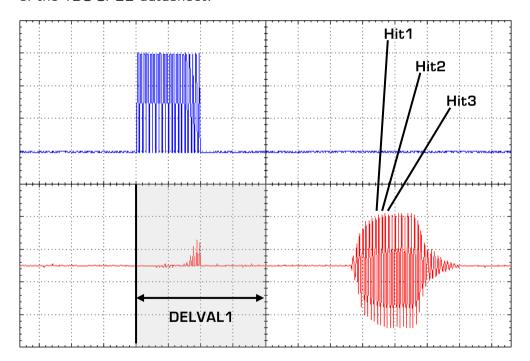


Figure 2.7: Sent and received pulse sequence (Sent pulse=1V/Div.; Received pulse=200mV/Div.; Timebase=10µs)

3.4 Temperature measurement

A pair of PT 1000 sensors in combination with a temperature stable 1k reference resistor (R9, 50 ppm), is used for hot / cold temperature difference measurement.

A 100 nF COG type capacitor operates as load capacitor (C8). To minimize the number of external components the GP22 internal Schmitt-Trigger is used.

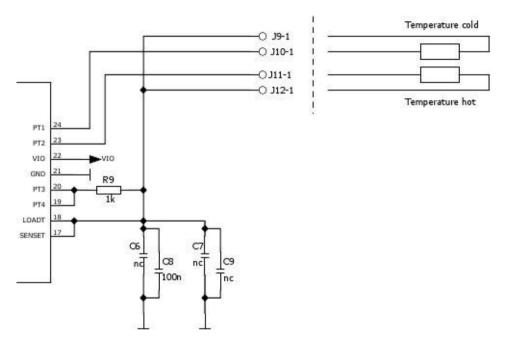
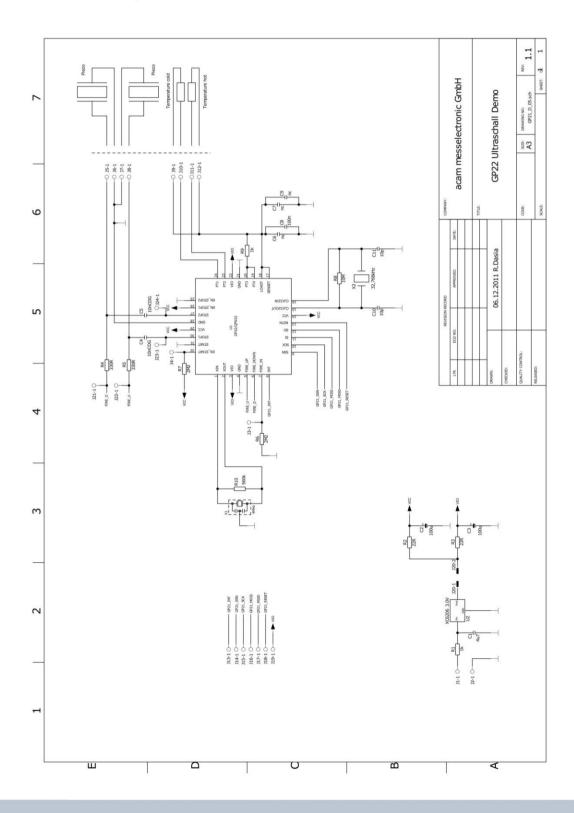


Figure 2.8 Temperature measurement circuit



4 Layout & Schematics of a demo board

4.1 Full Schematics



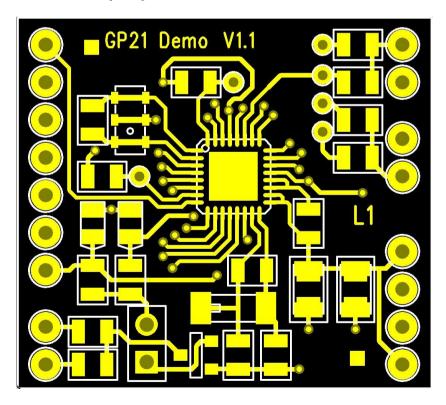
4.2 Layout

The PCB has significant influence on the measurement quality so stick as close as possible to the design and the recommendations given in this chapter. Then a 2 layer should be sufficient. The demo board is the same for TDC-GP21 and TDC-GP22, so the name on the PCB was not changed.

Summary of the most important layout considerations:

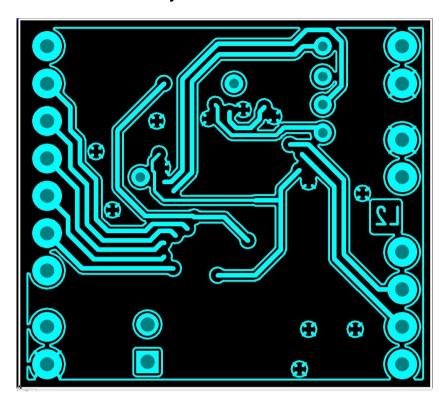
- Place the oscillators very close to the device
- Do NOT cross the SPI lines with the load or I/O lines
- Do NOT cross the load line with the oscillator lines
- Place the bypassing capacitors C2 and C3 close to the supply voltage pins of the
 GP22
- Keep the temperature port lines as short and symmetric as possible
- If possible, use flooded planes around the oscillators

4.2.1 Top Layer

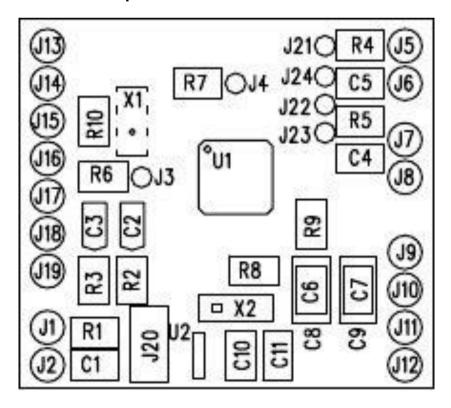




4.2.2 Bottom Layer



4.2.3 Component Placement





5 Example configuration

The following chapter gives an example configuration for a heat meter application and describes the settings of all relevant parameters. A detailed description of the configuration bits is further provided in section 3 of the TDC-GP22 datasheet.

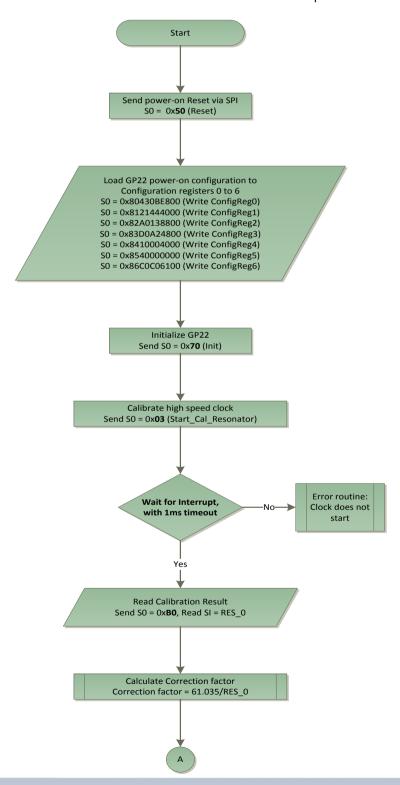
Register	Value	Typical example configuration
Register O	'h430BE800	ANZ_FIRE = 20 (see register 6, too) DIV_FIRE = 3, fire pulse frequency = 4 MHz/4 = 1.0 MHz ANZ_PER_CALRES = 0, the 4 MHz is calibrated by a 61.035µs measurement DIV_CLKHS = 0, the 4 MHz ceramic oscillator is internally used as it is START_CLKHS = 2, the ceramic oscillator has 480 µs to settle ANZ_PORT = 1, use all 4 ports for the temperature measurement TCYCLE = 1, 512 µs cycle time for the temperature measurement ANZ_FAKE = 1, 7 fake measurements SEL_ECLK_TMP = 1, use 4 MHz for the temperature measurement cycle definition CALIBRATE = 1, mandatory in measure mode 2 to be on NO_CAL_AUTO = 0, mandatory in measure mode 2 to have auto-calibration MESSB2 = 1, switch on measure mode 2 for measuring > 2 µs. NEG_STOP/NEGSTART = 0, all set to rising edges IDO = hOO
Register 1	'h21444000	HIT2 = 2, HIT1 = 1: calculate 1. Stop - Start in measure mode 2 EN_FAST_Init = 0, off HITIN2 = 0 HITIN1 = 4, measure 3 stops (in measure mode 2 this includes the start, too, giving 4 hits) CURR32K = 0, use default SEL_START_FIRE = 1, use the internal direct wiring from the fire pulse buffer to the TDC start SEL_TST02 = 0, EN_START active SEL_TST01 = 0, FIRE_IN pin is used as fire in ID1 = hO0
Register 2	'hAO138800	EN_INT = b0101, interrupt given by time_out, ALU ready or Timeout. (see also register 6) RFEDGE1 = RFEDGE2 = 0, use only rising edges DELVAL1 = 5000, the first stop is accepted after 39.0625 µs ID2 = h00

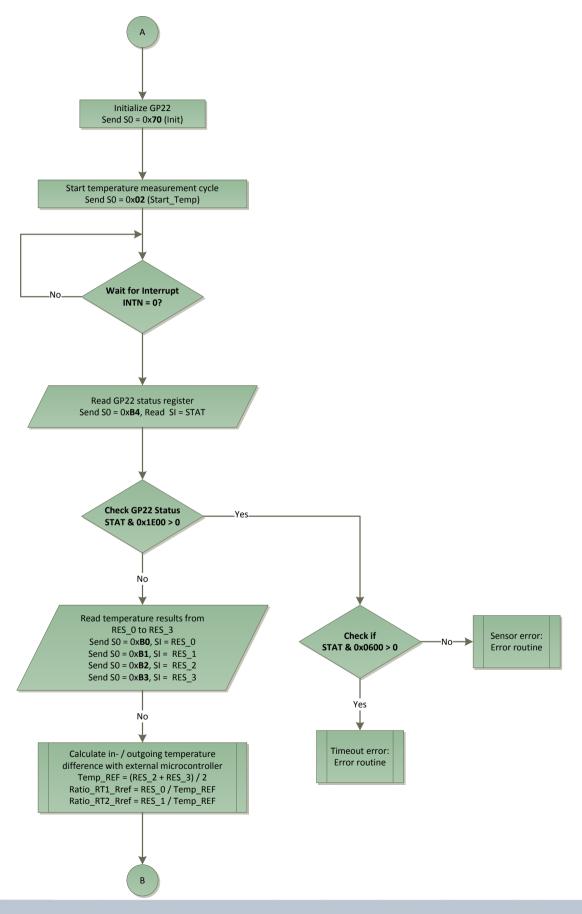
Register 3	'hDOA24800	EN_AUTOCALC_MB2 = 1, automatic calculation of all 3 hits EN_FIRST_WAVE = 1, first hit detection mechanism is enabled EN_ERR_VAL = 0, there is enough time to read the status register SEL_TIMO_MB2 = 2, time out is generated after 1024 μs DELREL1 = 8, DELREL2 = 9, DELREL3 = 10, measure the 8th, 9th and 10th stop after the first hit ID3 = h00
Register 4	'h10004000	DIS_PW = 0, pulse width measurement is not disabled EDGE_PW = 0, pulse width measured on rising edge OFFSRNG1 = 0, no negative offset OFFSRNG2 = 1, OFFS = 0: total offset = 20 mV + 0 mV = 20 mV ID4 = h00
Register 5	'h40000000	CON_FIRE = 2, enable FIRE_UP. If opcode Start_TOF_Restart is used FIRE_UP and FIRE_DOWN are used alternately for up and down flow measurements. The configuration described here then starts the measurement cycle with an up-flow measurement. EN_STARTNOISE = 0, switch off DIS_PHASESHIFT = 0, phase noise unit is active to improve the statistical behavior REPEAT_FIRE = 0, no sing-arround PHASE_FIRE = 0, no phase change in the fire pulse sequence ID5 = hOO
Register 6	'hCOCO6100	EN_ANALOG = 1, use the internal analog circuit NEG_STOP_TEMP = 1, use the internal Schmitt trigger for the temperature measurement DA_KORR = 0, offset is set in register 4 TW2 = 3, 300 µs delay to charge up the capacitors of the highpass EN_INT = b1101, interrupt given by time_out, ALU ready or end of EEPROM action (see also register 2) START_CLKHS = 2, the ceramic oscillator has 480 µs to settle (see also register 0) CYCLE_TEMP = 0, use factor 1.0 for the Start_Temp_Restart CYCLE_TOF = 0, use factor 1.0 for the delay between two TOF measurements HZ60 = 0, 50 Hz base FIREO_DEF = 1, mandatory when using the internal analog circuit GUAD_RES = 1, use 23 ps BIN DOUBLE_RES = 0 TEMP_PORTDIR = 0, standard order for T measurement ANZ_FIRE = 20 (see register 0, too) ID6 = h00



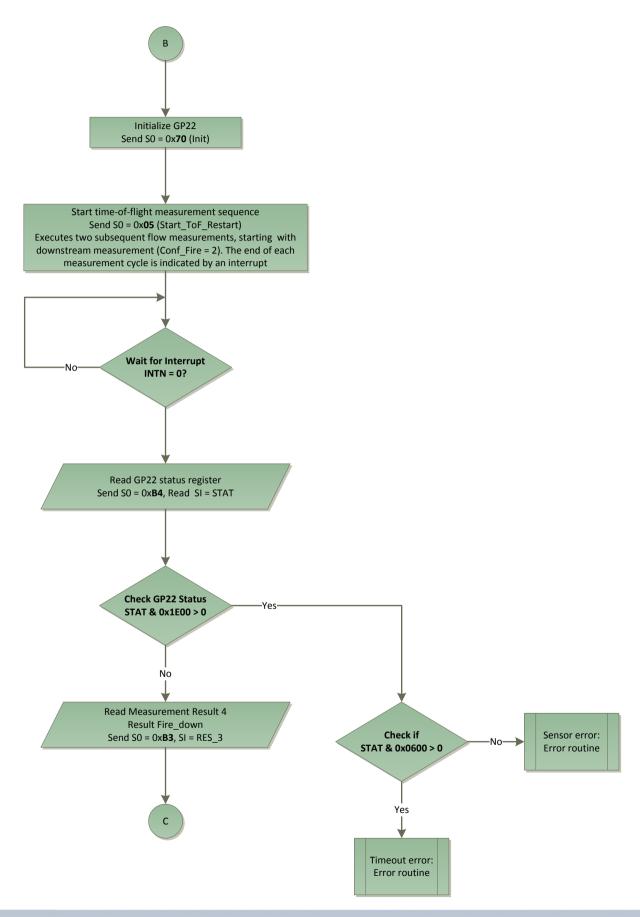
6 Software Implementation

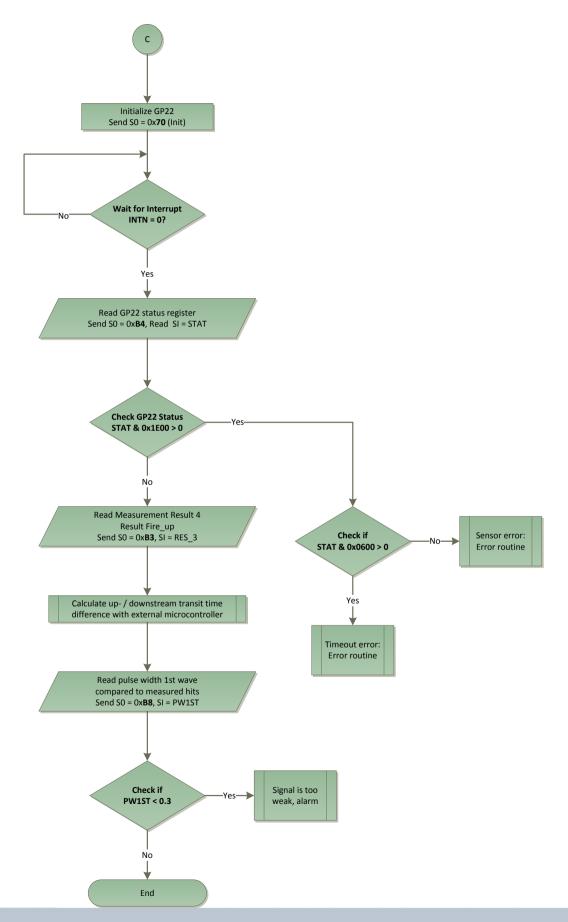
This chapter describes a typical measurement flow. Error routines or plausibility checks of the measured results are not within the scope of this example.











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Description:

After an initial power-on reset the basic register configuration is transferred to the TDC-GP22 and the device is initialized through calling the init-instruction.

Then the Start_CAL_Resonator instruction forces the GP22 to execute a calibration of the GP22 high speed clock.

From now on the complete program flow is interrupt driven.

The external microcontroller reads the result and calculates the ratio from the measured result RES_O and the reference value that is given by the number of 32.768 Hz clock cycles that are used for calibration. Here, we use two periods of the 32.768 kHz clock according to the ANZ_PER_CALRES parameter in the example configuration. This equals to a reference value of $61,035~\mu s$.

After that the init instruction resets the pointer result register and the interrupt line, reinitializes the TDC-GP22 and prepares it for the next measurement.

The temperature measurement sequence is started by sending the Start_Temp opcode. By doing that the GP22 executes the temperature measurement sequence. The end is indicated by an interrupt. The microcontroller then checks the GP22 status register for errors and reads the results from result register RES_0 to RES_3 to calculate the temperature difference. The formulas are described in section 2.2 of this paper.

Again, the init instruction prepares the GP22, but now for the time-of-flight measurement sequence.

With the Start_ToF_Restart instruction the TDC-GP22 automatically executes the complete measurement sequence for a transit time measurement in Fire_Downstream and Fire_Upstream direction. Here, we start with the downstream measurement (CONF_FIRE = 2) and send a pulse packet of 20 pulses (ANZ_FIRE = 20). After reception of the echo signal the TDC-GP22 starts calculating the transit times from its internally stored raw values. It automatically calculates the three time intervals between the three stops and the start and also the sum of the three. An interrupt indicates the end of the calculation.

After checking the status register the result of the downstream measurement is available in result register RES_3. They are read from the external microcontroller and stored for further calculation.

After these steps the init instruction prepares the device for the upstream measurement sequence. It starts automatically (according the repetition rate that is specified by the HZ6O and CYCLE_TOF parameters in register 6) and executes the same steps as described for the downstream measurement.

The external microprocessor reads the downstream and upstream result and calculates the amount of heat by using the formulas described in section 2.1 of this paper.

Finally the PW1ST register gives the ratio of the width of the first half wave compared to the half period of the received signal. The ratio can be used as indicator for the signal strength.



7 Example Code

This is a generic example code for a complete heat meter measurement flow including clock calibration of the high speed ceramic resonator, written for a STM32 microprocessor. The whole source code can be downloaded at following link: http://www.acam.de/fileadmin/Download/software/UFC/GP22 main ANO32.c

```
* Function Name : main
              : Main program.
* Description
* Input
               : None
              : None
* Output
* Return
              : None
void main(void)
 ENTR_CRT_SECTION();
 /* Setup STM32 system (clock, PLL and Flash configuration) */
 SystemInit();
 EXT_CRT_SECTION();
 // Choose your Slot (SPI1, SPI2)
 void* Bus_Type = SPI1;
 /* controlled loop */
 while (Dummy var!=11) // To control the loop, e.g. (Dummy var!=7)
   if (Dummy var==10) Dummy var=0; // Infinite loop
   if(configured_true==FALSE)
     configured_true = TRUE;
     SPIx_GPIOs_Init(Bus_Type);
     SPIx Interface Init(Bus Type);
     gp22 send 1byte(Bus Type, Power On Reset);
     Dly100us((void*)5);
                                  // 500 us wait for GP22
     // Writing to the configuration registers (CR)
     // CRO: ANZ_FIRE=d20 DIV_FIRE=d3 ANZ_PER_CALRES=d0 ANZ_PORT=1...
     gp22_wr_config_reg(Bus_Type, 0x80, 0x430BE800);
     // CR1: ...
     gp22_wr_config_reg(Bus_Type, 0x81, 0x21444000);
     // CR2: EN INT=b0101 RFEDGE1=RFEDGE=0 DELVAL1=d5000 ID2=0
     gp22 wr config reg(Bus Type, 0x82, 0xA0138800);
     // CR3: EN_AUTOCALC=1 EN_FIRST_WAVE=1 DELREL1=d8 DELREL2=d9 DELREL3=d10
     gp22 wr config reg(Bus Type, 0x83, 0xD0A24800);
     // CR4: DIS_PW=0 EDGE_PW=0 OFFSRNG1=0 OFFSRNG2=1 OFFS=0 ID4=0
```

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```
gp22_wr_config_reg(Bus_Type, 0x84, 0x10004000);
    // CR5: FIRE UP=1
    gp22 wr config reg(Bus Type, 0x85, 0x40000000);
    // CR6: ...
    gp22 wr config reg(Bus Type, 0x86, 0xC0C06100);
   }
   // .....
   // ......Calibrate High Speed Clock......
   // ......Temperature Measurment.....
   // .....TIME OF FLIGHT MEASUREMENT.....
   // .....Sum result of multihit values......
if((Dummy var==0) | (Dummy var==10))
   //-----
   // Start Calibrate High Speed Clock Cycle
   gp22_send_1byte(Bus_Type, Init);
   gp22_send_1byte(Bus_Type, Start_Cal_Resonator);
   // Wait for INT Slot x
   if (Bus Type==SPI1) while (GPI0 ReadInputDataBit(GPI0D, GPI0 Pin 4)==1);
   if (Bus Type==SPI2) while (GPIO ReadInputDataBit(GPIOE, GPIO Pin 11)==1);
   //Calculate Correction factor (ANZ PER CALRES)
   CLKHS freq corr fact = 61.035/
    gp22_read_n_bytes(Bus_Type, 4, 0xB0, 0x00, 16) * CLKHS freq;
   printf("\n Correction factor for clock = %1.3f\n", CLKHS freq corr fact);
   CLKHS_freq_cal *= CLKHS_freq_corr_fact; // Calibrated Clock frequency
}
if((Dummy var==0) | (Dummy var==5) | (Dummy var==10))
   //-----
   // Start Temperature Measurement Cycle
   gp22_send_1byte(Bus_Type, Init);
   gp22 send 1byte(Bus Type, Start Temp);
   // Wait for INT Slot x
   if (Bus_Type==SPI1) while (GPIO_ReadInputDataBit(GPIOD, GPIO Pin 4)==1);
   if (Bus Type==SPI2) while (GPIO ReadInputDataBit(GPIOE, GPIO Pin 11)==1);
   // Read the Status Register
   printf ("\nStatus Register = 0x%04X", gp22_read_status_bytes(Bus_Type));
   Error Bit = gp22 status count error(Bus Type);
   if (Error_Bit > 0)
    gp22 analyse error bit(Bus Type);
    printf("\nTemp-Measurement are skipped\n");
   else
   {
```

UFC



```
//discharge time in us
      Temp_PT1 = gp22_read_n_bytes(Bus_Type, 4, 0xB0, 0x00, 16) / CLKHS_freq_cal;
      Temp PT2 = gp22 read n bytes(Bus Type, 4, 0xB0, 0x01, 16) / CLKHS freq cal;
      Temp_PT3 = gp22_read_n_bytes(Bus_Type, 4, 0xB0, 0x02, 16) / CLKHS_freq_cal;
      Temp PT4 = gp22 read n bytes(Bus Type, 4, 0xB0, 0x03, 16) / CLKHS freq cal;
      Temp REF = (Temp PT3 + Temp PT4) / 2;
      // Calculate Temp_cold at PT1
      Ratio RT1 Rref
                     = Temp_PT1/Temp_REF / gain_corr_fact;
                      = Ratio RT1 Rref * R0 at 0C;
      R1
      Temp cold in Celcius = (-R0 at 0C *Coeff A +sqrt(
                              ((R0 at 0C *Coeff A)*(R0 at 0C *Coeff A))
                                -4*R0 at 0C *Coeff B *(R0 at 0C - R1) ) )
                                  /(2 *R0 at 0C *Coeff B);
      // Calculate Temp_hot at PT2
      Ratio RT2 Rref
                      = Temp_PT2/Temp_REF / gain_corr_fact;
                      = Ratio RT2 Rref * R0 at 0C;
      Temp_hot_in_Celcius = (-R0_at_0C *Coeff_A +sqrt(
                             ((R0 at 0C *Coeff A)*(R0 at 0C *Coeff A))
                               -4*R0 at 0C *Coeff B *(R0 at 0C - R2) ) )
                                 /(2 *R0 at 0C *Coeff B);
      // Print result
      printf("\n PT1= %6.3fµs / PT2= %6.3fµs \n PT3= %6.3fµs / PT4= %6.3fµs",
            Temp PT1, Temp PT2, Temp PT3, Temp PT4);
      printf("\n Ratio RT1/Rref= %2.5f / Ratio RT2/Rref= %2.5f",
            Ratio RT1 Rref, Ratio RT2 Rref);
      printf("\n Temp_cold= %3.3f°C / Temp hot= %3.3f°C\n",
            Temp_cold_in_Celcius, Temp_hot_in_Celcius);
    }
}
    //-----
    // Start Time Of Flight Measurement Cycle
    gp22_send_1byte(Bus_Type, Init);
    gp22 send 1byte(Bus Type, Start TOF Restart);
    Error_Bit=0;
    // Wait for INT Slot x, downstream
    if (Bus Type==SPI1) while (GPIO ReadInputDataBit(GPIOD, GPIO Pin 4)==1);
    if (Bus Type==SPI2) while (GPIO ReadInputDataBit(GPIOE, GPIO Pin 11)==1);
    // Read the Status Register
    //printf ("\nStatus Register = 0x%04X", gp22 read status bytes(Bus Type));
    Error Bit += gp22 status count error(Bus Type);
    // Sum result of multihit values (Result DOWN), discharge time in us
    average_Result_down = gp22_read_n_bytes(Bus_Type,4,0xB0,0x03,16)/CLKHS_freq_cal;
    // Devider for multihit sum (1..3)
    average_Result_down /= 3;
    average_Result_down *= 1000; // discharge time in ns
```

```
gp22_send_1byte(Bus_Type, Init);
// Wait for INT Slot x, upstream
if (Bus Type==SPI1) while (GPIO ReadInputDataBit(GPIOD, GPIO Pin 4)==1);
if (Bus Type==SPI2) while (GPIO ReadInputDataBit(GPIOE, GPIO Pin 11)==1);
// Read the Status Register
//printf ("\nStatus Register = 0x%04X", gp22_read_status_bytes(Bus_Type));
Error_Bit += gp22_status_count_error(Bus_Type);
// Sum result of multihit values (Result UP), discharge time in μs
average Result up = gp22 read n bytes(Bus Type,4,0xB0,0x03,16)/ CLKHS freq cal;
// Devider for multihit sum (1..3)
average Result up /= 3;
average Result up *= 1000; // discharge time in ns
if (Error Bit > 0)
 gp22 analyse error bit(Bus Type);
 printf("\nTOF-Measurement are skipped\n");
else
  // Result after two measurements (first Result down then Result up)
 TOF up = average Result up;
  TOF down = average Result down;
  PW1ST += gp22 read n bytes(Bus Type, 1, 0xB0, 0x08, 7);
  printf("\n Result Up= %6.3f ns / Down= %6.3f ns", TOF up, TOF down);
  Time of flight diff = TOF up - TOF down;
  printf("\n Difference Up-Down = %6.3f ns", Time of flight diff);
  Time_of_flight_sum = TOF_up + TOF_down;
  printf("\n Sum Up-Down = %6.3f ns\n", Time_of_flight_sum);
  // to add up
  TOF diff sum += Time of flight diff;
  TOF diff square_sum = TOF_diff_square_sum
                          +(Time of flight diff * Time of flight diff);
  TOF sum sum += Time of flight sum;
  sum counter ++;
  if (sum counter > no of avg)  // Output after no_of_avg measurements
    TOF diff avg = TOF diff sum / no of avg;
    printf("\n Avg. value of difference = %6.3f ns", TOF diff avg);
    Std_Dev_of_Diff = sqrt( (TOF_diff_square_sum
                        -(TOF diff square sum/no of avg)) / (no of avg-1));
    printf("\n Std.Dev. of Diff. = %6.1f ps", Std_Dev_of_Diff*1000);
    printf("\n PW1ST = %1.2f\n", PW1ST/(no_of_avg));
   Std_Dev_of_Diff = 0;
    TOF diff sum = 0;
    TOF_diff_square_sum = 0;
```

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```
sum_counter = 1;
PW1ST = 0;
}

Dummy_var++; // To Control the loop
} // End while Dummy_var
} //End main
```



8 Revision History

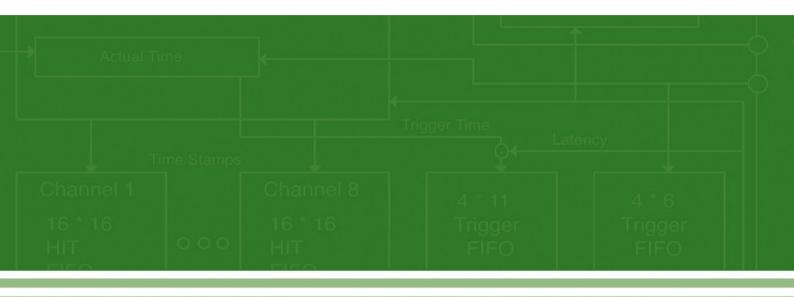
04.12.2012 First Edition

28.01.2013 Version 1.1 for release, section 2.2 Gain Correction Factor added,

section 5 Register 5 Fire Up/Down corrected, section 7 Source Code

with Gain Correction Factor modified





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