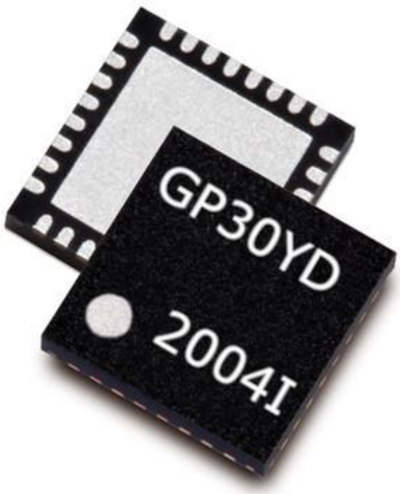
TDC-GP30



First Hit Level Determination and Regulation

Application Note

FHL Regulation (former AN540)

Revision: 2

Release Date: 2021-01-11

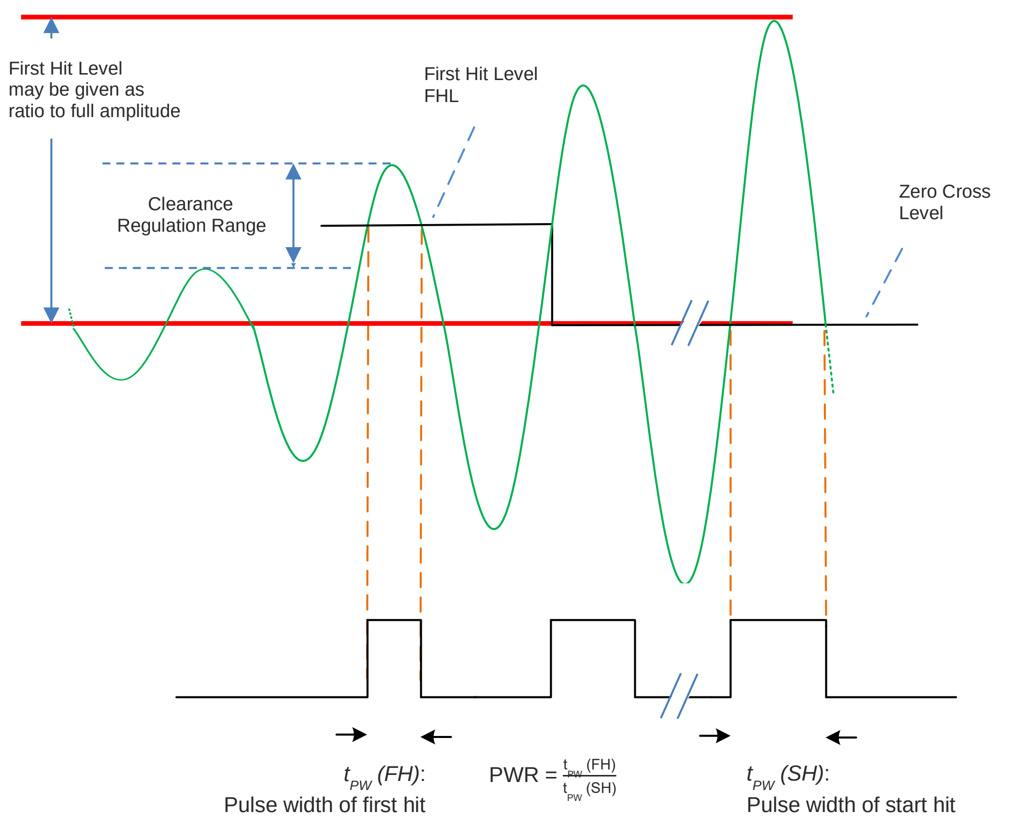
Content Guide

1 Introduction

TDC-GP30 derives precise time-of-flight (TOF) information by evaluating the zero crossings of a received ultrasound signal. Since the received waveform has many zero crossings, a definite and unambiguous numbering of zero cross points is required for a stable and reliable measurement result. This application note gives an introduction to first hit level (FHL) regulation methods to achieve the desired stability.

As background, the TDC-GP30 transmitter generates a rectangular pulse train ("fire burst") that gets applied to a piezo-electric transducer. After passing through the medium under test (i.e. water, gas, other fluid, etc.) the TDC-GP30 receiver detects the corresponding receive burst. Due to the transducer's band filter characteristic, the receive burst sequence takes the shape of a sinusoidal burst signal, consisting of a sequence of waves (see Figure 1) When properly configured the TDC-GP30 can precisely determine the arrival time of a specific wave's zero crossing point that will be used for Time-of-Flight (TOF) measurements. The selected zero crossing points are converted into digital edge signals which define the received hits.

Figure 1: First Wave Detection



For the TOF measurement, typically a sequence of received hits is used. This sequence begins at the so-called “start hit” (SH). The length of this sequence as well as the position of the start hit are defined by the user. For example, the SH could be defined as the 8th received hit after the so-called “first hit” (FH). This way, the first hit is utilized to consistently determine the relative position of the receive hit sequence within the receive burst. This application note discusses how to consistently determine a stable FH position.

TDC-GP30 offers an amplitude and pulse width measurement of the receive wave to define and determine a stable FH. Below are the steps to accomplish this:

1. ANALYZE WAVES: Measure the first few received signal wave amplitudes individually, using the TDC-GP30. (see section 2 “Analysis of Amplitude with Flow and Temperature Variation”). Figure 1 shows four received waves with increasing peak amplitude.
2. Note: It is possible to monitor the receive burst waveform signal using an oscilloscope. Please use caution as impedance loading from the scope probe will likely influence the measured signal.
3. DETERMINE FIRST HIT (FH): Compare the peak amplitude of each wave to the amplitude of its immediate predecessor wave. The wave with the highest amplitude difference from the preceding wave is a good candidate to be chosen for defining the first hit (FH). In Figure 1 the second visible wave is determined to define the first hit (FH).
4. DEFINE CLEARANCE REGULATION RANGE AND FIRST HIT LEVEL (FHL): The amplitude range between the peak of the first hit’ wave and the peak of its immediate predecessor is called the “clearance” regulation range. The first hit level FHL, different from the zero cross level, will be used going forward to determine the first hit FH. The FHL is a threshold amplitude level chosen to be between the peak values of the FH wave and the preceding adjacent wave. Figure 1 shows the clearance range between the first and second waves with the FHL defined within that range.
5. START HIT (SH): The “start hit” (SH) is chosen as a fixed subsequent hit, for example the eighth hit after the FH. Note that it is not recommended to use the first hit itself or its direct successor as SH, since these two hits are not referenced to the zero cross level, but rather to the FHL (see Figure 1). Other selection criteria for the definition of SH, like increased noise of early hits or possible interference, are beyond the scope of this application note.
6. PULSE WIDTH RATIO (PWR): The first hit’s pulse width tpw(FH) is measured at the wave which defines the first hit as the time interval between when the instantaneous receive amplitude rises above the FHL, crests and then decreases to below the FHL. It is shown in red dashed lines on the left side in Figure 1. The pulse width tpw(SH) of the SH is shown in red dashed lines on the right side in Figure 1. Note that tpw(SH) refers to the time interval

between the zero crossings of the corresponding wave. The “pulse width ratio” (PWR) is the ratio of tpw(FH) / tpw(SH). PWR has some maximal value when FHL is close to the preceding wave’s peak level and approaches 0 when the FHL approaches the next wave’s peak amplitude. PWR is thus a figure of merit than can be used in subsequent TOF measurements to help keep the FHL clear from levels where the first hit detection might erroneously switch to an undesired neighboring wave.

7. This procedure is the first important step of the FHL selection. Until here, determining FHL is not related to firmware functionality and can be used in remote control operation as well. But now it should be noted that the result of the selection process described above can change over temperature, production tolerances and aging. For some devices and transducers it may even depend on flow and pressure. The goal is to obtain reliable and stable first hit detection under the influence of all these different factors. Upcoming sections of this document discuss determining the first hit (FH) under different environmental conditions.

Information

The definition of the FHL can be thought of in several different contexts as follow:

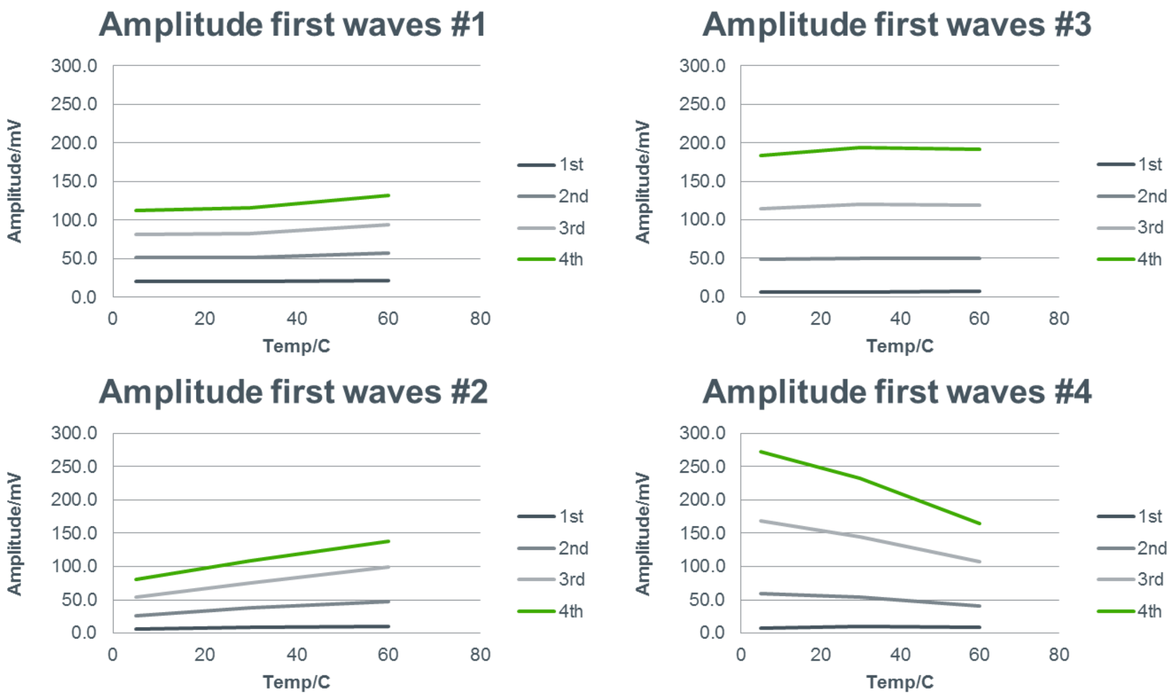
- FHL as configurable value (System Handling Registers, addresses 0x0DA / 0x0DB)
  Parameters ZCD_FHL_U / ZCD_FHL_D are from -255 to 255
- FHL as physical value (voltage of FHL_U / FHL_D), 1 LSB = 0.88 mV
  Voltages VFHL_U / VFHL_D are from -224 mV to 224 mV

The actual physical value is VFHL = ± 0.88mV * ZCD_FHL. The Pulse Width Ratio can also be used to track FHL.

Information

Sometimes it may make sense to choose a FHL using narrower clearance range. This may improve stability over temperature variations.

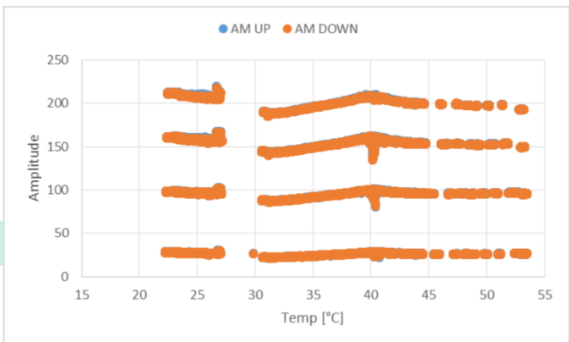
Figure 2: Different Trends of Amplitude



These example plots demonstrate how different receive wave amplitudes - and with them the corresponding FHL levels – can vary over temperature for different spool pieces #1 to #4. Accordingly, different spool pieces may require different FHL regulation methods for stable first hit detection.

In the next section a spool piece with following behavior is used.

Figure 3: Amplitudes First Waves

Graph	Description
	Example of early measurements of first wave amplitudes. It should be pointed out that the measurements should be repeatable before trying to define optimal FHL settings. This example shows some typical deviations that should be avoided. They can be identified more easy when doing larger numbers of measurements in the parameter range. For example at 27°C and at 40°C inconsistent measurements can be seen, and the values around 27°C also do not really fit the higher temperature measurements.

1.1 Possible Risk having no Regulation

Normal operation

The receive burst typically needs several waves to reach the full amplitude. When the amplitude decreases and passes the FHL then the detection will happen with the next wave and the TOF jumps by one period. To avoid this, the user should look for the two amplitudes with the biggest clearance. In case of variations of the amplitude the pulse width information can be used for regulation of the FHL, so that the FHL is always in the mid of the subsequent waves.

Bad operation

In case of a low receive amplitude the slope of the signal will be very low when a wave's amplitude reaches the FHL. Under this specific condition, the signal input to the comparator (signal versus FHL) is very flat. Any noise - and as the amplitude in this case is low, there will be noise - will trigger the comparator multiple times. A similar situation is observed in gas applications with lower fire frequency like 200kHz or less.

Now a second feature becomes effective. The TOF measurement does not start directly with the first hit level detection, but after a set number of hits, set by TOF_START_HIT_NO. This is typically set to 7 or 8. There is a counter that counts the zero crossings after the FHL detection and then releases the TOF measurement. Coming back to the situation where the FHL is close to the amplitude, the multiple trigger for the comparator makes this counter count. As a consequence, the frontend does not wait the set number of hits but starts earlier with the TOF measurement.

Example: TOF_START_HIT_NO = 8, With FHL = peak of amplitude the comparator gets triggered 4 times. This means the counter has already 3 surplus counts and starts already with the 5th hit, the TOF will be 3 periods less than expected. In this specific situation the TOF is always is less than expected by multiples of the period.

This will be avoided by a good selection of the first hit level and a combination with a regulation of that.

2 Analysis of Amplitude over Flow and Temperature

First, it is necessary to examine the variation of amplitudes of the individual waves of the receive burst within the operating range (temperature and flow).

The next subsections illustrate different situations. As introduction, FHL, PWR and amplitude are shown at constant flow and temperature. Next, the influence of temperature variation is shown. And finally the temperature and flow variations cover the full operating range.

From these data the limits for PWR and FHL can be extracted.

Now follows an abstract description of what to do to accomplish this analysis.

GP30 Configuration:

Start with a well working configuration at zero flow and change only the following points.

- Post Processing disable
- Watchdog disable
- Every calibration (e.g. ZC, AM, HSCLK) after each measurement
- AM Measurement stops after 1st Hit
- (PWR Measurement needs at least 3 Hits)

Process of data collection:

- Configure TDC-GP30
- Start with defined flow and temperature and with FHL = min
- Start loop to measure amplitude (AM) until FHL = max
- Measure amplitude with TDC-GP30
- Increase FHL (e.g. by step)
- After each pass of the loop, vary the flow and start the loop again.
- As soon as the flow range had been covered, vary the temperature and start the loop over the flow range again.
- Analyze the data collection to define limits for FHL and therefore PW

Parameter Range:

- First Hit Level
FHL max = 200
FHL min > = 5
FHL step = 2
- Numbers of collected Values (e.g. 2 or more)
- Pump Control
- Averaged (e.g. 4)

Collected Values:

- FHL UP/DOWN — First hit level measured by TDC-GP30
- TOF1 UP/DOWN — First TOF value measured by TDC-GP30
- PWR UP/DOWN — Pulse width ratio measured by TDC-GP30
- AM UP/DOWN — Received amplitude measured by TDC-GP30
- DIFF TOF — Calculated by TDC-GP30 Evaluation software
- SUM TOF UP/DOWN — Calculated addition of measured SUMTOF AVG
- Temp [°C] — Water temperature, measured with external sensor
- Flow [l/h] — Flow rate, measured with external sensor
- Flow Avg [l/h] — Averaged flow rate, measured with external sensor

Information

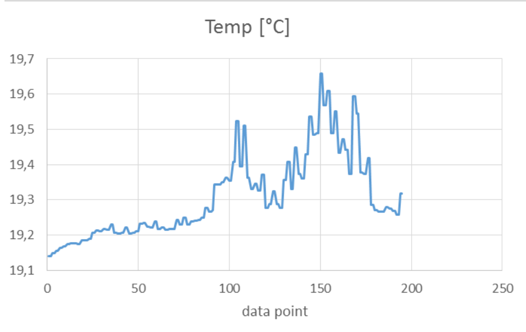
Due to the difficulty of keeping the temperature constant with different flow rates, it is advisable to collect the data in a good pace.

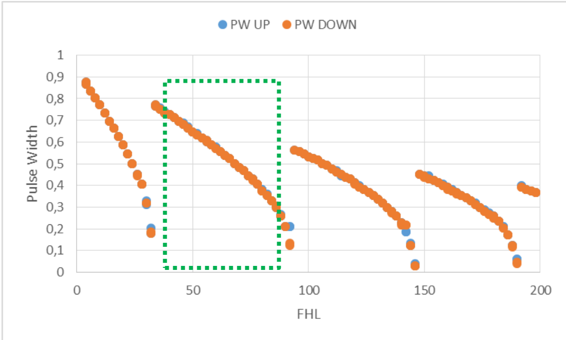
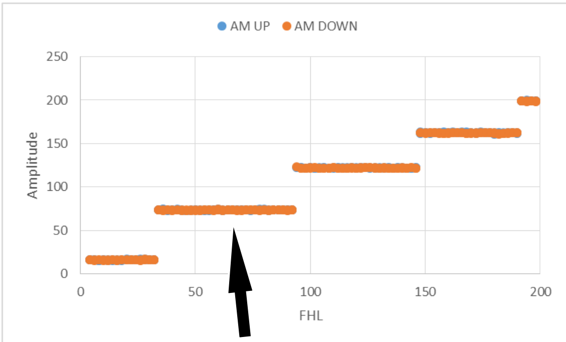
To get a first and quick overview of the analysis, only low and high temperature would be helpful.

2.1 Measurement at Constant Flow and Constant Temperature

- Flow = zero flow
- Temperature = about 19 °C

Figure 4: Measurement at Constant Flow and Constant Temperature

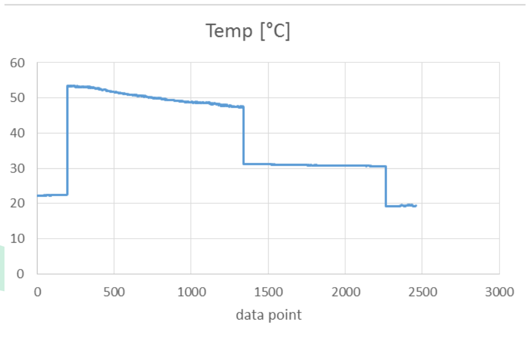
Graph	Description
	Measured water temperature. It is not important to keep the temperature very constant. It only has to cover the required area.

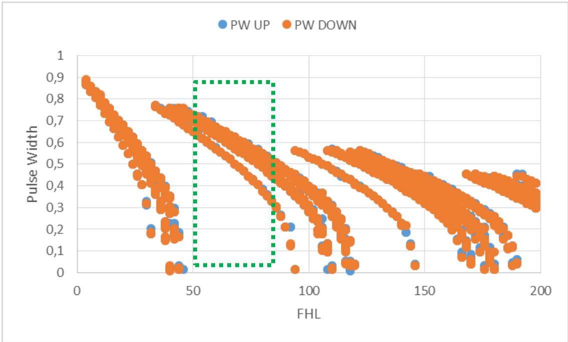
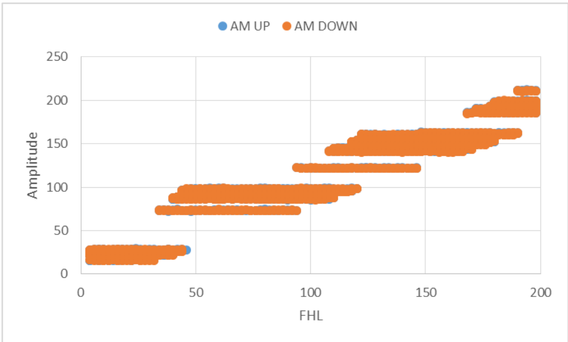
	Pulse width vs. FHL. The pulse width approaches zero with increasing FHL, and jumps to a high value again when jumping to the next wave (compare next graph). The green area marks a good range for the FHL level to stay with the same wave over chosen temperature.
	Measured amplitude of the first wave vs. FHL. With increasing FHL, the first hit detection jumps to the next wave when FHL exceeds the peak amplitude. At these steps, the amplitude of the next wave is measured and PWR jumps to a high value (see above). At the same point, the measured TOF also changes (not shown). The graph shows amplitudes of first 5 waves of receive burst, measured by increasing the FHL (zero flow, fixed temperature). The difference between neighboring amplitudes is the clearance, indicated by the width of the lines. The bigger the clearance the better FHL mode will work.

2.2 Measurement at Constant Flow and Variable Temperature

- Flow = zero flow
- Temperature = 20 °C to 55 °C

Figure 5: Measurement at Constant Flow and Constant Temperature

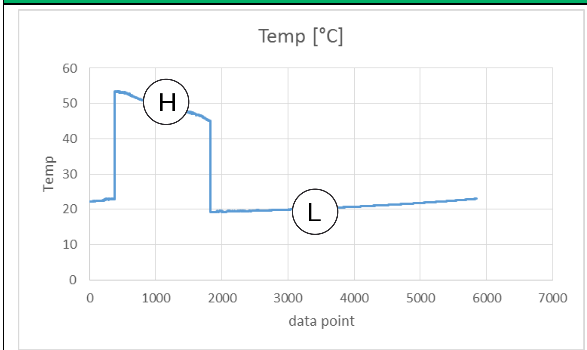
Graph	Description
	Again, it is not necessary to set a dedicated temperature but to vary it. The water temperatures of the test points should cover the desired operation range.

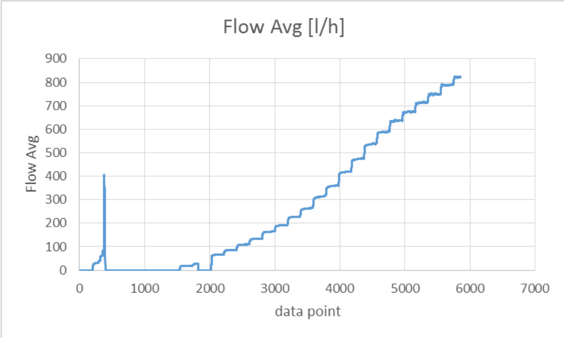
	The pulse width gets smaller with increasing FHL, and gets high again when jumping to the next wave. Also the temperature has an impact and broadens the spread of PWR for a given wave. The green area marks a good range for the FHL level to maintain the same first wave over the whole temperature range. Due to temperature variation this is narrower than for a fixed temperature.
	Amplitudes of first 5 waves of receive burst, measured by increasing the FHL (zero flow, fixed temperature). Shows the difference between them = clearance. The bigger the clearance the better FHL mode will work.

2.3 Measurement at Variable Flow and Variable Temperature

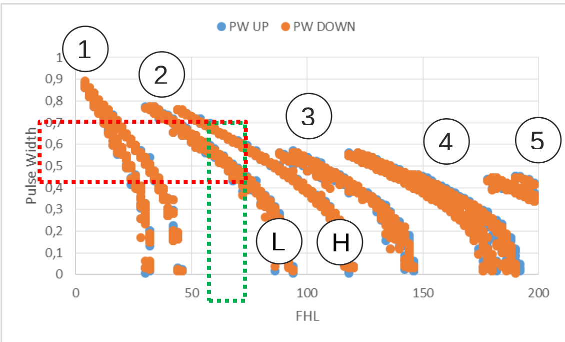
- Flow = 0 l/h – 850 l/h
- Temperature = low (20 °C) and high (50 °C)

Figure 6: Measurement at Constant Flow and Constant Temperature

Graph	Description
	Again, it is not necessary to set a dedicated temperature but to vary it. It only has to cover the required area. “H” and “L” marked the high and low temperature.



It is not necessary to set a dedicated flow but to vary it and to measure it. The flow variation shall cover the full operating range.



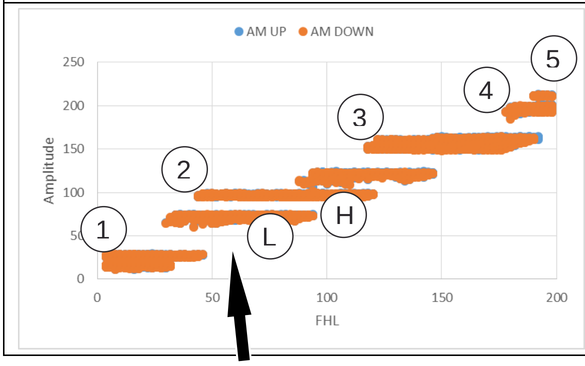
The pulse width gets smaller with increasing FHL, and gets high again when jumping to the next wave. Also the temperature and flow have an impact and broaden the spread of PWR for a given wave.

The green area marks a good range for the FHL to stay with the same wave over the whole operating range. Due to temperature and flow variation this further narrowed.

55 < FHL < 70 (means between 48.4 mV and 61.6 mV)

Accordingly the PWR varies from 0.43 to 0.71 (red area)

The blue frame stands for the first to the fifth wave. “H” and “L” marked the pulse width at high and low temperature.



Amplitudes of first 5 waves of receive burst, measured by increasing the FHL (zero flow, fixed temperature).

Shows the difference between them = clearance. The bigger the clearance the better FHL mode will work.

The blue frame stands for the first to fifth wave. “H” and “L” marked the amplitude at high and low temperature.

3 Description of Assembler Code

3.1 Result of the Analysis of Amplitude

The following values were obtained due to the spool piece shown in section 2.3 Measurement at Variable Flow and Variable Temperature.

3.1.1 Coarse FHL Regulation to Stay within Limits

Only when leaving the range, the firmware will increase or decrease the FHL to be in the range again. For increased FHL regulation lower deviation of regulation "clearance".

The range for regulation "clearance": 55 < FHL < 70

Accordingly, the PWR varies from 0.43 to 0.71

After configuration of TDC-GP30 with initial FHL (for this spool piece, FHL = 62) and setup following parameter:

PWR_LIMIT_MAX (7fpp) = 0x5A (= decimal 90 --> 0.703125)

PWR_LIMIT_MIN (7fpp) = 0x37 (= decimal 55 --> 0.4296875)

3.1.2 Permanent FHL Regulation

Compared to our flow firmware, the regulation will be done permanently and also indicates when you are outside the configured range.

New range for regulation "clearance": FHL = 62

Accordingly, the new PWR varies from 0.54 to 0.65

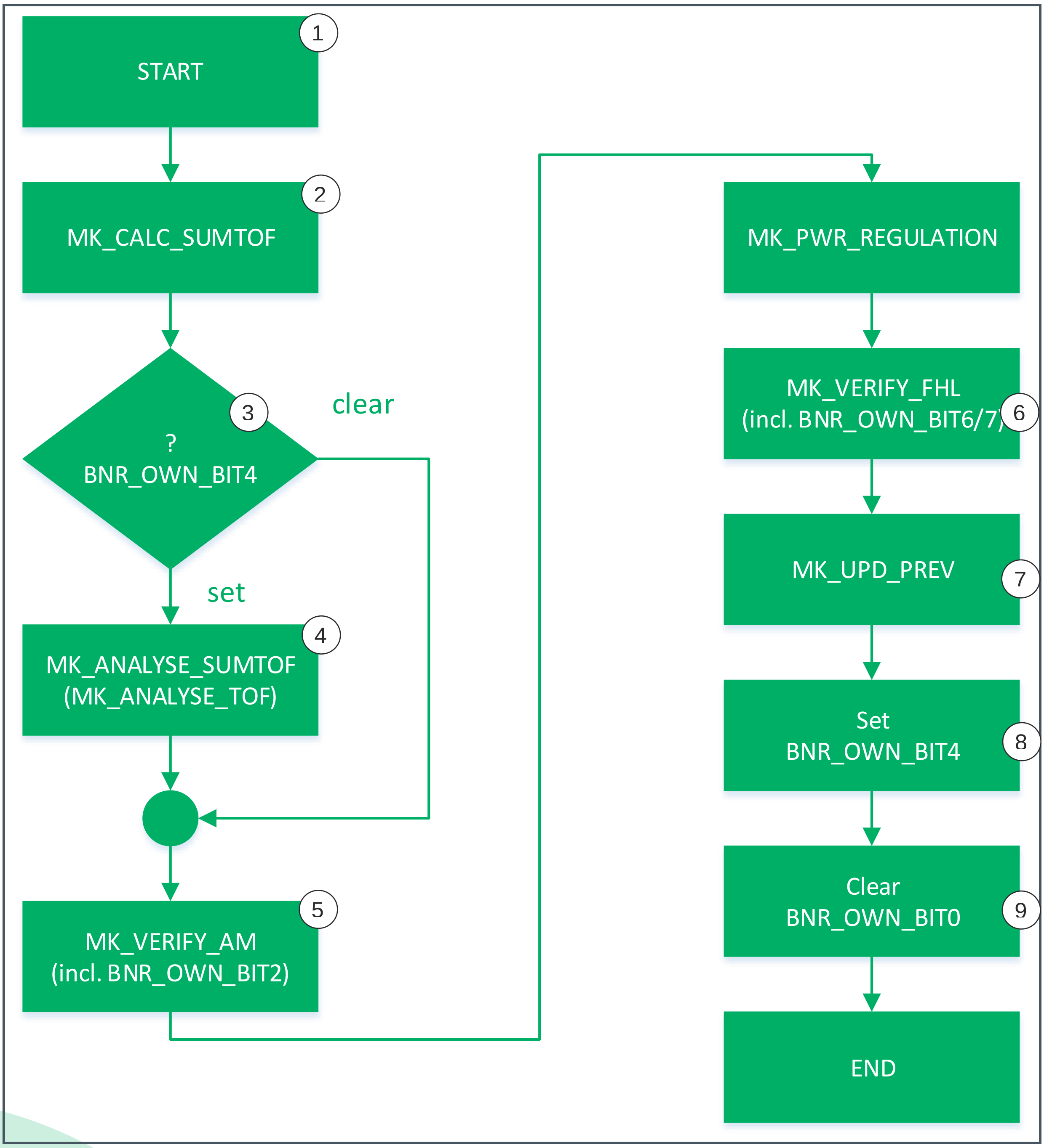
For a permanent FHL regulation set min and max to the same value.

PWR_LIMIT_MAX (7fpp) = 0x4C (= decimal 76 --> 0.59375)

PWR_LIMIT_MIN (7fpp) = 0x4C (= decimal 76 --> 0.59375)

3.2 Flow Chart

Figure 7: Flow Chart



1. START
   As long as BNR_OWN_BIT0 is set, the FHL calculation is executed
2. MK_CALC_SUMTOF
   Calculates the SUMTOF

3. BNR_OWN_BIT4
   Will be set at the end of FHL calculation
4. MK_ANALYSE_SUMTOF* (MK_ANALYSE_TOF*)
   Remark: This block is not completely integrated in the FHL Regulation.
   Analysis of the SUMTOF (TOF UP / TOF DOWN) will be executed after the second run
   if there is a period jump, BNR_OWN_BIT1 is set and stops further FHL calculation
5. MK_VERIFY_AM*
   Remark: This block is not completely integrated in the FHL Regulation.
   Compares current AM (UP and DOWN) with AM_LIMIT_MIN
   otherwise BNR_OWN_BIT2 is set or cleared
6. MK_PWR_REGULATION
   regulates the first hit level (UP and DOWN) depends on the pulse width ratio
7. MK_VERIFY_FHL
   verifies previous FHL with current FHL (UP and DOWN) and depends on any difference
   BNR_OWN_BIT6/7 is set or cleared.
8. MK_UPD_PREV
   store current values as previous parameters to verify with next values
9. END
   At the end, set BNR_OWN_BIT4 and
   clear BNR_OWN_BIT0 to indicate that the FHL calculation is done

Information

Further details about each subroutine are shown in the assembler source code.

4 Declaration

Table 1: Pin Description

CONST	Value	Description
OWN_FLAG	0x50	Own Flag Register
BNR_OWN_BIT0	0	Bit Number, FHL Calculation (jump into subroutine and clear at the end)
BNR_OWN_BIT1	1	Bit Number, ERROR: period jump, cleared not implemented (t.b.d.)
BNR_OWN_BIT2	2	Bit Number, ERROR: amplitude under minimum limit, cleared by subroutine
BNR_OWN_BIT4	4	Bit Number, "1" = FHL Calculation (first run was completed)
BNR_OWN_BIT5	5	Bit Number, "1" = Zero Cross Calibration was done
BNR_OWN_BIT6	6	Bit Number, "1" = FHL_UP Regulation is active
BNR_OWN_BIT7	7	Bit Number, "1" = FHL_DOWN Regulation is active
AM_LIMIT_MIN	0x41	Compare to FDB_US_AM_U and FDB_US_AM_D (e.g. 0x2E000)
PWR_LIMIT_MAX	0x42	7fpp (0.7 = decimal 90 = 0x5A) initialized in subroutine MK_FWI_FHL1
PWR_LIMIT_MIN	0x43	7fpp (0.3 = decimal 38 = 0x27) initialized in subroutine MK_FWI_FHL1
FDB_US_SUMTOF_ADD_ALL	0x44	Calculated SUMTOF
FDB_US_SUMTOF_ADD_ALL_PREV	0x45	Previous calculated SUMTOF
FDB_US_TOF_0_U_PREV	0x46	Previous TOF0_UP value
FDB_US_TOF_0_D_PREV	0x47	Previous TOF0_DOWN value
SHR_ZCD_FHL_U_PREV	0x48	Previous FHL_UP value
SHR_ZCD_FHL_D_PREV	0x49	Previous FHL_DOWN value
SUMTOF_LIMIT	0x40000	SUMTOF_LIMIT multiplied by 250ns/2^16 = 1us
HALF_T_REF	0x20000	1/2 * T reference = 1/2 * 0x40000 * 250ns/2^16 = 1/2 * 1us
FW_ROMVERSION_REV	0xA1	ROM Class + ROM Version

FW_VERSION_NUM	0xF20000	Special FW ("F" = FW Class + FW Version) (0x00 to 0xFF)
FW_VERSION_MAJ	0x000000	FW Major Revision (0x0 to 0xF)
FW_VERSION_MIN	0x000000	FW Minor Revision (0x0 to 0xF)
FW_VERSION_BLD	0x000000	Build Number (0x00 to 0xFF)
FW_VERSION	FW_VERSION_NUM + FW_VERSION_MAJ + FW_VERSION_MIN + FW_VERSION_BLD	

Attention

Following CONST parameter are not completely integrated in the simple FHL Regulation

- AM_LIMIT
- SUMTOF_LIMIT
- HALF_T_REF

5 Summary / Results

Depending on the requirements of the ultrasonic flow meter, spool piece and transducers, the first hit level needs to be regulated or simply it can use a fixed first hit level over temperature and over flow.

For a stable and dependable FHL regulation process, irregular events have to be considered. These events are not taken into account in the preceding example:

- Empty spool piece - how can the regulation resume to the desired state without knowledge of the prior state (e.g. medium temperature).
  The same applies to correct initialization.
- Aging of the sensor (transducers, aging of the spool piece by deposits,...)

  and /or changing amplitude of the received signal for any other reason.
- Change of required FHL by flow Measurement at different temperatures

  e.g. heat meter is running with cold water and hot water.
- Limited criteria of FHL

  e.g. what is the minimum and maximum FHL.
- Corrupted measurement (bubbles etc.) should always be excluded from FHL regulation. Criteria for detection of corrupted measurements have to be developed and implemented.

- It should be noted that in this ASM source code the FHL regulation for UP and DOWN is independent of one another.

Alternatively, TDC-GP30-F01, including the flow firmware offers a number of auxiliary measurements and settings to support stable first hit detection:

- Peak amplitude measurement of selected waves of the receive signal
- First hit pulse width ratio (PWR) measurement to optimize the quality of the first hit detection
- Automated zero crossing calibration
- First hit level setting to detect the chosen wave at some particular amplitude

The available regulation methods in overview:

- Method 1, Keep FHL constant
- Method 2, Return to a trusted FHL in case of inconsistency
- Method 3, Offset trusted FHL
- Method 4, Fallback method

Any of these methods can be combined with the following options:

- Option A, Regulate PWR
- Option B, Define FHL as ratio to receive amplitude
- Option C, Activate FHL regulation modes only in failure case

For further information about flow firmware, please refer to the following document:

- TDC-GP30-F01 datasheet volume 4 “Firmware, Memory and ROM Overview”

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7 Document Status

Table 2: Document Status

Document Status	Product Status	Definition
Product Preview	Pre-Development	Information in this datasheet is based on product ideas in the planning phase of development. All specifications are design goals without any warranty and are subject to change without notice.
Preliminary Datasheet	Pre-Production	Information in this datasheet is based on products in the design, validation or qualification phase of development. The performance and parameters shown in this document are preliminary without any warranty and are subject to change without notice.
Datasheet	Production	Information in this datasheet is based on products in ramp-up to full production or full production which conform to specifications in accordance with the terms of ScioSense B.V. standard warranty as given in the General Terms of Trade.
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8 Revision Information

Table 3: Revision History

Revision	Date	Comment	Page
0.9	2019-12-11	Initial Version	
2	2021-01-08	Transfer to ScioSense format Section 1.1 added	All 7

Note(s) and/or Footnote(s):

1. Page and figure numbers for the previous version may differ from page and figure numbers in the current revision.
2. Correction of typographical errors is not explicitly mentioned.

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