

Agrigel UFO2/3 I²C firmware

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Table 1: Revision list

date	comment	author
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1 Introduction

This document constitutes a brief description of how to use the customized D-Flow UFO firmware that makes it possible to change the D-Flow UFO ASIC default configuration using the I²C protocol. Also how the transit times and volume flow can be read by I²C is described.

1.1 References

[1] I²C-bus specification and user manual. Protocol specification, NXP Semiconductors, 4 April 2014. (Revision 6).

1.2 Definitions and abbreviations

UFO ASIC D-Flow application specific integrated circuit

US Ultrasonic

SRAM Static random-access memory

EEPROM Electrically erasable programmable read-only memory

t_{std} US transit time in standard direction

t_{rev} US transit time in reverse direction

2 I2C communication protocol

The overall requirement for the configuration ability in the firmware is to be able to change all the relevant parameter settings of the UFO2 firmware using the I2C bus protocol. All communication uses a 16 bit addressing mode, see table 2. The EEPROM used in the system is configured to address 0x1010000(rw) and the ASIC to 0x1010111(rw). The format of the write and read operations are described in figure 1 and figure 2. For a more comprehensive specification of the I2C protocol, see reference [1].

The UFO configuration is stored in flash memory. Since the flash memory needs to be programmed in a strict sequence one page at a time, the parameters needs to be placed in SRAM before it is written to FLASH. Parameters are therefore sent in blocks of 512 bytes to SRAM (a complete flash page). Programming of flash is then done automatically by the firmware by writing the appropriate command to the UFO ASIC, see table 4. Verification of the data stored in flash can be done by reading back the content after a write operation is completed.

The SRAM memory layout is depicted in table 3. Valid commands to be written to the 'command' field are given in table 4. The scratch pad is the SRAM area used to store the configuration page before it is written to the flash memory. All data is stored in little-endian format.

External microcontroller need to clear the status field by writing a '0' before sending a new command to be able to detect when the ASIC has updated the status. The result for a given command is then obtained by polling the corresponding memory address until the value is different from '0'. To minimize the number of I2C memory accesses both status, payload data and command can be written in sequence, e.g. writing 512 bytes to flash can be done by doing a sequential write from address 0x2000 to 0x2207. This will then include clear of status, write of configuration data to the scratch pad and an update of the command field to program a flash page. As command is the last word written, flash will only be updated when the scratch pad is filled with relevant data.

Note that since the configuration size is less than two pages (870 bytes vs. 1024 bytes) the scratch pad only need to be partially filled with relevant configuration data when the second flash page is updated. The remaining data up to the full page size of 512 bytes could then be treated as 'don't care' but for simplicity and consistency check it is preferable filled with zeros or other well defined value.

When an update of the flash configuration area has been made a command to restart the UFO has to be written for the new configuration to take effect, see table 4. Therefore the complete cycle for doing an configuration update will look like depicted by the flowchart in figure 3. **NOTE: Arg 1 of the command to program a page is the start address of the flash page that should be updated, which is 0xFA00 for the first page and 0xFC00 for the second page.**

US transit times and volume flow from the last measurement is readily available by reading out the data from the corresponding addresses given in table 3.

Slave address	Description
0000 XXX	reserved addresses
1010 XXX	reserved for 16 bit addressing mode
1111 0AA	reserved for 10 bit addressing mode
1111 1XX	reserved addresses
all other addresses	usable address space
X = don't care; A = upper bits of 10 bit address	

Table 2: I²C address ranges

Section	Access	Start address	Native format	Size [bytes]	Contains
status	r/w	0x2000	uint16	2	command result
scratch pad	r/w	0x2002	-	512	payload data
cmd	r/w	0x2202	uint16	6 (2 x 3)	command
arg1			uint16		arg 1
arg2			uint16		arg 2
t_std ¹	r	0x2208	double	8	transit time, downstream [s]
t_rev ¹	r	0x2210	double	8	transit time, upstream [s]
vol_flow ²	r	0x2218	uint16	2	volume flow [ml/min]
...	r	0x221A	-	-	end

¹ Invalid transit time are reported as '0'.

² Invalid volume flow is reported as 0xFFFF.

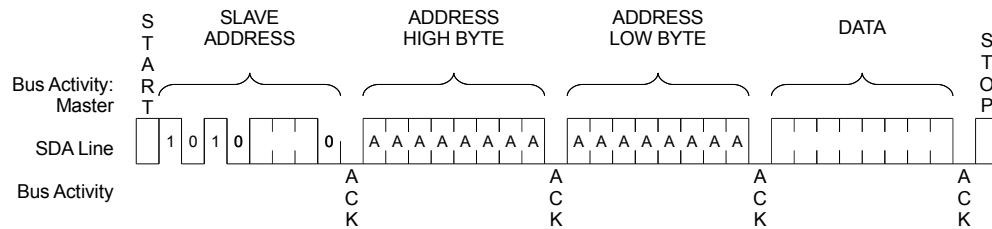
Table 3: Memory organization

Command	cmd	arg1	arg2	result
Program page 512 bytes	0x0102	addr ¹	-	0x0001: success 0xFFFF: fail
Restart UFO	0x5555	0x5555	0x5555	0x0001: success 0xFFFF: fail

¹ Start address of the flash page that should be updated, which is 0xFA00 for the first page and 0xFC00 for the second page.

Table 4: I²C command organization

Random Write (16 bit addressing mode)



Sequential Write (16 bit addressing mode)

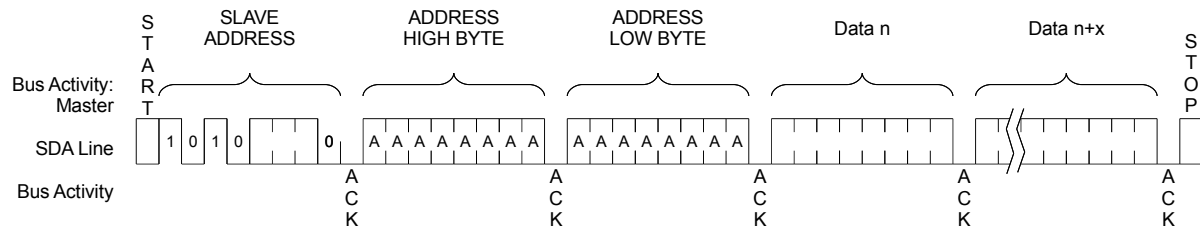
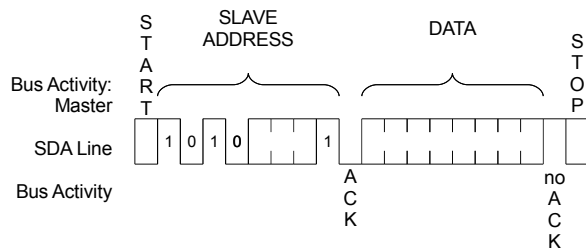
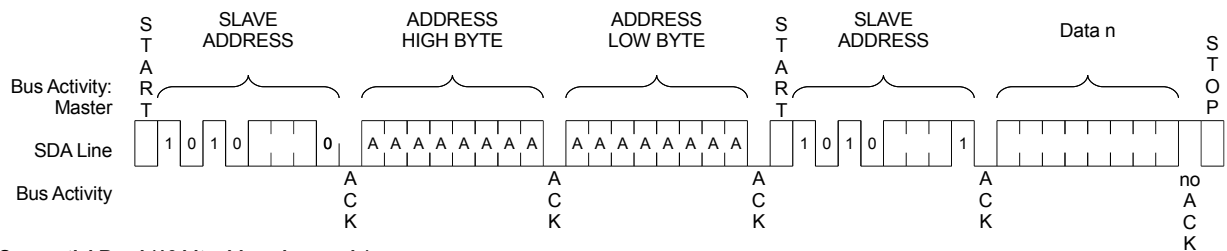


Figure 1: Writing to the ASIC using I²C 16 bit addressing mode

Current Address Read (16 bit addressing mode)



Random Read (16 bit addressing mode)



Sequential Read (16 bit addressing mode)

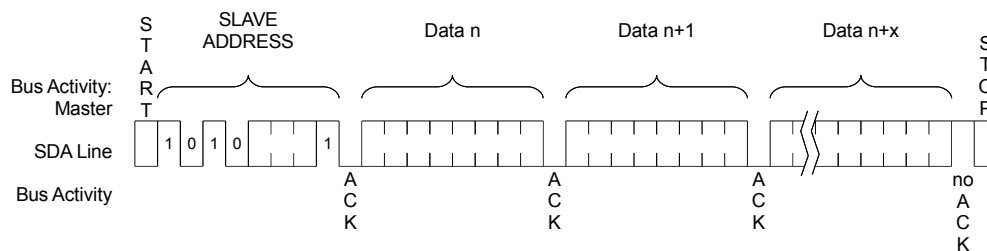


Figure 2: Reading from the ASIC using I²C 16 bit addressing mode

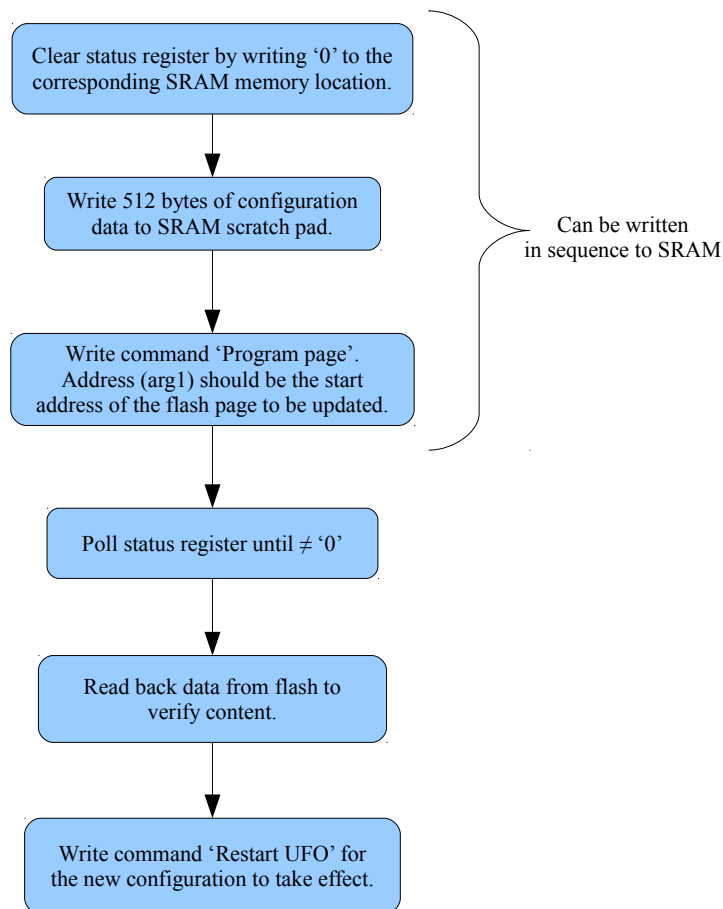


Figure 3: Sequence to update UFO configuration by I²C

3 UFO configuration parameters

This section describes the UFO configuration parameters that are accessible (rw) via the I²C interface.

3.1 List of configuration parameters

Table 5 shows the configurable parameters, their size in bytes and the corresponding location in flash. All valid parameter ID values that could be used in the UFO settings area of this table are given in table 6.

Section	Parameter	Address	Native format	Size [bytes]	Byte nr
	STATE [-]	0xFA00	uint16	2	1
Production	FW_VER_MAIN [-]	0xFA02	uint8	1	3
	FW_VER_SUB [-]	0xFA03	uint8	1	4
	RUNNINGNUMBER [-]	0xFA04	uint32	4	5
	CALIBRATIONTIME [-]	0xFA08	uint32	4	9
	VALID_PARAMS [-]	0xFA0C	uint16	2	13
UFO settings	PARAM_ID_1 [-]	0xFA0E	uint16	2	15
	PARAM_VALUE_1 [-]	0xFA10	uint16	2	17
	PARAM_ID_2 [-]	0xFA12	uint16	2	19
	PARAM_VALUE_2 [-]	0xFA14	uint16	2	21
	-	-	-	-
	PARAM_ID_20 [-]	0xFA5A	uint16	2	91
	PARAM_VALUE_20 [-]	0xFA5C	uint16	2	93
Calc settings	MEAS_INTERVAL [ms]	0xFA5E	uint16	2	95
Mechanical	LEN [m]	0xFA60	double	8	97
	DIA [m]	0xFA68	double	8	105
	DSOS [s]	0xFA70	double	8	113
	DZC [s]	0xFA78	double	8	121
	MIN_TT [s]	0xFA80	double	8	129
	MAX_TT [s]	0xFA88	double	8	137
Curves	K_CURVE0_COL_RES	0xFA90	double	120	145
	K_CURVE0_COL_TEMP	0xFB08	double	120	265
	K_CURVE0_LEN	0xFB80	uint16	2	385
	K_CURVE1_COL_TEMP	0xFB82	double	120	387
	K_CURVE1_COL_VISC	0xFBFA	double	120	507
	K_CURVE1_LEN	0xFC72	uint16	2	627
	K_CURVE2_COL_RE	0xFC74	double	120	629
	K_CURVE2_COL_K	0xFCEC	double	120	749
	K_CURVE2_LEN	0xFD64	uint16	2	869

Table 5: UFO firmware configuration parameters

3.2 Description of configuration parameters

A short description of the available configuration parameters are presented below.

3.3 Production parameters

STATE Currently not used.

FW_VER_MAIN Place holder for main version (1 byte).

FW_VER_SUB Place holder for sub version (1 byte).

Parameter	ID value	UFO2	UFO3
PARAM_UL_CONFIG_DIR1_ON_ID	3	X	X
PARAM_UL_LOOPC_ID	6	X	X
PARAM_UL_SMARK_ID	7	X	X
PARAM_UL_SSPACE_ID	8	X	X
PARAM_UL_ANASAMPLE_ID	9	X	X
PARAM_UL_PRE_MEAS_DELAY_CAL_ID	10	X	X
PARAM_UL_PRE_MEAS_DELAY_0_ID	11	X	X
PARAM_UL_PRE_MEAS_DELAY_1_ID	12	X	X
PARAM_UL_INIT_PULSE_DELAY_ID	13	X	X
PARAM_UL_LAST_PULSE_DELAY_ID	14	X	X
PARAM_UL_REF_CONFIG_VALUE_ID	16	X	X
PARAM_AG_STAGE1_AUTO_R1_ID	22	X	X
PARAM_AG_STAGE1_AUTO_GM1_ID	23	X	X
PARAM_AG_STAGE1_CONFIG_MIN_R1	26	X	X
PARAM_AG_STAGE1_CONFIG_MIN_GM1_ID	27	X	X
PARAM_AG_STAGE1_CONFIG_LOWEST_ID	28	X	X
PARAM_AG_STAGE1_CONFIG_R1_SEARCH_ID	29	X	X
PARAM_AG_STAGE1_CONFIG_GM1_SEARCH_ID	30	X	X
PARAM_AG_STAGE2_A2_ID	35	X	X
PARAM_AG_STAGE2_R2_ID	36	X	X
PARAM_AG_OTHER_SEL_HP_ID	39	X	X
PARAM_AG_OTHER_SEL_PAD_BP_ID	41	X	X
PARAM_AG_PTRIGLEV_PTRIGLEV_ID	49	X	X
PARAM_AG_PTRIGLEV_PTRIGLEV_LOW_ID	50	X	X
PARAM_AG_PTRIGLEV_PTRIGLEV_HIGH_ID	51	X	X
PARAM_TX_PCONFIG_ID	54	X	X
PARAM_TX_PCONFIG_0_ID	55	X	X
PARAM_TX_PCONFIG_1_ID	56	X	X
PARAM_TX_PCONFIG_2_ID	57	X	X
PARAM_TX_PCONFIG_3_ID	58	X	X
PARAM_TX_EXC_LENGTH_ID	62	X	X
PARAM_TX_EXC_CONFIG_SEL_N70_ID	64	X	X
PARAM_TX_MSEQ_EXCLEVEL_ID	69	X	X
PARAM_TX_MSEQ_OUTPUTENABLE_ID	70	X	X

Table 6: List of valid UFO parameter IDs

RUNNINGNUMBER Place holder for running number, 0...4294967295.

CALIBRATIONTIME Place holder for calibration date, YYYYMMDDHH (0 .. 4294967295).

3.4 UFO settings

PARAM_UL_CONFIG_DIR1_ON If set to 1 both t_{std} and t_{rev} are measured. If set to 0 only t_{std} is measured.

LOOPC Number of sing around loops used for averaging in each measurement. In order to properly use the embedded measurement mode 3, LOOPC should be set to $n * 8 + 4 (n \geq 0)$.

SMARK This parameter defines the beginning of the time window in which the received signal should appear. SMARK starts counting at the moment of excitation on the sending transducer. This time depends on the transducer distance. Value is expressed in 16 MHz clock cycles. Smaller value than $10\mu s$ is not recommended.

SSPACE This parameter defines the end of the time window in which the received signal should appear. SSPACE starts counting at the moment of SMARK. Must be set to cover all variations in transit time due to temperature and flow rate changes. This setting depends on the transducer distance. Value is expressed in 16 MHz clock cycles.

UL_ANASAMPLE Time from start of SSPACE until the signal zero offset is captured. Value is expressed in 16 MHz clock cycles.

UL_PRE_MEAS_DELAY_CAL Delay time before doing an US measurement during AGC. Value is expressed in 16 MHz clock cycles.

UL_PRE_MEAS_DELAY_0 Delay time before doing a t_{std} US measurement. Value is expressed in 16 MHz clock cycles.

UL_PRE_MEAS_DELAY_1 Delay time before doing a t_{rev} US measurement. Value is expressed in 16 MHz clock cycles.

UL_INIT_PULSE_DELAY Common delay time before a measurement to let the driver stabilize before the excitation. Value is expressed in 16 MHz clock cycles.

UL_LAST_PULSE_DELAY Common delay time after a measurement to let the UFO evaluate PTRIG_HIGH and PTRIG_LOW levels before the amplifier becomes inactive. Value is expressed in 16 MHz clock cycles.

UL_REF_CONFIG Delay time used for settling of the US amplifier before starting a measurement. Value is expressed in 16 MHz clock cycles.

AG_STAGE1_AUTO_R1 Defines the gain setting of AGC stage 1 together with GM1. It can be set manually but if an AGC is issued and PARAM_AG_STAGE1_CONFIG_R1_SEARCH is set to 1 the value might change.

AG_STAGE1_AUTO_GM1 Defines the gain setting of AGC stage 1 together with R1. It can be set manually, but if an AGC is issued and PARAM_AG_STAGE1_CONFIG_GM1_SEARCH is set to 1 the Gm1 value might change if R1 reaches its maximum or minimum value.

PARAM_AG_STAGE1_CONFIG_MIN_R1 Minimum r1 value for a search.

PARAM_AG_STAGE1_CONFIG_MIN_GM1 Minimum gm1 value for a search.

PARAM_AG_STAGE1_CONFIG_LOWEST If set to 1, the AGC searches for the lowest gain which results in a signal amplitude greater than PTRIGLEV_LOW.

PARAM_AG_STAGE1_CONFIG_R1_SEARCH If set to 1, r1 search is on during AGC. If set to 0, the current r1 will be fixed.

PARAM_AG_STAGE1_CONFIG_GM1_SEARCH If set to 1, gm1 search is on during AGC. If set to 0, the current gm1 will be fixed.

AG_STAGE2_A2 Controls the gain setting of AGC stage 2 together with r2. This value will stay fixed through an AGC.

AG_STAGE2_R2 Controls the gain setting of AGC stage 2 together with a2. This value will stay fixed through an AGC.

AG_OTHER_SEL_HP Select high pass frequency of the bandpass filter. Allowed values are 1-15 but recommended value is 15.

PARAM_AG_OTHER_SEL_PAD_BP Toggles whether or not the signal is output on the BP-pins. If set to 4 the signal is output, if set to 0 output is disabled.

PTRIGLEV_PTRIGLEV When the signal amplitude exceeds PTRIGLEV the time measurement functions is triggered. The required value of PTRIGLEV is determined by the shape of the received signal. The shape of the received signal is a product of the whole system, depending on for instance the transducers, the electronics and the shape of the inner flow tube. The minimum value is dependent on the amplitude of reflexes present during measurement. The amplitude of the reflexes is expected to vary due to different transducers and flow tubes used. The temperature also effects the amplitude of these reflexes. Maximum PTRIG value can be found by examining the amplitude of the first negative excursion of the received signal. The recommended PTRIG value is in the middle of the range between minimal and maximum values for each meter size. This leaves headroom for differences in both transducers and meter body.

PTRIGLEV_LOW Defines the lower threshold value used by the AGC. It should be higher than PTRIGLEV.

PTRIGLEV_HIGH Defines the upper threshold value used by the AGC, it should be equal or higher than PTRIGLEV_LOW.

TX_PCONFIG Zero flow trimming when using TX excitation.

3.5 CalcSettings

MEAS_INTERVAL Ultrasonic measurement interval expressed in milliseconds.

3.6 Mechanical parameters

LEN Distance between the transducers expressed in meters.

DIA Flow tube diameter expressed in meters.

DSOS Delay to compensate for the propagation delay in both transducers and electronics. This delay is determined during the calibration procedure. Expressed in seconds.

DZC Delay to compensate for any unbalance between the up- and downstream measurements. This delay is determined during calibration. Expressed in seconds.

MIN_TT Minimum valid transit time, see *MAX_TT*.

MAX_TT Maximum valid transit time expressed in seconds. Used together with *MIN_TT* to define the range of allowed transit times. Outside this range the transit times are reported as '0' and the volume flow as 0xFFFF via the I²C interface.

3.7 K-curves

K_CURVE0_COL_RES Temperature sensor resistance (*res*) vs. temperature (*temp*), column *res*. See table 7.

K_CURVE0_COL_TEMP Temperature sensor resistance vs. temperature, column *temp*. See table 7.

K_CURVE1_COL_TEMP Temperature vs. viscosity (*visc*), column *temp*. See table 8.

K_CURVE1_COL_VISC Temperature vs. viscosity, column *visc*. See table 8.

K_CURVE2_COL_RE Reynolds number (*Re*) vs. K-factor (*K*), column *Re*. This field is usually determined during calibration in production but the default values are shown in table 9.

K_CURVE2_COL_K Reynolds number vs. K-factor, column *K*. This field is usually determined during calibration in production but the default values are shown in table 9.

row	res	temp
1	921.6	-20.0
2	960.9	-10.0
3	1000.0	0.0
4	1039.0	10.0
5	1077.9	20.0
6	1116.7	30.0
7	1155.4	40.0
8	1194.0	50.0
9	1232.4	60.0
10	1270.8	70.0
11	1309.0	80.0

Table 7: Temperature sensor resistance vs. temperature

row	temp	visc
1	0.0	1.7920e-006
2	10.0	1.3080e-006
3	20.0	1.0040e-006
4	30.0	8.0500e-007
5	40.0	6.6100e-007
6	50.0	5.5600e-007
7	60.0	4.7700e-007
8	70.0	4.1700e-007
9	74.0	3.9690e-007
10	0.0	0.0
11	0.0	0.0

Table 8: Temperature vs. viscosity

row	Re	K
1	1364	0.9791
2	2107	1.0236
3	3153	1.0482
4	4054	1.0763
5	5002	1.0997
6	6085	1.0844
7	6993	1.1068
8	9507	1.1022
9	11005	1.1211
10	12317	1.1287
11	14537	1.1298
12	15695	1.1194
13	16716	1.1388
14	17848	1.1394
15	20823	1.1449

Table 9: Reynolds number vs. calibration factor