ESF Series I2C Interface	
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DOCUMENT TRACKING TABLE

Version	Date	Reason for change
0.1	10/11/2017	Issue 1
0.1	22/03/2018	Added S/W reset option.

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Reference Documents

[1] The I^2C bus specification, Version 2.1, January 2000, NXP semiconductors

1. Introduction

In this document, the I^2C compatible communication interface, the instruction set and timing diagram are illustrated.

2. Serial Interface

2.1 General Interface Description (I^2C)

The ESF Series Sensor facilitates an Inter-Integrated Circuit (I^2C) compatible interface communication with a master device. For full description of the interface please refer to [1]. When used in I^2C compatible mode, the ESF sensor acts only as a slave device and does not, in any case, drive the SCL line. The clock rate supported in this mode is up to 400 kHz. The signals of the I/O connector of the sensor can be seen in Table 1 below.

PIN	NAME	FUNCTION
1	NC	No Connect
2	NC	No Connect
3	VDD	Power Supply, positive rail
4	GND	Power Supply, ground rail
5	SDA	Serial Data I/O, data input/output bidirectional port
6	SCL	Serial Clock, clock signal from master to slave device

Table 1: I/O Connector Configuration (I^2C Mode)

2.2 Timing Specifications and Diagrams

The timing specifications of the I^2C communication are shown in Table 2.

SERIAL INTERFACE (I2C)						
Parameter	**Description**	**Min**	**Typ**	**Max**	**Units**	**Comments**
T_{SCL_HIGH}	SCL High Pulse Width	1.25			µsec	
T_{SCL_LOW}	SCL Low Pulse Width	1.25			µsec	
Ts_{START}	Start Condition Setup Time	400			nsec	Minimum time from SCL rising edge to SDA falling edge
Th_{START}	Start Condition Hold Time	400			nsec	Minimum time from SDA falling edge to SCL falling edge
Ts_{STOP}	Stop Condition Setup Time	400			nsec	Minimum Time from SCL rising edge to SDA rising edge
Ts_{DATA}	Data Setup Time	200			nsec	Minimum time from SDA change to SCL rising edge

Th_{DATA}	Data Hold Time	400			nsec	Minimum Time from SCL falling edge to SDA change
T_{PS}	Stop Condition to Start Condition Time	800			nsec	Minimum time between a Stop and a Start Condition
OTHER SYSTEM DELAYS						
T_R	Response Time (Output Update Rate)		2		msec	
$T_{DigitalRDY}$	Time from unit power up, to when the digital output data are valid		300		msec	

Table 2: I²C Timing Specifications (Continued)

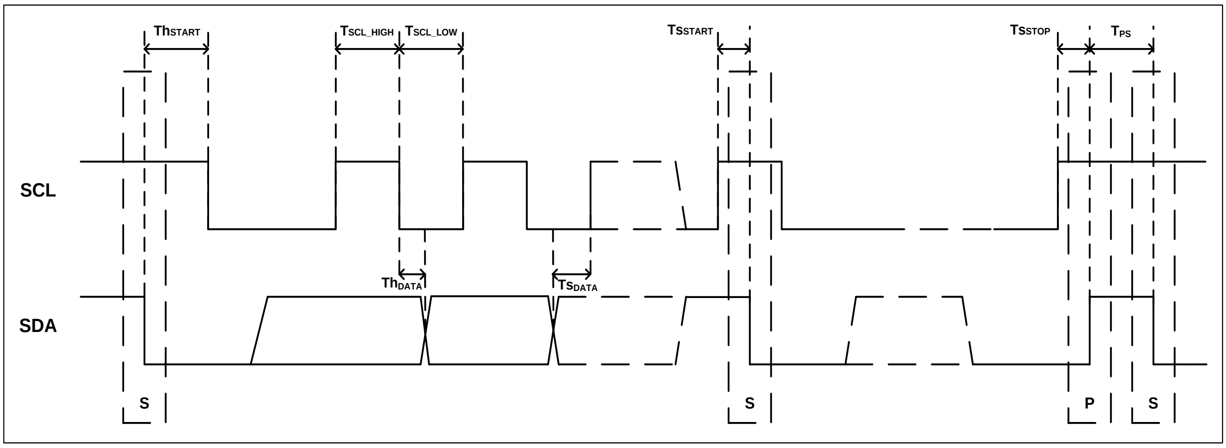

Figure 1: I²C Interface Timing Diagram

2.3 Register Description

The sensor contains four read-only registers. They are: the ***Flow Data Register***, the ***Temperature Data Register***, the ***Status Register*** and the ***Serial Number Register***.

The ESF sensor Flow Data Register provides a 16-bit, 2's complement digital output (i.e. -32768 ~ 32767) which corresponds to the calibrated and temperature compensated data. The calibrated data is calculated internally by the calibration and temperature compensation logic. It can be read through the Flow Data Register, shown in Table 3. The 2 bytes which compose the 16-bit calibrated data should be read by using a multiple read transaction within the specified time before a new sample updates the data register.

The Temperature Date Register is also a calibrated 16-bit length number which corresponds to the correction temperature of the device. The only difference is that the output is an unsigned integer (i.e. 0 ~ 65536) unlike the signed Flow Data Register.

***Flow Data Register* (0x00) / *Temperature Data Register* (0x01)**

ADDRESS	REGISTER NAME	TYPE	DEFAULT VALUE (Hex)	MNEMONIC
0x00, 0x01	Calibrated Data Byte 1	R	Variable	CAL_DATA[15:8]
	Calibrated Data Byte 2	R	Variable	CAL_DATA[7:0]

Table 3: Flow and Temperature Data Register Structure

The ESF sensor Status Register provides information about the status of the sensor and the firmware version of the device. The register is 3 bytes long. Table 4 summarizes the structure of the Status Register. Interpretation of the status byte can be seen in Table 6 later on.

***Status Register* (0x02)**

ADDRESS	REGISTER NAME	TYPE	DEFAULT VALUE (Hex)	MNEMONIC
0x02	Status Byte	R	Variable	STATUS[7:0]
	F/W Version Byte 1	R	Fixed ID	FW_VER_BEFORE_DECIMAL_POINT[7:0]
	F/W Version Byte 2	R	Fixed ID	FW_VER_AFTER_DECIMAL_POINT[7:0]

Table 4: Status Register Structure

Each ESF sensor is uniquely identified by a unique 32-bit serial number. This number can read from the Serial Number Register and is 4 byte unsigned integer. Table 5 summarizes the structure of the register.

***Serial Number Register* (0x03)**

ADDRESS	REGISTER NAME	TYPE	DEFAULT VALUE (Hex)	MNEMONIC
0x03	Serial Number Byte 1	R	Fixed ID	SER_NO[31:24]
	Serial Number Byte 2	R	Fixed ID	SER_NO[23:16]
	Serial Number Byte 3	R	Fixed ID	SER_NO[15:8]
	Serial Number Byte 4	R	Fixed ID	SER_NO[7:0]

Table 5: Serial Number Register Structure

2.4 Data Transactions

At power on reset, the sensor defaults to transmission of the contents of the Flow Data Register. If the master device transmits the selected sensor address **(0x45)** with a high in the $R/\overline{W}$ bit position, the ESF Sensor returns the contents of the Flow Data Register after acknowledging (ACK) by holding the SDA line low. The master should then provide at least 18 clock pulses on the SCL line in order to readout the two Flow Data Bytes. An acknowledge bit (ACK) should be provided by the master on each byte received by holding the SDA line low while providing a clock. The same frame structure also applies to a Temperature Data transaction. An example of such a transaction can be seen in figure 2 below.

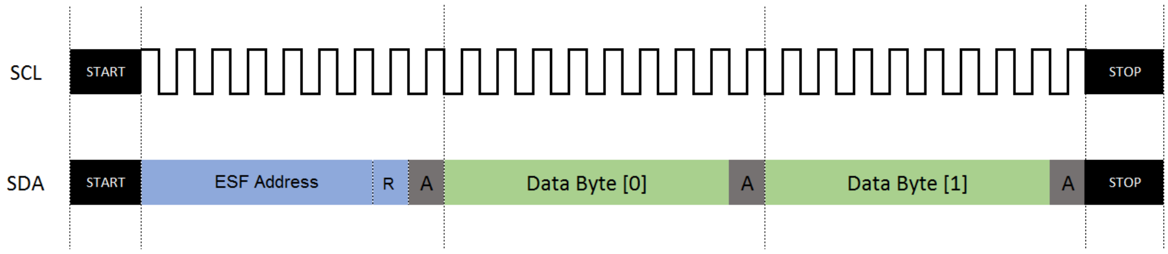

Figure 2: Read Flow/Temperature Data Register (I^2C)

In order to get a temperature reading or any other reading apart from the flow value, the user needs to change the default register to the register he wishes to read from. Once the register is changed, the device will continue to give the results from the specific register on every following read transaction. It will remain in this state until either the device is powered down or the user changes the register. To change the register, first the ESF Sensor address **(0x45)** should be transmitted with the $R/\overline{W}$ bit set low. This notifies the device that user wishes to change register. The following byte sent by the master corresponds to the new register address from which the user wants to read from. While in the same transaction, the user has 2 choices: 1) end the transmission here by sending a stop bit. On the next read, the contents of the new register will be placed on the bus by the slave device, or 2) send a start bit followed by another read byte. The 4th byte of the frame will be the device's response with data from the new register. After the final byte is transmitted, a final stop bit should be sent to complete the transaction. Note that an acknowledge bit (ACK) should be provided by the master on each byte received by holding the SDA line low while providing clock. Figures 3 and 4 illustrate the two above cases.

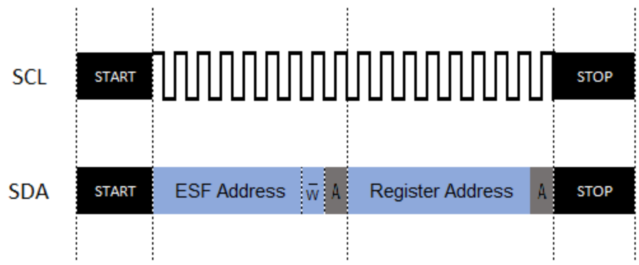

Figure 3: Changing a register.

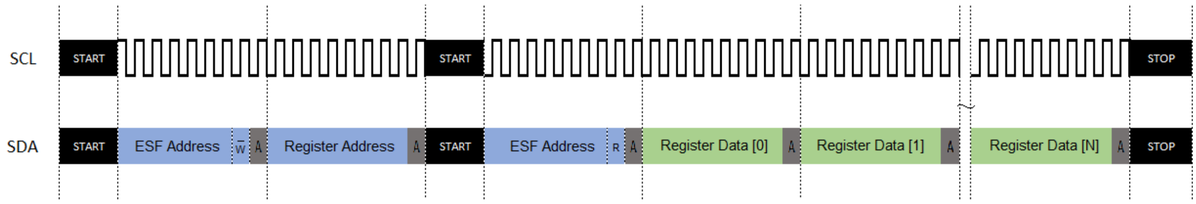

Figure 4: Changing a register and reading content in the same transaction.

In all cases, if the sensor address is not recognized by the unit, a Not Acknowledge (NACK) bit will be transmitted by holding the SDA line high. The serial interface will reset and further clock pulses on the SCL line will have no effect until a valid address is transmitted. Likewise if after each data byte the master does not acknowledge by holding SDA line low, the sensor unit serial interface will reset and the transaction shall be stopped.

2.5 Data Interpretation

2.5.1 Flow Data Register (0x00)

In ESF series sensors flow data transactions, data arrives MSB first. Flow is represented as a 16-bit, signed two's complement number. The lowest number in the Flow Data Register is 0x8000 (-32768 in Decimal) and the highest number is 0x7FFF (32767 in Decimal). In unidirectional ESF sensors output data higher than 0x8000 must be ignored.

Calibrated flow (in SLPM) can be calculated using the following formula:

$$Flow_{SLPM} = \frac{Digital\ Output}{32768} * Full\ Scale\ Flow * 1.1 \qquad (1)$$

As an example consider, the following received bytes:

Flow Register Byte [0] = 0x3F
Flow Register Byte [1] = 0xFF

Using equation 1, and assuming a sensor with full scale flow of 200 SLPM, the current output flow is calculated to be **109.9932 SLPM**.

In the bidirectional version of ESF series sensors equation 1 still applies. The 16^{th} bit of the Flow Data Register will be set indicating a negative number or reverse flow.

As an example consider the following received bytes:

Flow Register Byte [0] = 0xFC
Flow Register Byte [1] = 0x18

Using equation 1, under the same conditions described above, the output flow would be calculated to **-6.7139 SLPM**.

The Flow Data Register is updated with a frequency of typically 500 Hz (2msec). Reading data faster than this frequency will result in the consecutive read of the same data sample.

2.5.2 Temperature Data Register (0x01)

Temperature is represented as a 16-bit, unsigned integer number. The lowest number in the Temperature Data Register is 0x0000 (0 in Decimal) and the highest number is 0xFFFF (65535 in Decimal).

Calibrated Temperature (in C^o) can be calculated using the following formula:

$$Temperature_{Celsius} = \frac{Digital\ Output}{65535} * 50 \quad (2)$$

As an example consider, the following received bytes:

Temperature Register Byte [0] = 0x84
Temperature Register Byte [1] = 0x32

Using equation 2, the current output temperature is calculated to be **25.82 C^o**.

2.5.3 Status Register (0x02)

When reading the ESF sensor Status Register, 3 bytes are returned. The first byte read (or MSB) in the packet is the Status Byte. The Status Byte indicates possible faults detected by the sensor internal self-check mechanism. Its structure is as follows:

Status

BIT7	BIT6	BIT5	BIT4	BIT3	BIT2	BIT1	BIT0
Reserved (0)	Reserved (0)	Reserved (0)	Flash Corruption Indicator Bit	Reserved (0)	Reserved (0)	Reserved (0)	Reserved (0)

Table 6: Status Byte Structure

Upon power up, the sensor performs an internal self-check of its code and calibration data stored in its non-volatile memory. If any of these is found corrupted, BIT4 of the Status Byte is set to indicate the fault. If the Status Byte returned is 0x00 then the sensor operates as expected.

WARNING

In case of code or calibration data corruption, output data should be considered invalid. The sensor should be returned to ESS S.A. for repair.

Besides the status byte, the Status Register also contains the Firmware version of the ESF sensor which consists of the last 2 bytes in the register. ESS's firmware has the following format: x.y, where x and y have a maximum decimal range of 255. So the first byte x (of the F/W bytes) is the number before the decimal point and the next byte y is the number after the decimal point.

As an example consider the following received bytes:

Status Register Byte [0] = 0x00
Status Register Byte [1] = 0x02
Status Register Byte [2] = 0x0B

From the above we can see that the status of the device is **0** and the F/W version is **2.11**.

2.5.4 Serial Number Register (0x03)

The Serial Number Register contains the unique serial number which is 4 bytes long and is interpreted as an unsigned 32-bit number.

As an example consider the following received bytes:

Serial No Register Byte [0] = 0x01
Serial No Register Byte [1] = 0x05
Serial No Register Byte [2] = 0x62
Serial No Register Byte [3] = 0x1F

The serial number 0x0105621F corresponds to **17130015** in decimal.

2.6 Software Reset (0xFE)

The device has an additional option to perform a software reset (firmware version 0.4 and later) via the I^2C communication interface. This option could be useful in specific cases depending on the application. For instance, the user could issue a S/W reset to assure correct initialization after a hot-plug connection.
The procedure to reset the device is the same as changing a register, followed by the byte **0xFE**. In other words, the user must first send the byte 0x8A (7 bit address plus write bit) and then the byte 0xFE. The device will then return its acknowledge bit and immediately reset itself. After 10 milliseconds, the device will be ready to give its first valid sample.

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