MFP257B1C

Features

- Monolithic CMOS thermal flow sensor
- SPI Interface
- 16bits flow output (bi-direction)
- On-chip10bits gas temperature sensor
- Excellent hysteresis and repeatability
- High sensitivity and accuracy
- Power down mode
- 2.7V~5.5V Single Supply Operation
- RoHS Compliant

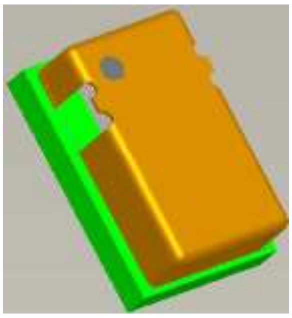

Figure 1 MFP257B1C

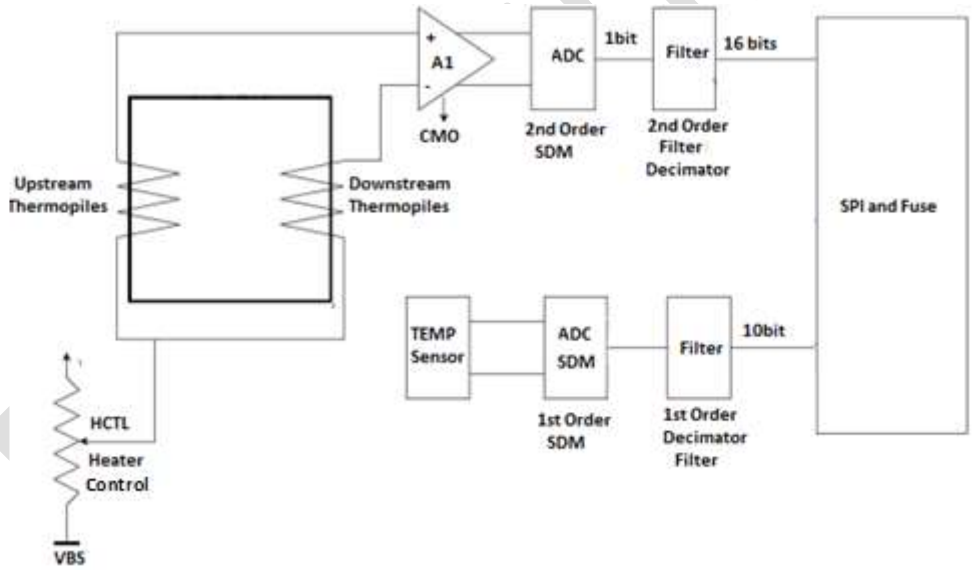

Figure 2 - Block Diagram

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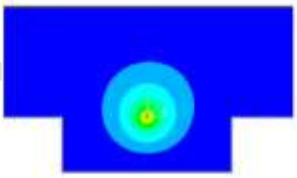
General Descriptions

MFP257B1C is a customized thermal gas flow sensor (see Fig.1) based on MEMSIC's proprietary CMOS technology for thermal mass flow sensing. The monolithic flow sensor chip, mounted on the PCB, can be assembled in different flow channels to be made into different types of flow meters for accurate flow measurement and control. MFP257B1C is designed to use SPI digital communication protocol. It also has a power down mode enabled through the SPI interface for optimal power management. There is a gas temperature sensor integrated in the flow sensor chip to monitor the actual flowing gas temperature, which is used for gas temperature calibration of the flow sensor. The gas temperature data can also be read out 10-bit output also through SPI interface.

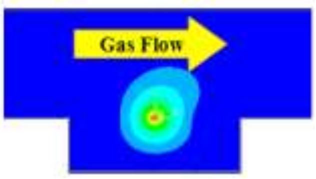
Please refer to Fig.2 for MFP257B1C functional block diagram. MFP257B1C operates over supply range from 2.7 to 5.5V.

Theory of Operation

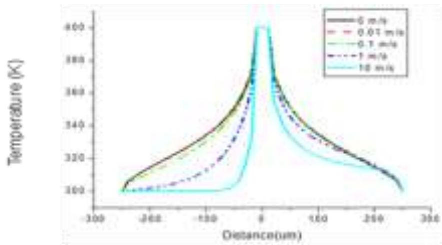
The MEMSIC flow chip is a MEMS-based thermal mass flow sensor fabricated on a monolithic CMOS IC process. A single micro heater, centered in the silicon chip is suspended across a cavity. Equally spaced aluminum/polysilicon thermopiles are located symmetrically on flow direction of the micro heater. The heater resistor is switched across the supply at high frequency. The average heater power is regulated as to maintain preset common mode voltage of the upstream and downstream thermopiles. Under zero flow, a temperature gradient is symmetrical about the micro heater, so that the temperature is the same at both downstream and upstream thermopiles, causing both to output the same voltage. For non-zero flow, the velocity of a fully-developed laminar air flow will disturb the temperature profile around the micro heater, due to heat transfer, causing them to be asymmetrical (Fig.3b). The temperature, and hence voltage output of the two thermopiles will then be different. The differential voltage at the thermopile outputs is directly proportional to the flow rate. Higher flow rates result in larger asymmetry in the temperature profile of micro heater and cause larger differential voltages (Fig.3c).



a: Zero Gas Flow



b:Non-zero Gas Flow



c: Temperature profile around the micro heater

Fig.3: Operating Principle of Thermal Mass Flow Sensor

Absolute Maximum Ratings*

Supply Voltage (V_{DD}) ……………….. -0.5 to +7.0V
Storage Temperature …….................-40°C to +150°C
Maximum Exposed Flow……………..40m/s
Maximum Pressure …….…………….10 Bar
Shock ……………………..………….. 1000g, 0.5ms
Vibration ………………………………1g, 5 to 200 Hz
Reflow Peak Temperature……………..255°C

*Stresses above those listed under Absolute Maximum Ratings may cause permanent damage to the device. This is a stress rating only; the functional operation of the device at these or any other conditions above those indicated in the operational sections of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

MFP257B1C Characteristics[1]

Parameter	Condition	Min	Typical	Max	Unit
Supply DC Voltage		2.7	3.3	5.5	V
Operating Temperature		-40		85	°C
Storage Temperature		-40		105	°C
Temperature Sensor resolution			0.3		ºC/LSB
Temperature Accuracy	Room Temperature		3.0		ºC
	-40 to 85ºC	-10		10	ºC
Gas Temperature Sensor output	From -40°C to 85°C $T_{Out(°C)}$= (Tcount-426.2)/3.4176.	289		718	Count
Flow Output Range	Full scale flow range	0		65535	Count
Null Output (approx.)	Output lower than null value indicates reversed flow	32718	32768	32818	Count
Power Consumption	Adjustable based on the customer's requirement	3		18	mW
	Sleep mode			0.01	µA
SPI Output Rate				150	Hz
Sensor Response Time		15			ms
Zero Flow Rate Output	25°C	-25		25	Count

Materials

Parameter	MFP257B1C
Wetted Materials	Silicon, Silicon Nitride, Epoxy, FR4, Gold Plated Brass
RoHS, REACH	Fully RoHS and REACH Compliant

Digital SPI interface

MFP257B1C employs SPI interface to receive commands from an external host, as well as to report measured data. A timing diagram of a read/write operation is shown in Fig.4, while the detailed SPI timing characteristics are demonstrated in Fig.5.

The following four pins are involved in SPI communication:

- Serial Select (SS), active high, indicates beginning of a read/write event. This is controlled by the master device.
- MOSI (Master Out Slave IN). Since MFP257B1C is a slave, this is the input to the circuit.
- MISO (Master In Slave Out). This is the output of this circuit.
- SCK (Serial Clock) is driven by the master and determines timing of all events.

Since multiple devices can share SCK, MISO, and MOSI lines, MISO line driver is high impedance when SS is low. Every communication event begins with SS transitioning high, and ends when SS falls. There must be exactly 24 rising SCK edges between rising and falling edges of SS. The MOSI pin should only change on the falling edge of SCK, and remain stable during rising edges of SCK. The SPI timing characteristics is listed in Table 1. The SPI clock frequency is 2 MHz typical. If the Master wants to write to MFP257B1C, the first bit in the transmission should be a 1, followed by 6-bit register address, MSB first. Then 1 bit is a no care followed by 16 bits, MSB first, to be written to the register. Six address bits allow up to 64 different registers. If the Master wants to read data from MFP257B1C, the first data in the transmission should be a 0, followed by 6 address bits and a single no-care bit. Starting on the 9-th rising edge of the SCK, data can be read on MISO pin. It will be changing on the falling clock edge, and it should be latched on the rising edge. Output data is shifted MSB first.

Sensor and EEPROM share the same three pins of SPI, they are MOSI, MISO, and SCK.

CS1 for sensor, (See Connecting Pins Description on Page 2)

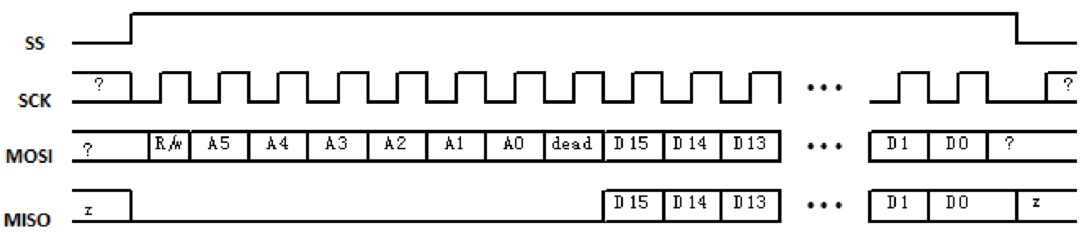


Fig. 4: SPI Timing Diagram

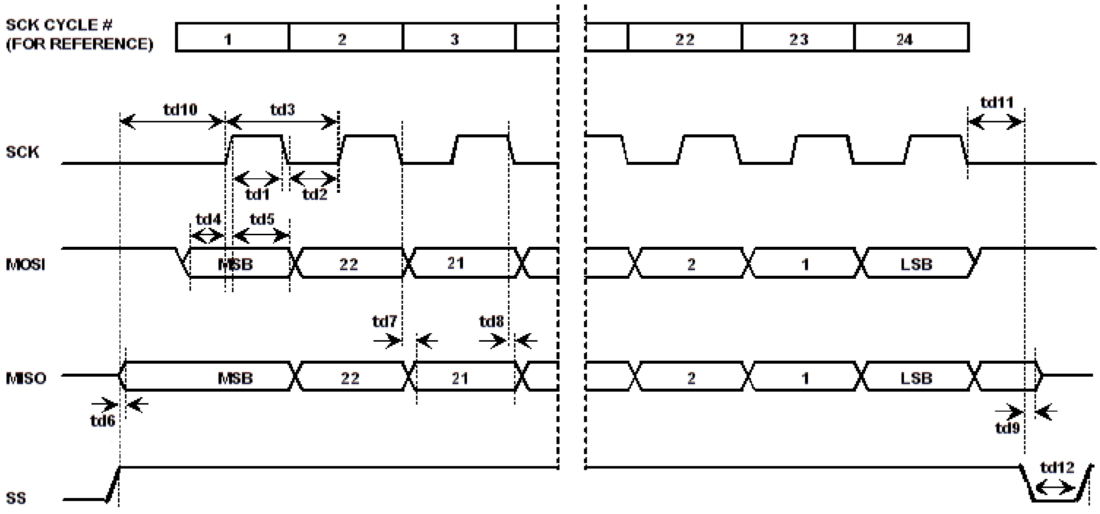


Fig. 5: Schematic of SPI Timing and Characteristics

Table 1: SPI Timing Characteristics

No.	Symbol	Parameter	Conditions	Min	Typical	Max	Units
1		SPI Operating Frequency			2	8	MHz
2		Data Register Update Rate				100	Hz
3	td1	SCK High Time		.5 x td3 - 13			ns
4	td2	SCK Low Time		.5 x td3 - 13			ns
5	td3	SCK Period		125			ns
6	tr, tf	SCK Rise/Fall Time	0.1xVDD - 0.9xVDD			13	ns
7	td4	Data Input (MOSI) Setup Time		37			ns
8	td5	Data Input (MOSI) Hold Time		49			ns
9	td6	Data Out (MISO) Access Time				43	ns
10	td7	Data Out(MISO) Valid After SCK				30	ns
11	td8	Data Output (MISO) Lag Time		0			ns
12	td9	Data Output (MISO) Disable Time				750	ns
13	td10	Enable (CSB) Lead Time		.5 x td3			ns
14	td11	Enable (CSB) Lag Time		.5 x td3			ns
15	td12	Sequential Transfer Delay		1.5 x td3			ns

Control Register Map

For MFP257B1C SPI registers, please see the Table below.

Address	Name	R/W, Master=0	R/W, Master=1	Bit15	Bit14	Bit13	Bit12	Bit11	Bit10	Bit9	Bit8	Bit7	Bit6	Bit5	Bit4	Bit3	Bit2	Bit1	Bit 0
0	Flow	R	R	Flow15	Flow14	Flow13	Flow12	Flow11	Flow10	Flow 9	Flow 8	Flow7	Flow 6	Flow 5	Flow 4	Flow 3	Flow2	Flow1	Flow0
2	Temp	R	R	N/A	N/A	N/A	N/A	N/A	N/A	T9	T8	T7	T6	T5	T4	T3	T2	T1	T0
4	Status	R/W		N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Temp DRDY	Flow DRDY
5	Control	W	W	RST	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Temp Dis	N/A	N/A	N/A	N/A	N/A	PD

Register 0 is 16-bit FLOW data output. This register is read-only.

Register 2 is Temperature data. Since this data is only 10 bits, six MSB's are set to 0. This register is read-only. The gas temperature sensor provides 10-bit (0.3°C/LSB) from -40°C to 85°C; $T_{Out(°C)}$= (Tcount-426.2)/3.4176. The gas temperature sensor accuracy is +/-1ºC near at 25°C and +/-3°C near at -40°C and 85°C.

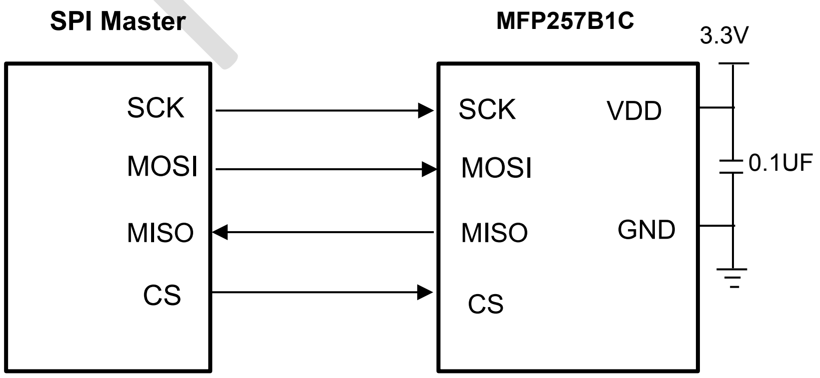
Please kindly note that the temperature sensor needs to be disabled firstly and then be enabled every time when the chip is powered up. This can avoid the instability issue of the temperature sensor. This setting can be done by writing 1 to TempDis bit (Bit6) in Control Register (Register5) to turn it off (Disable), followed by writing 0 to turn it on (Enable).

Register 4 is the Status register. When Flow and Temperature measurements are completed and the data is ready to be read, the 2 LSB's are set to 1. Bit 0 indicates Flow data is ready. Bit 1 indicates Temperature data is Ready. All the other bits are always 0's, which are not available.

Register 5 is Control, Bit 0 is a power down bit. Writing a 1 into this location will put MFP257BC into low power mode. This standby current is lower than 1µA. Bit 6 Temperature Disable. Writing a 1 into it turns off temperature sensor. All the other bits are not available.

Pin Assignment

The schematic to interface with a SPI Master is shown in Fig. 6 below.



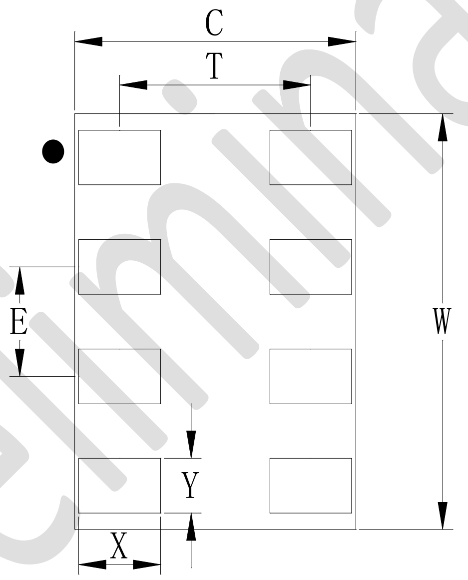
Note: the capacitor should be placed as close as possible to the VDD pin

Fig. 6 Schematic of Pin Assignment

Pinout Configuration

Pin No.	Name	Description
1	VDD	Digital power supply, reference voltage for SPI interface(2.7V-5.5V)
2	GND	Connect to ground
3	TEST	Test pin
4	NC	Not used
5	CLK	Serial clock for SPI bus
6	MISO	Master in Slave Out, SPI output pin
7	MOSI	Master Out, Slave In, SPI input pin
8	CS	Chip Select

PCB Footprint



Unit	**mm**		
Dimension	MIN	NOM	MAX
C	5.14	5.15	5.16
W	7.59	7.60	7.61
X		1.5	
Y		1.0	
E		2.0	
T		3.35	

ESD

The electronics of the MFP257B1C comply with the following ESD standards:

-JESD22-C101F (750V CDM)

-JEDEC JS-001-2012 (2KV HBM)

-JESD22-A115C (200V MM)

Although the sensor complies with these standards, it does not mean the sensor is immune against ESD. The sensor is shipped in an antistatic tray to prevent electrostatic discharge. To avoid damage to the sensor, ground yourself using a grounding strap or by touching a grounded object before touching the sensor. Furthermore, store the parts in an antistatic package when not in use.

Sensor Handling

The sensors of the MFP257B1C are designed to be robust with the cover. There is a damage risk of by rough handling. MEMSIC does not guarantee proper operation in case of improper handling.

Note: avoid applying any mechanical stress to the solder joints as well as the cover of the sensor during or as a result of PCB assembly.

The sensor ships in an antistatic package to prevent electrostatic discharge (ESD), which can damage the part. To avoid such damage, ground yourself using a grounding strap or by touching a grounded object. Furthermore store the parts in the antistatic package when not in use.

Shipment Packaging

MFP257B1C are shipped in tape and reel. The drawing of the packaging tapes is shown in Fig.7 below. Each Sensor is traceable through its built-in unique serial number.

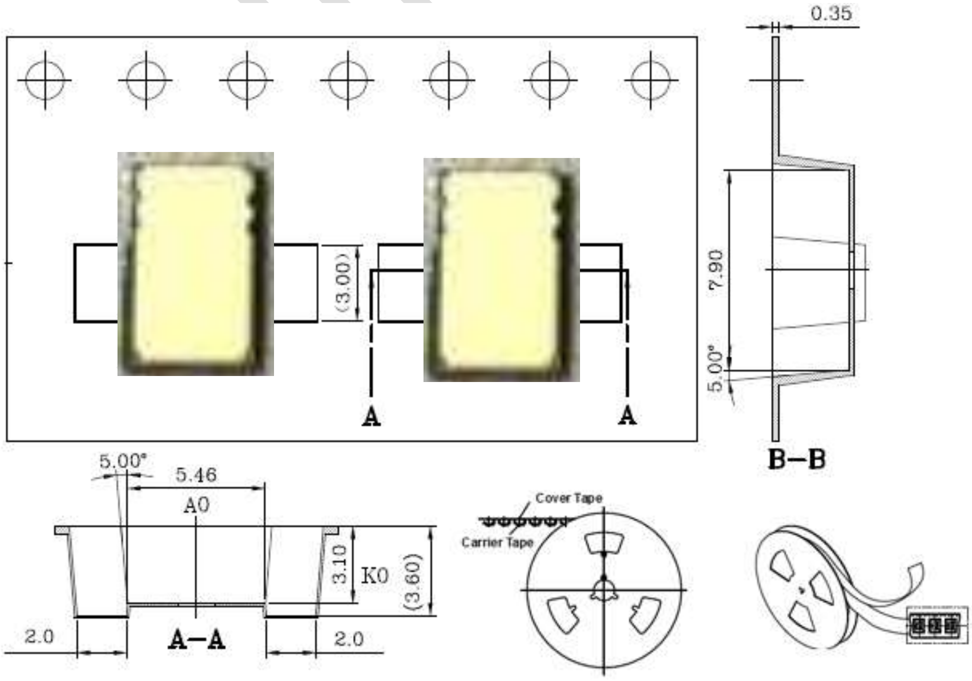
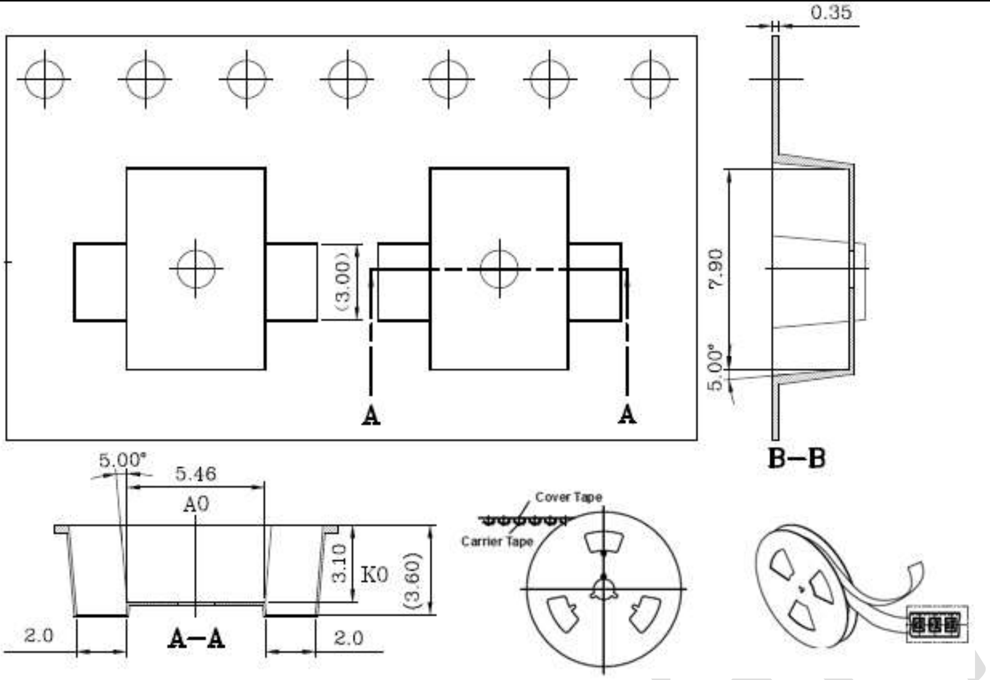


Fig. 7 Shipment Packaging (unit in mm)



Mechanical Dimensions

Unit: mm, Tolerance:± 0.1 mm (Unless otherwise specified)

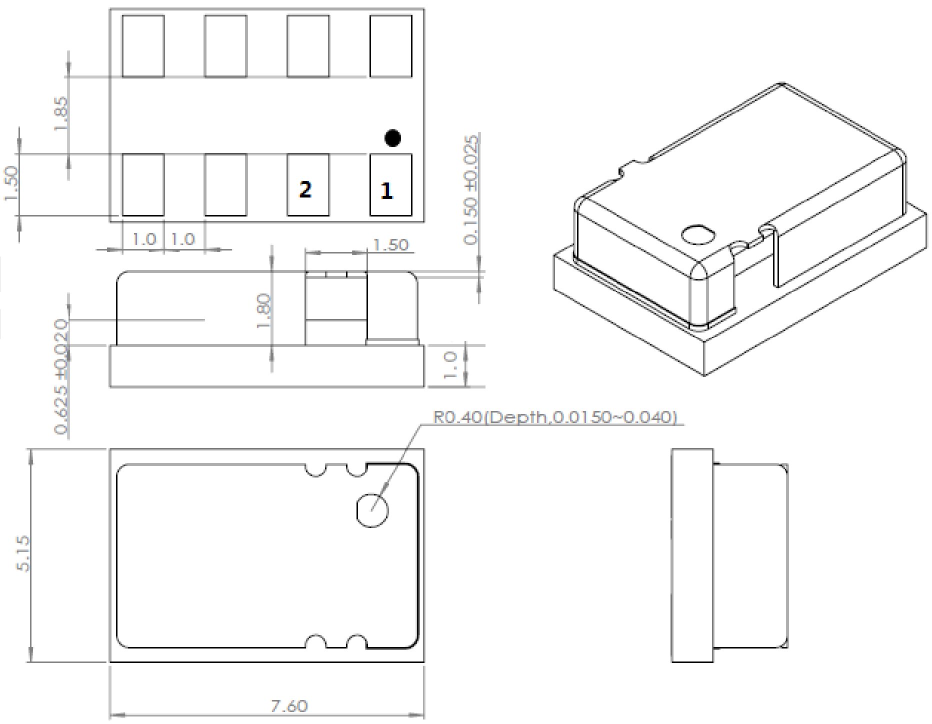


Fig. 8 MFP257B1C_1 Mechanical Drawing

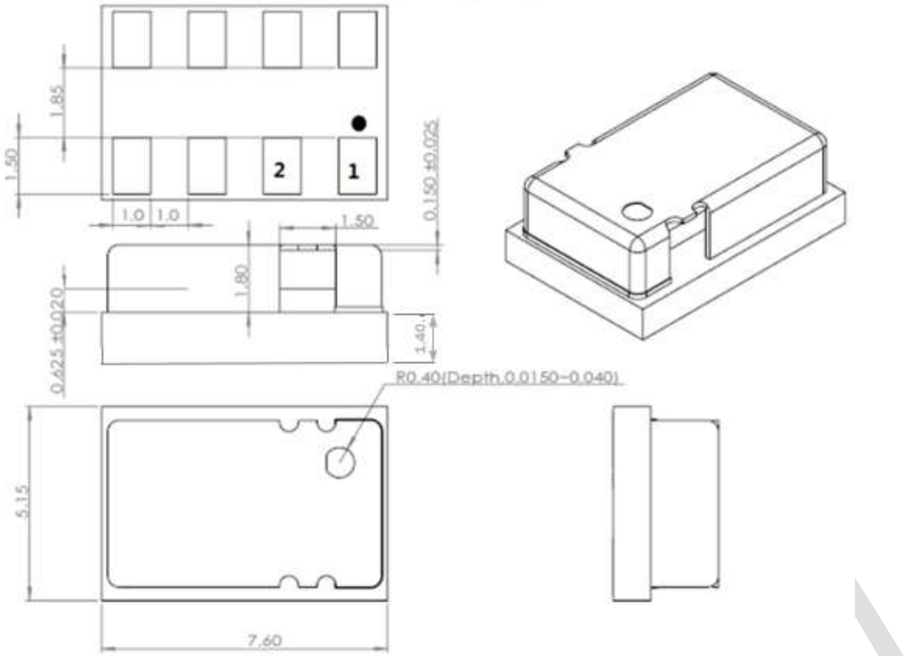


Fig. 9 MFP257B1C_2 Mechanical Drawing

Product Name	PCB Thickness
MFP257B1C_1	1.0 mm
MFP257B1C_2	1.4 mm

Revision History

Date	Author	Version	Changes Record
June 2017	SYXIAO	V1.0	Initial release
8/13/2018	Chengpeng	V1.1	Change temperature accuracy to 3.0, +/-10; change sleep mode current to 0.01uA; add Reflow Peak Temperature
4/28/2019	Chengpeng	V1.2	Add 1.4mm drawing

Features

- Monolithic CMOS thermal flow sensor
- SPI Interface
- 16bits flow output
- On-chip10bits gas temperature sensor
- High sensitivity
- Power down mode through SPI interface
- 2.7V~5.5V Single Supply Operation
- ROHS/REACH Compliant

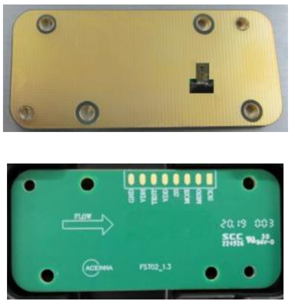


Fig. 1 MFP2100 COB

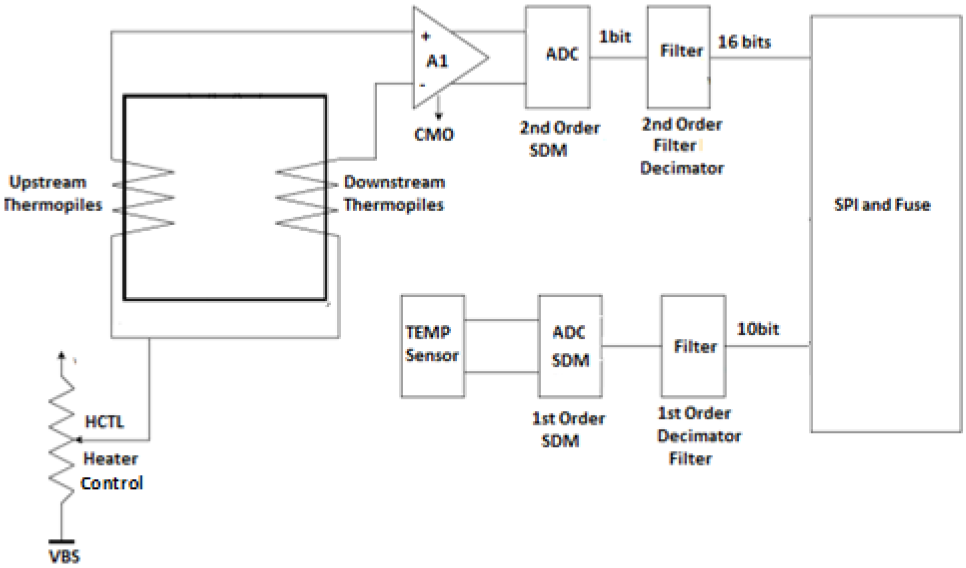


Figure 2 - Block Diagram

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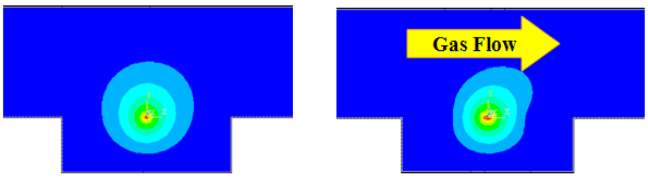
General Descriptions

MFP2100COB is a customized thermal gas flow module (see Fig.1) based on ACEINNA's proprietary CMOS technology for thermal mass flow sensing. The monolithic flow sensor chip, mounted on the PCB, can be assembled in different flow channels to be made into different types of flow meters for accurate flow measurement and control. MFP2100COB is designed to use SPI digital communication protocol. It also has a power down mode enabled through the SPI interface for optimal power management. There is a gas temperature sensor integrated in the flow sensor chip to monitor the actual flowing gas temperature, which is used for gas temperature calibration of the flow module. The gas temperature data can also be read out 10-bit output also through SPI interface.

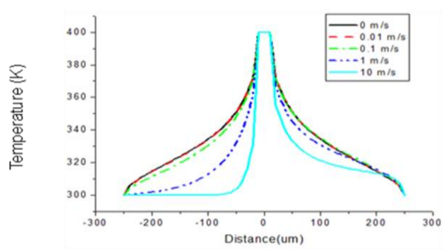
Please refer to Fig.2 for MFP2100COB functional block diagram. MFP2100COB operates over supply range from 2.7 to 5.5V.

Theory of Operation

The ACEINNA flow chip is a MEMS-based thermal mass flow sensor fabricated on a monolithic CMOS IC process. A single micro heater, centered in the silicon chip is suspended across a cavity. Equally spaced aluminum/polysilicon thermopiles are located symmetrically on flow direction of the micro heater. The heater resistor is switched across the supply at high frequency. The average heater power is regulated as to maintain preset common mode voltage of the upstream and downstream thermopiles. Under zero flow, a temperature gradient is symmetrical about the micro heater, so that the temperature is the same at both downstream and upstream thermopiles, causing both to output the same voltage. For non zero flow, the velocity of a fully-developed laminar air flow will disturb the temperature profile around the micro heater, due to heat transfer, causing them to be asymmetrical (Fig.3b). The temperature, and hence voltage output of the two thermopiles will then be different. The differential voltage at the thermopile outputs is proportional to the flow rate. Higher flow rates result in larger asymmetry in the temperature profile of micro heater and cause larger differential voltages (Fig.3c).



a: Zero Gas Flow b:Non-zero Gas Flow



c: Temperature profile around the micro heater

Fig.3: Operating Principle of Thermal Mass Flow Sensor

Absolute Maximum Ratings*

Supply Voltage (V_{DD}) ……………….. -0.5 to +7.0V
Storage Temperature ……...............-40°C to +150°C
Maximum Exposed Flow……………..40m/s
Maximum Pressure ……….…………..10 Bar
Shock ……………………..………….. 1000g, 0.5ms
Vibration ………………………………..1g, 5 to 200 Hz

*Stresses above those listed under Absolute Maximum Ratings may cause permanent damage to the device. This is a stress rating only; the functional operation of the device at these or any other conditions above those indicated in the operational sections of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

MFP2100COB Characteristics

Parameter	Condition	Min	Typical	Max	Unit
Supply DC Voltage		2.7	3.3	5.5	V
Operating Temperature		-40		85	°C
Storage Temperature		-40		105	°C
Temperature Sensor resolution			0.3		ºC/LSB
Temperature Accuracy	Room Temperature		3.0		ºC
	-40 to 85ºC	-10		10	ºC
Gas Temperature Sensor output	From -40°C to 85°C $T_{Out(°C)}$= (Tcount-426.2)/3.4176.	289		718	Count
Flow Output Range	Full scale flow range	0		65535	Count
Null Output (approx.)	Output lower than null value indicates reversed flow	32718	32768	32818	Count
Power Consumption		2.9	3.0	3.1	mA
	Sleep mode			1.0	µA
SPI Output Rate				150	Hz
Sensor Response Time		15			ms
Zero Flow Rate Output	25°C	0		25	Count

Digital SPI interface

MFP2100COB employs SPI interface to receive commands from an external host, as well as to report measured data. A timing diagram of a Read/Write operation is shown in Fig.4, while the detailed SPI timing characteristics are demonstrated in Fig.5.

The following four pins are involved in SPI communication:

● Serial Select (SS), active high, indicates beginning of a Read/Write event. This is controlled by the master device.

● MOSI (Master Out Slave IN). Since MFP2100COB is a slave, this is the input to the circuit.

● MISO (Master In Slave Out). This is the output of this circuit.

● SCK (Serial Clock) is driven by the master and determines timing of all events.

Since multiple devices can share SCK, MISO, and MOSI lines, MISO line driver is high impedance when SS is low. Every communication event begins with SS transitioning high, and ends when SS falls. There must be exactly 24 rising SCK edges between rising and falling edges of SS. The MOSI pin should only change on the falling edge of SCK, and remain stable during rising edges of SCK. The SPI timing characteristics is listed in Table 1. The SPI clock frequency is 2 MHz typical. If the Master wants to write to MFP2100COB, the first bit in the transmission should be a 1, followed by 6-bit register address, MSB first. Then 1 bit is a no care followed by 16 bits, MSB first, to be written to the register. Six address bits allow up to 64 different registers. If the Master wants to read data from MFP2100COB, the first data in the transmission should be a 0, followed by 6 address bits and a single no-care bit. Starting on the 9-th rising edge of the SCK, data can be read on MISO pin. It will be changing on the falling clock edge, and it should be latched on the rising edge. Output data is shifted MSB first.

Sensor and EEPROM share the same three pins of SPI, they are MOSI, MISO, and SCK. CS1 for sensor, (See Connecting Pins Description on Page 2)

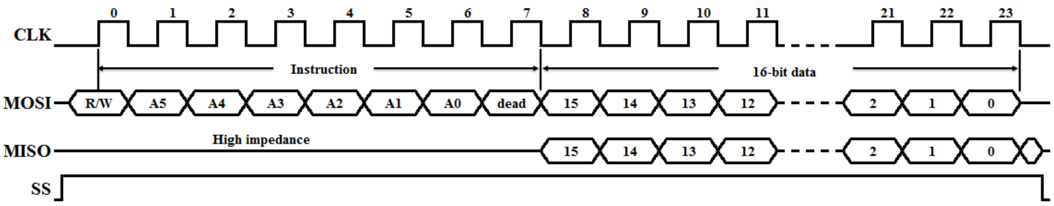


Fig. 4: SPI Timing Diagram

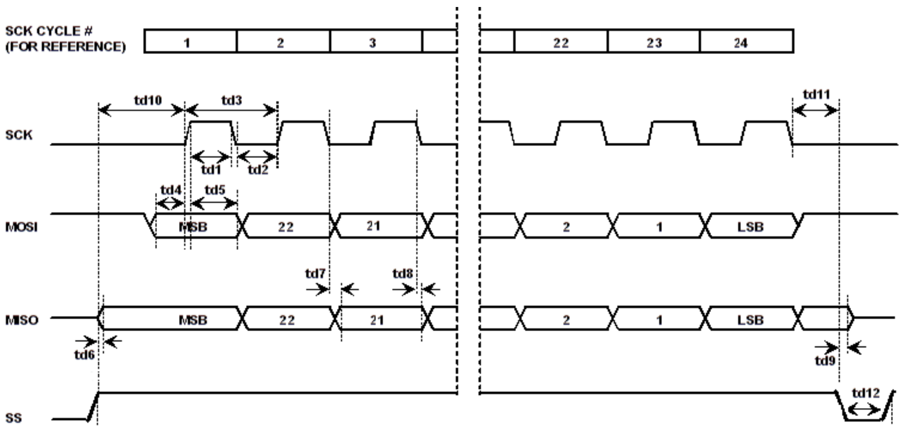


Fig. 5: Schematic of SPI Timing and Characteristics

Table 1: SPI Timing Characteristics

No.	Symbol	Parameter	Conditions	Min	Typical	Max	Units
1		SPI Operating Frequency			4	8	MHz
2		Data Register Update Rate				100	Hz
3	td1	SCK High Time		.5 x td3 - 13			ns
4	td2	SCK Low Time		.5 x td3 - 13			ns
5	td3	SCK Period		125			ns
6	tr, tf	SCK Rise/Fall Time	0.1xVDD - 0.9xVDD			13	ns
7	td4	Data Input (MOSI) Setup Time		37			ns
8	td5	Data Input (MOSI) Hold Time		49			ns
9	td6	Data Out (MISO) Access Time				43	ns
10	td7	Data Out(MISO) Valid After SCK				30	ns
11	td8	Data Output (MISO) Lag Time		0			ns
12	td9	Data Output (MISO) Disable Time				750	ns
13	td10	Enable (CSB) Lead Time		.5 x td3			ns
14	td11	Enable (CSB) Lag Time		.5 x td3			ns
15	td12	Sequential Transfer Delay		1.5 x td3			ns

Control Register Map

For MFP2100COB SPI registers, please see the Table 2 below.

Table 2: MFP2100COB SPI registers

Address	Name	R/W, Master=0	R/W, Master=1	Bit15	Bit14	Bit13	Bit12	Bit11	Bit10	Bit9	Bit8	Bit7	Bit6	Bit5	Bit4	Bit3	Bit2	Bit1	Bit 0
0	Flow	R	R	Flow15	Flow14	Flow13	Flow12	Flow11	Flow10	Flow 9	Flow 8	Flow7	Flow 6	Flow 5	Flow 4	Flow 3	Flow2	Flow1	Flow0
2	Temp	R	R	N/A	N/A	N/A	N/A	N/A	N/A	T9	T8	T7	T6	T5	T4	T3	T2	T1	T0
4	Status	R/W		N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Temp DRDY	Flow DRDY
5	Control	W	W	RST	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Temp Dis	N/A	N/A	N/A	N/A	N/A	PD

Register 0 is 16-bit FLOW data output. This register is read-only.
Register 2 is Temperature data. Since this data is only 10 bits, six MSB's are set to 0. This register is read-only. The gas temperature sensor provides 10-bit (0.3°C/LSB) from -40°C to 85°C; $T_{Out(°C)}$= (Tcount-426.2)/3.4176. The gas temperature sensor accuracy is +/-1ºC near at 25°C and +/-3°C near at -40°C and 85°C.
Please kindly note that the temperature sensor needs to be disabled firstly and then be enabled every time when the chip is powered up. This can avoid the instability issue of the temperature sensor. This setting can be done by writing 1 to TempDis bit (Bit6) in Control Register (Register5) to turn it off (Disable), followed by writing 0 to turn it on (Enable).
Register 4 is the Status register. When Flow and Temperature measurements are completed and the data is ready to be read, the 2 LSB's are set to 1. Bit 0 indicates Flow data is ready. Bit 1 indicates Temperature data is Ready. All the other bits are always 0's, which are not available.

Register 5 is Control, Bit 0 is a power down bit. Writing a 1 into this location will put MFP2100COB into low power mode. This standby current is lower than 1µA. Bit 6 Temperature Disable. Writing a 1 into it turns off temperature sensor. All the other bits are not available.
Please kindly note that the temperature sensor need to be disabled firstly and then be enabled every time when the power is switched on to avoid the issue of the temperature sensor stability. This setting can be done by writing 1 to TempDis bit (Bit6) in Control Register (Register5) to turn it off (Disable), followed by writing 0 to turn it on (Enable).

Connector Pin Description

Pin	Name	Description
1	GND	Connect to ground
2	VDH	Heater power supply
3	TEST	Test pin, Factory use only
4	VDD	Digital power supply, reference voltage for SPI interface(3.3V recommended)
5	SS	Serial Select pin, part of FST02 SPI interface
6	MOSI	Master Out, Slave In, SPI input pin
7	MISO	Master In, Slave Out, SPI output pin
8	SCK	Serial clock for SPI bus

Materials

Parameter	MFP2100COB
Wetted Materials	Sensor chip(Silicon, Silicon Nitride, Silicon Oxide), Epoxy, Gold
RoHS	Fully RoHS Compliant

ESD

The electronics of the MFP2100COB comply with the following ESD standards:

-JESD22-C101F (750V CDM)

-JEDEC JS-001-2012 (2KV HBM)

-JESD22-A115C (200V MM)

Although the sensor complies with these standards, it does not mean the sensor is immune against ESD. The sensor is shipped in an antistatic tray to prevent electrostatic discharge. To avoid damage to the sensor, ground yourself using a grounding strap or by touching a grounded object before touching the sensor. Furthermore, store the parts in an antistatic package when not in use.

Sensor Handling and Packaging

The sensors of the MFP2100COB is very fragile without any protection. There is a damage risk of by rough handling. Please avoid applying any mechanical stress on the sensor chip during PCB assembly. ACEINNA does not guarantee proper operation in case of improper handling.
MFP2100COB are shipped in trays of 21pcs with per tray. The tray dimension is 320mm × 230mm × 12.5mm. Each senor is traceable through its unique series number, which is aligned with the one in sensor.

Mechanical Dimensions

Notes:

Unit: mm, Tolerance:± 0.1 mm (Unless otherwise specified)

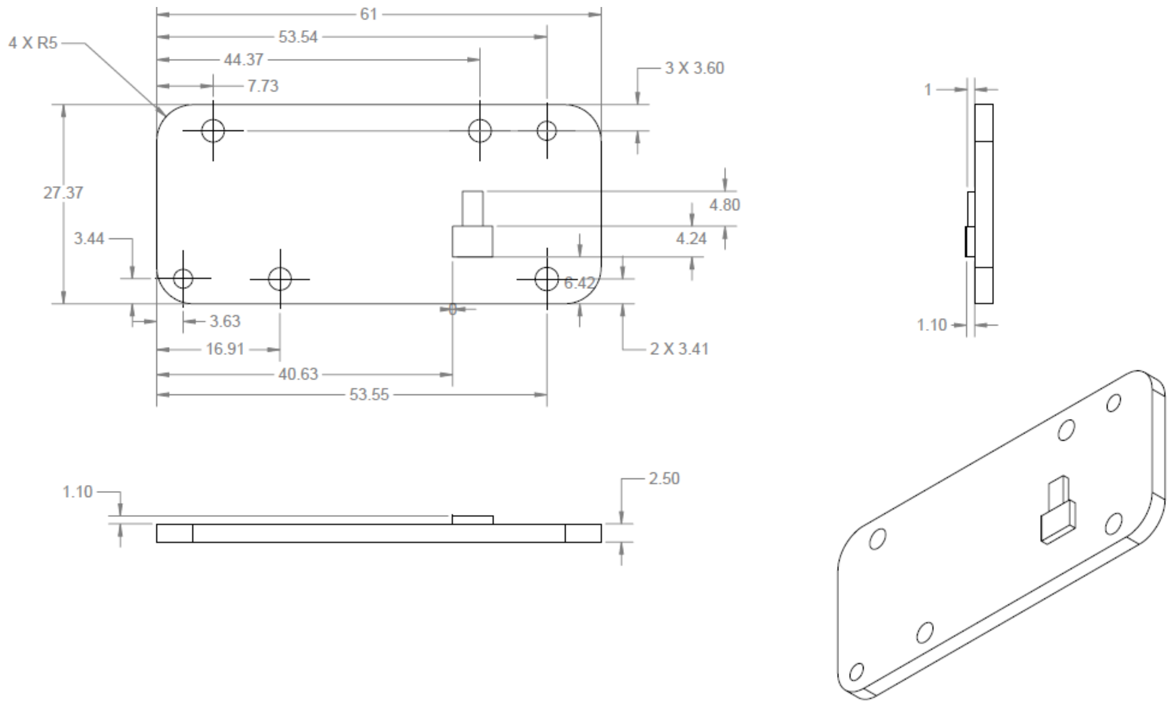


Fig.6 MFP2100COB module assembly drawing and mechanical dimensions

Schematic

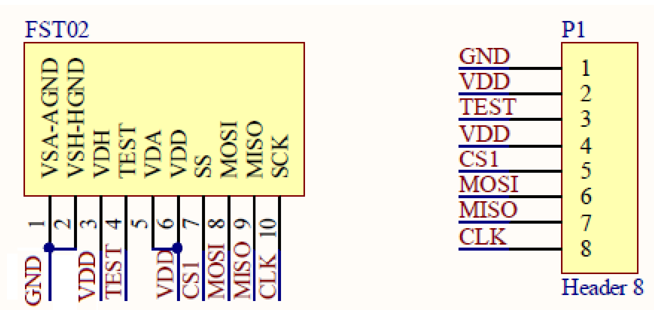


Fig.7 Schematic of MFP2100COB Layout Design

Revision History

Date	Author	Version	Changes Record
June 2015	SYXIAO	V1.0	Initial release
July 2017	SYXIAO	V1.1	The wetted materials are modified to be biocompatible; Added the ESD specification; Added the shipping information.
March 2018	SY.XIAO	V1.2	Changed the company name from MEMSIC to ACEINNA. Updated the PCB mechanical design to better match the customer's flow channel.
June 2019	CP JI	V1.3	Remove REACH Compliant; changed Temperature Accuracy to +/-3 C/+/-10 C; changed package information; updated company information

Features

- Monolithic CMOS thermal flow sensor
- SPI interface
- 16bits flow output
- On-chip10bits gas temperature sensor
- High sensitivity
- Power down mode through SPI interface
- 2.7V~5.5V single supply operation
- RoHS/REACH compliant and ADI free
- Biocompatible (ISO10993-5,ISO10993-10)
- FDA conformity(CFR Code of federal regulation Title 21, §177)

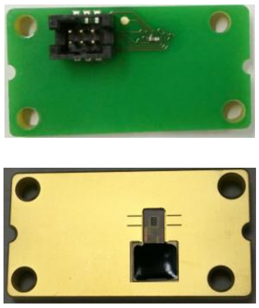


Fig. 1: MFP21630B1

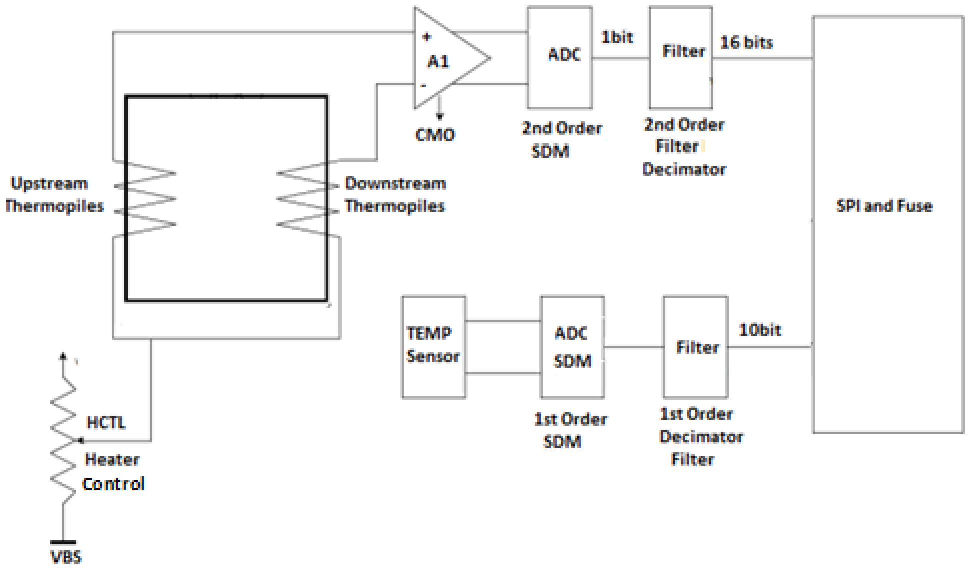


Figure 2 - Block Diagram

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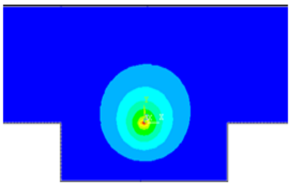
General Descriptions

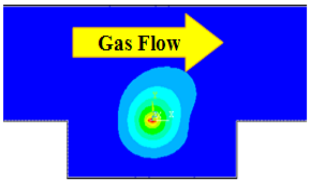
MFP21630B1 is a customized thermal gas flow module (see Fig.1) based on ACEINNA's proprietary CMOS technology for thermal mass flow sensing. The monolithic flow sensor chip, mounted on the PCB, can be assembled in different flow channels to be made into different types of flow meters for accurate flow measurement and control. MFP21630B1 is designed to use SPI digital communication protocol. It also has a power down mode enabled through the SPI interface for optimal power management. There is a gas temperature sensor integrated in the flow sensor chip to monitor the actual flowing gas temperature, which is used for gas temperature calibration of the flow module. The gas temperature data can also be read out 10-bit output also through SPI interface.
Please refer to Fig.2 for MFP21630B1 functional block diagram. MFP21630B1 operates over supply range from 2.7 to 5.5V.

Theory of Operation

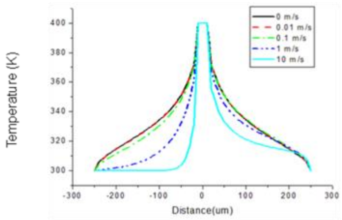
The ACEINNA flow chip is a MEMS-based thermal mass flow sensor fabricated on a monolithic CMOS IC process. A single micro heater, centered in the silicon chip is suspended across a cavity. Equally spaced aluminum/polysilicon thermopiles are located symmetrically on flow direction of the micro heater. The heater resistor is switched across the supply at high frequency. The average heater power is regulated as to maintain preset common mode voltage of the upstream and downstream thermopiles. Under zero flow, a temperature gradient is symmetrical about the micro heater, so that the temperature is the same at both downstream and upstream thermopiles, causing both to output the same voltage. For non zero flow, the velocity of a fully-developed laminar air flow will disturb the temperature profile around the micro heater, due to heat transfer, causing them to be asymmetrical (Fig.3b). The temperature, and hence voltage output of the two thermopiles will then be different. The differential voltage at the thermopile outputs is proportional to the flow rate. Higher flow rates result in larger asymmetry in the temperature profile of micro heater and cause larger differential voltages (Fig.3c).



a: Zero Gas Flow



b:Non-zero Gas Flow



c: Temperature profile near the micro heater

Fig.3: Operating Principle of Thermal Flow Sensor

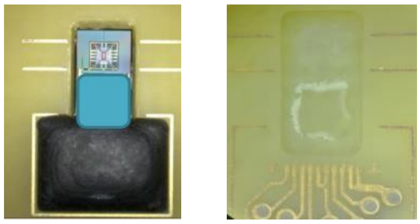
MFP21630B1 Characteristics

Parameter	Condition	Min	Typical	Max	Unit
Supply DC Voltage		2.7	3.3	5.5	V
Operating Temperature		-40		85	°C
Storage Temperature		-40		105	°C
Temperature Sensor Span		-125		175	°C
Temperature Sensor resolution			0.3		°C/LSB
Temperature Sensor Offset		-3		3	°C
Temperature Accuracy	At Room Temperature	-1		1	ºC
	-40 to 85ºC	-3		3	ºC
Temperature Sensor Slop			3.4176		N/A
Gas Temperature Sensor output	From -40°C to 85°C $T_{Out(°C)}$ = (Tcount-426.2)/3.4176	289		718	Count
Flow Output Range	Full scale flow range	0		65535	Count
Null Output (approx.)	Output lower than null value indicates reversed flow, GC=000,OAR=0,AOA=0	32743	32768	32793	Count
Heater Power	3.3 V @ Zero flow	5.94	6.27	6.60	mW
Power Down Current				1.0	uA
SPI Output Rate			130		Hz
Sensor Response Time	t63.2, HCLST at 25kHz, OSC at 65kHz	10			ms
Chip position in the PCB Cavity	Distance between cavity end to chip end in X axis(left X+, right X-)	0.1		0.3	mm
	Distance between cavity end to chip end in Y axis (Y+)	0.1		0.45	mm

Sensor Chip Assembly Process

- **Definition of "half die-attach"**

In order to minimize the stress, for the epoxy dispensing, the epoxy should be dispensed under the ASIC area only (non-sensitive area), like the blue marked area as shown in Fig.4 below. No epoxy is dispensed under the suspended bridges. This is so-called half die-attach.

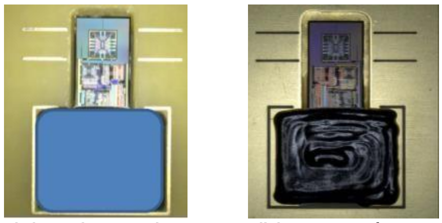


(a) Schematic (b) Example

Fig.4: Schematic of "half die-attach" (epoxy dispensing)

- **Definition of "full globtop"**

For the globtop process, the epoxy should cover all paths and vias, like the blue marked area as shown in Fig.5 below. This is so-called full globtop.



(a) Schematic (b) Example

Fig. 5: "Full globtop" (epoxy dispensing)

No glob-top epoxy is allowed to flow into the PCB cavity like the area of red marks as shown in Fig.6 below.

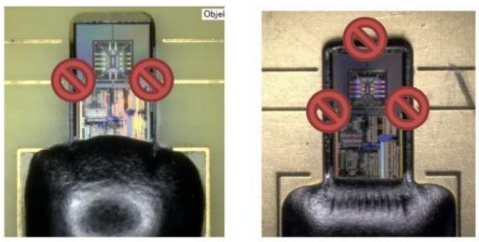
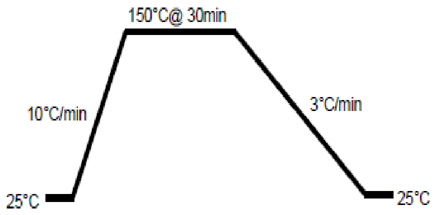


Fig. 6: Schematic of bleeding issue with globtop

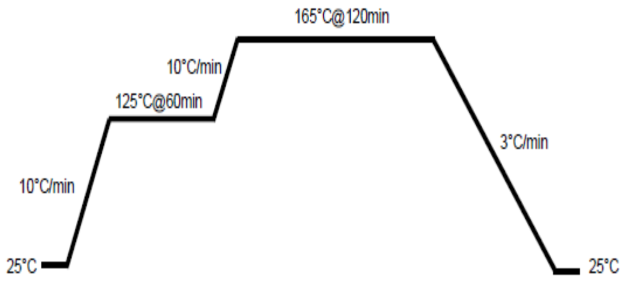
- **Epoxies Curing Schedules**

The die-attach epoxy is used St8801, which has been certificated to be biocompatible by the manufacturer Panacol. The curing schedule is 120°C@30min with the ramp-up rate of 10°C /min and ramp-down rate of 3°C/min, shown in Fig. 7(a).

The globtop epoxy is used JD739. No biocompatible certificate has been performed for it for now. But the manufacturer Everwide recommends the low reaction rate curing schedule of 125°C@30min plus 165°C @120min for medical applications. The oven ramp-up rate and ramp-down rate are also 10°C /min and 3°C/min, respectively. This curing process can increase the passing rate of bacteria's activity test for the biocompatibility certificate. The curing profile is shown in Fig. 7(b).



(a) Die-attach epoxy St8801



(b) Glob-top epoxy JD-739

Fig. 7: Epoxies curing schedule

Digital SPI interface and fuses

MFP21630B1 employs SPI interface to receive commands from an external host, as well as to report measured data. A timing diagram of a Read/Write operation is shown in Fig.8, while the detailed SPI timing characteristics are demonstrated in Fig.9.

The following four pins are involved in SPI communication:

● Serial Select (SS), active high, it should be pulled high before Read/Write operation controlled by the master device.

● MOSI (Master Out Slave IN). Since MFP21630B1 is a slave, this pin is the input of the circuit.

● MISO (Master In Slave Out). This pin is the output of this circuit.

● SCK (Serial Clock) is driven by the master and determines timing of all events.

Since multiple devices can share SCK, MISO, and MOSI pins, MISO pin driver is high impedance when SS is low. Every communication event begins with SS pin transitioning high, and ends when SS falls. There must be exactly 24 rising SCK edges between rising and falling edges of SS. The MOSI pin should only change on the falling edge of SCK, and remain stable during rising edges of SCK. The SPI timing characteristics is listed in Table 1. The SPI clock frequency is 2 MHz typical. If the Master wants to write to MFP21630B1, the first bit in the transmission should be a 1, followed by 6-bit register address, MSB first. Then 1 bit is a no-care bit, followed by 16 bits, MSB first, to be written to the register. Six address bits allow up to 64 different registers. If the Master wants to read data from MFP21630B1, the first data in the transmission should be a 0, followed by 6 address bits and a single no-care bit. Starting on the 9-th rising edge of the SCK, data can be read on MISO pin. It will be changing on the falling clock edge, and it should be latched on the rising edge. Output data is shifted MSB first.

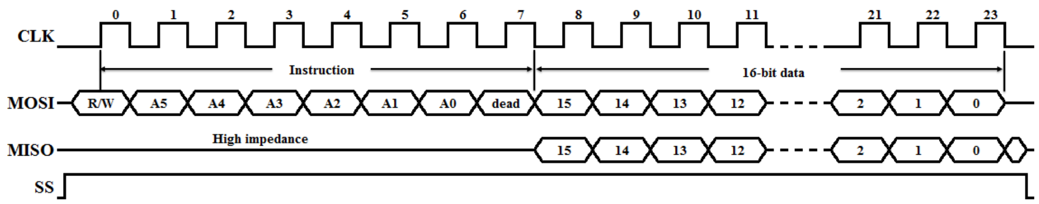


Fig. 8: SPI Timing Diagram

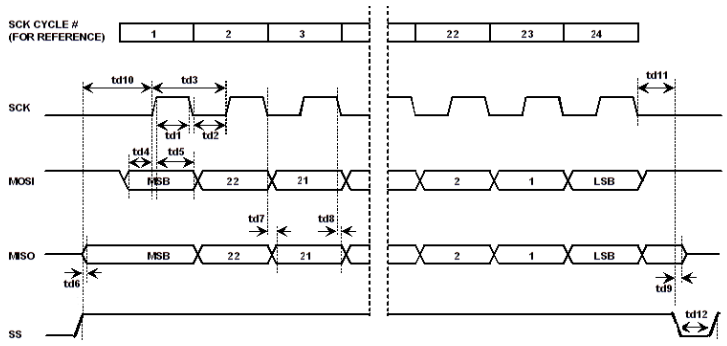


Fig. 9: Schematic of SPI Timing and Characteristics

Table 1: SPI Timing Characteristics

No.	Symbol	Parameter	Conditions	Min	Typical	Max	Units
1		SPI Operating Frequency			2	8	MHz
2		Data Register Update Rate				100	Hz
3	td1	SCK High Time		.5 x td3 - 13			ns
4	td2	SCK Low Time		.5 x td3 - 13			ns
5	td3	SCK Period		125			ns
6	tr, tf	SCK Rise/Fall Time	0.1xVDD - 0.9xVDD			13	ns
7	td4	Data Input (MOSI) Setup Time		37			ns
8	td5	Data Input (MOSI) Hold Time		49			ns
9	td6	Data Out (MISO) Access Time				43	ns
10	td7	Data Out(MISO) Valid After SCK				30	ns
11	td8	Data Output (MISO) Lag Time		0			ns
12	td9	Data Output (MISO) Disable Time				750	ns
13	td10	Enable (CSB) Lead Time		.5 x td3			ns
14	td11	Enable (CSB) Lag Time		.5 x td3			ns
15	td12	Sequential Transfer Delay		1.5 x td3			ns

Absolute Maximum Ratings*

Supply Voltage (V_{DD}) ……………….. -0.5 to +7.0V
Storage Temperature ……................-40°C to +150°C
Maximum Exposed Flow……………..40m/s
Maximum Pressure ……….…………..10 Bar
Shock ……………………..…..……….. 1000g, 0.5ms
Vibration ………………………………..1g, 5 to 200 Hz

*Stresses above those listed under Absolute Maximum Ratings may cause permanent damage to the device. This is a stress rating only; the functional operation of the device at these or any other conditions above those indicated in the operational sections of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

Connector Pin Description

Pin	Name	Description
1	VDD	Digital power supply, reference voltage for SPI interface (3.3V recommended)
2	MOSI	Master Out, Slave In, SPI input pin
3	SCK	Serial clock for SPI bus
4	MISO	Master In, Slave Out, SPI output pin
5	GND	Connect to ground
6	CS	Serial Select pin for sensor’s SPI bus

Control Register Map

For MFP21630B1 SPI registers, please see the Table 2 below.

Table 2: MFP21630B1 SPI registers

Address	Name	R/W, Master=0	R/W, Master=1	Bit15	Bit14	Bit13	Bit12	Bit11	Bit10	Bit9	Bit8	Bit7	Bit6	Bit5	Bit4	Bit3	Bit2	Bit1	Bit0
0	Flow	R	R	Flow15	Flow13	Flow12	Flow12	Flow11	Flow10	Flow9	Flow8	Flow7	Flow6	Flow5	Flow4	Flow3	Flow2	Flow1	Flow0
2	Temp	R	R							T9	T8	T7	T6	T5	T4	T3	T2	T1	T0
4	Status	R/W																Temp DRDY	Flow DRDY
5	Control	W	W	RST									Temp Dis	ST					PD
10	OTP0	R/W	R	PID15	PID14	PID13	PID12	PID11	PID10	PID9	PID 8	PID7	PID6	PID5	PID4	PID3	PID2	PID1	PID0
11	OTP1	R/W	R	PID31	PID30	PID29	PID28	PID27	PID26	PID25	PID24	PID23	PID22	PID21	PID20	PID19	PID18	PID17	PID16
12	OTP2	R/W	R	HCTL5	HCTL4	HCTL5	HCTL2	HCTL1	HCTL0	HCLST1	HCLST0					PID35	PID34	PID33	PID32
13	OTP3	R/W	R	GCX1	GCX0	OAR1	OAR0	AOA7	AOA6	AOA5	AOA4	AOA3	AOA2	AOA1	AOA0	OSC2	OSC1	OSC0	
14	OTP4	R/W	R	Master	PID37	PID36												GCX2	
17	BlowF	W	W	Attempt to write to this address will cause fuse blow on next rising SCK edge															

Register 0 is **16-bit Flow** data. This register is read-only. The PDM (Pulse Density Modulator) controller is selected, the MUX is setup so the PDM pulses control the heater switches.
Register 2 is Temperature data. Since this data is only 10 bits, six MSB’s are set to 0. This register is read-only. The gas temperature sensor provides 10-bit (0.3°C/LSB) from -40°C to 85°C; $T_{Out(°C)}$= (Tcount-426.2)/3.4176, and its accuracy is +/-1ºC near at 25°C and +/-3°C near at -40°C and 85°C.
Please kindly note that the temperature sensor needs to be disabled firstly and then be enabled every time when the power is switched on to avoid the issue of the temperature

sensor stability. This can be achieved by writing 1 to TempDis bit (Bit6) in Control Register (Register5) to turn it off (Disable), and then write 0 to Bit6 to turn it on (Enable).

Register 4 is the **Status**. When Flow and Temperature measurements are completed and the data is ready to be read, the 2 LSB's are set to 1. Bit 0 indicates Flow data is ready. Bit 1 indicates Temperature data is Ready. All the other bits are always 0's. The register is erased, all 3 bits together by writing any data to it.

Table 3: List of part bits of Register 14-12

OTP bits #:	Name	Description
1	Master	Prevents future programming
2	OAR [1:0]	Offset adjust range
6	HCTL [5:0]	Heater power adjust. Straight binary coding. 0 is lowest power.
3	GCX [2:0]	Coarse gain selects of first X amplifier (7, 10, 14, 20, 25, 30, 35, 40)
3	OSC [2:0]	Oscillator frequency adjust. 2's complements coding. 100 is highest frequency with70kHz.
2	HCLST [1:0]	Clock Frequency of HCL integrator. Adjusts startup time. 00->6.25kHz, 01->12.5, 10->25, 11->50kHz.
7	AOA [7:0]	Analog Offset Adjust. Sign-magnitude coding.
5	TOA [4:0]	Temp Sensor Offset adjust.
4	TSA [3:0]	Temp Sensor Slope Adjust
0	STS	Self-Test Select (swallow 12.5, 25, 50, 100%) MOVED TO CONTROL REGISTER
32	PID [31:0]	Part ID, serial number

Register 5 is **Control**, Bit 0 is a power down bit. Written 1 into this bit, MFP21630B1 will go into low power mode. This standby current is lower than 1uA. Bit 6 Temperature Disable. Writing a 1 into it turns off temperature sensor. Bits 5 is Self-Test Enable (ST) bit. When set to a 1, it enables self-test. The self-test bit can be used for the damage detection for the sensor. Please refer to the following steps to detect the damage by self-test.

(1) Set Register 5, bit 5 to 0 (non self-test mode), read the Register 0 and record its readings **Output 1**(it is not the fixed data but a range, depending on the part status including the failure modes)

(2) Set resister 5, bit 5 to 1, read the Register 0 and recording its reading **Output 2**

(3) Compare the difference between **Output 1** and **Output 2**. If the **Output 1** is very close to **Output 2** (the absolute value of **Output 2- Output** 1 is <500 count, depending on the flow channel, the heater power setting and GC setting), it means that this unit is BAD. If the **Output 1** is obviously different from **Output 2** (the absolute value of **Output 2- Output 1** is >2000 count, depending on the flow channel, the heater power setting and GC setting), it means this unit is GOOD.

Registers 10-14 are fuses. These fuses can be read anytime. Part of fuses are listed in Table 3.

Register 10-11：32 bits are allocated to Part ID as series numbers. This allows over 1 billion combinations. Such unique identification would allow us to match the part ID with a possibly large number of trim coefficients stored somewhere else. These 32 fuses do not have any analog functions associated with them.

Register 12 bits 15-10: This is a 6-bit trim [5:0], so there are 64 available positions.

The upstream and downstream thermopiles regulate the heater power. These bits set the thermopile common-mode voltage, which is programmable between certain voltage ranges in a specific steps. HCTL bits are encoded in 2's complement format, with all 0's being the center of the trim range. Larger codes correspond to larger heater power ranging from 0.4mW to 13mW.

Register 12 bits 9-8, Register 12 bits 3-1: Like any feedback from control loop, the heater controller can produce oscillations or ringing while settling. The integrator is used to provide dominant pole and stabilize the loop. Its unity gain frequency is proportional to its clock frequency. To optimize settling behavior of the loop, it may be beneficial to increase the integrator unity gain frequency in cases when loop gain reduces. Since loop gain proportional to the supply voltage squared, operating the part at lower voltage reduces loop gain. In such case increasing integrator clock will result in faster startup time without the danger of oscillations.

The integrator frequency is defined by fuses HCLST [1:0]. Once these fuses are blown, selected integrator frequency will be used to clock the HCTL integrator. There are four different clock frequencies available: 6.25, 12.5, 25, and 50 kHz. It requires to characterize our parts to determine which setting is optimum.

Register 13 bits 15-14 and **Register 14, bits 1:** Eight gain settings can be selected based on three control bits.

The offset adjust circuit consists of an adjustable PMOS current source OADAC and resistors R3. Switches select whether the current is pushed into the positive or negative half-circuit and define the polarity of the offset adjust trim. The value of the resistors is controlled by bits OAR **Register 14, Bits 13-12**, **OAR.** It stands for Offset Adjust Range.

Register 14 bits 11-4, AOA. It adjusts the polarity and current delivered by the current source. Sign – magnitude coding is used: MSB defines the polarity, while the rest of the bits define the value of the current. Setting AOA to all zeroes turns off the offset adjust circuit.

Register 14, Bit 15(MSB) Master. Once it is blown, no further fuse blowing is allowed. Besides, the chip will not respond to SPI writes to Registers 10-14.

Register 17 (11h) BlowF (Blow Fuse): To blow a fuse. Once the Master fuse is blown, no additional fuse blown is allowed. It means all settings are fixed and can't be changed any more. Based on the customer's requirements, ACEINNA provide the recommended settings for the parameters, shown in table 4 below.

Table 4: The settings for the parameters

Parameters	Condition	Min	Typical	Max	Unit
HCTL (Heater Current)	3.3VDC, 25ºC	1.8	1.9	2.0	mA
BG	25ºC	1.22	1.23	1.24	V
HCLST	25+/-2kHz		25		kHz
OSC		60	65	70	kHz
OAR		32743	32768	32793	Count
GC	7×				
HMODE	PDM				

ESD

The MFP21630B1 parts comply with the following ESD standards:

-JESD22-C101F (750V CDM)

-JEDEC JS-001-2012 (2KV HBM)

-JESD22-A115C (200V MM)

Although the sensor complies with these standards, it does not mean the sensor is immune against ESD. The sensor is shipped in an antistatic tray to prevent electrostatic discharge. To avoid damage to the sensor, ground yourself using a grounding strap or by touching a grounded object before touching the sensor. Furthermore, store the parts in an antistatic package when not in use.

Bill of Materials*

Direct Material	Description	Manufacturer	Manufacturer PN
Flow sensor chip	Thickness 0.625mm, diced by laser plus blade process	MEMSIC	
MFP21630B1 PCB	S1000-2M, Tg 170; Size: 30mm*16mm*3mm, 2-layer, one surface with golden treatment; UL94_V0	Hongyuen Electronics	
Bonding wire	Si-AL wire,1.25mil	3C	
Die-attach epoxy	St8801	Panacol	St8801
Globtop epoxy	JD739-4	EVERWIDE	JD739-4
Connector	1.27mm (0.05in.) pitch, Shrouded header, 6 contacts	Amphenol ICC	20021221-00006C4LF
Capacitor	MLCC - SMD/SMT 0402 0.1uF 50volts X7R 10%	TDK	810-C1005X7R1H104K

*All materials are RoHS and Reach compliant, and ADI free. For the wetted materials of Silicon, silicon nitride, epoxy and gold, the materials are biocompatible (ISO-10993-5, ISO-10993-10)and FDA conformal(CFR Code of federal regulation Title 21, §177)

Sensor Handling

The sensors of the MFP21630B1 are fragile with suspended bridge structure. There is a damage risk of by rough handling. ACEINNA does not guarantee proper operation in case of improper handling. Please avoid applying any mechanical stress to the solder joints as well as the cover of the sensor during or as a result of PCB assembly.

The sensor ships in an antistatic package to prevent electrostatic discharge (ESD), which can damage the part. To avoid such damage, ground yourself using a grounding strap or by touching a grounded object. Furthermore, please store the parts in the antistatic package when not in use.

Shipment Packaging

MFP21630B1 units are shipped in the anti-static trays of 40pcs with up to 10 trays per box. The tray dimension is 280mm × 190mm × 17mm. Each Sensor is traceable through its built-in unique serial number. The serial number consists of twelve digits. The description is demonstrated in Fig.10 below.

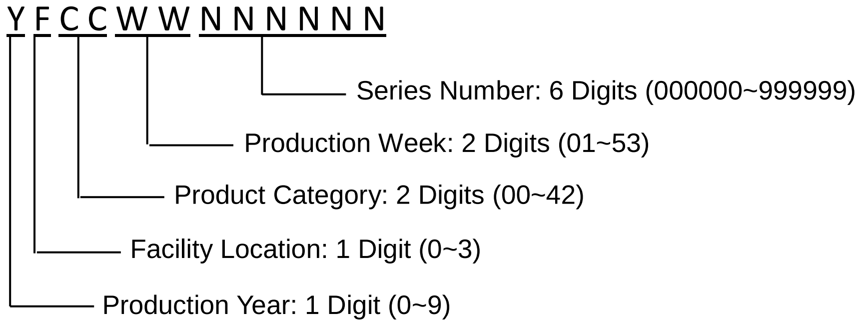


Fig. 10 Built-in Series Number

Sensor visual inspection

100% sensor visual inspection, Choose the convex sensor bridge as a good product.
Convex Sensor Bridge as shown in Fig.11 below.

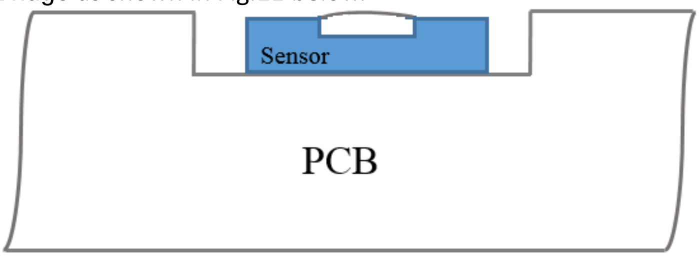


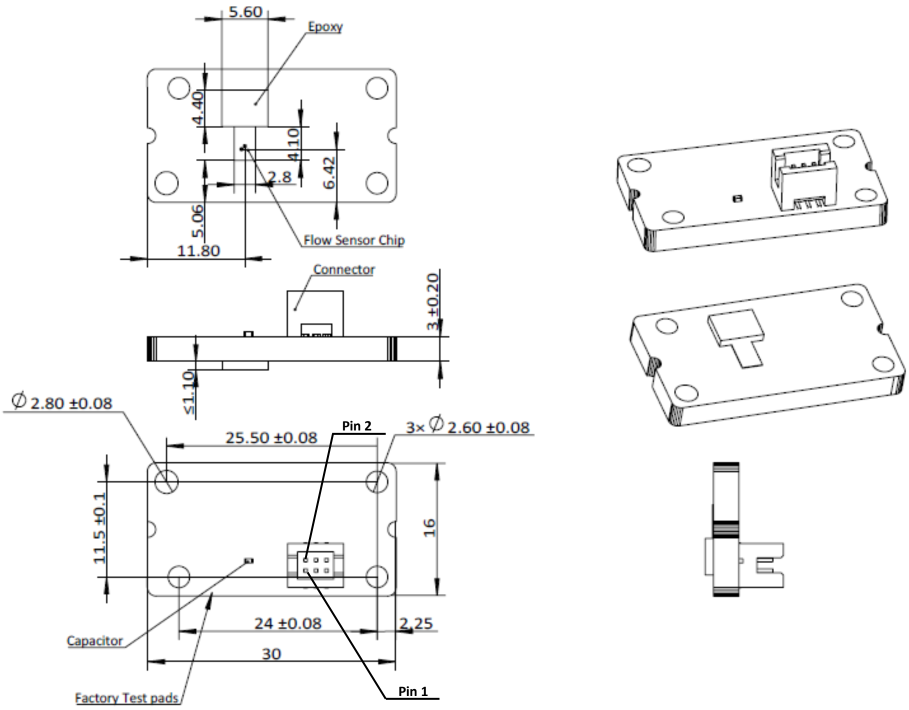
Fig.11 Convex Sensor Bridge

Mechanical Dimensions

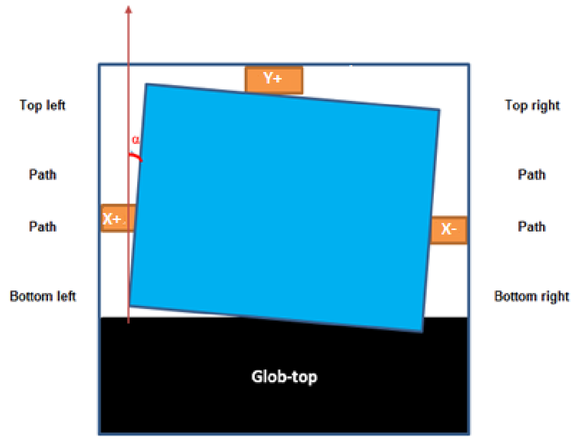
<u>Notes:</u>

Unit: mm, Tolerance: ± 0.1 mm (Unless otherwise specified)

(1) The bonded chip height: -100 to 20μm with respect to PCB surface.
(2) The bonded chip tilting (Left to Right, Top to Bottom) is ≤+/-15μm.
(3) The alignment angle is ≤2º.
(4) Outer dimensions: Length × Width ×Thickness = (30.0mm +/- 0.10mm) × (16.0mm +/- 0.10mm) × (3.0mm +/- 0.20mm).
(5) Position holes tolorance: +/-0.08mm
(6) Diameter holes tolorance: +/-0.08mm
(7) Position and lateral dimension cavity: Length(Vertical to flow) × Width(Parallel to flow) = (5.2mm+/-0.10mm) × (2.8mm+/-0.10mm).



(a). Mechanical Drawing



(b) Sensor chip assembly position

Fig.12 MFP21630B1 Mechanical Dimensions

Schematic

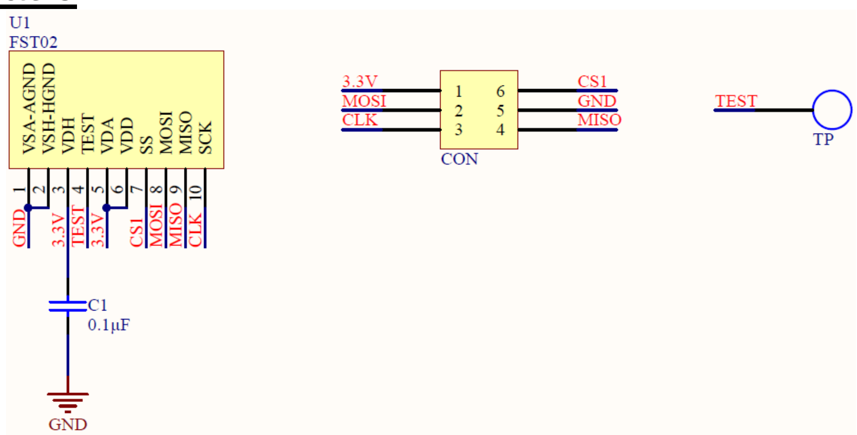


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Fig.13 Schematic of MFP21630B1 Layout Design

Revision History

Date	Author	Version	Changes Record
March 2016	SYXIAO	V1.0	Initial release
October 2016	SYXIAO	V1.1	Adjust sensor chip location; remove the EEPROM and the resistor, 4-layer PCB with 2.5mm thickness to 2-layer PCB with 3.0mm thickness, ADI free, PCB sensor side no green oil, routing optimization; add the more detailed sensor trimming fuses information.
May 2017	SYXIAO	V1.2	Specify the trim parameters and remove the trimming process; change the glob-top and die-attach glue for biocompatible applications.
September 2017	SYXIAO	V1.3	Change the electrical connector from BL112H-10S-TAGF to Amphenol ICC 20021221-00006C4LF; change the company name from MEMSIC to ACEINNA; add the ESD information; add the information of biocompatibility (ISO 10993-5, ISO 10993-10) as well as FDA conformity (CFR Code of federal regulation Title 21, §177) for the wetted materials.
January 2018	SYXIAO	V1.4	Change the plastic shipping tray size. Change the PCB cavity size. Change 1 out of 4 alignment holes diameter. Change the heater power from 2.0mA typical to 1.9mA typical.
March 2018	SYXIAO	V1.5	Change the heater power from 2.0mA typical to 1.9mA typical. Change the globtop epoxy from St5894 to Everwide JD739-4
May 2018	SYXIAO	V1.6	Changed the SN rule to match the actual definition.
May 2018	SYXIAO	V1.7	Modified the SN definition to match the common rule of ACEINNA products.
July 2018	SYXIAO	V1.8	Changed the die-attach epoxy from St5894 to St8801; Add the PCB spec of UL 94_V0; added the new chapter about the definition of sensor chip assembly process.
August 2018	SYXIAO	V1.9	Changed the bonded chip heightrange from -100um ~0 to -100um ~ 20um; added the examples for the die-attach and globtop epoxies dispensing; added the chapter of sensor chip assembly process.
Jan 2019	YCLIU	V2.0	Remove the mechanical dimensions in Characteristics tables Modification of schematic diagram Adder Sensor visual inspection