ANEXOS

ANEXO A
BOMBA PERISTÁLTICA

1. INTRODUCCIÓN

Este anexo se divide en tres partes. En primer lugar se realiza una breve descripción de la bomba peristáltica utilizada y de su principio de funcionamiento. Después hay una caracterización realizada para conocer su comportamiento y finalmente se aporta la hoja de características proporcionada por el fabricante.

2. DESCRIPCIÓN DE LA BOMBA

La bomba peristáltica es un tipo de bomba de desplazamiento positivo, es decir, tiene una parte de succión y otra de expulsión. El fluido se mueve a través de un tubo flexible colocado dentro de una cubierta circular de la bomba.

El movimiento de la bomba es llevado a cabo por un motor paso a paso. La cubierta circular de la bomba tiene 8 rodillos que giran alrededor del eje central del rotor aplastando un tubo flexible. Este aplastamiento es el que produce la presión que origina el movimiento del fluido a través del tubo.

En la figura 29 se puede ver un ejemplo del principio de funcionamiento de este tipo de bombas, en concreto el de una bomba peristáltica de tres rodillos.

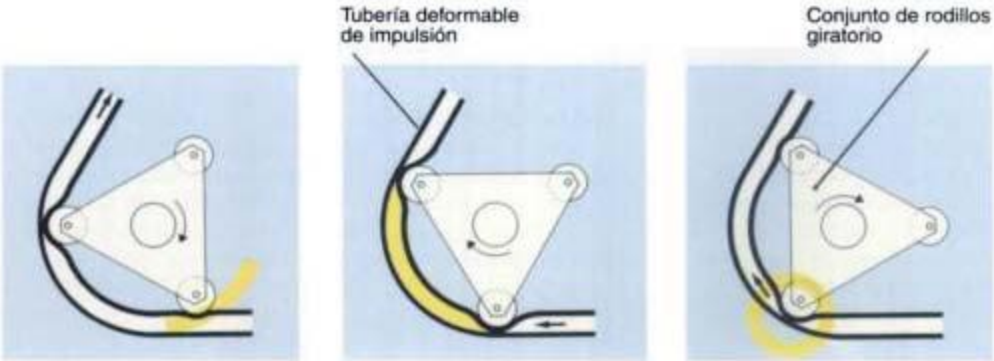


FIGURA 29: PRINCIPIO DE FUNCINAMIENTO DE UNA BOMBA PERISTÁLTICA

El volumen de contenido desplazado por la bomba en cada vuelta, dependerá del diámetro interior del conducto utilizado y del aplastamiento sufrido en el mismo por los rodillos.

Para el control de la bomba el fabricante incluye una placa de circuito impreso con la que podemos controlar los niveles de flujo. Para ello hay un pequeño conmutador rotatorio BCD con el que se pueden seleccionar 15 velocidades diferentes del motor.

En la figura 30 se puede ver una imagen de la bomba peristáltica junto con la placa de circuito impreso de control aportada por el fabricante.

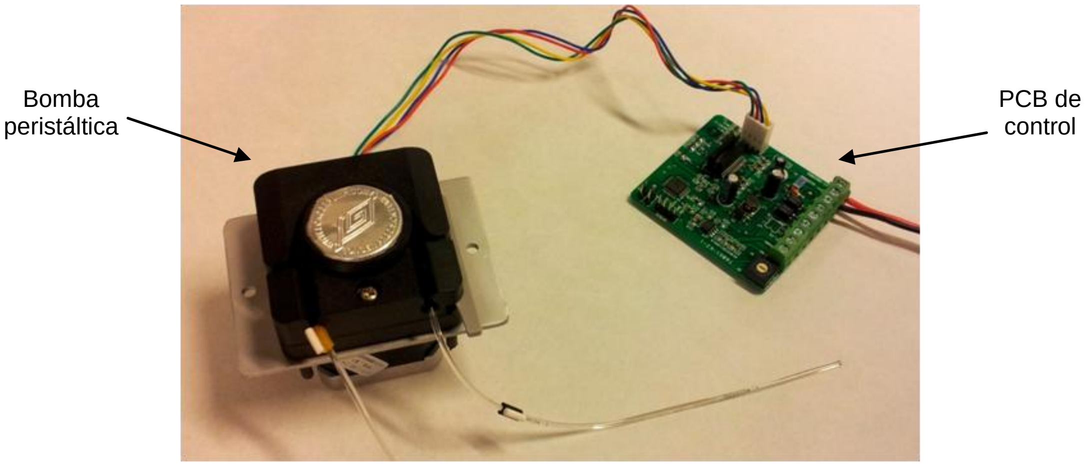


FIGURA 30: BOMBA PERISTÁLTICA Y PCB DE CONTROL

3. CARACTERIZACIÓN

Se ha realizado una caracterización en la que se ha medido el flujo en función de la velocidad del motor en revoluciones por minuto para distintos diámetros de tubo. Para extraer conclusiones acerca del comportamiento de la bomba se han realizado las mediciones para tubos de diferentes tamaños de diámetro.

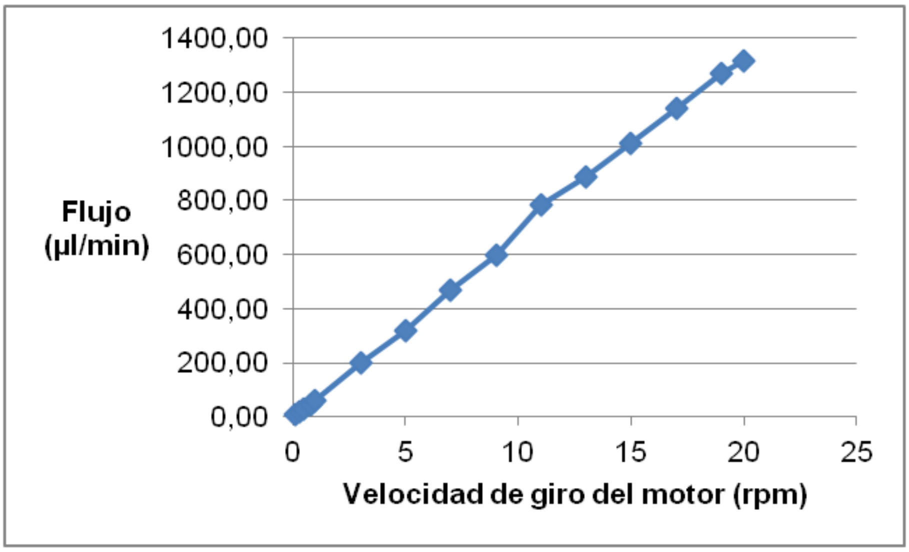
Para la realización de la caracterización se ha utilizado agua desionizada. El agua se hace circular por el tubo de la bomba y se va dejando caer en un vaso durante un tiempo determinado. Una vez finalizado ese tiempo se pesa el vaso con el agua desionizada en una báscula con resolución de 1 mg. A este peso se le resta el tamaño del recipiente, y el resultado se divide por el tiempo en que se ha estado bombeando.

En las páginas siguientes se muestran los diferentes resultados obtenidos.

TUBO 1,34 MM DIÁMETRO INTERNO

Posición BCD	Velocidad (rpm)	Flujo (µl/min)
1	0,1	7,25
2	0,3	19,25
3	0,5	31
4	0,8	47,5
5	1	62
6	3	199,25
7	5	317,5
8	7	470,25
9	9	600
A	11	785,5
B	13	887
C	15	1013,25
D	17	1139,25
E	19	1270,25
F	20	1316,75

(a)



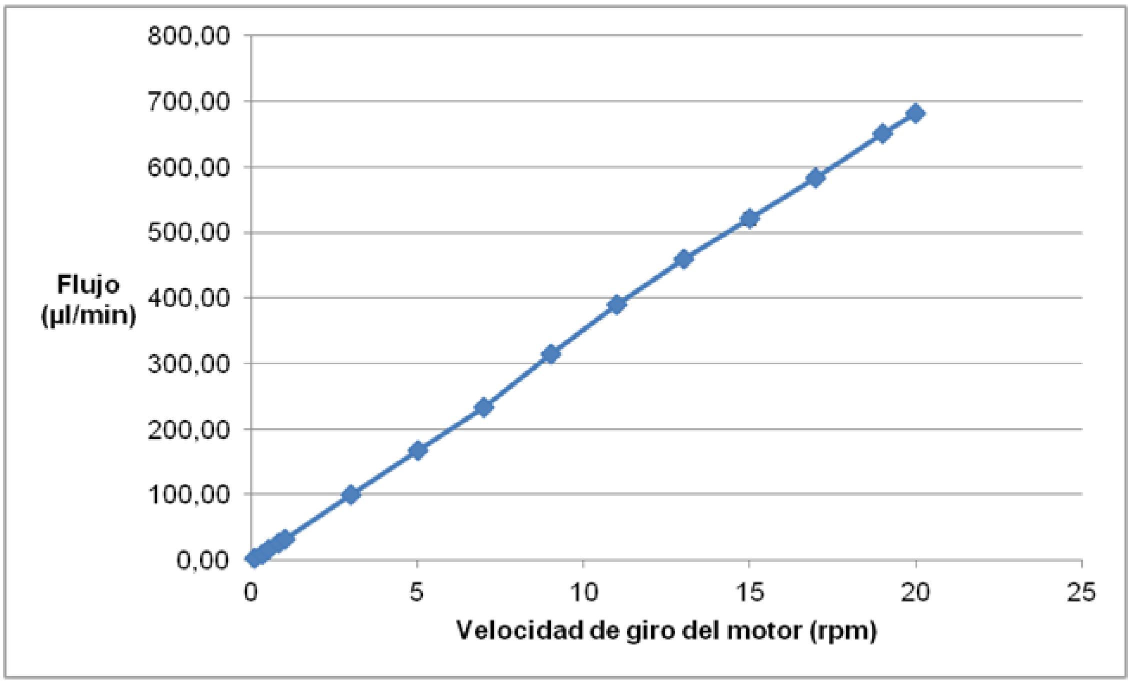
(b)

FIGURA 31: CARACTERIZACIÓN DE LA BOMBA PERISTÁLTICA PARA TUBO DE 1,34 MM, (a) TABLA DE VALORES, (b) GRÁFICO

TUBO 0,88 MM DIÁMETRO INTERNO

Posición BCD	Velocidad (rpm)	Flujo (µl/min)
1	0,1	2,75
2	0,3	9,75
3	0,5	16,25
4	0,8	25,5
5	1	32,5
6	3	99,25
7	5	168,25
8	7	234
9	9	315,25
A	11	390,5
B	13	459,75
C	15	520,5
D	17	583,75
E	19	650
F	20	681,5

(a)



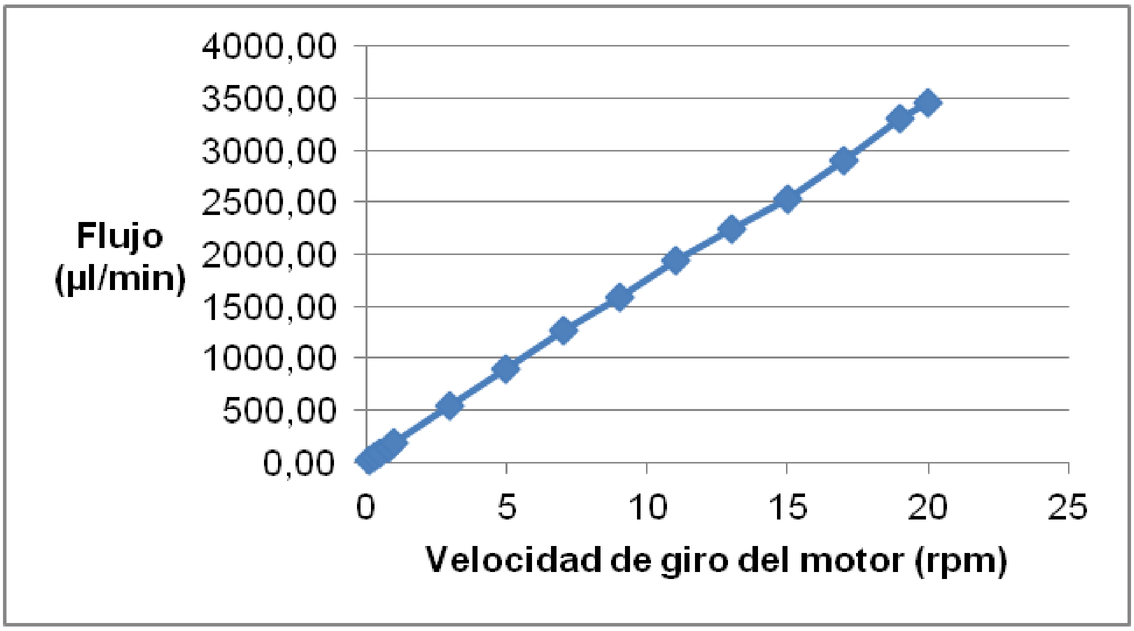
(b)

FIGURA 32: CARACTERIZACIÓN DE LA BOMBA PERISTÁLTICA PARA TUBO DE 0,88 MM, (a) TABLA DE VALORES, (b) GRÁFICO

TUBO 3 MM DIÁMETRO INTERNO

Posición BCD	Velocidad (rpm)	Flujo (µl/min)
1	0,1	15
2	0,3	49,5
3	0,5	88,75
4	0,8	140
5	1	184
6	3	542,75
7	5	900,75
8	7	1262,5
9	9	1589,5
A	11	1933,5
B	13	2249,5
C	15	2539,5
D	17	2901
E	19	3308,5
F	20	3460

(a)



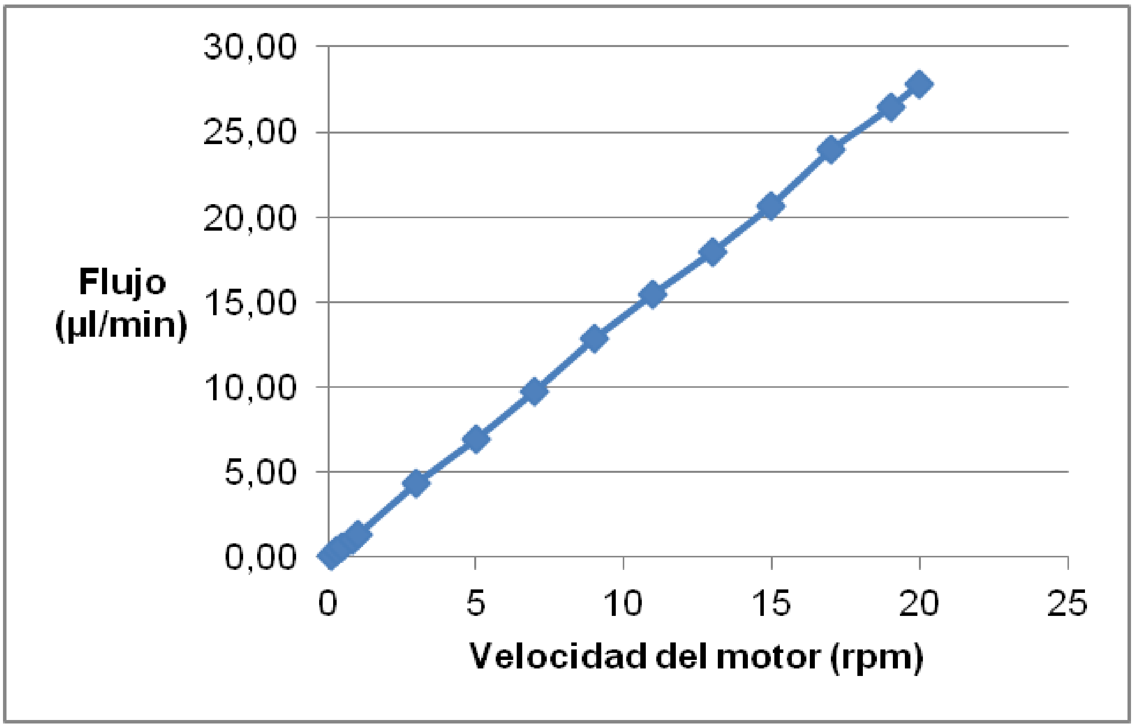
(b)

FIGURA 33: CARACTERIZACIÓN DE LA BOMBA PERISTÁLTICA PARA TUBO DE 3 MM, (a) TABLA DE VALORES, (b) GRÁFICO

TUBO 0,13 MM DIÁMETRO INTERNO

Posición BCD	Velocidad (rpm)	Flujo (µl/min)
1	0,1	0,07
2	0,3	0,40
3	0,5	0,67
4	0,8	1,07
5	1	1,33
6	3	4,40
7	5	6,90
8	7	9,73
9	9	12,90
A	11	15,50
B	13	18,00
C	15	20,70
D	17	24,00
E	19	26,50
F	20	27,80

(a)



(b)

FIGURA 34: CARACTERIZACIÓN DE LA BOMBA PERISTÁLTICA PARA TUBO DE 0,13 MM, (a) TABLA DE VALORES, (b) GRÁFICO

La principal conclusión a extraer de esta caracterización es que el flujo conseguido es directamente proporcional al diámetro del tubo utilizado. De esta manera, para lograr trabajar en diferentes rangos de operación lo único que habrá que hacer es cambiar el diámetro del tubo utilizado, lo que aporta una gran flexibilidad a la hora de realizar los experimentos.

4. Hoja de características

En las siguientes páginas se incluye las hojas de características necesarias para controlar la bomba peristáltica.

T60-S4/WX10-14 Operating Manual

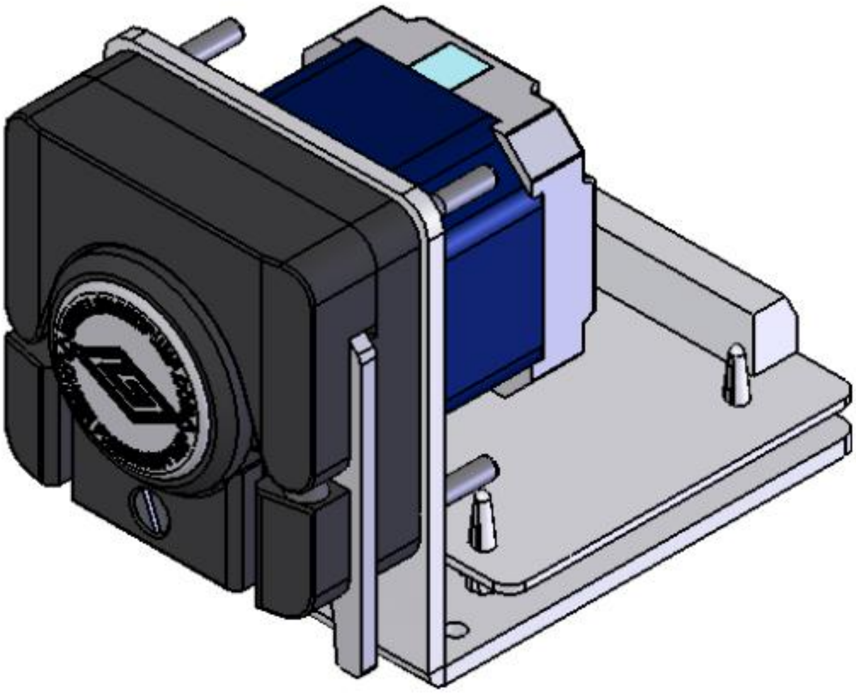


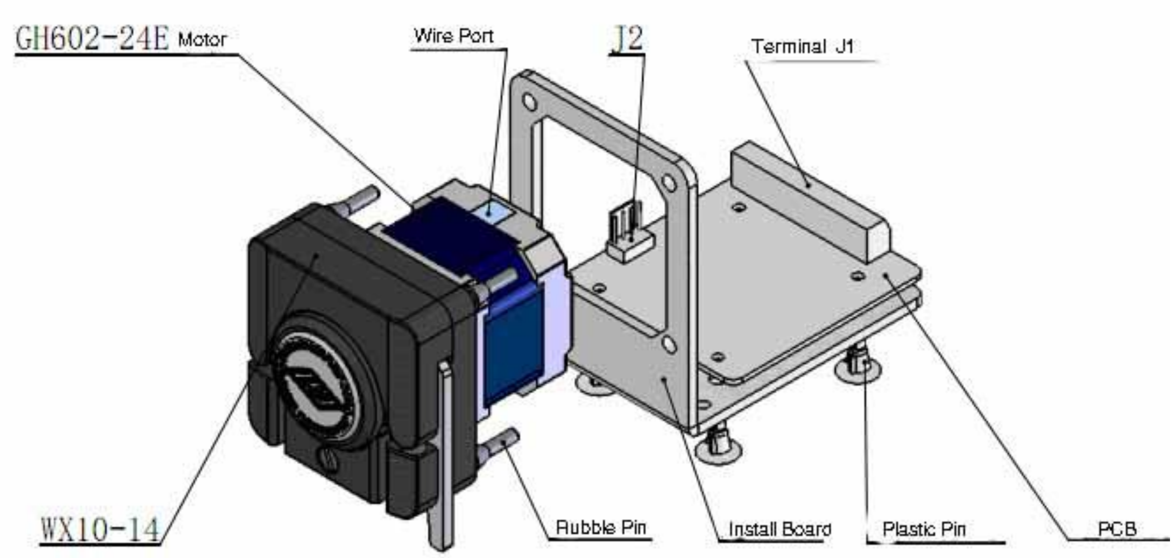
Table of Content

1. Pump Instruction

1.1 Main Features:

T60-S4 is one kind of typical OEM peristaltic pump; it can provide a flow range of 0.1 to 24 ml/min. It features compact size, simple operation; it can be powered by DC 11.4 – 25.2V. Pump speed can be adjusted through BCD dial switch which has 15 position corresponding to different speed under internal control mode; pump speed also can be adjusted by 0 to 10 KHz pulse signal under external control mode.

1.2 Pump Structure:



1.3 Technical Specifications

1.3.1 Main Functions:

Suitable pump head: WX10-14
Start/Stop control
Direction: Reversible
Internal speed control: BCD dial switch
External speed control: 0-10Hz pulse control

1.3.2 Technical Parameters:

Speed range under internal control: 1-60 rpm, see table 2 to know speed grade
Speed range under external control: 0-60 rpm, speed resolution is 0.1 rpm.
Speed tolerance: ≤±0.6rpm
Start/Stop control: on-off control, pump runs in suspension circuit; pump stops in close circuit.
Direction control: on-off control, pump runs clockwise in suspension circuit, pump runs count-clockwise in close circuit.
Tubing: Tubing ID≤3mm, wall thickness 0.8-1.0mm
Power supply: 11.4 to 25.2V DC or 100 – 240V AC adapter 50/60Hz
Power consumption: ≤10W
Operating environment: Ambient temperature 0-40℃, relative humidity <80%
Dimension: (length*width*height) 106×60×78mm
Weight: 0.43kg

2. Terminal Definition:

2.1 Wiring Terminal Instruction

J1 terminal layout

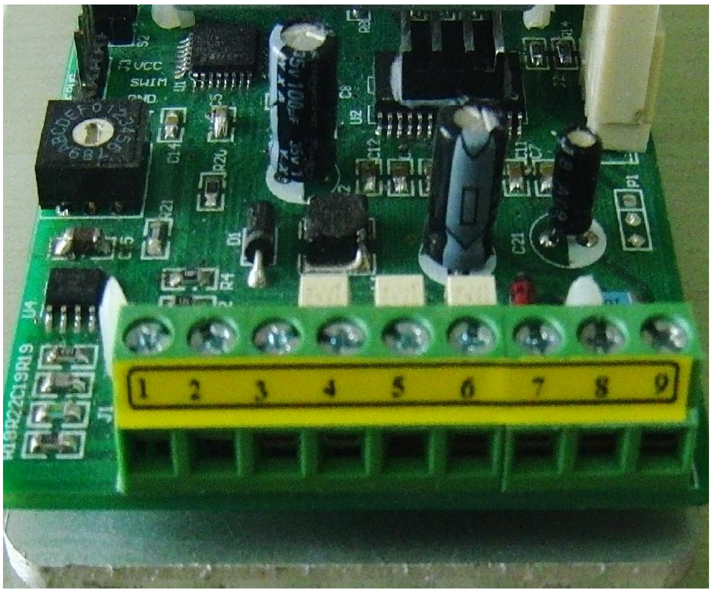


Table 1:

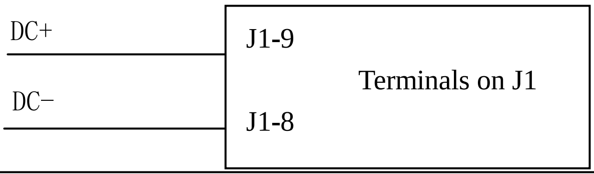
Terminal No.	Terminal Definition	Mark on PCB	Terminal No.	Terminal Definition	Mark on PCB
1	Suspension		6	CW/CCW signal	Z/F
2	Suspension		7	CW/CCW, start/stop control public end	G
3	Pulse signal+	P_IN	8	DC power supply -	G
4	Pulse signal-	P_COM	9	DC power supply +	24+
5	Start/stop signal	R/S			

2.2 Power Supply Port:

Suitable power supply is DC11.4-25.2V, or customer can use SMPS or adapter to power up pump if customers only have AC100-240V.

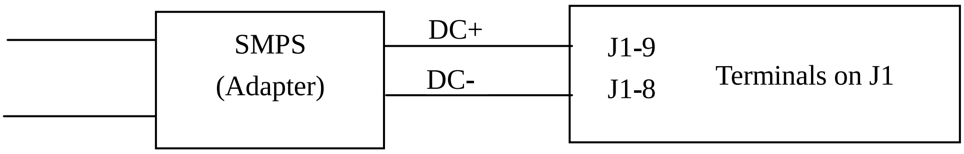
2.2.1 Wiring Diagram Using DC Power Supply:

Suitable power supply is DC 11.4-25.2 V, power consumption≥10W, wiring diagram shown as below:

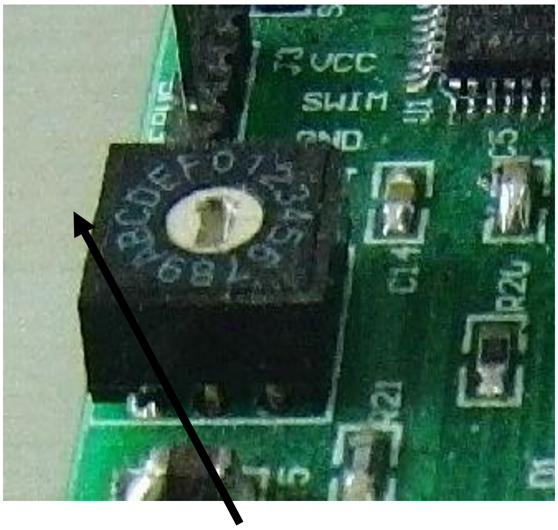


2.2.2 Wiring Drawing Using AC Power Supply:

Power supply is AC100-240V, adopt SMPS or adapter to output 11.4 – 25.2V DC, power consumption≥10W, wiring diagram shown as below:



2.2.3 BCD Dial Switch Instruction:



BCD Dial Switch

Table 2: BCD Position Corresponding to Speed

Control Mode	BCD Dial Switch Position	Speed（RPM）
BCD	0	stop
	1	0.1
	2	0.3
	3	0.5
	4	0.8
	5	1
	6	3
	7	5
	8	7
	9	9
	A	11
	B	13
	C	15
	D	17
	E	19
	F	20

3. Operation Instruction:

3.1 Drive Operation Procedure

3.1.1 Internal Control Operation

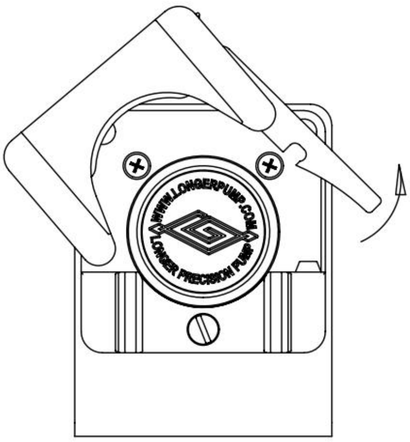
- First use suitable power supply, connect the wire according to Table 1,
- Power up the pump to adjust speed according to Table 2.

3.1.2 External Control Operation

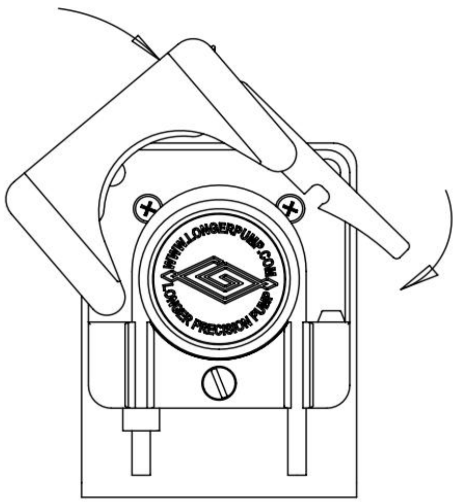
- First make sure there are suitable power supply and speed control signal for the pump,
- Connect the wire for power supply and signal.
- Turn BCD dial switch to position “0”, turn on the pump and signal source to adjust the speed.

3.2 Pump Head Operation Procedure

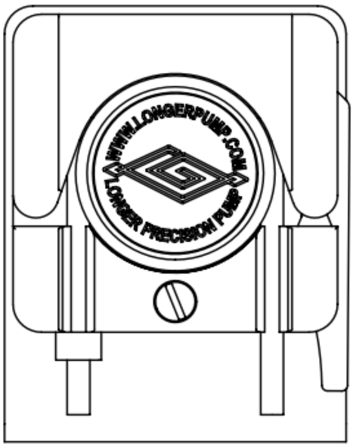
First open the pump head,



Load the tubing and adjust the tubing position.



Close the pump head.



Power up the pump, pump runs.

4. Pump Configuration

4.1 Product Type List Table

Type	Drive & pump head	Product Code
T60-S4	T60-S4&WX10-14	05.54.009

4.2 Accessory List Table

No.	Name	规格、型号	Part Code
1	Adapter	GM-120-150	
2	Operating Manual	T60-S4&WX10-14	
3	Silicone Tubing	0.5×0.8	
4		2.4×0.8	
5		1×1	
6		2×1	
7		3×1	
8	Pharmed Tubing	0.76×0.85	
9		1.02×0.85	
10		1.65×0.8	
11	TYGON3607	0.76×0.86	
12		1.52×0.86	
13		1.85×0.86	

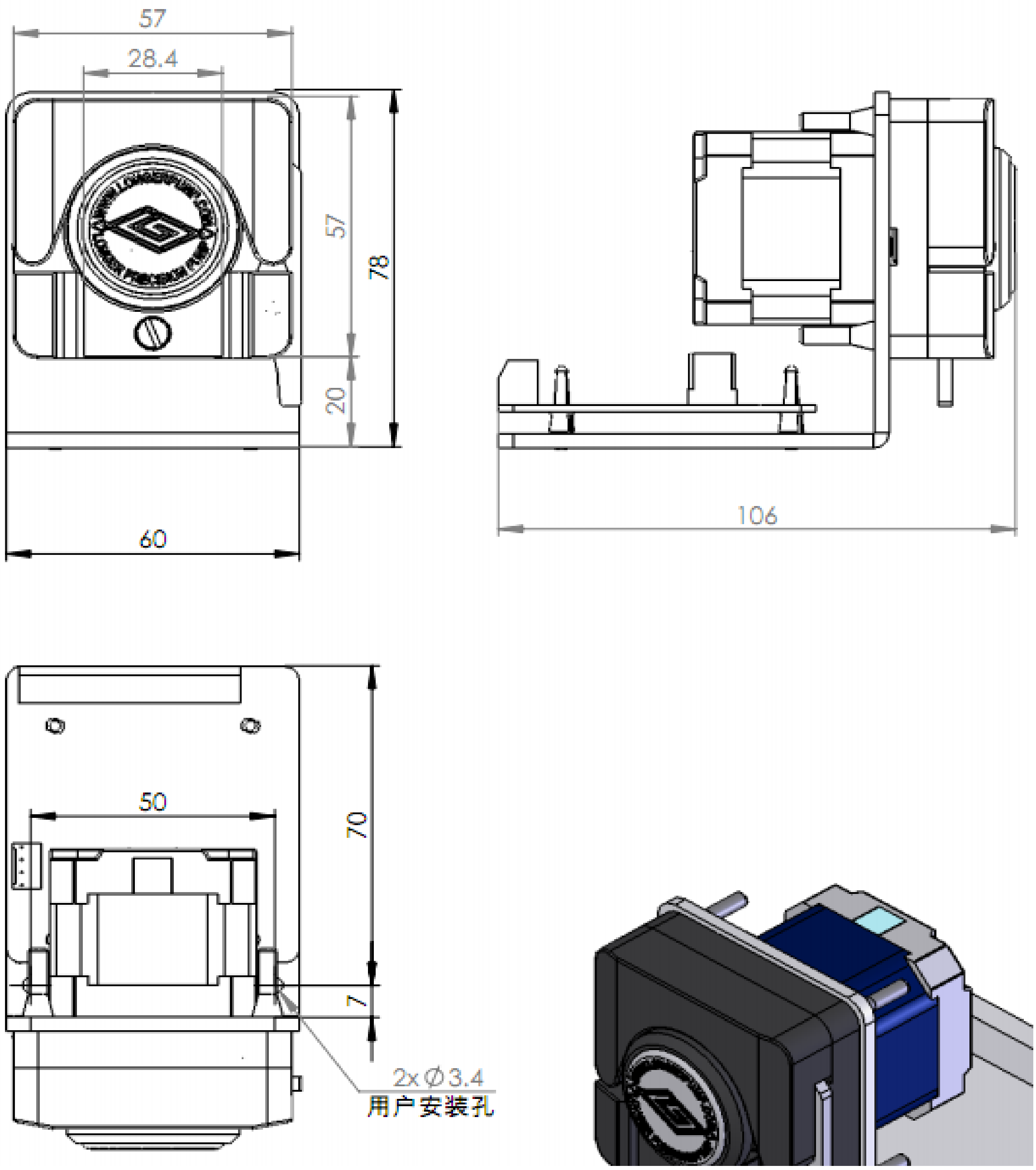
4.3 Product Configuration Table

No.	Suitable Pump	Power Supply	Accessory
1	T60-S4&WX10-14	11.4-25.2V DC	
2		100-240V AC	Adapter

No.	Suitable Product	Ref. flow rate （ml/min）	Tubing Type
1	T60-S4&WX10-14	0.79	0.5×0.8 Silicone tubing

2		17.6	2.4×0.8 Silicone tubing
3		3.54	1×1 Silicone tubing
4		13.1	2×1 Silicone tubing
5		24.7	3×1 Silicone tubing
6		2.20	0.76×0.85 Pharmed tubing
7		3.47	1.02×0.85 Pharmed tubing
8		8.0	1.65×0.80 Pharmed tubing
9		2.20	0.76×0.86 TYGON3607
10		7.6	1.52×0.86 TYGON3607
11		9.8	1.85×0.86 TYGON3607

5. Installation Drawing:



6. Maintenance:

- When the pump is idle, we recommend you to release the tubing from pressure. This helps to protect the tubing from unnecessary strain and prolongs its service life
- Keep rollers clean and dry. This will prolong the service lives of tubing and pump head.
- The surface of drive and the pump head are not organic solvent and aggressive liquids resistant. Please pay attention when using.

7. Warranty:

The warranty period for this product is one year. If repair or adjustment is necessary within the warranty period, the problem will be corrected at no charge if it is not due to misuse or abuse on your par t, as determined by the manufacturer. Repair costs outside the warranty period, or those resulting from product misuse or abuse, may be invoiced to you.

8. Contact Us:

Baoding Longer Precision Pump Co., Ltd
Building A, Chuangye Center, Baoding National
High-Tech Industry Development Zone
Baoding, Hebei, China 071051
Email: longer@longerpump.com
Tel: 86-312-3110087
Fax: 86-312-3168553
www.longerpump.com

ANEXO B
BOMBA DE MEMBRANA

1. INTRODUCCIÓN

Este anexo se divide en tres partes. En primer lugar se realiza una breve descripción de la bomba de membrana utilizada y de su principio de funcionamiento. Después aparece una caracterización realizada para conocer su comportamiento y finalmente se aporta la hoja de características proporcionada por el fabricante.

2. PRINCIPIO DE FUNCIONAMIENTO

La bomba de membrana es un tipo de bomba de desplazamiento positivo en la que el aumento de presión se realiza por el empuje de unas paredes elásticas (membranas) que varían el volumen de la cámara aumentándolo y disminuyéndolo alternativamente. El principio de funcionamiento de las microbombas de Bartels se basa en un piezoeléctrico en combinación con válvulas de retención pasivas.

Un cerámico piezoeléctrico montado sobre una membrana recubierta de material metálico se deforma cuando se aplica tensión. La bajada resultante provoca que el fluido sea desplazado fuera de la cámara.

Las válvulas de retención situadas a ambos lados de la cámara definen el sentido del flujo. Cuando la tensión disminuye, la correspondiente deformación de los piezoeléctricos provoca que la membrana suba quedando en la posición de inicio, haciendo, a su vez, que la cámara aspire medio y se vuelva a llenar. Todo este ciclo se describe gráficamente en la figura 35.

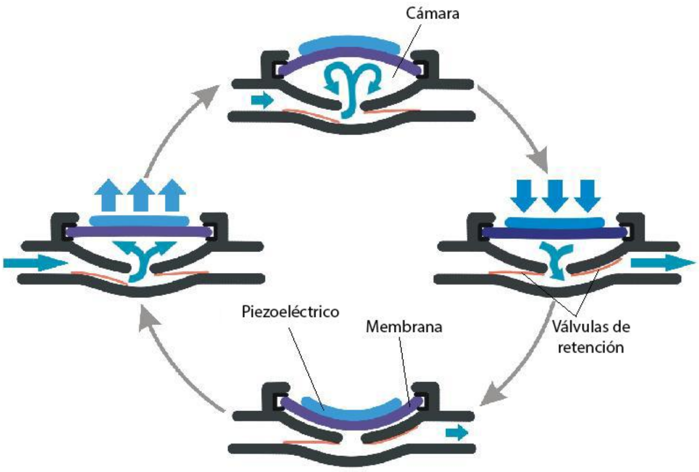


FIGURA 35: DESCRIPCIÓN GRÁFICA DEL CICLO DE UNA MEMBRANA

La bomba puede hacer varios cientos de estos ciclos de bombeo en cada segundo. El comportamiento de la bomba vendrá dado, en un principio, por los parámetros de amplitud, frecuencia y forma de onda de la señal eléctrica.

La microbomba mp6 de Bartels Mikrotechnik está basada en el principio de funcionamiento descrito, con la diferencia de que incorpora dos piezoeléctricos dentro de una única carcasa. Estos piezoeléctricos actuarán de manera opuesta, es decir, cuando uno esté llenando su cámara, el otro la estará vaciando, como se puede ver en la figura 36.

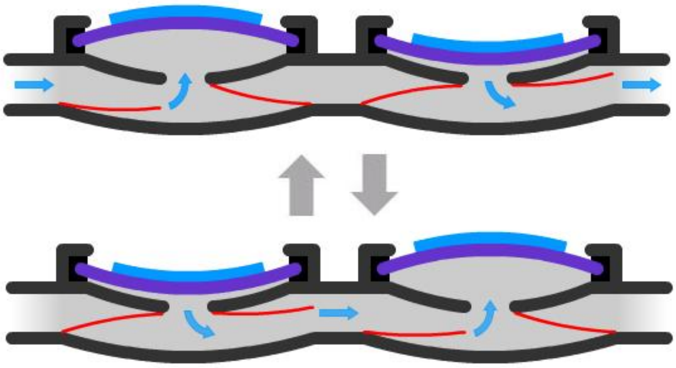


FIGURA 36: DESCRIPCIÓN GRÁFICA DEL CICLO DE UNA BOMBA DE DOS MEMBRANAS

Para el control de la bomba se ha utilizado el circuito integrado mp6-OEM, del mismo fabricante de la bomba. Este circuito proporciona la señal eléctrica que la bomba necesita para funcionar. El control se basa en la variación de la amplitud y la frecuencia.

3. CARACTERIZACIÓN

Para saber si la microbomba mp6 es apta o no para la realización de experimentos de cultivo celular hay que estudiar el comportamiento de la bomba. El fabricante solo aporta 3 gráficas (figura 37) acerca de este comportamiento. Además de esto, los datos que se pueden observar se sitúan en el rango de los ml/min, mientras que se desean flujos de µl/min.

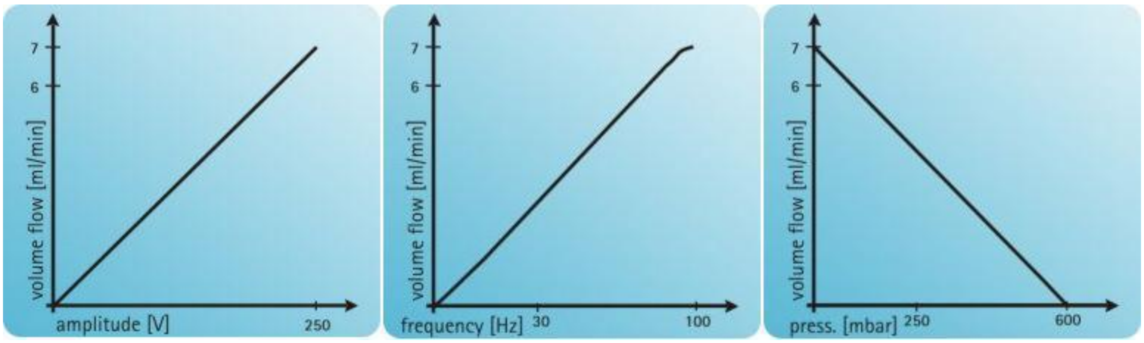


FIGURA 37: GRÁFICAS DE LA MICROBOMBA APORTADAS POR EL FABRICANTE

Por estas razones ha habido que realizar una caracterización completa de la bomba, para así conocer su comportamiento en el rango deseado.

La caracterización consiste en realizar mediciones del flujo de salida a medida que varían los parámetros de entrada. Estos parámetros de entrada serán la frecuencia en hercios y la amplitud en voltios pica a pico.

Para medir el flujo de salida se han utilizado unos pequeños recipientes de plástico llamados “tubos Eppendorf”. Estos tubos recogen el flujo de salida durante un tiempo determinado. Después se pesa el tubo en una báscula de precisión, de resolución 1 mg. A este peso se le resta el peso que tenía el eppendorf vacío y este resultado se divide por el tiempo que hemos estado recogiendo la muestra.

Para variar los parámetros de entrada amplitud y frecuencia se ha utilizado un generador de señal fabricado por el grupo Gemm. Este generador de señal proporciona una onda cuadrada de amplitud y frecuencia variables. La amplitud puede variarse entre 80 y 250 Vpp y la frecuencia entre 25 y 225 Hz. Esta variación se realiza con un ordenador utilizando el programa “Labview”.

La caracterización se ha realizado con dos circuitos fluídicos diferentes.

El primer circuito fluídico (figura 38) sobre el que se ha realizado la caracterización incluye, además de la bomba de membrana, un reservorio y un encapsulado. También se ha incluido un *by-pass*, que consiste en hacer que parte del flujo aportado por la bomba circule por un camino alternativo y no por el encapsulado. De esta forma se reduce el flujo que circula por el chip, consiguiendo así unos niveles de flujo más cercanos a 1 µl/min.

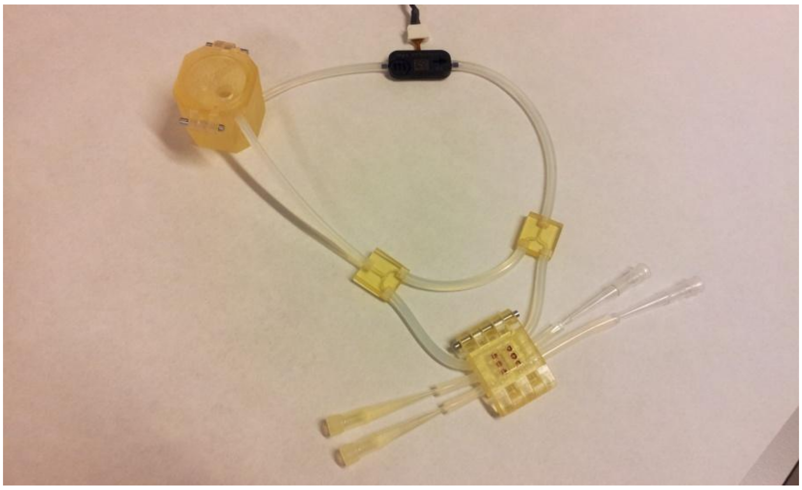
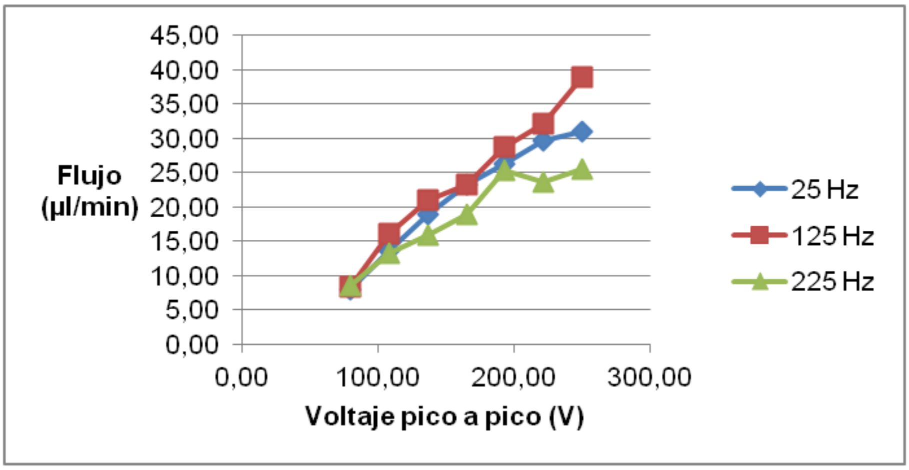


FIGURA 38: *SETUP* MICROFLUÍDICO CON *BY-PASS*

GRÁFICO CAUDAL-AMPLITUD A FRECUENCIAS DE 25, 125 Y 225 HZ

Vpp (Vpp)	Flujo (µl/min)		
	25 Hz	125 Hz	225 Hz
80,00	8,07	8,43	8,53
108,30	13,73	16,07	13,20
136,60	18,87	20,93	15,97
165,00	23,30	21,30	18,87
193,30	26,30	28,83	25,43
221,60	29,70	32,20	23,73
250,00	30,97	38,97	25,53

(a)



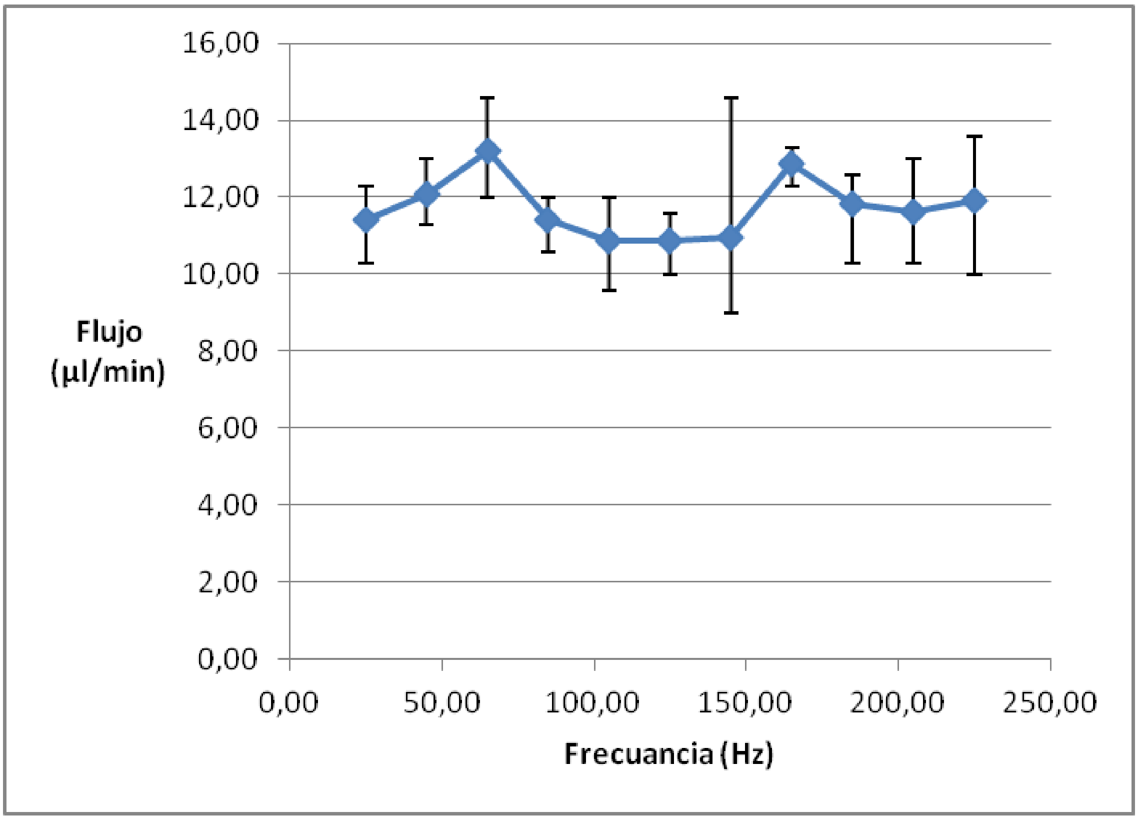
(b)

FIGURA 39:CARACTERIZACIÓN DE LA BOMBA DE MEMBRANA PARA SETUP CON BY-PASS, (A) TABLA DE VALORES, (B) GRÁFICO COMPARATIVO

GRÁFICO CAUDAL-FRECUENCIA A AMPLITUD 80 VPP

Frecuencia (Hz)	Flujo (µl/min)
25,00	11,40
45,00	12,10
65,00	13,20
85,00	11,40
105,00	10,87
125,00	10,87
145,00	10,97
165,00	12,87
185,00	11,83
205,00	11,63
225,00	11,93

(a)



(b)

FIGURA 40: CARACTERIZACIÓN DE LA BOMBA DE MEMBRANA PARA SETUP CON BY-PASS, (a) TABLA DE VALORES, (b) GRÁFICO

Para el segundo circuito montado se ha eliminado el *by-pass* y se ha colocado un encapsulado con mayor resistencia fluídica. Este montaje se puede ver en la figura 41.

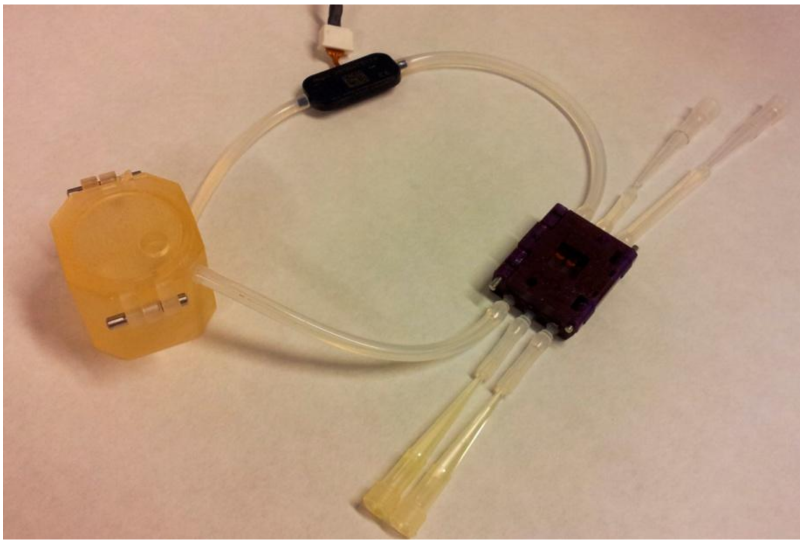
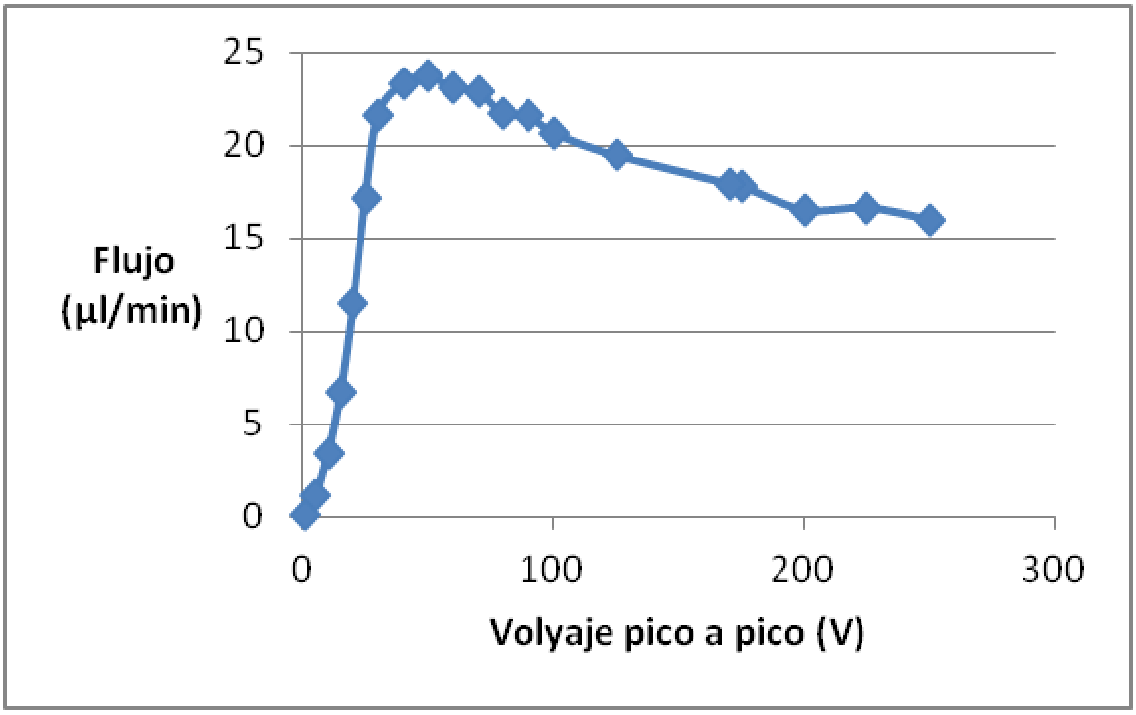


FIGURA 41: *SETUP* MICROFLUÍDICO SIN *BY-PASS*

BARRIDO AMPLITUDES A 25 HZ 1

Amplitud (Vpp)	Flujo (µl/min)
250	16,014
225	16,658
200	16,531
175	17,803
170	17,929
125	19,46
100	20,697
90	21,605
80	21,685
70	22,875
60	23,098
50	23,718
40	23,357
30	21,645
25	17,186
20	11,475
15	6,759
10	3,426
5	1,157
1	0,105

(a)



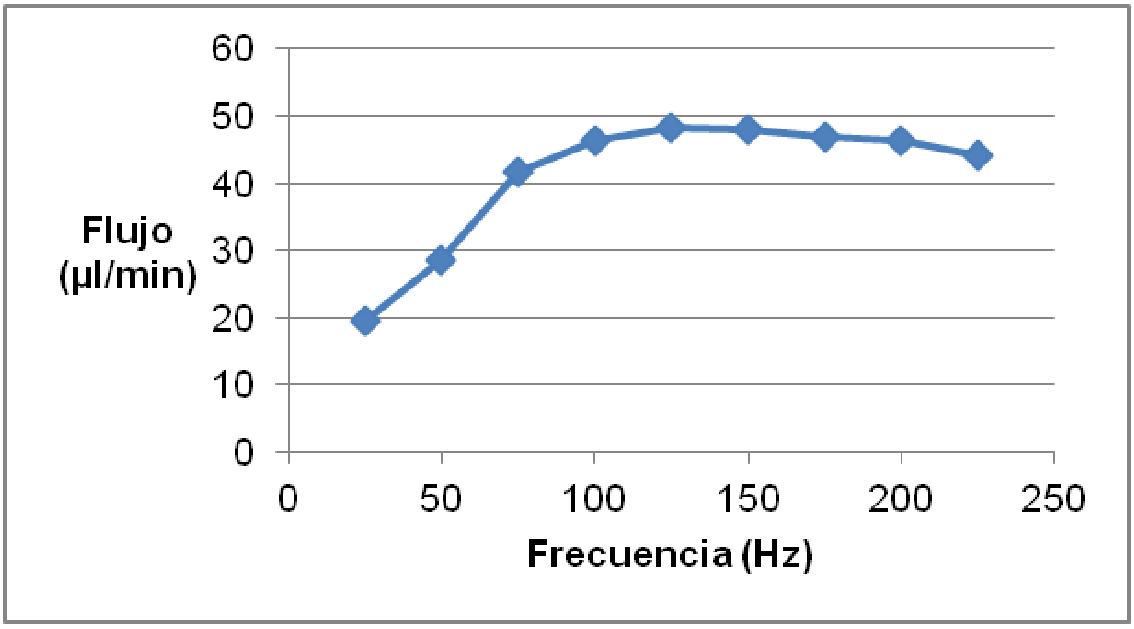
(b)

FIGURA 42: CARACTERIZACIÓN DE UNA BOMBA DE MEMBRANA PARA SETUP SIN BY-PASS, (A) TABLA DE VALORES, (B) GRÁFICO

BARRIDO DE FRECUENCIAS BOMBA 1 A 80 VPP

Frecuencia (Hz)	Flujo (µl/min)
25	19,54991057
50	28,50106977
75	41,58544
100	46,19086614
125	48,35822222
150	48,09296825
175	46,84161905
200	46,29205578
225	44,0223871

(a)



(b)

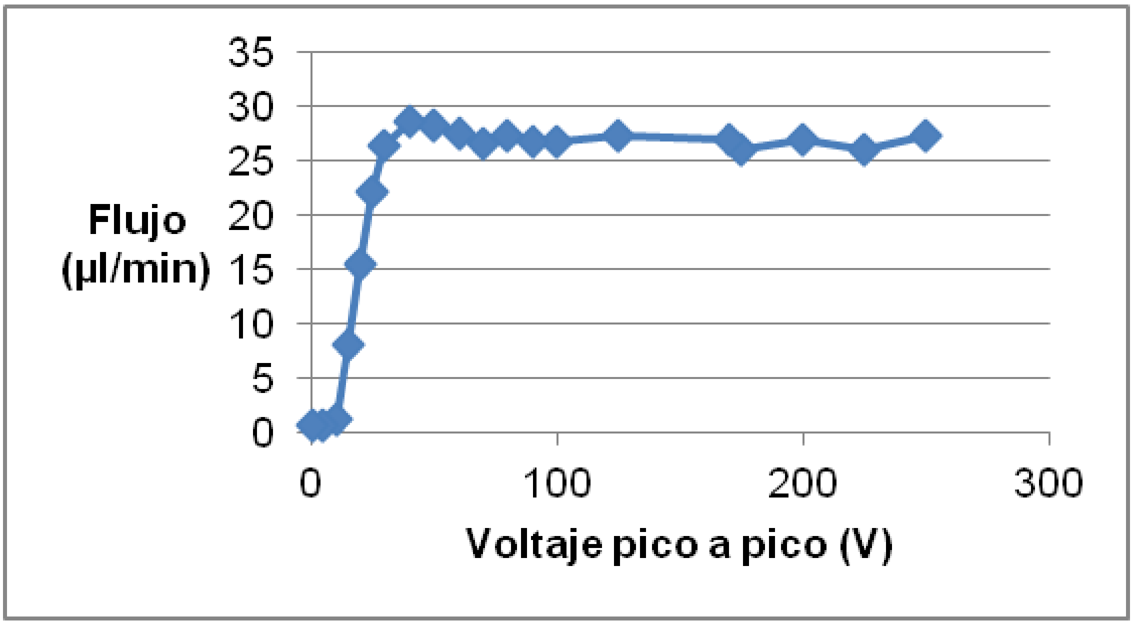
FIGURA 43: CARACTERIZACIÓN DE LA BOMBA DE MEMBRANA PARA SETUP SIN BY-PASS, (a) TABLA DE VALORES, (b) GRÁFICO

Con el mismo circuito se ha cambiado la bomba por otra de la misma serie que, en teoría, debería comportarse igual. Se ha vuelto a realizar el barrido de amplitudes.

BARRIDO DE AMPLITUDES BOMBA 2

Amplitud (Vpp)	Flujo (µl/min)
250	27,274
225	26,087
200	27,019
175	25,99
170	26,932
125	27,336
100	26,892
90	26,859
80	27,384
70	26,616
60	27,58
50	28,278
40	28,721
30	26,341
25	22,119
20	15,429
15	7,949
10	1,096
5	0,663
1	0,557

(a)



(b)

FIGURA 44: CARACTERIZACIÓN DE UNA SEGUNDA BOMBA DE MEMBRANA PARA SETUP SIN BY-PASS, (a) TABLA DE VALORES, (b) GRÁFICO

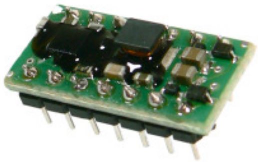
La conclusión a la que nos lleva esta caracterización es que la variación de los parámetros de entrada de amplitud y frecuencia hace variar el flujo en la salida. Sin embargo esta variación es fuertemente dependiente de todos los elementos del *setup*, incluso de la propia bomba, lo que hace que el nivel de flujo en la salida sea prácticamente incontrolable con este método.

4. HOJA DE CARACTERÍSTICAS

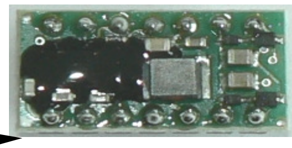
En las siguientes páginas se incluye las hojas de características necesarias para controlar la microbomba mp6 con el circuito integrado mp6-OEM

7. The mp6-OEM controller

The mp6-OEM is a small, easy to use low cost driving circuit developed for the mp6 micropump. It generates up to 235 V peak to peak voltage from a 3-5 V supply.
Its low power consumption makes it ideal for battery powered handheld devices or even solar powered devices. The module can be integrated into a PCB design like a 14 pin DIL package.
Build in interface allows the user to adapt frequency and/or amplitude to its application by the use of a few additional components or a microcontroller.
In order to locate Pin 1, please refer to the following figure. Looking onto the mp6-OEM from the top with the black encapsulation on the left side, Pin 1 is in the lower left. The pin is as well marked by a small white spot.



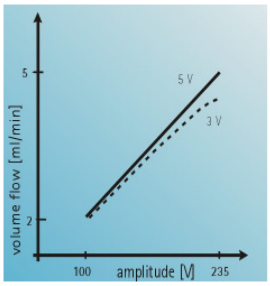
Pin 1



7.1 Technical specifications mp6-OEM

Dimensions	10,5 x 20,5 x 6 mm³
Pumping media	liquids or gases
Adjustable parameters	amplitude / frequency
Amplitude range	85 – 235 V
Frequency range	25 – 120 Hz (frequencies up to 1000 Hz possible, but output voltage will decrease, frequencies down to 1 Hz are possible using an external frequency source)
Signal form	trapezoid
Power supply	2.5 – 5.5 V DC (5V recommended for full performance)
Current consumption	approx. 30 mA at 5 V
Max. flow rate mp6 (typ.)	4.5 ml/min (water)
Pin layout	DIL 14, Horizontal spacing ~2,54 mm, vertical ~7,62 mm

7.2 Typical flow characteristics



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7.3 Connecting the mp6 to the mp6-OEM controller

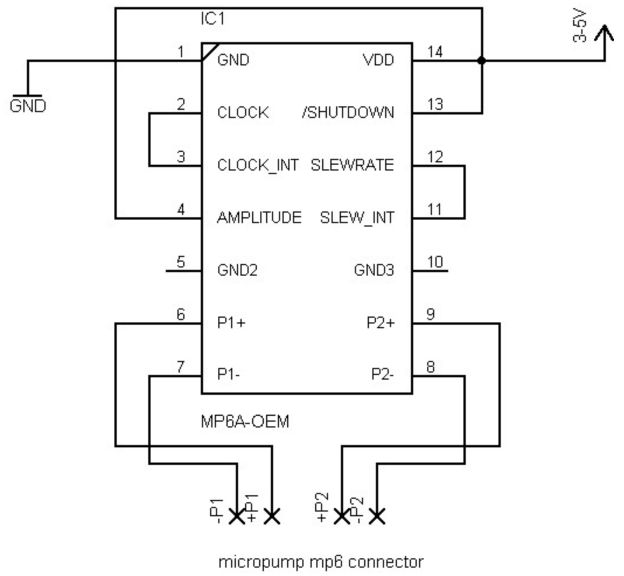
The mp6 pump can be connected to the mp6-OEM via a standard electrical connector manufactured by Molex, see chapter 4.1.1

DANGER
THE MP6-OEM MODULE CAN CARRY HIGH VOLTAGE ! BE CAREFUL, WHILE CONNECTING AND HANDLING THE MODULE!

7.4 Typical schematics

7.4.1 Fixed pump rate

The mp6-OEM can drive the mp6 without the need of external components. In this case the pumps frequency and amplitude is fixed determined by internal components to 235 V and 100 Hz.



Schematic 1: Fixed amplitude of 235 V and fixed frequency of 100 Hz ±10 % with internal components.

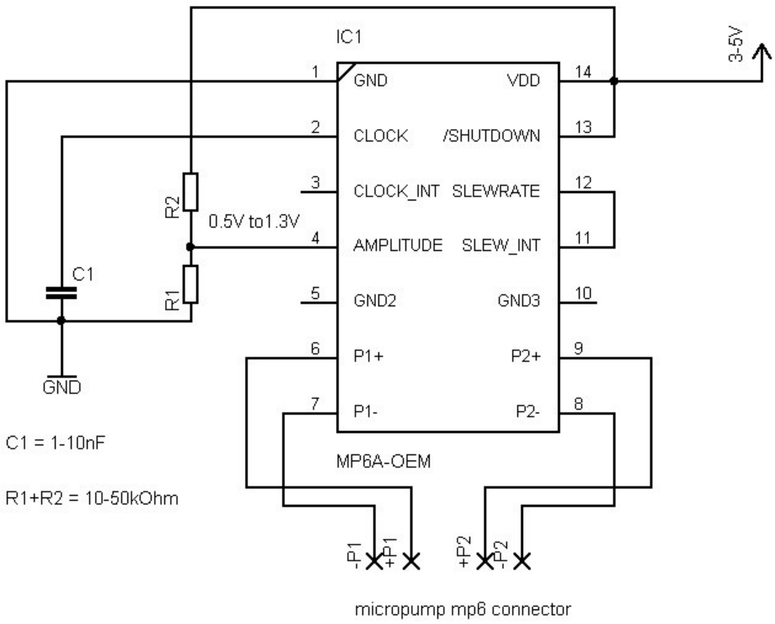
7.4.2 Pump rate set by external components

In this example the frequency and the amplitude is set by external components. The amplitude can be varied from approximately 85 V to 235 V peak to peak. The frequency can be changed from 25 Hz to 120 Hz. For higher frequencies the amplitude will decrease. Lower frequencies are also possible but stability of the output signal needs to be checked.

To set the amplitude, either a potentiometer with 10 kOhms, or a voltage divider of two resistors R1 and R2 as shown in the schematic 2 can be used. The voltage at the amplitude pin can be calculated with the following formula (voltage divider)

$$V_{AMPLITUDE} = V_{DD} \cdot \frac{R1}{R1 + R2}$$

The relation between the voltage at the amplitude pin and the output voltage is shown in table 7.1



Schematic 2: Frequency and amplitude set with external components

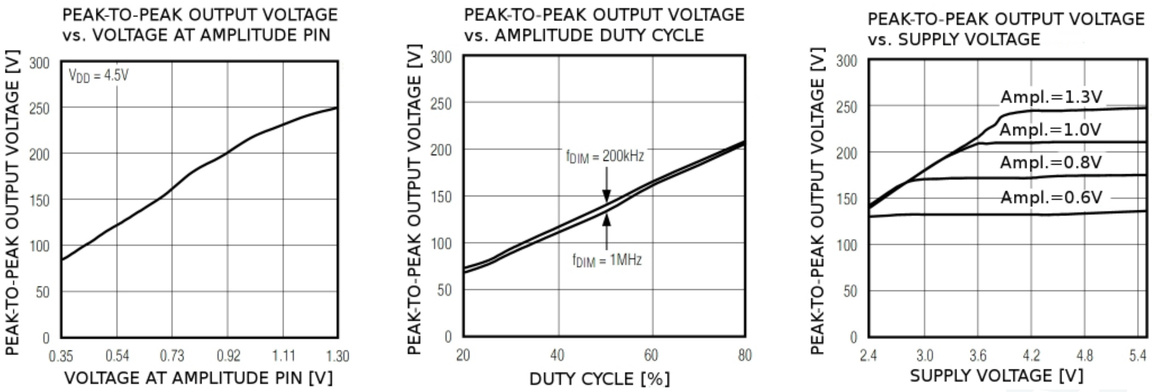


Table 7.1 : Behaviour of output voltage according to external circuitry

To set the frequency, a capacitor C1 between in the nF range can be used as shown in the schematic 2 above. Typical capacitor values are shown in the following table 7.2.

For frequencies that are lower than 20 Hz, an external frequency signal needs to be applied as described in chapter 7.4.3.

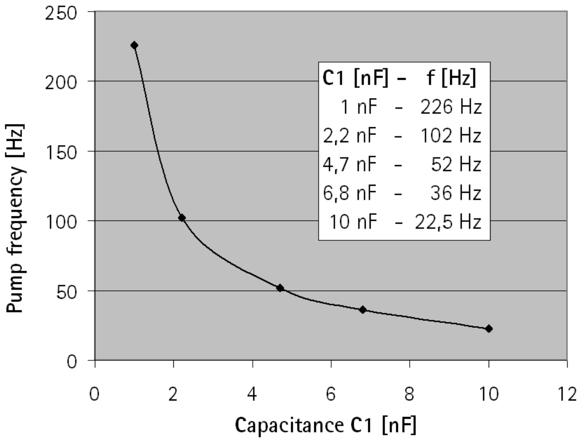


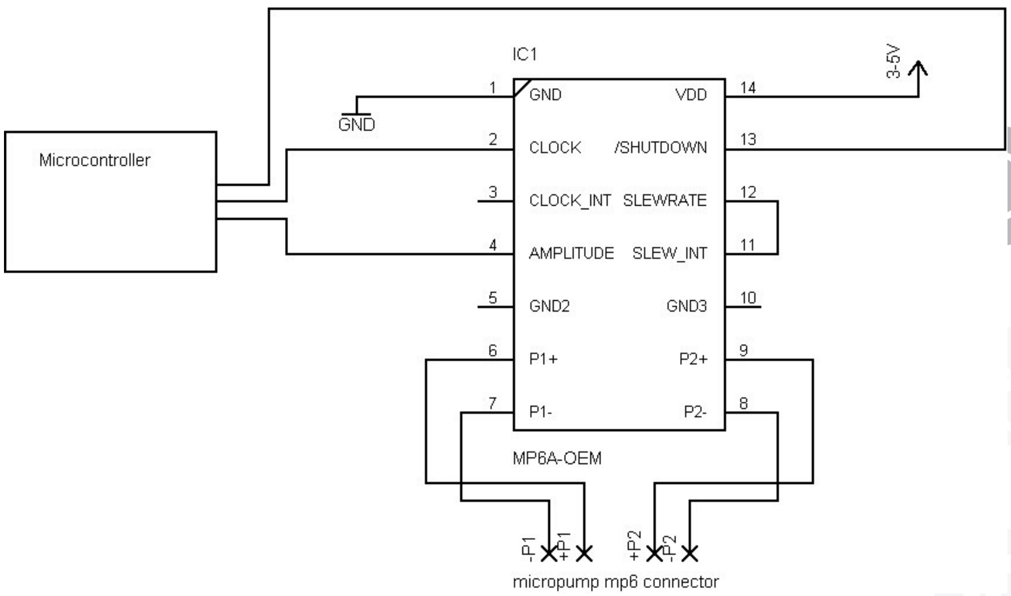
Table 7.2 : Typical capacitor values for different pump frequency values

7.4.3 Pump rate control via microcontroller

To control the mp6-OEM with a microcontroller, an external clock with four times the desired frequency connected to the CLOCK pin can directly set the output frequency. In this case the pump frequency can be decreased down to the single Hz range. Working at pump frequencies below 25 Hz, the duty cycle of the frequency signal needs to be high (95% on time) to result in an appropriate output signal.

The amplitude can either be adjusted by an analog voltage according to table 7.1, or by an equivalent PWM signal with a frequency between 0.2 and1 MHz connected to the AMPLITUDE pin (see table 7.1 for details). The PWM signal should be higher than 1.3 V to make the output solely dependent on the duty cycle of the PWM signal.

For a minimum of power consumption the electronics can be switched off by applying zero volts to the AMPLITUDE input and the SHUTDOWN port, but the most efficient way is to cut the power supply.



Schematic 3: External control via microcontroller

7.5 Electrical characteristics

One mp6 connected, internally defined frequency and slew rate

Parameter	Symbol	Conditions	Min.	Typ.	Max.	Units
Power Supply Voltage	VDD		2.5		5.5	V
Power Supply Current, average	IDD	VDD = 5 V (1)			30	mA
Control voltage AMPLITUDE			0.35		1.3	V
Peak to Peak Output Voltage	Vpump	AMPLITUDE =1.3 V	230	235	245	V
Peak to Peak Output Voltage	Vpump	AMPLITUDE = 0.35 V	85	100	120	V
PWM frequency AMPLITUDE			0.2		1	MHz
Internal Pump Frequency	F	VDD = 5 V (1)	90	100	110	Hz
Digital Inputs Low				0		V
Digital Inputs High			2		VDD	V
Capacity at Clock Input			1.0	2.2	10	nF
Input Current AMPLITUDE			1		3	µA
Current in shutdown mode				1,6		µA

(1) Output signal set by internal components

7.6 Pin description

VDD	Power supply voltage
GND	Ground
SHUTDOWN	To shutdown the device, AMPLITUDE <u>and</u> SHUTDOWN needs to be tied to GND.
CLOCK	Output frequency control, the frequency can be set to nominal 100 Hz by connecting this pin to CLOCK_INT (Schematic 1) A capacitor of 1 to 10 nF can be connected between this pin and GND to set another frequency (Schematic 2) The output frequency can be set by a clock signal with **<u>four times</u>** the desired output frequency
CLOCK_INT	Output frequency control, the frequency can be set to nominal 100 Hz by connecting this pin to CLOCK
AMPLITUDE	Apply a DC Voltage (0-1.3 V) or a PWM signal (0.2-1 MHz) to this input to adjust the amplitude of the output from 100 V to 235 V
SLEWRATE	Slew rate control. This pin is connected to SLEW_INT
SLEW_INT	Internal slew rate resistance, connect this pin to SLEW
GND2, GND3	Internally connected to GND, can be left unconnected
+P1	Piezo 1 positive (see connection diagram for the mp6)
-P1	Piezo 1 negative (see connection diagram for the mp6)
+P2	Piezo 2 positive (see connection diagram for the mp6)
-P2	Piezo 2 negative (see connection diagram for the mp6)

7.7 Noise reduction

If the noise generated by the pump is critical a series resistor of 2-10 kΩ in the P1+ and the P2+ line between the mp6-OEM and the pump will help. There is no limit for the resistor value but it will decrease the maximum pump performance.

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8. The mp6-EVA evaluation board

8.1 Safety notice

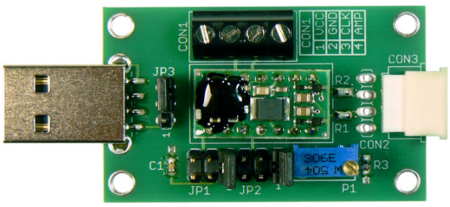
The mp6-OEM generates voltages of up to 250 V peak to peak. All parts of the mp6-EVA evaluation board can carry voltages in this range. Therefore the board should only be used by qualified personal. Although the output power of the module is very low, proper insulation according to the application conditions needs to be considered by the customer. This especially applies to the lower side of the PCB. Contact with water or other liquids needs to be prevented. The pump must not be changed while a driving voltage is applied to the board.

DANGER
THE EVALUATION BOARD CAN CARRY HIGH VOLTAGE ! BE CAREFUL, WHILE CONNECTING AND HANDLING THE BOARD!

8.2 Electrical specifications mp6-EVA evaluation board

As the evaluation board is based on the mp6-OEM module, all electrical characteristics and specifications of this product must be considered. Please see chapter 7 of this manual for more detail.

8.3 Functional elements



Elements are listed with their names according to the printed description on the PCB

Connectors:
CON 1 – Screw terminal for external power supply and external clock / amplitude signal
CON 2 – Solder terminal for extension cable to connect one mp6 micropump
CON 3 – Molex connector to connect one mp6 micropump
USB connector for voltage supply via USB

Jumpers:
JP1 – Jumper for pump frequency setting
JP2 – Jumper for pump amplitude setting
JP3 – Jumper for power supply setting

Others:
P1 – Variable resistor for amplitude adjustment

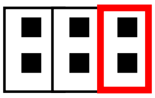
8.4 Operation

To operate a pump with the evaluation board, the following steps are necessary:

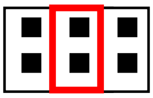
1) Connect the mp6 pump to the board according to the description in chapter 4.1.1. Due to the orientation of the connector, the pump needs to be inserted with its metallic contacts upwards.
2) Choose the pump frequency setting with Jumper 1
3) Choose the pump amplitude setting with Jumper 2
4) Choose the power supply setting with Jumper 3
5) Connect the board with the voltage source

8.4.1 Pump frequency setting with jumper J1

Setting of Jumper J1

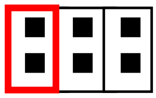


Internal frequency of the mp6-OEM (100 Hz)



Frequency defined by capacitor C1 (predefined to 300 Hz)*

*50 Hz in versions delivered until July 2011

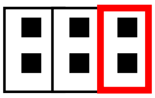


Frequency defined by CLK input on terminal CON1 – Pin 3

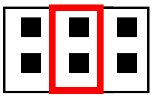
More information on the frequency setting with the CLK signal can be found in chapter 7.4.2. The capacitor C1 can as well be changed according to chapter 7.4.2 by resoldering.

8.4.2 Pump amplitude setting with jumper J2

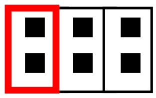
Setting of Jumper J2



Maximum voltage (235 V)



Amplitude defined by variable resistor P1

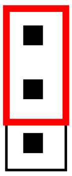


Amplitude defined by AMP input on terminal CON1 – Pin 4

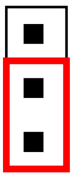
More information on the amplitude setting with the AMP signal can be found in chapter 7.4.1.

8.4.3 Operation voltage setting with jumper J3

Setting of Jumper J3



Driving voltage via screw terminal CON 1 Pin 1 (Vcc) and Pin2 (GND)



Driving voltage via USB port

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8.5 Connecting the pump via CON2

If the mp6 micropump should not be connected directly to the PCB with the Molex connector CON 3, an extension cable can be soldered to the connector CON 2.

The solder pads have the following pin assignment:

P2 +	(positive voltage piezo 2)
P2 –	(negative voltage piezo 2)
P1 –	(negative voltage piezo 1)
P1 +	(positive voltage piezo 1)

CON 2

For further details, please refer to chapter 4.1.1 of this manual. Please make sure that the cable can handle voltages up to 250 V peak-to-peak and ensure proper insulation of the cable.

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ANEXO C

SENSOR DE FLUJO

En el presente anexo se incluye la hoja de características que aporta Sensirion donde se describen las principales características a tener en cuenta para la elección del modelo de sensor. También se incluyen 3 *Application Notes* con la información necesaria para hacer las medidas de flujo mediante el protocolo de comunicación I2C.

LG16

Media Isolated Microfluidic Flow Sensor

- Liquid flow rates up to 5000 µl/min
- Resolutions down to sub nl/min
- Totally non invasive, pressures up to 200 bar
- Digital I²C interface or analog out 0-5 V

1 Introduction LG16

The LG16 Liquid Flow Sensor series enables fast, non invasive measurements of very low liquid flow rates below 5 ml/min. This product line is especially suited for OEM volume applications requiring small sized components with high performance at low cost. Excellent chemical resistance and bio-compatibility are ensured: The flow path of the LG16 Liquid Flow Sensors is formed by a simple, straight glass capillary. This Swiss made, non invasive sensors are based on Sensirion's patented CMOSens® Technology (US Patent 6,813,944 B2). The fourth generation MEMS sensors combine a thermal high precision sensor element with amplification circuits and digital intelligence for linearization and temperature compensation on one single microchip – the products core element.

2 Sensing Performance

Table 1: Model specific performance of LG16 (all data for medium H_2O, 20°C, 1 bar_{abs} unless otherwise noted)

Parameter	LG16-0025	LG16-0150	LG16-0430	LG16-1000	LG16-2000	
Maximum Flow Rate	1.50	7.00	50	1000	5000	µl/min
Lowest Calibrated Flow (LCF)	0.07	0.4	1.0	30	200	µl/min
Digital Resolution at LCF (16 bit)	0.084	0.24	0.60	12	150	nl/min
Accuracy[a] above LCF	10	5.0	5.0	5.0	5.0	% of m.v.[b]
Accuracy below LCF	0.5	0.25	0.1	0.15	0.2	% of full scale
Signal Noise, 16 bit digital output	4.5	4.5	4.5	4.5	4.5	LSB
- at LCF	0.002	0.010	0.025	0.25	3.0	µl/min
- at Maximum Flow Rate	0.004	0.040	0.300	5.0	20	µl/min
Signal Noise, analog output, RMS	< 2					mV
Temperature Coefficient	0.15	0.09	0.13	0.1	0.1	(% m.v.[b]) / K
Mounting Orientation Sensitivity[c]	-	<0.4	<0.4	1.0	1.5	% of full scale
Flow Detection Response Time τ_{63}	40			40		ms
Response Time On Power-Up	120			120		ms
Digital Sampling Rate, 16 bit	74			74		ms
Digital Sampling Rate, 9 bit	1			1		ms
Operating Temperature	+10…+50			+10…+50		°C
Ambient storage temperature	-10…+60			-10…+60		°C

3 Output Signals

The OEM flow sensor LG16 shows bi-directional, linear transfer characteristics. The product comes fully calibrated for water – for volume applications flow calibration for methanol or other media is available on request.

[a] Better available on request.
[b] Measured value
[c] Normal position: Horizontal flow channel

The LG16 can be ordered as analog output version (0…5V, LG16-xxxx-A) or as digital output version (LG16-xxxx-D). Digital communication between a master and the LG16-xxxx-D sensor runs via the standard I²C-interface. The physical interface consists of two bus lines, a data line (SDA) and a clock line (SCL). These lines can be used on 3.3V or 5.0V level with a clock frequency of 100 kHz. For the detailed specifications of this I²C communication refer to the Sensirion "User Manual I²C-Mode SF04".

4 Electrical and Mechanical Specifications

4.1 Electrical Specifications

Table 2: DC Characteristics.

Parameter	Conditions	Min.	Typ.	Max.	Units
Power Supply DC, VDD	for digital out I²C type	3.5	7.0	12[a]	V
	for analog out type	6.0	7.0	12[a]	V
Operating Current	V_{DD} = 3.5 V, no load		6.8		mA
	V_{DD} = 12 V, no load		6.8		mA
Analog Out Voltage Range	negative to positive maximum flow (LG16-xxxx-A only), zero flow =2.5V	0.2		4.8	V
Load at Analog Out		10		∞	kΩ

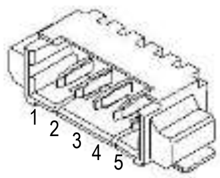
Table 3: I²C Output Characteristics

Parameter	Conditions	Min.	Typ.	Max.	Units
I²C Bus Clock Frequency			100		kHz
Output Voltage Low (SDA/SCL)	I_{sink} = 6mA		0.1	0.5	V
Low Level Output Current(SDA/SCL)				6	mA
High Level Input Voltage (SDA/SCL)		2.0			V
Low Level Input Voltage (SDA/SCL)				1.0	V

4.2 Electrical Connector and Pinout

Connector Type: 5 pin Molex PCB Header 53261-0590 (right angle) . Assembled flat ribbon cable Molex 1.25 mm Pitch Recptacle Type 51021-0500 (PicoBlade™ 51021) included.

Pin	
1	SDA (bi-directional)
2	SCL
3	VDD
4	GND
5	Analog out



4.3 Electrical Connection for Digital Communication via I²C

Digital communication between LG16-xxxx-**D** type sensors and an I²C master works on both 5V or 3.3V level. The SDA and SCL lines need to be connected via pull-up resistors with the bus voltage of the system. The individual I²C address of each sensor on the I²C bus can be set with a special interface tool.

[a] Keep supply voltage below 9V for high precision applications; exceeding 12V will lead to permanent damage of the sensor

4.4 Mechanical Specifications and Pressure Rating

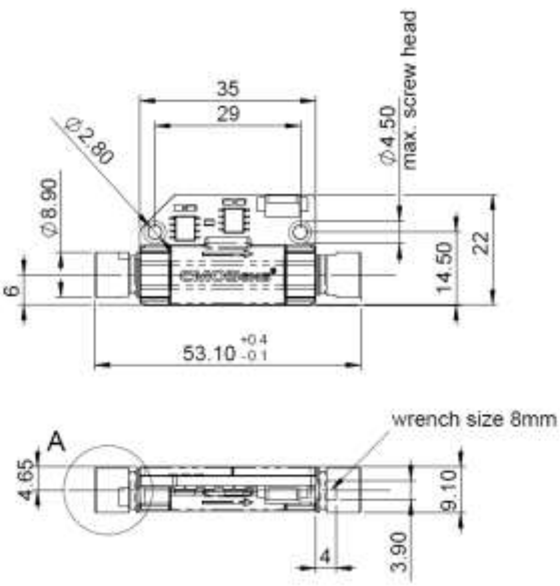
Inside the LG16 flow sensors a highly sensitive microsensor-chip is mounted on the outside of a straight glass capillary and allows to measure the flow through the wall (US Patent 6,813,944 B2) using a thermal principle.

Table 4: Mechanical Specifications and Pressure Rating

Parameter	LG16-0025	LG16-0150	LG16-0430	LG16-1000	LG16-2000
Fluid Connector Ports (Fittings)	UNF 6-40 for 1/32" OD tubing VICI® (Valco) Nanovolume™ compatible			¼-28 for 1/16" or 1/8" OD plastic tubing	
Wetted Materials:					
• Internal Sensor Capillary Material	Quartz Glass (Fused Silica)			Borosilicate Glass 3.3 (Duran®)	
• Fitting Material	100% PEEK™ (polyetheretherketone)				
• Additional Sealing Material	None			Teflon®	ETFE(Tefzel®)
Overpressure Resistance	**200 bar** 2900 psi		**100 bar** 1450 psi	**5 bar** 70 psi	**3 bar** 40 psi
Maximum Pressure Drop (at max. flow rate)	1.5 bar	5 mbar	5 mbar	2 mbar	1 mbar
Internal Sensor Capillary, Inner Diameter	25 µm	150 µm	430 µm	1.0 mm	1.8 mm
Total Internal Volume	1 µl	1.5 µl	5.1 µl	<30 µl	<90 µl
Total Mass	6 g				

Attention Fragile	
Mechanical shocks and connecting to the fittings without suitable tools leads to stress on the internal thin walled glass capillary and can cause it to break. • While tightening the fittings, fix the fluidic ports position with a wrench. • Test for leakage after every time new connections are made.	!

5 Physical Dimensions



6 Ordering Information

The LG16 flow sensors can be ordered for OEM volume applications. Each model is available with analog output (ending "-A") or with digital output (ending "-D").
Fluid connection material is not included.

Product	Article Number
LG16-2000-A	1-100403-01
LG16-2000-D	1-100404-01
LG16-1000-A	1-100405-01
LG16-1000-D	1-100406-01
LG16-0430-A	1-100852-01
LG16-0430-D	1-100853-01
LG16-0150-A	1-100409-01
LG16-0150-D	1-100410-01
LG16-0025-A	1-100427-01
LG16-0025-D	1-100428-01
LG16-0480-A	1-100407-01
LG16-0480-D	1-100408-01

7 Important Notices

7.1 Warning, personal injury

Do not use this product as safety or emergency stop devices or in any other application where failure of the product could result in personal injury. Do not use this product for applications other than its intended and authorized use. Before installing, handling, using or servicing this product, please consult the data sheet and application notes. Failure to comply with these instructions could result in death or serious injury.

If the Buyer shall purchase or use SENSIRION products for any unintended or unauthorized application, Buyer shall defend, indemnify and hold harmless SENSIRION and its officers, employees, subsidiaries, affiliates and distributors against all claims, costs, damages and expenses, and reasonable attorney fees arising out of, directly or indirectly, any claim of personal injury or death associated with such unintended or unauthorized use, even if SENSIRION shall be allegedly negligent with respect to the design or the manufacture of the product.

7.2 ESD Precautions

The inherent design of this component causes it to be sensitive to electrostatic discharge (ESD). To prevent ESD-induced damage and/or degradation, take customary and statutory ESD precautions when handling this product.

See application note “ESD, Latchup and EMC” for more information.

7.3 Warranty

SENSIRION warrants solely to the original purchaser of this product for a period of 12 months (one year) from the date of delivery that this product shall be of the quality, material and workmanship defined in SENSIRION’s published specifications of the product. Within such period, if proven to be defective, SENSIRION shall repair and/or replace this product, in SENSIRION’s discretion, free of charge to the Buyer, provided that:

- notice in writing describing the defects shall be given to SENSIRION within fourteen (14) days after their appearance;
- such defects shall be found, to SENSIRION’s reasonable satisfaction, to have arisen from SENSIRION’s faulty design, material, or workmanship;
- the defective product shall be returned to SENSIRION’s factory at the Buyer’s expense; and
- the warranty period for any repaired or replaced product shall be limited to the unexpired portion of the original period.

This warranty does not apply to any equipment which has not been installed and used within the specifications recommended by SENSIRION for the intended and proper use of the equipment. EXCEPT FOR THE WARRANTIES EXPRESSLY SET FORTH HEREIN, SENSIRION MAKES NO WARRANTIES, EITHER EXPRESS OR IMPLIED, WITH RESPECT TO THE PRODUCT. ANY AND ALL WARRANTIES, INCLUDING WITHOUT LIMITATION, WARRANTIES OF MERCHANTABILITY OR FITNESS FOR A PARTICULAR PURPOSE, ARE EXPRESSLY EXCLUDED AND DECLINED.

SENSIRION is only liable for defects of this product arising under the conditions of operation provided for in the data sheet and proper use of the goods. SENSIRION explicitly disclaims all warranties, express or implied, for any period during which the goods are operated or stored not in accordance with the technical specifications.

SENSIRION does not assume any liability arising out of any application or use of any product or circuit and specifically disclaims any and all liability, including without limitation consequential or incidental damages. All operating parameters, including without limitation recommended parameters, must be validated for each customer’s applications by customer’s technical experts. Recommended parameters can and do vary in different applications.

SENSIRION reserves the right, without further notice, (i) to change the product specifications and/or the information in this document and (ii) to improve reliability, functions and design of this product.

7.4 RoHS and WEEE Statement

The LG16 product family complies with requirements of the following directives:

EU Directive 2002/96/EC on waste electrical and electronic equipment(**WEEE**), OJ13.02.2003; esp. its Article 6 (1) with Annex II.

EU Directive 2002/95/EC on the restriction of the use of certain hazardous substances in electrical and electronic equipment (**RoHS**), OJ 13.02.2003; esp. its Article 4.

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User Manual for I²C Flow and Differential Pressure Sensors

I²C Functional Description

Summary

This document describes the communication with the Sensirion SF04 mass flow sensor chip. Communication between a master and the SF04 sensor system runs via the digital I²C-interface. The document contains all essential commands and some basic descriptions of the SF04 I²C protocol. For the detailed specifications please check the document "The I²C-Bus Specification, Version 2.1, January 2000" from NXP. (http://www.nxp.com/products/interface_control/i2c).

The instructions in this document are valid for all Sensirion sensors containing a SF04 mass flow sensor chip and offering I²C protocol. Particularly the communication with the following Sensirion products is covered:

- SDP600 Series
- LG16, LG216

The document contains basic knowledge to access the sensor as well as additional information for advanced users.

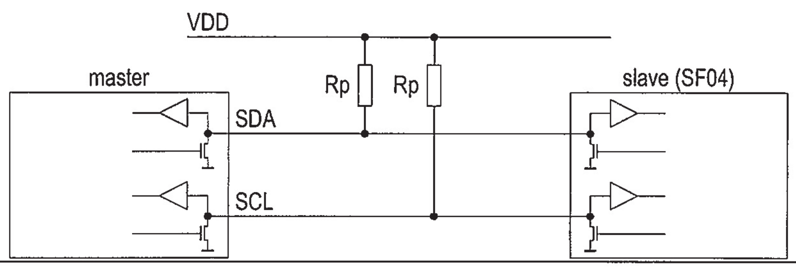
1. Connecting Instructions – External Circuit Elements

Bi-directional bus lines are implemented by the devices (master and slave) using open-drain output stages and a pull-up resistor connected to the positive supply voltage.

The recommended pull-up resistor value is dependent on the system setup (capacity of the circuit/cable, bus clock frequency). In most cases, 10 kΩ resistors are a reasonable choice. Connect the sensors GND and the VDD line to the supply voltage specified in your sensors datasheet.

The capacitive loads on SDA and SCL line have to be the same. It is important to avoid asymmetric capacitive loads.

I²C External Circuit Elements



Both bus lines, SDA and SCL, are bi-directional and therefore require an external pull-up resistor.

2. I²C Address

The I²C address consists of a 7-digit binary value. By default, the I²C address of the SF04 is set to 64 (binary: 1000 000). The address is always followed by a write bit (0) or read bit (1). The default hexadecimal I²C header for read access to the sensor is therefore h81, for write access it is h80.

Contact Sensirion if the I²C address has to be changed.

3. Communication Protocol

Communication between a master and the SF04 sensor system runs via the digital I²C-interface. The physical interface consists of two bus lines, a data line (SDA) and a clock line (SCL). For the detailed specifications of the I²C protocol refer to the document "I2C-bus specification and user manual, Rev. 03 - 19 June 2007" from NXP. (http://www.standardics.nxp.com/support/documents/i2c/pdf/i2c.bus.specification.pdf)

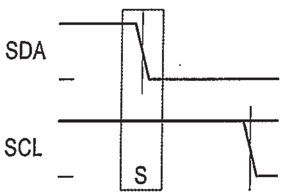
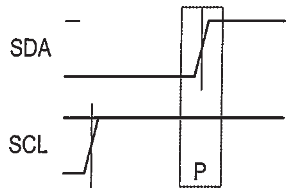
The standard bus clock frequency is 100kHz, max bus clock frequency is 400kHz.

Transmission START Condition (S)

The START condition is a unique situation on the bus created by the master, indicating to the slaves the beginning of a transmission sequence (bus is considered busy after a START).

Transmission STOP Condition (P)

The STOP condition is a unique situation on the bus created by the master, indicating to the slaves the end of a transmission sequence (bus is considered free after a STOP).

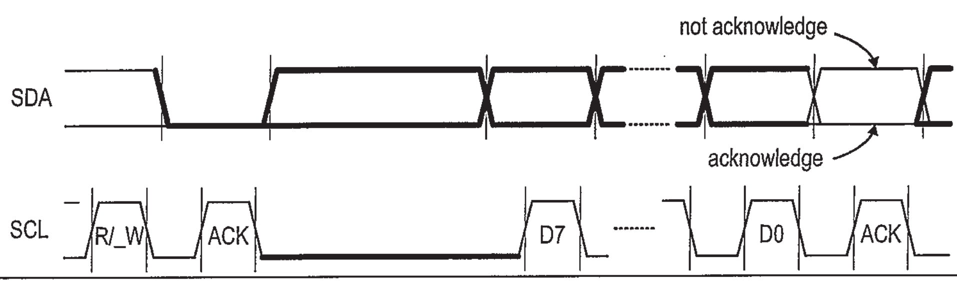
I²C Transmission Start Condition	*I²C Transmission Stop Condition*
 START condition	 STOP condition
A HIGH to LOW transition on the SDA line while SCL is HIGH	A LOW to HIGH transition on the SDA line while SCL is HIGH.

Acknowledge / Not Acknowledge

Each byte (8 bit) transmitted over the I²C bus is followed by an acknowledge pulse from the receiver, e.g. for transmission from master to slave the pulse is generated by the slave.

Transmission master to slave: in this case the slave generates an acknowledge pulse if it receives a valid command or data.

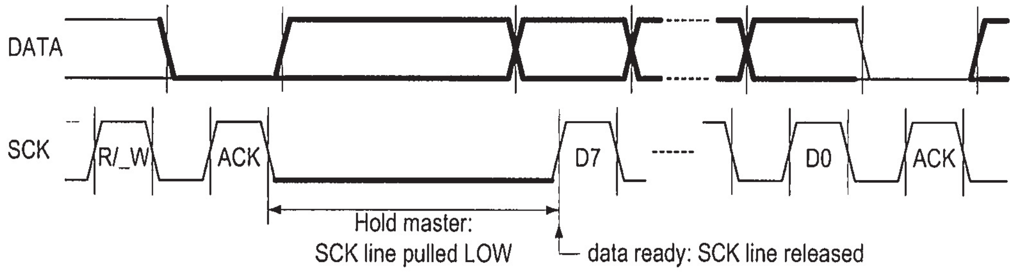
Transmission slave to master: the master generates an acknowledge pulse. If the acknowledge pulse is missing, the slave aborts the transmission of any following bytes and goes into idle mode.

I²C Acknowledge / Not Acknowledge

Each byte is followed by an *acknowledge* or a *not acknowledge* pulse, generated by the receiver

Handshake Procedure (Hold Master)

In a master-slave system it is normally the master dictating when the slaves shall receive or transmit data. However, in some situations a slave device may need time to store received data or prepare data to be transmitted. Therefore, a handshake procedure is required allowing the slave to indicate termination of internal processing.

I²C Hold Master



After the acknowledge-related SCL pulse, the SF04 sensor system (slave) can pull down the SCL line to force the master into a wait state. By releasing the SCL line the sensor system indicates that internal processing is terminated and that transmission can continue. (The bold lines indicate that the sensor system controls the SDA/SCL line.)

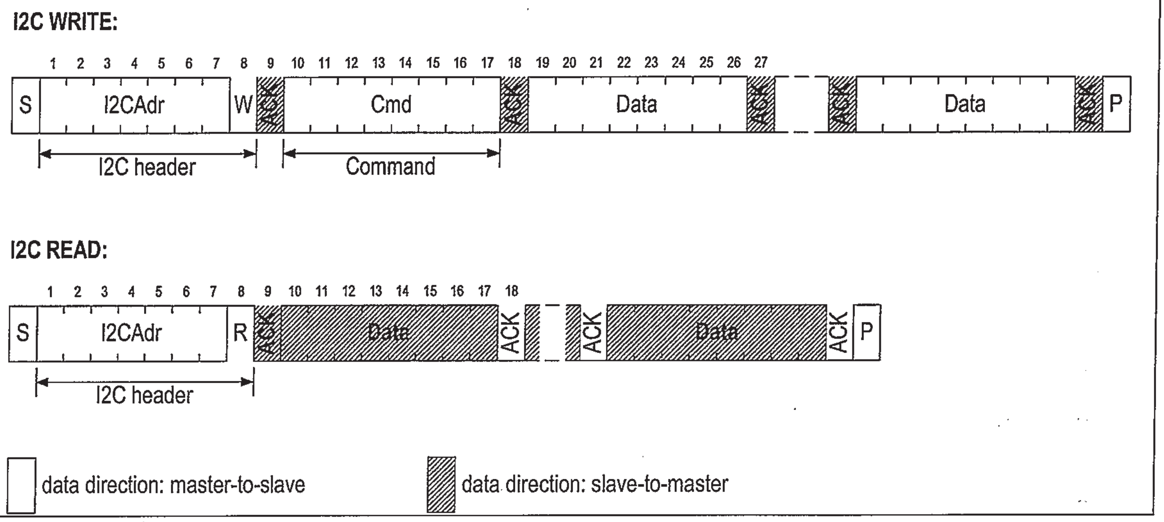
4. Data Transfer Format

For I²C protocol, data is transferred in byte packages, i.e., in frames of 8 bit length. Each byte is followed by an acknowledge bit. Data is transferred with the most significant bit (MSB) first.

The data transfer format is shown in the following figures. A data transfer sequence is initiated by the master producing the START condition (S) and sending a header byte. The I²C header is made up of the 7-bit I²C device address and a data direction bit (R/_W).

The value of the R/_W bit in the header determines the data direction for the entire rest of the data transfer sequence: if R/_W = 0 (WRITE) the direction remains master-to-slave, if R/_W = 1 (READ) the direction changes to slave-to-master after the header byte.

I²C Read And Write



5. Command Set and Data Transfer Sequences

A command is made up of a 8-bit command code. The last bit of the command code represents the data direction (R/_W). A command can therefore be regarded as having a WRITE and a READ mode (e.g., write or read a register). However, for some commands only one of the two modes exists.

In WRITE mode the data direction remains master-to-slave, while in READ mode it changes to slave-to-master after the header. However, for I^{2}C the data direction may not change after the command byte, since the R/_W bit of the preceding I^{2}C header has already determined the direction to be master-to-slave. In order to invoke commands in READ mode using I^{2}C, the following principle is applied. Upon successful (acknowledged) reception of a command byte, the sensor system stores the command nibble internally. The READ mode of this command is then invoked by initiating an I^{2}C data transfer sequence with R/_W = 1.

The following table summarizes the basic command set; patterns not listed in this table are undefined and may lead to arbitrary results.

8 Bit Command Code	*Command*
hE2	write user register
hE3	read user register
hE4	write advanced user register
hE5	read advanced user register
hE7	read read-only register 1
hE9	read read-only register 2
hF1	**trigger flow / differential pressure measurement**
hF3	trigger temperature measurement (raw data is default for most products)
hF5	trigger VDD measurement (raw data is default for most products)
hFE	**soft reset**

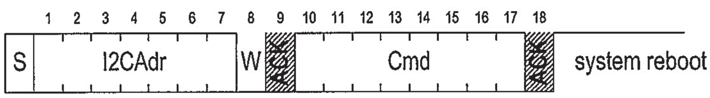
The sensor system now only considers a command if the preceding I^{2}C device address matches the value stored internally. If a correctly addressed sensor system recognizes a valid command and access to this command is granted, it responds by pulling down the SDA line during the subsequent acknowledge-related SCL pulse (**ACK**). In any other case it leaves the SDA line released (**NACK**).

In the following subsections the individual commands are considered in more detail and the data transfer sequences are specified. Hatched areas with **bold** face font indicate that the sensor system controls the SDA line.

Soft Reset

Force a reboot of the sensor system without switching the power off and on again. Upon reception of this command the sensor system reinitializes the control/status register contents from the EEPROM and starts operation according to the settings.

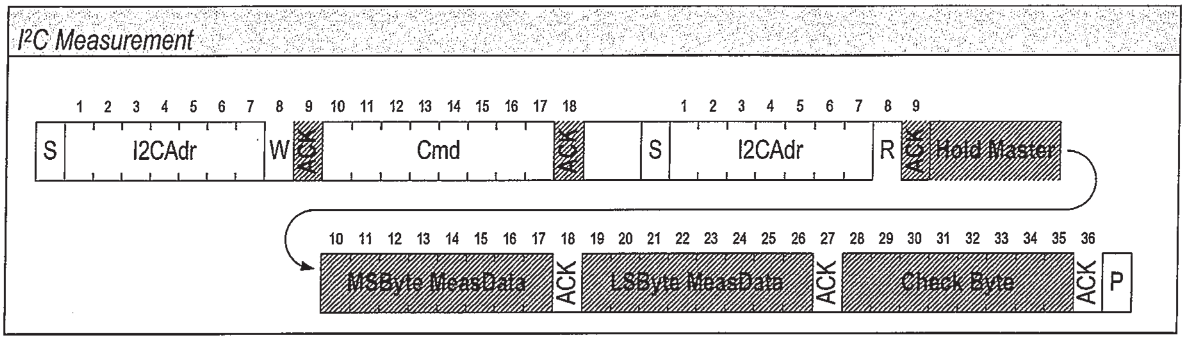
I^{2}C Soft Reset



Trigger Measurement

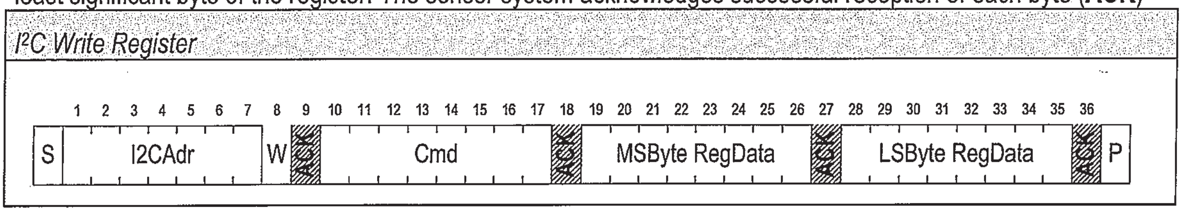
Upon reception of the header with R/_W=1, the sensor system produces the hold-master condition on the bus until the first measurement is completed (see chapter 0 for timing). Once the hold-master condition is suspended, the master can read the result as two consecutive bytes. A CRC byte follows if the master continues clocking the SCL line after the second result byte. The sensor system checks whether the master sends an acknowledge after each byte and aborts the transmission if not. Note that two transfer sequences are needed. The first sequence stores the command, while the second sequence invokes the previously stored command in READ mode.

To convert the measurement to a physical value, the scale factor and measurement unit can be read out from the sensor. Please refer to the datasheet or the according application note.



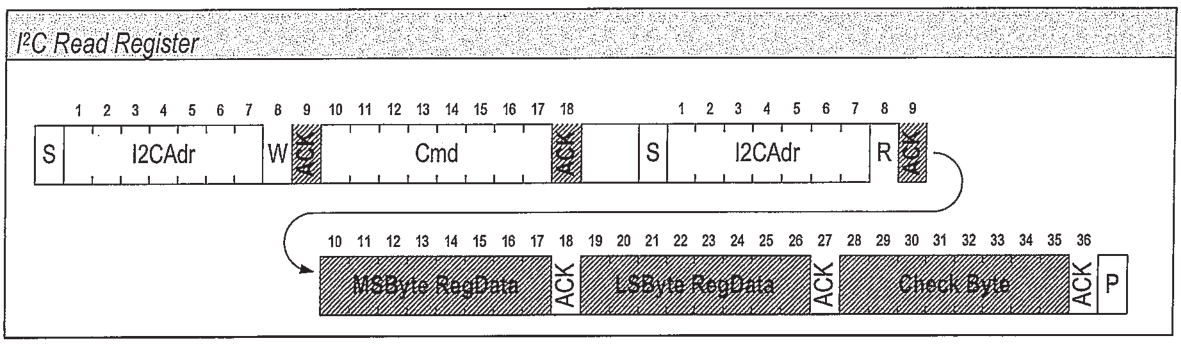
Write Register

Overwrite the register addressed by the command. After the command byte the sensor system reads the new register value from the bus. The first byte is stored as the most significant byte, the second byte is stored as the least significant byte of the register. The sensor system acknowledges successful reception of each byte (**ACK**)



Read Register

Read the content of the register addressed by the command. After the header with R/_W=1, the sensor system writes the register value to the bus. The first byte written is the most significant byte, the second byte the least significant byte of the register. A CRC byte follows if the master continues clocking the SCL line after the second byte. The sensor system checks whether the master sends an acknowledge after each byte and aborts the transmission if not. Note that two transfer sequences are needed. The first sequence stores the command, while the second sequence invokes the previously stored command in READ mode.



6. Control/Status Registers

All functions and options of the SF04 sensor system are controlled by the contents of the control/status registers. The registers are initialized at boot time and can be read and written via the serial bus interface.

The available registers are

Name	*Width [bit]*	*Description*
User Register	16	Basic user settings
Advanced User Register	16	Advanced user settings
Read-Only Register 1	16	Read-only system configurations and status indications
Read-Only Register 2	16	Read-only system configurations

The following tables contain a detailed description of the register contents.

User Register

Bit	*#Bits*	*Description/Coding*
15:12	4	not used
11:10	2	advanced settings (do not change) → *Before changing register entries, please read out the preset entry and do not change the advanced settings.*
10	1	scale/shift correction for temp. and supply voltage measurement **0: off (default for most products)** 1: on
9	1	flow measurement linearization 0: off **1: on (default)**
8:7	2	selector factory setting (FS: configuration of analog signal path) **00: use FS0 of active calibration field (default)** 01: use FS1 of active calibration field 10: use FS2 of active calibration field 11: use FS3 of active calibration field → *Utilization and content of factory settings are dependent on the specific device. Contact Sensirion for further information.*
6:4	3	selector active calibration field (i.e., active LUT (look-up-table)) **000: calibration field 0 (default)** 001: calibration field 1 010: calibration field 2 011: calibration field 3 100-111: calibration field 4 → *Utilization and content of calibration fields are dependent on the specific device. Contact Sensirion for further information.*
3:0	4	advanced settings (do not change) → *Before changing register entries, please read out the preset entry and do not change the advanced settings.*

Advanced User Register

Bit	*#Bits*	*Description/Coding*
15:12	1	advanced settings (do not change) → *Before changing register entries, please read out the preset entry and do not change the advanced settings.*
11:9	3	resolution of measurement 000: 9 bit (flow); 6 bit (temperature/supply voltage) 001: 10 bit (flow); 7 bit (temperature/supply voltage) 010: 11 bit (flow); 8 bit (temperature/supply voltage) 011: 12 bit (flow); 9 bit (temperature/supply voltage) 100: 13 bit (flow); 10 bit (temperature/supply voltage) 101: 14 bit (flow); 11 bit (temperature/supply voltage) 110: 15 bit (flow); 12 bit (temperature/supply voltage) 111: 16 bit (flow); 13 bit (temperature/supply voltage) → *Default settings dependent on product.*
8:0	9	advanced settings (do not change) → *Before changing register entries, please read out the preset entry and do not change the advanced settings.*

Read-Only Register 1

Bit	*#Bits*	*Description/Coding*
15:14	2	not used
13	1	status: data format used during most recent measurement 0: unsigned 1: signed (2's complement)
12	1	status: BIST membrane test failed (updated during measuring only) 0: membrane test ok 1: membrane test failed
11	1	not used
10	1	status: successful register initialization from EEPROM 0: failed 1: successful
9:3	7	I²C device address of sensor chip preset value: 1000000
2:0	3	advanced information

Read-Only Register 2

Bit	*#Bits*	*Description/Coding*
15:3	13	advanced info
2:0	3	active configuration field (at sensor initialization) 000: configuration field 0 001: configuration field 1 010: configuration field 2 011: configuration field 3 100-111: configuration field 4

7. CRC-8 Redundant Data Transmission

Cyclic redundancy check (CRC) is a very popular technique used for error detection in data transmissions. In this technique, the transmitter appends an n-bit check sequence to the actual data sequence. The check sequence holds redundant information about the data sequence and allows the receiver to detect transmission errors. Computation of the check sequence can be seen as the remainder of a polynomial division, where the dividend is the binary polynomial defined by the data sequence, and the divisor is a so-called generator polynomial. Transmitter and receiver must agree on which generator polynomial is used, or, in other words, on a specific CRC type. There are various standard CRC types.

The SF04 sensor system implements the CRC-8 standard based on the generator polynomial

$x^8 + x^5 + x^4 + 1$.

Note that CRC protection is only applied for the transmission direction slave-to-master (i.e. the sensor system can append a CRC check byte to data sent to the master), but not for the direction master-to-slave. For further information, see the according application note.

8. Processing Time for digital output

The following table summarizes the required processing time for various resolutions at 1.00 MHz clock frequency. The times given include data conversion only.

Resolution Flow [bit]	*Resolution Temp/VDD [bit]*	*Processing Time [ms]*		
		Min.	*Typ.*	*Max.*
9	6	0.5	0.8	0.9
10	7	1.0	1.3	1.5
11	8	2.0	2.4	2.6
12	9	4.1	4.6	4.9
13	10	8.2	8.9	9.4
14	11	16.4	17.5	18.5
15	12	32.8	34.8	36.7
16	13	65.5	69.3	73.2

9. Revision history

Date	Version	Changes
August 2009	v1.0	Preliminary release. This document substitutes the former "USER MANUAL, I2C-MODE, SF04 FLOW SENSOR"

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Application Note

First Steps with SF04 Flow Sensors: Read the Measurement Signal via I²C

Version 1.3 – June 2008

1 Introduction

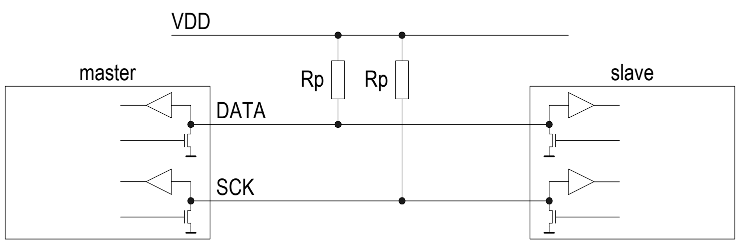
Diverse Sensirion OEM sensor products are based on the advanced digital microsensor chip SF04. Getting started with Sensirion I²C sensors based on this platform is rather simple. Basic knowledge in electrical engineering and a programmable I²C master (e.g. a micro controller or another suitable host) are required. Alternatively ask Sensirion for the NI8451-interface box. This application note provides information how to read the first flow or differential pressure measurement values via the I²C bus.

More detailed information can be found in the *"User Manual – I2C-Mode – SF04 Flow Sensor"*.

2 Connecting Instructions – I2C interface

Connect the I²C clock and data lines from your sensor (I²C slave) to the host system (I²C master). Connect the clock and data-lines with pull up resistors to the correct bus voltage level (e.g. 3.3V or 5V) specified in your sensors datasheet. The recommended pull-up resistor value is dependent on the system setup (capacity of the circuit/cable, bus clock frequency). In most cases, 10 kΩ resistors are a reasonable choice. Connect the sensors GND and the VDD line to the supply voltage specified in your sensors datasheet.

I²C External Circuit Elements



Both bus lines, DATA and SCK, are bi-directional and therefore require an external pull-up resistor.

The Sensirion I²C sensors come readily configured for normal flow or differential pressure sensing operation.

- There is no need for configuration of sensor registers.
- The default I²C address is h40.
- The I²C clock rate is 100kHz (max).

3 Read Out Measurement Signal

Every single measurement is triggered by a separate read operation.

To perform a measurement first ***write the command byte hF1 (trigger measurement***) to the sensor. In a second step ***perform a read operation*** to trigger the measurement and retrieve the flow or differential pressure information.

Upon reception of the I²C header with R/_W=1 (read data command), the sensor produces a hold-master condition on the bus (clock line is kept low) until the measurement is completed (duration depending on the configuration 1 up to 80 ms).

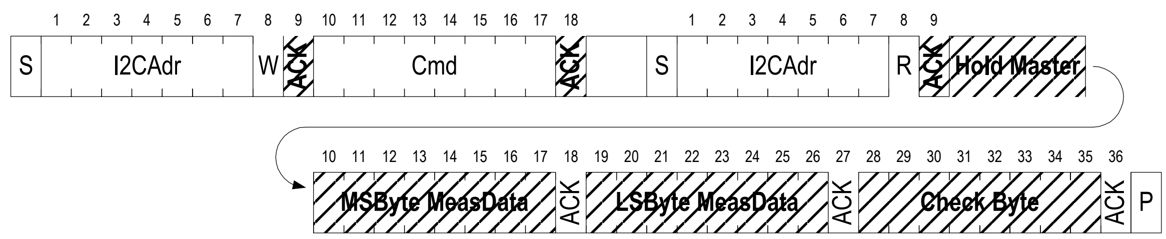
Make sure the I²C master is ready to wait during this period.

Once the hold-master condition is suspended, the master can read the result as two consecutive bytes which represent the current flow rate or differential pressure.

A CRC byte follows if the master continues clocking the SCK line after the second result byte. The sensor system checks whether the master sends an acknowledge after each byte and aborts the transmission if not.

Note that two transfer sequences are needed. The first sequence stores the command, while the second sequence invokes the previously stored command in READ mode.

I²C Measurement (pulsed measurement)



4 Scaling of Measurement Signal and Unit

For some standard products as SDP600/610, the default scaling factor and flow unit can be found in the datasheet. Nevertheless we strongly recommend to readout scaling factor and flow unit from the sensor itself.

A series of operations is needed for correct scaling and determination of the measurement signal.

The original calibrated signal read from the sensor is an integer number which is signed for bi-directional sensors and unsigned for uni-directional sensors. The integer value can be converted to the original unit the sensor has been calibrated for. For this the number has to be divided by the sensors 'scale factor' which is stored in the EEPROM.

The EEPROM address is composed of an EEPROM base address and an address offset. To determine the base EEPROM address for sensor information, bit <6:4> of User Register (called active configuration field) must be multiplied by h300. Than the Wordadr Offset of following table must be added to that address.

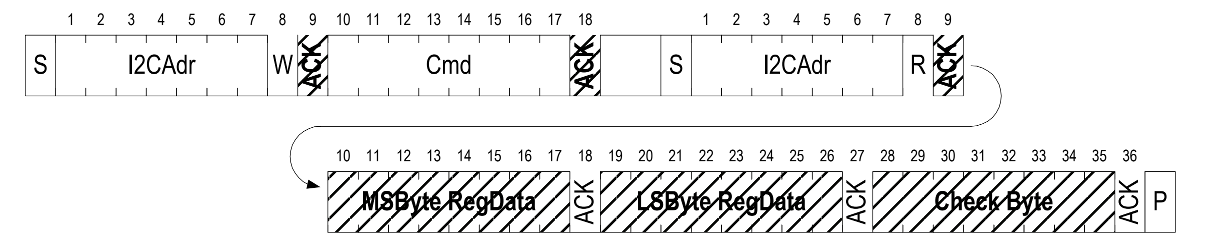
Wordadr Offset	*#Words*	*Description/Format*
h2B6	1	scale factor
h2B7	1	measurement unit (Coding defined in "User Manual I²C-Mode SF04")

4.1 Determine EEPROM Address for Scale Factor and Measurement Unit

To read out the User Register first *write the command byte hE3 (read user register)* to the sensor. In a second step *perform a read operation* to read the User Registers content. After the header with R/_W=1 the master can read the content of the User Register as two consecutive bytes.

A CRC byte follows if the master continues clocking the SCK line after the second result byte. The sensor system checks whether the master sends an acknowledge after each byte and aborts the transmission if not.

I²C Read Register



Using bit <6:4> of User Register content calculate the EEPROM address as described above.

This is a 12 bit value which needs to be extended by 4 LSB bits of any value.

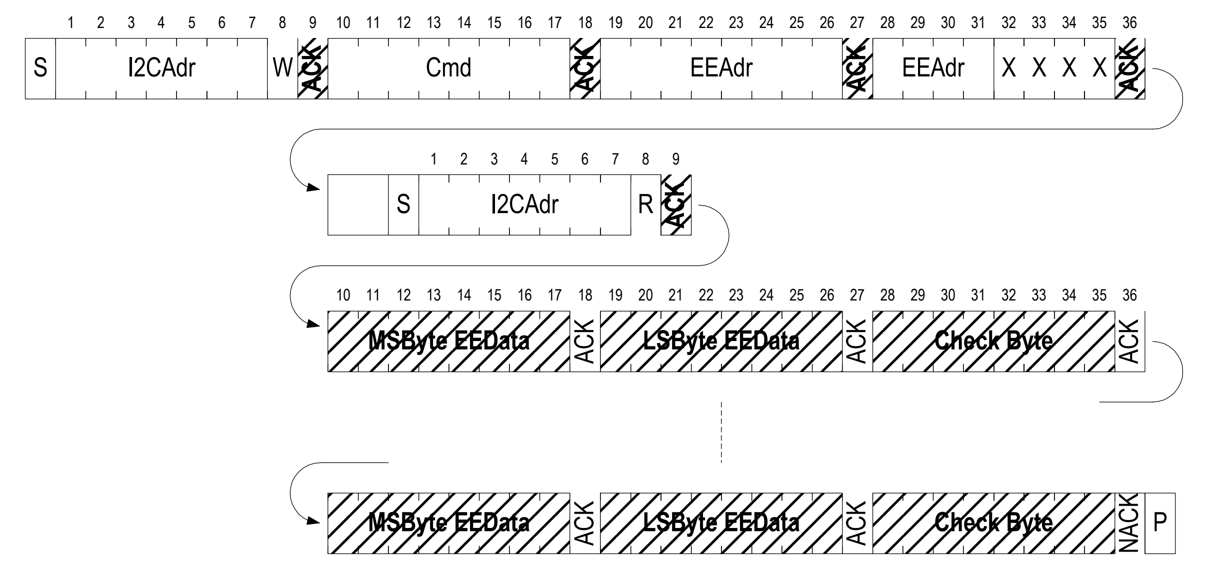
4.2 Read Out Scale Factor and Measurement Unit from EEPROM

To prepare for the read out the EEPROM content (scale factor and measurement unit) now w*rite the command byte hFA (set EEPROM address register and read/write)* to the sensor and *perform a two byte write operation* with the two EEPROM address bytes.

In a second step *perform a read operation* to read the scale factor and measurement unit. After the header with R/_W=1 the master can read the scale factor as two consecutive bytes. The sensor writes the EEPROM word at the actual address to the bus, followed by a CRC byte. The sensors internal address register is automatically increased after the completed word write out. Therefore, if the master continues clocking the SCK line after the CRC byte, the next EEPROM word (which is the measurement unit in this case) with corresponding CRC byte is written to the bus.

Now divide the integer value by the determined scale factor to calculate the absolute flow or differential pressure value. The number which has been read out of the EEPROM for the flow unit has to be de-coded according to the system given in chapter 4.3.

I²C Read EEPROM



4.3 Measurement Unit Coding

*Bit <3:0> (x*1)*	*Dimension*	*Prefix*
0 – 3	t.b.d.	
3	1e-9	n
4	1e-6	µ
5	0.001	m
6	0.01	c
7	0.1	d
8	1	1
9	10	-
10	100	h
11	1000	k
12	1e6	M
13	1e9	G
15 – 15	t.b.d.	

*Bit <7:4> (x*16)*	*Time Base*	*Comment*
0	no time base	e.g. pressure / totalized flow
1	per microsecond	
2	per millisecond	
3	per second	
4	per minute	
5	per hour	
6	per day	
7 – 15	t.b.d.	

*Bit <12:8> (x*256)*	*Volume / Pressure*	*Comment*
0	norm liter (0°C, 1013 hPa)	typically for gas flow
1	standard Liter (20°C, 1013 hPa)	typ. gas flow
2 – 7	t.b.d.	
8	liter (liquid)	typ. liquid flow
9	gram	typ. liquid flow
10 – 15	t.b.d.	
16	pascal	pressure
17	bar	pressure
18	meter H2O	pressure
19	inch H2O	pressure
20 – 23	t.b.d.	

*Bit <15:13> (x*8192) are not defined*

Examples:

Unit	*Code*
nl/s	8*256 + 3*16 + 3 = 2099
m3/s	8*256 + 3*16 + 11 = 2107
mln/min	0*256 + 4*16 + 5 = 69
sccm	1*256 + 4*16 + 6 = 326
hPa	16*256 + 0*16 + 10 = 4106

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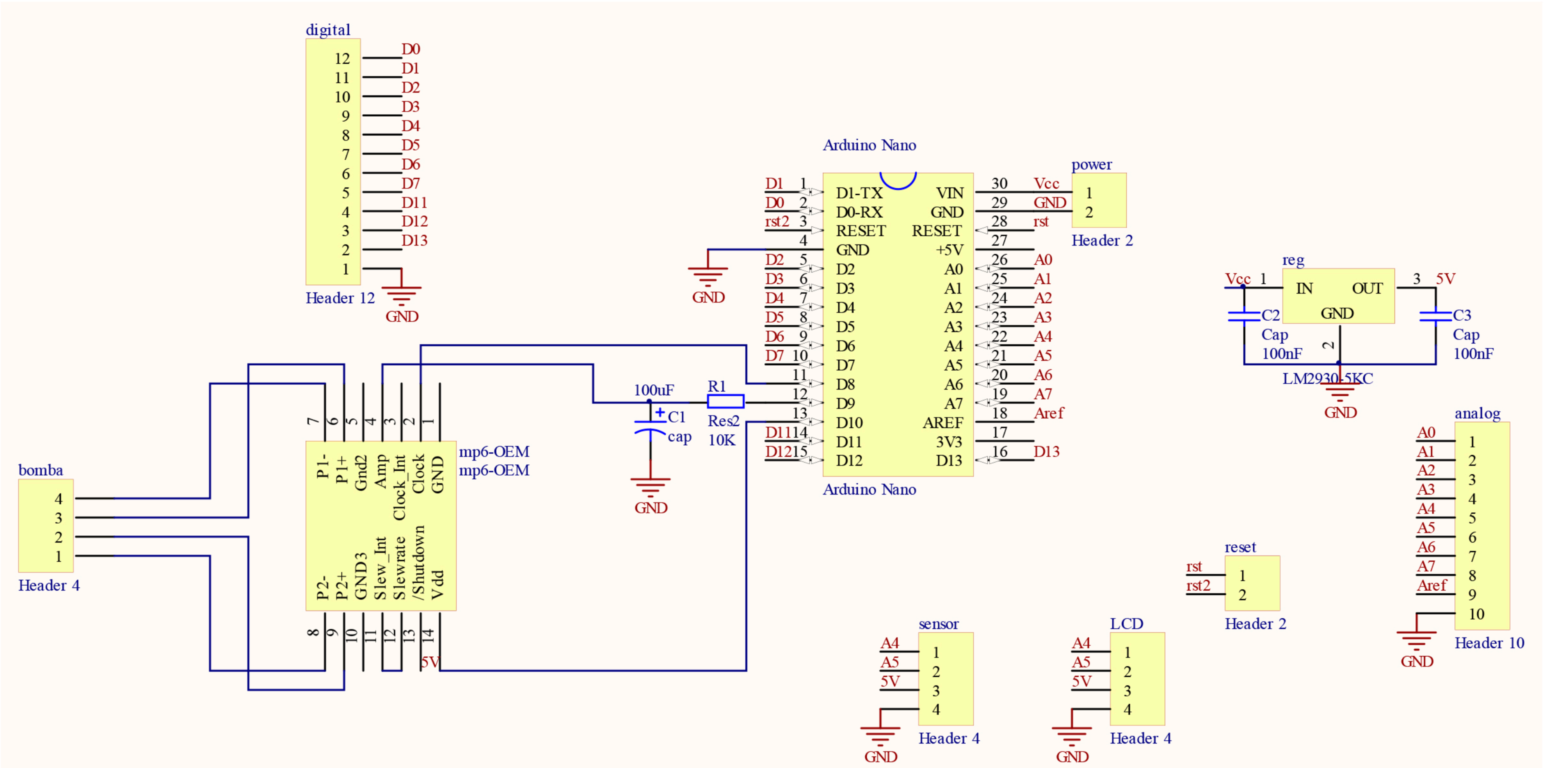
ANEXO D
HARDWARE

En este anexo se sitúa el esquemático del circuito electrónico diseñado para el control de flujo en lazo cerrado. También se aporta la imagen del diseño de la PCB en la que se encuentra todo el *hardware* utilizado, cuyos componentes se encuentran en la lista de materiales.

El programa utilizado para diseñar la placa de circuito impreso ha sido Altium Designer.

1. PLANO ESQUEMÁTICO

En la página siguiente se representa el plano correspondiente al esquema electrónico del circuito de control del *setup.*



Grupo GEMM				
Dibujado	Fecha: 5/08/2012	Torrejón García, Alberto	Firma:	Plano nº: 1
Comprobado	Fecha: 8/08/2012	Monge Prieto, Rosa	Firma:	
Escala: 1/1	CONTROL BOMBA DE MEMBRANA Esquema general del circuito			GEMM Group of Structural Mechanics and Material Modelling

2. LISTA DE COMPONENTES (BOM)

Comment	Description	Designator	Footprint	LibRef	Quantity
Header 10	Header, 10-Pin	analog	HDR1X10	Header 10	1
Arduino Nano		Arduino Nano	DIP30 nano	Arduino Nano	1
Header 4	Header, 4-Pin	bomba, LCD, sensor	HDR1X4	Header 4	3
cap	Solid Aluminum Capacitor with Organic Semiconductor Electrolyte: 1uF, 16V, Bulk Pack	C1	A	94SC105X0016ABP	1
Cap	Capacitor	C2, C3	VP32-3.2	Cap	2
Header 12	Header, 12-Pin	digital	HDR1X12	Header 12	1
mp6-OEM		mp6-OEM	DIP14 mp6	mp6-OEM	1
Header 2	Header, 2-Pin	power, reset	HDR1X2	Header 2	2
Res2	Resistor	R1	AXIAL-0.4	Res2	1
LM2930-5KC	3-Terminal Positive R	reg	KC03	LM2930-5KC	1

FIGURA 45: LISTADO DE COMPONENTES PARA LA PCB

3. PCB

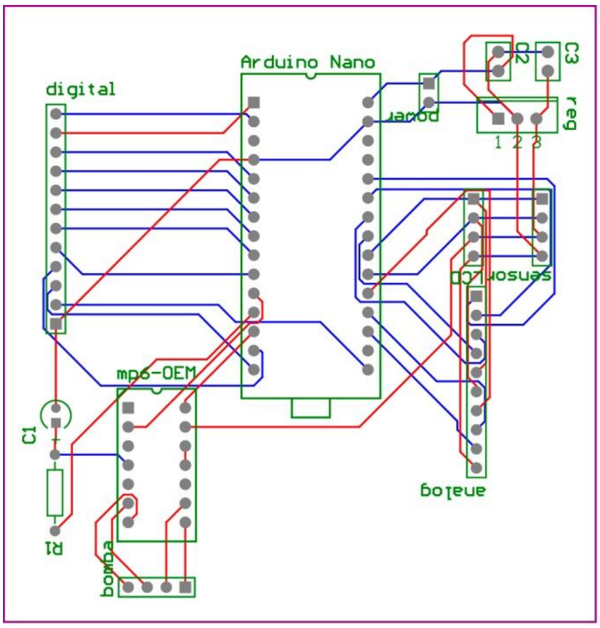


FIGURA 46: PCB DE CONTROL DEL *SETUP*

ANEXO E
SOFTWARE

1. INTRODUCCIÓN

En este anexo se puede ver el código del programa almacenado en la memoria del microcontrolador y los diagramas de flujo en los que éste está basado.

2. ESTRUCTURA PRINCIPAL

Como en cualquier programa, primero se declaran las variables, luego hay una rutina de *reset* y a continuación se sitúa el bucle principal que se estará repitiendo permanentemente.

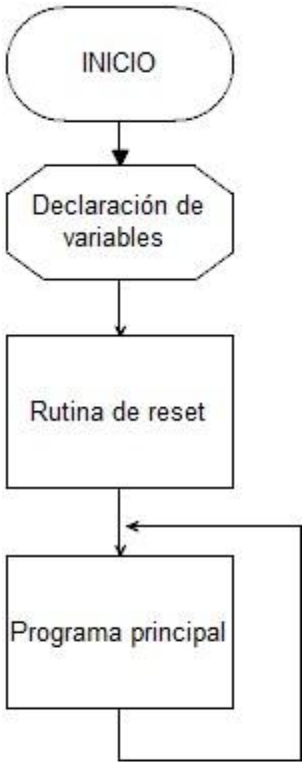


FIGURA 47: DIAGRAMA DE FLUJO DE LA ESTRUCTURA PRINCIPAL DE UN PROGRAMA

```
/* Insertar variables: */

/* Rutina de reset: */
void setup() {
  // ...
}

/* Bucle principal: */
void loop() {
  // ...
}
```

3. RUTINA DE RESET

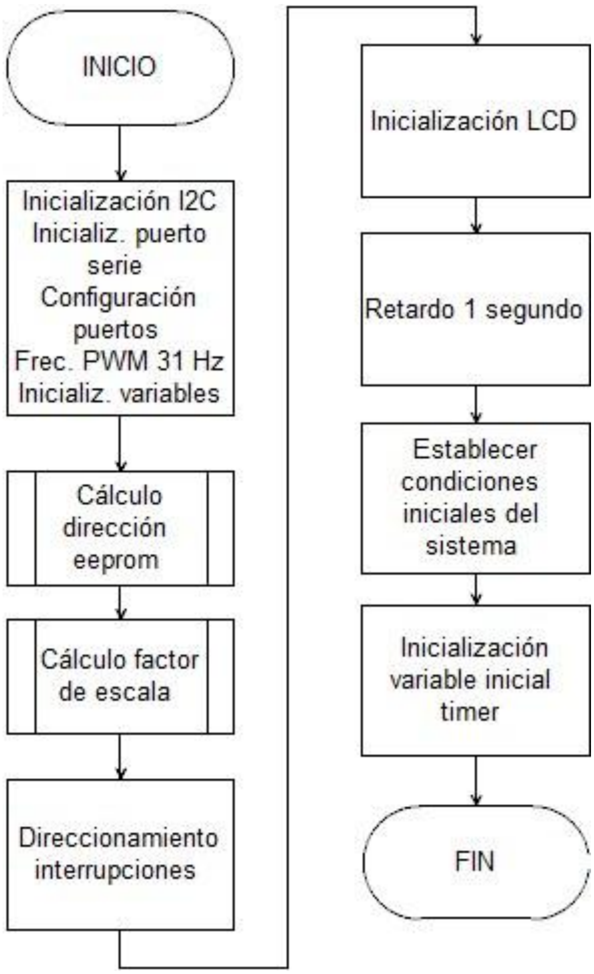


FIGURA 48: DIAGRAMA DE FLUJO DE LA RUTINA DE RESET

```
void setup() {

  Wire.begin(); //Inicialización librería comunicación I2C
  Serial.begin(9600);  //Inicialización comunicación por el puerto serie a 9600 baudios
  DDRB = 0xFF;
  DDRD = 0; //Inicialización puertos
  setPwmFrequency(10,1024); //fijar frecuencia PWM a 3 Hz
  val = 0;
  frecuencia = 100;
  pwm = 18;
  consigna = 0;
  duty = 0; //inicializo variables básicas
  tiempoexcel = 3000; //selecciono tiempo de toma de datos en excel
  kp = 350;
  ki = 2;
  kd = 0.5;
  Serial.println("CLEARDATA"); // borrar datos de excel
  eepromadress1(); //cálculo de la dirección Eeprom
  factordeescala(); //cálculo del factor de escala
  lcd.init(); //inicializacion LCD
  lcd.backlight(); //encendido LCD
  lcd.setCursor(0,0);
  lcd.print("BIENVENIDO      "); //mensaje de bienvenida
  attachInterrupt(0,suboflujo,RISING);
  attachInterrupt(1,bajoflujo,RISING); //interrupciones con flanco de subida
  delay(1000);
  tone(8,frecuencia);
  analogWrite(9,pwm);
  analogWrite(10,duty);
  start1=millis(); //inicio variable con el dato del timer del micro
}
```

4. PROGRAMA PRINCIPAL

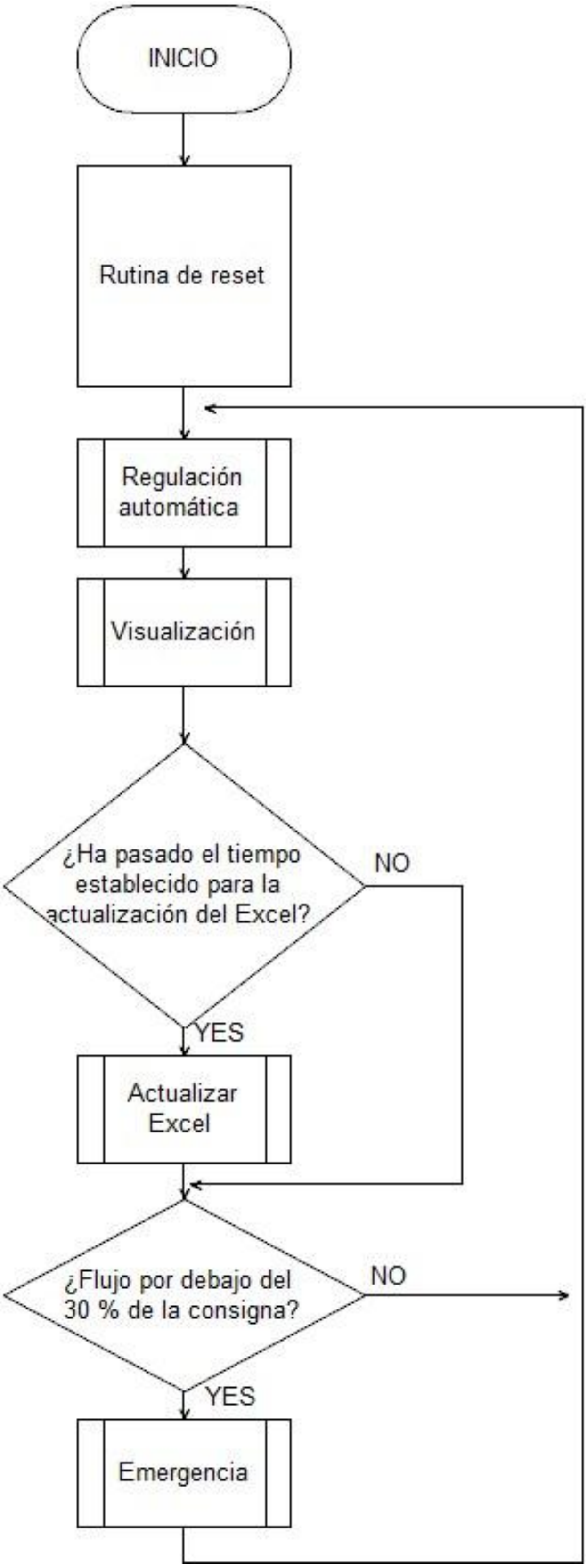


FIGURA 49: DIAGRAMA DE FLUJO DEL PROGRAMA PRINCIPAL

```
void loop() {
  regula(); //salto a subrutina de regulación automática
  visualizarmedida(); //salto a subrutina de visualización
  now = millis(); //tomo dato del timer
  if (now - start1 > tiempoexcel) {
    excel(flujomedido); // si ha pasado el tiempo determinado se actualiza el excel
    start1 = millis(); //reinicio contador de tiempo
  }
  if (flujomedido < consigna*0.3) {
    atope(); //Salto a subrutina de urgencia
  }
}
```

5. Subrutina regulación automática

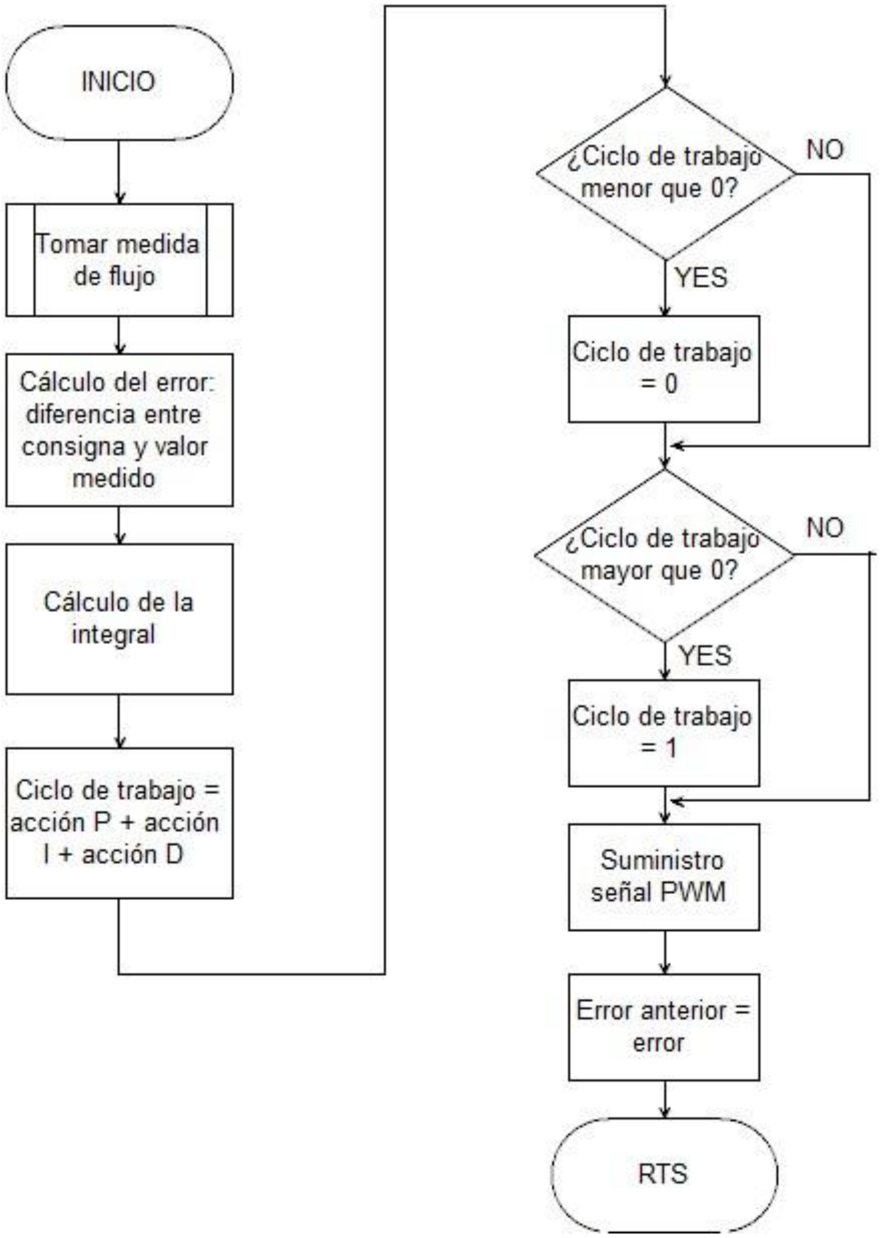


FIGURA 50: DIAGRAMA DE FLUJO DE LA SUBRUTINA DE REGULACIÓN

```
void regula() {
  flujomedido = tomarmedida(); //actualizo valor del flujo real
  error = consigna - flujomedido; //cálculo del error
  integral = integral + 0.116 * error; //cálculo de la integral
  duty = kp*error + ki*integral + kd*(error - erroranterior)/0.116; //cálculo de la acción
  if (duty < 0) {
    duty = 0;
  }
  if (duty > 255) {
    duty = 255;
    //límites superior e inferior para el Ciclo de Trabajo (0 y 100%)
  }
  analogWrite(10,duty); //saco señal PWM a la alimentación del mp6-OEM
  erroranterior = error;
}
```

6. SUBRUTINA VISUALIZACIÓN EN LCD

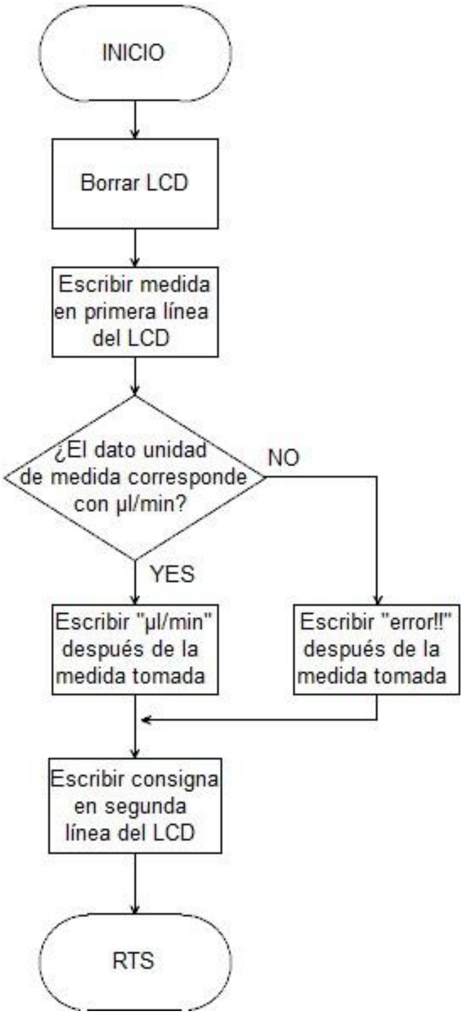


FIGURA 51: DIAGRAMA DE BLOQUES DE LA SUBRUTINA DE VISUALIZACIÓN

```
void visualizarmedida() {
  lcd.clear();
  lcd.setCursor(0,0);
  lcd.print(flujomedido); //visualización del valor real de flujo
  if (measurementunit = 0b0000100001000100) {
    lcd.print("  µl/min"); //si la unidad de medida es µl/min se visualiza
  } else {
    lcd.print("  error!!");//si la unidad de medida no es la esperada se indica error
  }
  lcd.setCursor(0,1);
  lcd.print(consigna);//visualización consigna
}
```

7. SUBRUTINA PARA EXPORTAR DATOS EN EXCEL

FIGURA 52: DIAGRAMA DE FLUJO DE LA SUBRUTINA DE ENVÍO DE DATOS EXCEL

```
void excel(float val1){
  Serial.print("DATA,TIME,"); // envío comando a excel
  Serial.println(val1); // envío dato a excel
}
```

8. SUBRUTINA DE EMERGENCIA

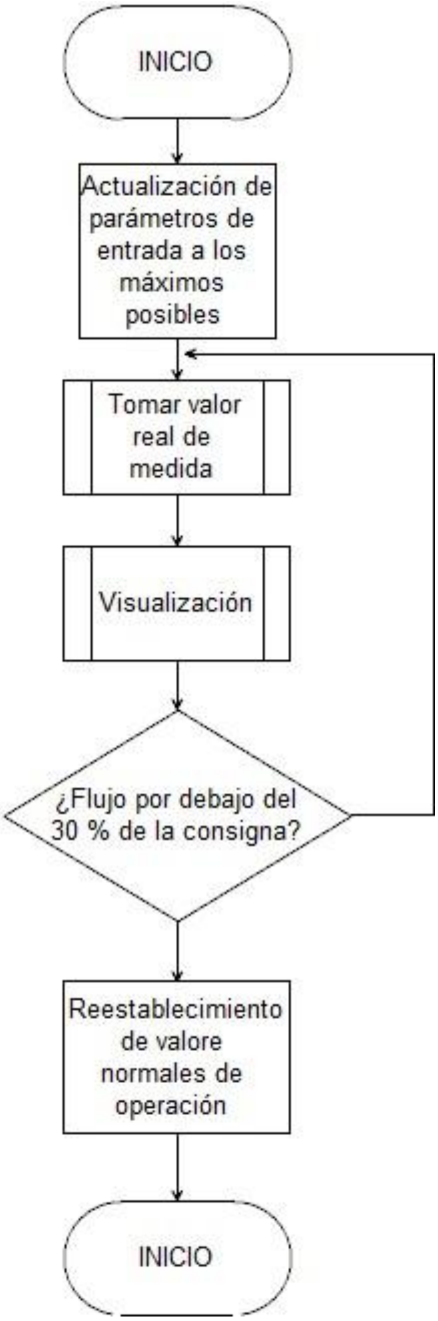


FIGURA 53: DIAGRAMA DE FLUJO DE LA SUBRUTINA DE EMERGENCIA

```
void atope() {
  while (flujomedido < consigna*0.3) { /*Bucle para que el programa quede "atrapado"
hasta volver a condiciones normales de operación*/
    frecuencia = 480; //frecuencia máxima
    pwm = 66; //amplitud máxima
    duty = 255; //ciclo de trabajo del 100%
    tone(8,frecuencia);
    analogWrite(9,pwm);
    analogWrite(10,duty);
    flujomedido = tomarmedida();
    visualizarmedida(); //Se toma la medida del flujo y se visualiza en LCD
  }
  frecuencia = 100; //frecuencia normal de operación reestablecida
  pwm = 18; //amplitud normal de operación reestablecida
  duty = 0; //ciclo de trabajo minimo de operación reestablecida
  tone(8,frecuencia);
  analogWrite(9,pwm);
  analogWrite(10,duty);
}
```

9. SUBRUTINA PARA TOMAR UNA MEDIDA

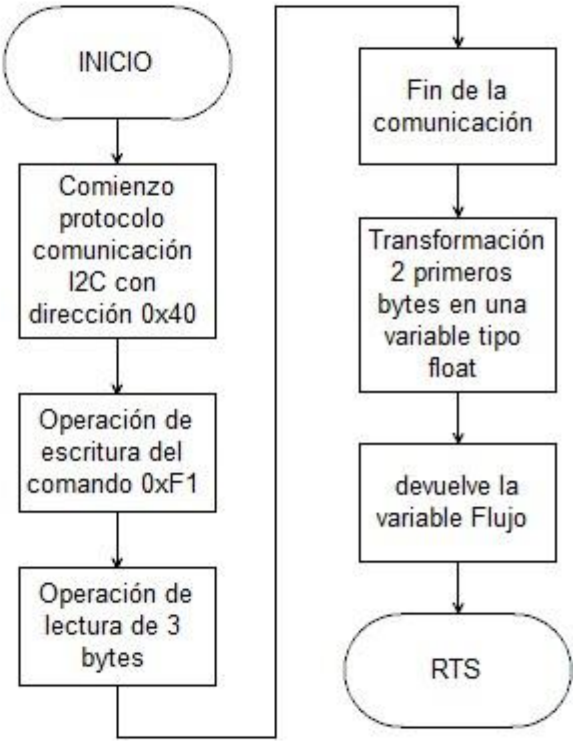


FIGURA 54: DIAGRAMA DE FLUJO DE LA SUBRUTINA QUE TOMA UNA MEDIDA

```
float tomarmedida() {

  float flujo;
  Wire.beginTransmission(0x40); //Comienzo de protocolo de comunicación I2C
    Wire.write(0xF1); //Escritura de comando
    Wire.requestFrom(0x40, 3);    // Lectura de 3 Bytes
    hmedida = Wire.read();
    lmedida = Wire.read(); //Bytes de la medida
    crcmedida = Wire.read();
    Wire.endTransmission(); //Fin de la transmisión
    medida = int(word(hmedida,lmedida));
    flujo = float(medida)/scalefactor + 0.03 ; //Cálculo del valor real de flujo
    return flujo; //la medida de flujo es devuelta a la variable flujomedido
}
```

10. SUBRUTINAS PARA EL CÁLCULO DEL FACTOR DE ESCALA Y LA UNIDAD DE MEDIDA

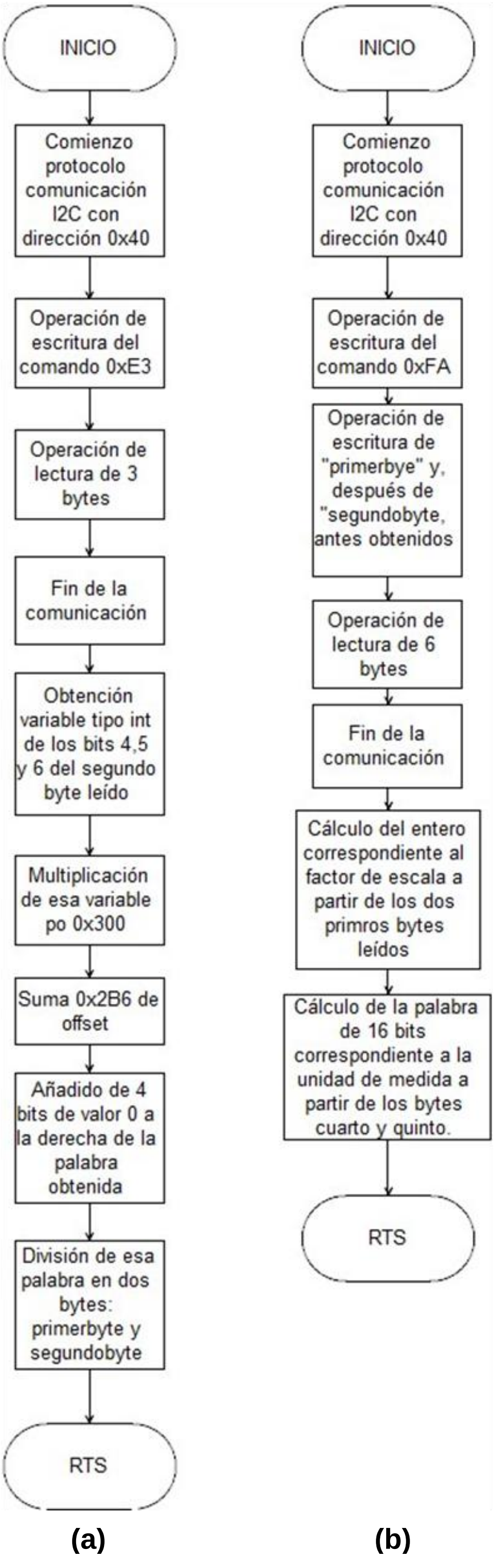


FIGURA 55: DIAGRAMAS DE FLUJO DE LAS SUBRUTINAS, (a) CÁLCULO DE DIRECCIÓN EEPROM Y (b) CÁLCULO FACTOR DE ESCALA Y UNIDAD DE MEDIDA

//CALCULAMOS DIRECCIÓN EEPROM

```
void eepromadress1() {
  Wire.beginTransmission(0x40); /*Comienzo del protocolo de comunicación I2C con sensor de flujo*/
  Wire.write(0xE3); //escritura comando
  Wire.requestFrom(0x40, 3); //lectura de 3 Bytes
  hur = Wire.read(); //Byte alto del User Register
  lur = Wire.read(); //Byte bajo del User Register
  crcur = Wire.read();
  Wire.endTransmission(); //Fin de la comunicación
  userregister = (lur >> 4) & 0b00000111; //máscara de los bits 4,5y6 del User Register
  userregisterint = int(userregister); //Se ha calculado el entero correspondiente al User Register
  eepromadress = (userregisterint * 0x300) + 0x2B6;
  eepromadressword = word(eepromadress);
  palabraescribir = (eepromadressword << 4) & 0b1111111111110000; /*Cálculo de la dirección Eeprom*/
  primerbyteescribir = byte ((palabraescribir >> 8) & 0b0000000011111111);
  segundobyteescribir = byte (palabraescribir & 0b0000000011111111); /*Dirección Eeprom separada en 2 Bytes*/
}
//CÁLCULO DEL FACTOR DE ESCALA
void factordeescala() {
  Wire.beginTransmission(0x40); /*Comienzo del protocolo de comunicación I2C con sensor de flujo*/
  Wire.write(0xFA); //escritura comando
  Wire.write(primerbyteescribir);
  Wire.write(segundobyteescribir); //escritura de la Dirección Eeprom
  Wire.requestFrom(0x40, 6); //lectura de 6 Bytes
  hscalefactor = Wire.read();
  lscalefactor = Wire.read(); //Bytes del factor de escala
  crcscalefactor = Wire.read();
  hmeasurementunit = Wire.read();
  lmeasurementunit = Wire.read(); // Bytes de la unidad de medida
  crcmeasurementunit = Wire.read();
  Wire.endTransmission(); //Fin de la comunicación
  sfword = word(hscalefactor,lscalefactor);
  scalefactor= int(sfword); //Cálculo del factor de escala
  measurementunit = word(hmeasurementunit,lmeasurementunit); //Cálculo de la unidad de medida
}
```

11. PROGRAMA COMPLETO

```
//LIBRERÍAS
#include <Wire.h> //librería para comunicación I2C
#include <LiquidCrystal_I2C.h> //librería para LCD vía I2C

//DECLARACIÓN DE VARIABLES
int medida;
byte hmedida, lmedida, crcmedida, hur, lur, crcur, userregister, primerbyteescribir, segundobyteescribir;
byte hscalefactor, lscalefactor, crcscalefactor, hmeasurementunit, lmeasurementunit, crcmeasurementunit;
word eepromadressword, palabraescribir, sfword, measurementunit;
unsigned int userregisterint, eepromadress, scalefactor;
float flujomedido;
int val = 0;
int pwm, frecuencia, duty;
float consigna;
unsigned long start1, now, tiempoexcel;
float ki, kd, error, integral, erroranterior;
int kp;

LiquidCrystal_I2C lcd(0x27,16,2);//inicialización de la comunicación I2C del LCD

//FIJAR FRECUENCIA PWM A 31 HZ
void setPwmFrequency(int pin, int divisor) {
  byte mode;
  if(pin == 5 || pin == 6 || pin == 9 || pin == 10) {
    switch(divisor) {
      case 1: mode = 0x01; break;
      case 8: mode = 0x02; break;
      case 64: mode = 0x03; break;
      case 256: mode = 0x04; break;
      case 1024: mode = 0x05; break;
      default: return;
    }
    if(pin == 5 || pin == 6) {
      TCCR0B = TCCR0B & 0b11111000 | mode;
    } else {
      TCCR1B = TCCR1B & 0b11111000 | mode;
    }
  } else if(pin == 3 || pin == 11) {
    switch(divisor) {
      case 1: mode = 0x01; break;
      case 8: mode = 0x02; break;
      case 32: mode = 0x03; break;
      case 64: mode = 0x04; break;
      case 128: mode = 0x05; break;
      case 256: mode = 0x06; break;
      case 1024: mode = 0x7; break;
      default: return;
    }
    TCCR2B = TCCR2B & 0b11111000 | mode;
  }
}
//CALCULAMOS DIRECCIÓN EEPROM
void eepromadress1() {
  Wire.beginTransmission(0x40); //Comienzo del protocolo de comunicación I2C con sensor de flujo
  Wire.write(0xE3); //escritura comando
  Wire.requestFrom(0x40, 3); //lectura de 3 Bytes
  hur = Wire.read(); //Byte alto del User Register
  lur = Wire.read(); //Byte bajo del User Register
  crcur = Wire.read();
  Wire.endTransmission(); //Fin de la comunicación
  userregister = (lur >> 4) & 0b00000111; //máscara de los bits 4,5y6 del User Register
  userregisterint = int(userregister); // Se ha calculado el entero correspondiente al User Register
  eepromadress = (userregisterint * 0x300) + 0x2B6;
  eepromadressword = word(eepromadress);
  palabraescribir = (eepromadressword << 4) & 0b1111111111110000; //Cálculo de la dirección Eeprom
  primerbyteescribir = byte ((palabraescribir >> 8) & 0b0000000011111111);
  segundobyteescribir = byte (palabraescribir & 0b0000000011111111); //Dirección Eeprom separada en 2 Bytes
}
//CÁLCULO DEL FACTOR DE ESCALA
void factordeescala() {
  Wire.beginTransmission(0x40); //Comienzo del protocolo de comunicación I2C con sensor de flujo
  Wire.write(0xFA); //escritura comando
```

```
  Wire.write(primerbyteescribir);
  Wire.write(segundobyteescribir); //escritura de la Dirección Eeprom
  Wire.requestFrom(0x40, 6); //lectura de 6 Bytes
  hscalefactor = Wire.read();
  lscalefactor = Wire.read(); //Bytes del factor de escala
  crcscalefactor = Wire.read();
  hmeasurementunit = Wire.read();
  lmeasurementunit = Wire.read(); // Bytes de la unidad de medida
  crcmeasurementunit = Wire.read();
  Wire.endTransmission(); //Fin de la comunicación
  sfword = word(hscalefactor,lscalefactor);
  scalefactor= int(sfword); //Cálculo del factor de escala
  measurementunit = word(hmeasurementunit,lmeasurementunit); //Cálculo de la unidad de medida
}

void atope() {
  while (flujomedido < consigna*0.3) { //Bucle para que el programa quede "atrapado" hasta volver a condiciones normales de operación
    frecuencia = 480; //frecuencia máxima
    pwm = 66; //amplitud máxima
    duty = 255; //ciclo de trabajo del 100%
    tone(8,frecuencia);
    analogWrite(9,pwm);
    analogWrite(10,duty);
    flujomedido = tomarmedida();
    visualizarmedida(); //Se toma la medida del flujo y se visualiza en LCD
  }
  frecuencia = 100; //frecuencia normal de operación reestablecida
  pwm = 18; //amplitud normal de operación reestablecida
  duty = 0; //ciclo de trabajo minimo de operación reestablecida
  tone(8,frecuencia);
  analogWrite(9,pwm);
  analogWrite(10,duty);
}

float tomarmedida() {
  float flujo;
  Wire.beginTransmission(0x40); //Comienzo de protocolo de comunicación I2C
    Wire.write(0xF1); //Escritura de comando
    Wire.requestFrom(0x40, 3);    // Lectura de 3 Bytes
    hmedida = Wire.read();
    lmedida = Wire.read(); //Bytes de la medida
    crcmedida = Wire.read();
    Wire.endTransmission(); //Fin de la transmisión
    medida = int(word(hmedida,lmedida));
    flujo = float(medida)/scalefactor + 0.03 ; //Cálculo del valor real de flujo
    return flujo; //la medida de flujo es devuelta a la variable flujomedido
}

void visualizarmedida() {
  lcd.clear();
  lcd.setCursor(0,0);
  lcd.print(flujomedido); //visualización del valor real de flujo
  if (measurementunit = 0b0000100001000100) {
    lcd.print("  µl/min"); //si la unidad de medida es µl/min se visualiza
  } else {
    lcd.print("  error!!");//si la unidad de medida no es la esperada se indica error
  }
  lcd.setCursor(0,1);
  lcd.print(consigna);//visualización consigna
}

void suboflujo() {
  consigna = consigna + 0.5; //interrupción para subir la consigna
}

void bajoflujo() {
  consigna = consigna - 0.5; //interrupción para subir la consigna
}

void excel(float val1){
  Serial.print("DATA,TIME,"); // envío comando a excel
  Serial.println(val1); // envío dato a excel
}

void regula() {
```

```
  flujomedido = tomarmedida(); //actualizo valor del flujo real
  error = consigna - flujomedido; //cálculo del error
  integral = integral + 0.116 * error; //cálculo de la integral
  duty = kp*error + ki*integral + kd*(error - erroranterior)/0.116; //cálculo de la acción
  if (duty < 0) {
    duty = 0;
  }
  if (duty > 255) {
    duty = 255;
    //límites superior e inferior para el Ciclo de Trabajo (0 y 100%)
  }
  analogWrite(10,duty); //saco señal PWM a la alimentación del mp6-OEM
  erroranterior = error;
 }

void setup() {
  Wire.begin(); //Inicialización librería comunicación I2C
  Serial.begin(9600);             //Inicialización comunicación por el puerto serie a 9600 baudios
  DDRB = 0xFF;
  DDRD = 0; //Inicialización puertos
  setPwmFrequency(10,1024); //fijar frecuencia PWM a 3 Hz
  val = 0;
  frecuencia = 100;
  pwm = 18;
  consigna = 0;
  duty = 0; //inicializo variables básicas
  tiempoexcel = 3000; //selecciono tiempo de toma de datos en excel
  kp = 350;
  ki = 2;
  kd = 0.5;
  Serial.println("CLEARDATA"); // borrar datos de excel
  eepromadress1(); //cálculo de la dirección Eeprom
  factordeescala(); //cálculo del factor de escala
  lcd.init(); //inicializacion LCD
  lcd.backlight(); //encendido LCD
  lcd.setCursor(0,0);
  lcd.print("BIENVENIDO      "); //mensaje de bienvenida
  attachInterrupt(0,suboflujo,RISING);
  attachInterrupt(1,bajoflujo,RISING); //interrupciones con flanco de subida
  delay(1000);
  tone(8,frecuencia);
  analogWrite(9,pwm);
  analogWrite(10,duty);
  start1=millis(); //inicio variable con el dato del timer del micro
}

void loop() {
  regula(); //salto a subrutina de regulación automática
  visualizarmedida(); //salto a subrutina de visualización
  now = millis(); //tomo dato del timer
  if (now - start1 > tiempoexcel) {
    excel(flujomedido); // si ha pasado el tiempo determinado se actualiza el excel
    start1 = millis(); //reinicio contador de tiempo
  }
  if (flujomedido < consigna*0.3) {
    atope(); //Salto a subrutina de urgencia
  }
}
```

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