

FGD-02F

Floating Gate Dosimeter (FGDOS®)



The power of small things

Target Specification. Preliminary

Rev. A0.11 Page 1/22

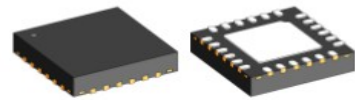
FEATURES

- FGDOS® radiation sensor with digital output
- 200 uGy (20 mrad) resolution
- Total radiation dose up to 250 Gy (TID)
- Chip Serial Number
- Interface for microcontroller applications
- QFN32 with two independent sensors for redundancy
- Programmable Sensitivity 5 kHz/Gy or to 30 kHz/Gy
- Passive detection mode (zero power consumption)
- Temperature monitor integrated on-chip
- 5V supply voltage

APPLICATIONS

- Radiation sensor
- Active and Passive Dosimetry
- Space
- Particle Physics Facilities

PACKAGE



QFN32 5x5m (2 sensors)

GENERAL DESCRIPTION

FGD-02F is a digital radiation sensor based in FGDOS® principle.

Sensor output is a frequency modulated pulse train proportional to radiation dose.

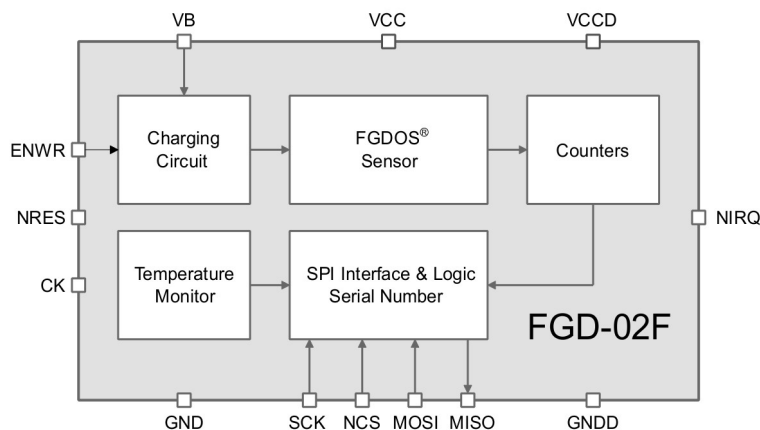
Internal counters allow radiation dose digital value to be read via SPI Interface.

Chip serial number is provided for sensor tracking.

In passive mode, the chip is still sensing the accumulated radiation dose even when there is no power supply.

Sensor temperature dependency is internally compensated.

Additionally, on-chip temperature sensor and reference channel are provided for extended precision applications, via digital post-processing .



BLOCK FUNCTIONAL DIAGRAM



FGD-02F

Floating Gate Dosimeter (FGDOS®)



The power of small things

Target Specification. Preliminary

Rev. A0.11 Page 2/22

CONTENTS

CONTENTS.....	2	INTERNAL TEMPERATURE MONITOR.....	14
PACKAGING INFORMATION AND DIMENSIONS.....	3	SERIAL ID NUMBER.....	14
Pin configuration QFN32-5x5 (top view) ..	3	SERIAL PHERIPHERAL INTERFACE (SPI).....	15
ABSOLUTE MAXIMUM RATINGS.....	4	SPI slave interface	15
THERMAL DATA.....	4	DATA POST-PROCESSING.....	16
ELECTRICAL CHARACTERISTICS.....	5	Background	16
PRINCIPLE OF OPERATION.....	7	Compensating for the FS and FR temperature dependence.....	16
QUICK SET-UP AND OPERATION EXAMPLE.....	8	REGISTER DESCRIPTION.....	18
BASIC OPERATION OVERVIEW.....	10	REGISTER MAP.....	20
OPERATION DESCRIPTION.....	10	DESIGN REVIEW: Notes On Chip Functions.....	21
MEASUREMENT WINDOW SETTING....	11	DATASHEET REVISION HISTORY.....	21
SENSITIVITY CONFIGURATION.....	12	SOLDERING CONSIDERATIONS.....	21
RECHARGING SYSTEM.....	12	DISCLAIMER.....	22
POWER SAVING MODE AND PASSIVE DETECTION.....	14	ORDERING INFORMATION.....	22

FGD-02F

Floating Gate Dosimeter (FGDOS®)

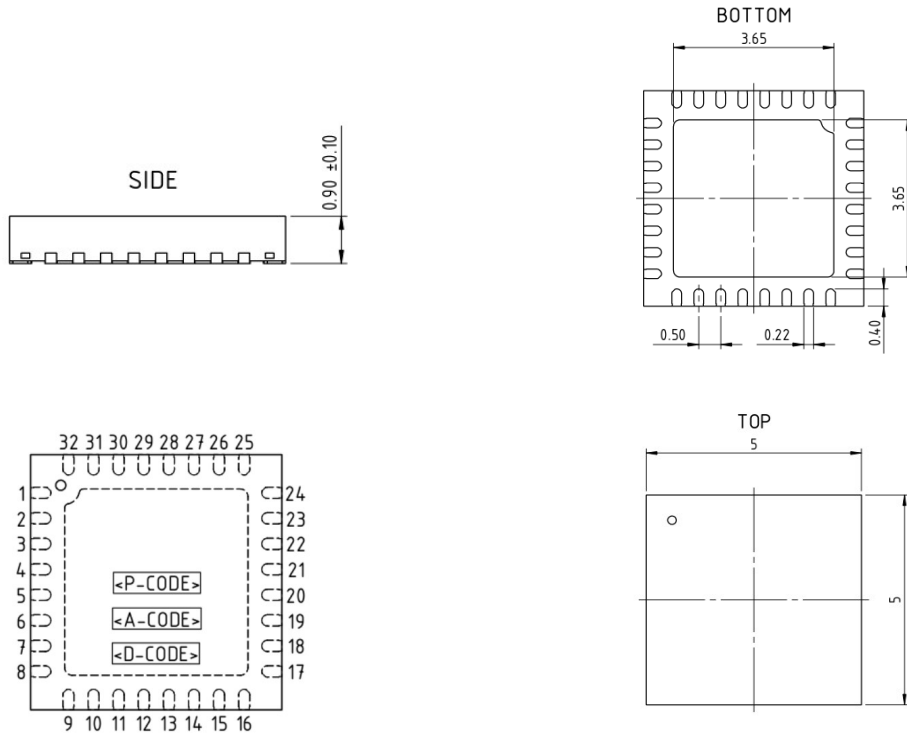


The power of small things

Target Specification. Preliminary

Rev. A0.11 Page 3/22

PACKAGING INFORMATION AND DIMENSIONS



Pin configuration QFN32-5x5 (top view)

The *Thermal Pad* is to be connected to a Ground Plane on the PCB.

Only pin 1 marking on top or bottom defines the package orientation

All dimensions given in mm

Tolerances according to JEDEC MO-220.

The approximated chip weight is 2 g

Pin	Name	Function
1	MISO-1	Serial Data Output <i>SENSOR-1</i>
2	NCS-1	Not Chip Select <i>SENSOR-1</i>
3	MOSI-1	Serial Data Input <i>SENSOR-1</i>
4	Rsv.	Connect to GND
5	N.C.	Not Connected
6	N.C.	Not Connected
7	NIRQ-1	Not Interrupt Req. <i>SENSOR-1</i>
8	VCCD-1	Dig. Power Supply <i>SENSOR-1</i>
9	GND-1	Ground <i>SENSOR-1</i>
10	VB-1	Recharge Voltage <i>SENSOR-1</i>
11	VCC-1	Power Supply <i>SENSOR-1</i>
12	GNDD-1	Digital Ground <i>SENSOR-1</i>
13	SCK-1	<i>Serial Clock SENSOR-1</i>
14	CK-2	<i>Window Clock SENSOR-2</i>
15	ENWR-2	<i>Enable Write SENSOR-2</i>
16	NRES-2	<i>Not Reset SENSOR-2</i>

Pin	Name	Function
17	MISO-2	Serial Data Output <i>SENSOR-2</i>
18	NCS-2	Not Chip Select <i>SENSOR-2</i>
19	MOSI-2	Serial Data Input <i>SENSOR-2</i>
20	Rsv.	Connect to GND
21	N.C.	Not Connected
22	N.C.	Not Connected
23	NIRQ-2	Not Interrupt Req. <i>SENSOR-2</i>
24	VCCD-2	Dig. Power Supply <i>SENSOR-2</i>
25	GND-2	Ground <i>SENSOR-2</i>
26	VB-2	Recharge Voltage <i>SENSOR-2</i>
27	VCC-2	Power Supply <i>SENSOR-2</i>
28	GNDD-2	Digital Ground <i>SENSOR-2</i>
29	SCK-2	<i>Serial Clock SENSOR-2</i>
30	CK-1	<i>Window Clock SENSOR-2</i>
31	ENWR-1	<i>Enable Write SENSOR-1</i>
32	NRES-1	<i>Not Reset SENSOR-1</i>



FGD-02F

Floating Gate Dosimeter (FGDOS®)



The power of small things

Target Specification. Preliminary

Rev. A0.11 Page 4/22

ABSOLUTE MAXIMUM RATINGS

These ratings do not imply permissible operating conditions; functional operation is not guaranteed. Exceeding these ratings may damage the device

Item No.	Symbol	Parameter	Conditions	Min	Max	Unit
G001	VB	Permissible Voltage at VB			20	V
G002	V()	Voltage at NIRQ, VCCD, VB, VCC, SCK, NCS, ENWR, NRES, MISO, NCS, MOSI, CK	Referenced to GND		5.5	V
G003	Vd()	ESD Susceptibility at all pins			TBD(*)	kV
G004	Tj	Junction Temperature		-40	150	°C
G005	Ts	Storage Temperature Range		-40	150	°C

(*) Electrostatic discharges may vary the charge stored in FGDOS®

THERMAL DATA

These ratings do not imply permissible operating conditions; functional operation is not guaranteed. Exceeding these ratings may damage the device

Item No.	Symbol	Parameter	Conditions	Min	Typ	Max	Unit
T01	Ta	Operating Ambient Temperature Range		-40		85	°C
T02	Rthja	Thermal Resistance Chip/Ambient	Mounted on PCB		25		K/W
T03	RthjTP	Thermal Resistance Chip/Thermal Pad			4		K/W

ELECTRICAL CHARACTERISTICS

Operating Conditions: VB=18V, VCC=4.5V .. 5.5V, VCCD = VCC, Tj=-40 .. 85 °C, Rad. source = Co60, TID=0Gy unless otherwise stated

Item No.	Symbol	Parameter	Conditions	Min	Typ	Max	Unit
Total Device							
001	VB	Permissible Programmer Voltage at VB	Referenced to GND	15	18	20	V
002	I(VB)	Recharge current at VB	Recharge Disabled Recharge Enabled			1 50	µA
003	VCC	Permissible Supply Voltage at VCC	Referenced to GND	4.5		5.5	V
004	I(VCC)	Supply current at VCC	POWR(2:0) = 111 High-sensitivity Mode Low-sensitivity Mode POWR(2:0) = 000			10 5 TBD	mA
005	VCCD	Permissible Supply Voltage at VCCD	Referenced to GND	4.5		5.5	V
006	I(VCCD)	Supply current at VCCD	POWR(2:0) = 111 POWR(2:0) = 000			2 TBD	mA
007	Vc(lo)	Clamp Voltage at VB,VCC, VCCD, MISO, NIRQ, ENWR, NCS, SCK, MOSI, CK	I()=10mA	-1.5		-0.6	V
008	f(CK)	Recommended CK frequency	ENGATE=0		32.768		kHz
Digital Input/Outputs							
100	Isc(lo)	Short Circuit Current lo at NIRQ, MISO		-40		-4	mA
101	Isc(hi)	Short Circuit Current hi at NIRQ, MISO		4		40	mA
102	Vs(lo)	Saturation Voltage lo at NIRQ, MISO	I()=2mA	-0.4			V
103	Vs(hi)	Saturation Voltage hi at NIRQ, MISO	I()=-2mA			0.4	V
104	Vt(hi)	Input Threshold Voltage hi at ENWR, NCS, SCK, MOSI, NRES, CK				2	V
105	Vt(lo)	Input Threshold Voltage lo at ENWR, NCS, SCK, MOSI, NRES, CK		0.8			V
106	I()pd	Pull down Current at ENWR, NCS, SCK, MOSI, NRES, CK		1		50	µA
Sensor Output							
200	PSRR()	Power supply rejection Ratio	High Sensitivity Configuration		0.5		Hz/mV
201	MDD()	Minimum Detectable dose	Constant Temperature, High Sensitivity Configuration		200		µGy
202	ΔFs()R	Frequency sensitivity	(*) High Sensitivity Configuration Low Sensitivity Configuration		30 5		kHz / Gy
203	RGmax	Maximum Gamma Dose (TID)			250		Gy
204	RPMmax	Maximum Proton Dose (TID)			200		Gy
205	ΔFs()An	Annealing Frequency variation after first recharge	(*) Measured 5 Days after		4		kHz
206	Fs()Noise	Sensor Frequency noise	Constant temperature, no radiation applied		10		Hz

FGD-02F

Floating Gate Dosimeter (FGDOS®)



The power of small things

Target Specification. Preliminary

Rev. A0.11 Page 6/22

207	LinG()	Gamma linearity response	Sensor within 20 kHz linear range		99		%
208	LinP()	Protons linearity response	Sensor within 20 kHz linear range		99		%
209	Fs()Temp	Frequency dependency to Temperature	High Sensitivity Configuration Low Sensitivity Configuration		130 500		Hz/°C
Reference Output							
300	Fr()	Reference Frequency	REF(2:0) = 100 Low Sensitivity Configuration High Sensitivity Configuration		130 50		kHz
301	Fr()Noise	Reference Frequency noise	Constant temperature, no radiation applied		10		Hz
302	Fr()Temp	Frequency dependency to Temperature	High Sensitivity Configuration Low Sensitivity Configuration		200 500		Hz/°C
Window Measurement Gate							
400	Tcklmin	Minimum CK low time between Sensor and Reference measurements	ENGATE=1			20	µs
Temperature Monitor							
501	Trange	Temperature Measurement Range		-40		125	°C
502	Tresol	Temperature Measurement Resolution			1		°C
503	Reading	Temperature Value Ranges	T _j = 125 °C T _j = -40 °C	200 40		230 60	Digits

(*) TID and Radiation Dose Rate as specified in attached report

FGD-02F

Floating Gate Dosimeter (FGDOS®)

sealicon

The power of small things

Target Specification. Preliminary

Rev. A0.11 Page 7/22

PRINCIPLE OF OPERATION

The **FGDOS®** principle of detection is based on a Floating Gate (FG) capacitor. Charge is pre-stored in the FG using an on-chip recharging system. This charge is stored indefinitely, unless ionizing radiation is applied. When this occurs, the pre-stored charge at FG discharges. Thus, monitoring the charge at the FG capacitor, radiation dose can be measured.

FGDOS® working principle is based on three basic steps, as shown in Figure 1:

1. Initial charge action of the FG up to target value (Zone A). In this step, the FG sensor core is evaluated and it is a factory procedure.
2. The FG discharges due to applied ionizing radiation (Zone B). The discharging rate of the sensor is highly linear with radiation dose.
3. Recharge is triggered when FG charge reaches the threshold value (Zone C).
4. The measured radiation dose can be obtained by reading the sensor output data, calculating the sensor value decrease and counting the number of recharges been triggered.

Following these basic steps, **FGDOS®** ensures working in a very linear zone of detection, keeping the charge in the FG between target and threshold value.

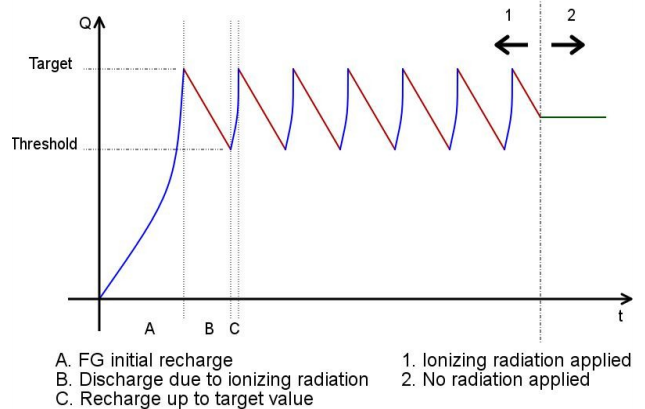


Figure 1. Working principle of **FGDOS®**

Note: More detailed information on the **FGDOS®** principle of operation, can be found at the following scientific publications:

1. S. Danzeca, J. Cesari, M. Brugger, L. Dusseau, A. Masi, A. Pineda, G. Spiezia, "Characterization and Modeling of a Floating Gate Dosimeter with gamma and protons at various energies", November 2014 IEEE Transactions on Nuclear Science, vol. 61, no. 6, pp 3451 – 3457, 2014.
2. J. Cesari, A. Barbancho, A. Pineda, G. Ruy and H. Moser "Floating Gate Dosimeter Measurements at 4M Lunar Flyby Mission", The Nuclear and Space Radiation Effects Conference (NSREC) Radiation Effects Data Workshop (REDW), Boston, July 2015.

FGD-02F

Floating Gate Dosimeter (FGDOS®)



The power of small things

Target Specification. Preliminary

Rev. A0.11 Page 8/22

QUICK SET-UP AND OPERATION EXAMPLE

This section provides, as an example, the steps for a quick set-up of **FGD-02F** working with the most common features:

- One (1) second long *Sensor* and *Reference* measurements
- High Sensitivity Mode (HS)
- Automatic recharging with interrupt on new data

These are the required configuration steps:

A) Power-on the device

1. Apply a 32.768 kHz clock at **CK** pin.
2. Apply supply voltage and wait until **NIRQ = 1**

B) Configure FGD-02F for HS mode, 1second long Measurement Windows, and Reference Oscillator to 50 kHz nominal frequency.

Addr. 0x0B = b01000000 = 0x40

Addr. 0x0C = b01111001 = 0x79

Addr. 0x0E = b00110000 = 0x30

C) Configure FGD-02F in Automatic Recharging mode with Interrupt on new data

1. Disconnect Recharging System
Addr. 0x0D = b00000000 = 0x00
2. Wait few *Measurement Window* cycles (e.g. 4 cycles) to allow *Reference* to stabilize.
3. Read *Reference* register **F1R(17:0)**
4. Configure **TARGET(7:0)** with the 8 MSB bits from **F1R(17:0)**

Addr. 0x09 = **F1R(17:10)**

Note:

Steps C.2 and C.3 are strictly necessary only for the first time sensor is used. In any other case, microcontroller may have stored typical F1R(17:10) value in order to write it into TARGET(7:0)

5. Configure **THRESHOLD(7:0)** with equivalent 30 kHz nominal value

Addr. 0x0A = b00011101 = 0x1D

Note:

FGD-02F is pre-charged in factory to a nominal, approximated value of 50kHz. However, it is possible the sensor suffers some discharge during soldering, or accidental exposure to radiation during transportation. In that cases, it may be desirable to force an initial recharge to ensure initial sensor value to be around 50kHz.

*To do so, configure **THRESHOLD(7:0)=TARGET(7:0)** for the first time the sensor is used. This initial recharge operation is finished when register RECHV=0.*

*Then, configure **THRESHOLD(7:0)** with equivalent 30 kHz nominal value*

6. Enable Interrupt on new data

Addr. 0x0E = b01110000 = 0x70

7. Enable Recharging System

Addr. 0x0D = b01000001 = 0x41

FGD-02F

Floating Gate Dosimeter (FGDOS®)



The power of small things

Target Specification. Preliminary

Rev. A0.11 Page 9/22

D) Read Measured Data

1. When **NIRQ** = 0 read all memory data
2. If a recharge is ongoing: **RECHEV** = 1. Disregard *Sensor* value. Go back to point D.1 and wait for next data.

E) Calculate Radiation value

1. Convert **F1S(17:0)** to frequency
2. Calculate radiation measured.

$$Radiation = \frac{f(Sensor)_n - f(Sensor)_{n-1}}{Sensitivity}$$

3. In case it is necessary, apply temperature compensation (see section DATA POST-PROCESSING)

FGD-02F

Floating Gate Dosimeter (FGDOS®)



The power of small things

Target Specification. Preliminary

Rev. A0.11 Page 10/22

BASIC OPERATION OVERVIEW

FGD-02F contains an **FGDOS®** sensor (*Sensor*) that discharges with radiation dose. The output is encoded in frequency and it decreases as the sensor discharges.

When the sensor value goes below a predefined value, it is possible to recharge the sensor and continue with the radiation dose measurement (see RECHARGING SYSTEM chapter).

FGD-02F also includes a reference oscillator (*Reference*), which provides a reference frequency for temperature compensation of the sensor. The value of *Reference* is not affected by radiation dose.

The typical operation procedure of **FGD-02F** can be summarize as follows:

1. *Sensor* is charged to a predefined target value. This value should be as close as possible to the value of *Reference*.
2. The chip measures *Sensor* and *Reference*, each during a specific time window (see MEASUREMENT WINDOW SETTING chapter).
3. *Sensor* and *Reference* are read. The *Sensor* value drop is proportional to the radiation dose.
4. The value of *Reference* can be used for compensating temperature effects (see DATA POST-PROCESSING chapter).
5. If the sensor goes below a predefined threshold value, it is recharged to the original value (see RECHARGING SYSTEM chapter).

OPERATION DESCRIPTION

The operation of **FGD-02F** consists on alternating consecutive measurements of the *Sensor* and the *Reference*. The duration of the measurement is called *Measurement Window*. During the *Measurement Window*, **FGD-02F** counts *Sensor* and *Reference* pulses alternatively. The duration of a *Measurement Window* is equal for the *Sensor* and the *Reference* and it is configurable.

Reading Sensor and Reference

The values of the *Sensor* and the *Reference* are available at internal registers **F1S(17:0)** (*Sensor*) and **F1R(17:0)** (*Reference*) as 18-bit registers (see Table 2 and Table 3).

F1S(17:0) and **F1R(17:0)** can be read via SPI interface. They are updated after each

corresponding *Measurement Window* has elapsed. Therefore, it is recommended to wait always at least two *Measurement Windows* (plus an additional safety time of 10% *Measurement Window*) between two consecutive read commands.

FGD-02F can generate an interrupt signal at **NIRQ** pin after both *Sensor* and *Reference Measurement Windows* are finished. This is achieved by setting **MNREV** bit high (see Table 20). **NIRQ** is an active low signal.

DNEW and **DNEWS** bits indicate if a new value is available since last individual bit check (see Table 7 and Table 8). They are cleared automatically after read.

MEASUREMENT WINDOW SETTING

The *Measurement Window* is the total time that **FGD-02F** keeps counting *Sensor* and *Reference* pulses. Short windows allow higher measuring rates, while long windows can be used for filtering the measured values.

The *Measurement Window* is governed by pin **CK** and bit **ENGATE** (see Table 10):

- If **ENGATE** = 0 the *Measurement Window* is determined by a specific amount of pulses at **CK** pin.
- If **ENGATE** = 1 the *Measurement Window* determined by the duration of an external pulse at **CK** pin.

Measurement Window as amount of CK pulses

With bits **WINDOW(1:0)** there are four possible **CK** amount of pulses to be selected (see Table 9). E.g., if **WINDOW(1:0)** = 11, the *Measurement Window* will be active during 4096 pulses at pin **CK**.

Knowing the frequency from the signal at **CK**, it is easy to calculate the *Sensor* frequency:

$$Sensor\ Frequency = \frac{FIS(17:0)}{Window\ Pulses\ amount} \times f(CK) \quad [Hz]$$

Similarly, the *Reference* frequency can be calculated.

Measurement Window gating at CK

In this configuration, the *Measurement Window* is active as long as **CK** pin is set high. Knowing the duration of **CK** pulse, *Sensor* frequency can be calculated:

$$Sensor\ Frequency = \frac{FIS(17:0)}{CK\ pulse\ duration} \quad [Hz]$$

Similarly, the *Reference* frequency can be calculated.

Figure 2 shows a timing diagram example of using *Measuring Window* gating at **CK**. **CK** must remain low a minimum time, $t_{ckl_{min}}$ (**El. Char. No. 400**), between a *Sensor* and a *Reference* measurement. **DNEWS** (see Table 8) is set when *Sensor* measurement is finished, and **DNEWWR** is set after a *Reference* measurement (see Table 7). If **MNREV** (see Table 20) is high, interrupt bit pin **NIRQ** will go low, signalling when the data should be read by serial communication. **DNEWS** and **DNEWWR** are cleared automatically after read.

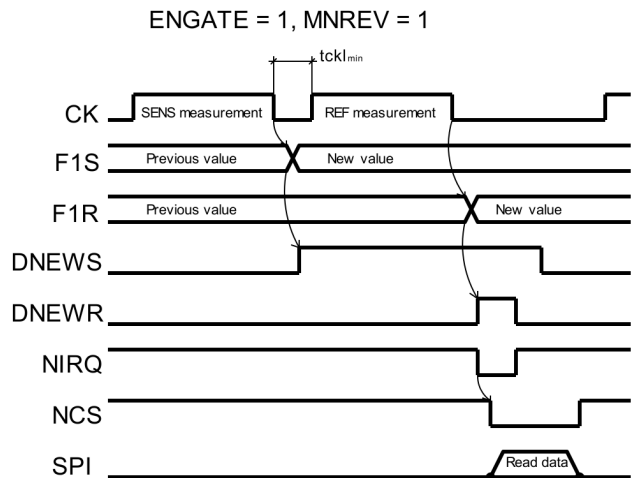


Figure 2: Sensor and Reference measurement with window gating

Count Overflow

F1S(17:0) and **F1R(17:0)** are 18-bit registers. If the selected *Measurement Window* is too long or the *Sensor* recharging value is too high, the registers might overflow. This event is flag through bits **F1SOVF** and **F1ROVF** (See Table 5 and Table 6).

SENSITIVITY CONFIGURATION

The *Sensor* offers two different sensitivity configurations, selected by bits **SENS(2:0)** (see Table 19):

- If **SENS(2:0)** = 100, Low Sensitivity configuration (LS) is selected. The recommended *Sensor* linear range goes from 110 kHz to 130 kHz. The sensitivity of the *Sensor* is lower, while the TID for triggering a recharge is higher.
- If **SENS(2:0)** = 001, High Sensitivity configuration (HS) is selected. The recommended *Sensor* linear range goes from 30 kHz to 50 kHz. The sensitivity of the *Sensor* is higher, while the TID for triggering a recharge is lower.

	kHz / Gy	Gy / Cycle
<i>High Sensitivity</i>	30	0.67
<i>Low Sensitivity</i>	5	4

Table 1: Sensitivity configuration

RECHARGING SYSTEM

The *Sensor* should be kept working within its linear range of 20 kHz. This range depends on the sensitivity configuration selected:

- High Sensitivity (HS): Typically from 30 kHz to 50 kHz.
- Low Sensitivity (LS): Typically from 110 kHz to 130 kHz.

The *Reference* should be configured to the maximum value of the linear range. This is achieved using **REF(2:0)** bits (See Table 4).

If the *Sensor* value is discharged below the linear range, a recharging system allows recharging it back to the original value. This value should be as close as possible to the *Reference* value. The recharging system requires an external supply voltage between 15 V and 20 V at pin **VB (El. Char. No. 001)**.

Two registers are available to define the upper and lower limits of the linear working range:

- **TARGET(7:0)** defines the maximum value (See Table 13). The recommended value is:
 - 50 kHz in HS
 - 130 kHz in LS

- **THRESHOLD(7:0)** defines the minimum value (see Table 14). The recommended values is:
 - 30 kHz in HS
 - 110 kHz in LS

TARGET(7:0) and **THRESHOLD(7:0)** are 8-bit registers. To evaluate if the *Sensor* is out of the linear range defined by **TARGET(7:0)** and **THRESHOLD(7:0)**, they must be compared with the 8 MSBs of **F1S(17:0)**.

Configuring Target and Threshold

TARGET(7:0) and **THRESHOLD(7:0)** registers can be directly configured by assigning the following values:

- **TARGET(7:0)** = **F1R(17:10)** with maximum linear *Sensor* frequency (50 kHz or 130 kHz typically).
- **THRESHOLD(7:0)** = **F1S(17:10)** with minimum linear *Sensor* frequency (30 kHz or 110 kHz typically).

FGD-02F

Floating Gate Dosimeter (FGDOS®)



The power of small things

Target Specification. Preliminary

Rev. A0.11 Page 13/22

Alternatively, the following expressions can be used for configuring both registers, depending on the *Measurement Window* selected.

For *Measurement Window* as amount of **CK** pulses:

$$TARGET(7:0) = \frac{f(Sensor)}{f(CK)} \times \frac{Window\ Pulses\ amount}{1023}$$

where $f(Sensor)$ is the maximum desired *Sensor* frequency (50 kHz or 130 kHz). The same expression can be used for **THRESHOLD(7:0)**.

For *Measurement Window* as gating at **CK**:

$$TARGET(7:0) = f(Sensor)(Hz) \times \frac{CK\ pulse\ duration}{1023}$$

where $f(Sensor)$ is the minimum desired *Sensor* frequency (30 kHz or 110 kHz). The same expression can be used for **THRESHOLD(7:0)**.

There are two main recharging modes, depending on bits **CHMODE(1:0)** (see Table 11):

- Manual Recharge
- Automatic Recharge

Independent of the recharging mode, to enable recharges the global bit **ECH** must be set high (see Table 12).

Automatic Recharge

If **CHMODE(1:0) = 01** the recharging system works automatically.

- When **F1S(17:10)** goes below **THRESHOLD(7:0)** a recharge start.
- When **F1S(17:10)** goes above **TARGET(7:0)** the recharge is stopped.

It is possible to track each recharge by setting **MNREV** bit low (see Table 20). **NIRQ** will be pulled low each time the *Sensor* is being recharged.

Bits **RCHCNT(3:0)** count the number of recharges carried out (see Table 18). They allow working with long periods between each data read. A read must be carried out before **RCHCNT(3:0)** reaches maximum value and it must be cleared manually by performing a write operation on address 0x01.

Bit **RCHEV** is a safety flag bit that indicates if a recharge is process (see Table 15).

Bit **RCHRQ** goes high if **F1S(17:10)** goes below **THRESHOLD(7:0)** (see Table 16). It can be used in combination with **ECH** bit to control when a recharge should be triggered in automatic mode.

Manual Recharge

In *Manual Recharge* the user controls the start and stop of the *Sensor* recharge. It can be controlled either by external pin or by internal bit:

- If **CHMODE(1:0) = 10** the system recharges the *Sensor* while **FCH** bit is left high (see Table 17).
- If **CHMODE(1:0) = 11** the system recharges the *Sensor* while **ENWR** pin is set high.

In *Manual Recharge* it is not necessary to use **TARGET(7:0)** and **THRESHOLD(7:0)**. To detect if the *Sensor* is within the linear range, **F1S(17:0)** must be polled. To relate the **F1S(17:0)** to the *Sensor* frequency the following expressions can be used, depending on the *Measurement Window* selected.

Measurement Window as amount of **CK** cycles:

$$F1S(17:0) = \frac{f(Sensor)}{f(CK)} \times Window\ Pulses\ amount$$

For *Measurement Window* as gating at **CK**:

$$F1S(17:0) = f(Sensor)(Hz) \times CK\ pulse\ duration$$

In manual recharge, the recharge counter is increased every time the user triggers a new recharge.

FGD-02F

Floating Gate Dosimeter (FGDOS®)



The power of small things

Target Specification. Preliminary

Rev. A0.11 Page 14/22

POWER SAVING MODE AND PASSIVE DETECTION

FGD-02F features two different modes for low and even zero power consumption: Power saving and Passive Detection Mode.

Both in Passive Detection and Power Saving Mode, the core of the sensor is still sensing and recording the received radiation dose.

For data reading, FGD-02F must be fully powered-one (Normal Operation). Once data reading operation is finished, it can be switched back to Passive Detection or Power Saving Mode-Mode.

Power Saving Mode

Bits **POWR(2:0)** allow reducing the power consumption by switching off some internal

functions, entering in a semi-iddle state (see Table 22):

- If **POWR(2:0)** = 000, power consumption is reduced.
- If **POWR(2:0)** = 111, power consumption is normal (Normal Operation)

Passive Detection Mode

FGDOS® can measure radiation dose with no supply voltage, acting as a passive radiation detector. Consumption of **FGD-02F** can be reduced to zero by switching off **VCC** and **VCCD** power supplies.

For data reading, **FGD-02F** must be powered-on. Once read, it can be switched back to passive detection mode.

INTERNAL TEMPERATURE MONITOR

FGD-02F includes an 8-bit temperature monitor with a range going from -40 °C to 125 °C and a resolution of 1 °C/LSB. The internal temperature can be obtained by reading **TEMP(7:0)** register, which is a read-only register (see Table 23).

Absolute read values may differ from one chip to another. An individual initial calibration of the temperature monitor is recommended.

The temperature monitor can be used to compensate temperature effects on the *Sensor*. The microcontroller can use a look-up table combined with the temperature value measured through **TEMP(7:0)** register.

SERIAL ID NUMBER

FGD-02F provides a 3 bytes-long unique individual serial number that can be read at address 0x10 to 0x12.

SERIAL PHERIPHERAL INTERFACE (SPI)

SPI slave interface

The SPI slave interface uses pins **NCS**, **SCLK**, **MISO** and **MOSI**. Pin **NCS** is the chip select pin and must be set lo by the SPI master in order to start communication. Pins **MISO** and **MOSI** are the data

communication lines and pin **SCLK** is the clock line generated by the SPI master (E.g. microcontroller).

The SPI protocol frames are shown in Figure 3. A communication frame consists of one address byte and at least one data byte. Bits 7:6 of the address



FGD-02F

Floating Gate Dosimeter (FGDOS®)



The power of small things

Target Specification. Preliminary

Rev. A0.11 Page 15/22

byte is the opcode used for selecting a read operation (set to "10") or a write (set to "01") operation. The remaining 6 bits are used for register addressing.

It is possible to transmit several bytes consecutively, if the **NCS** signal is not reset and **SCLK** keeps clocking. The address is internally incremented after each transmitted byte. Once the address reaches the last register (0x14h), it is reset back to 0x00.

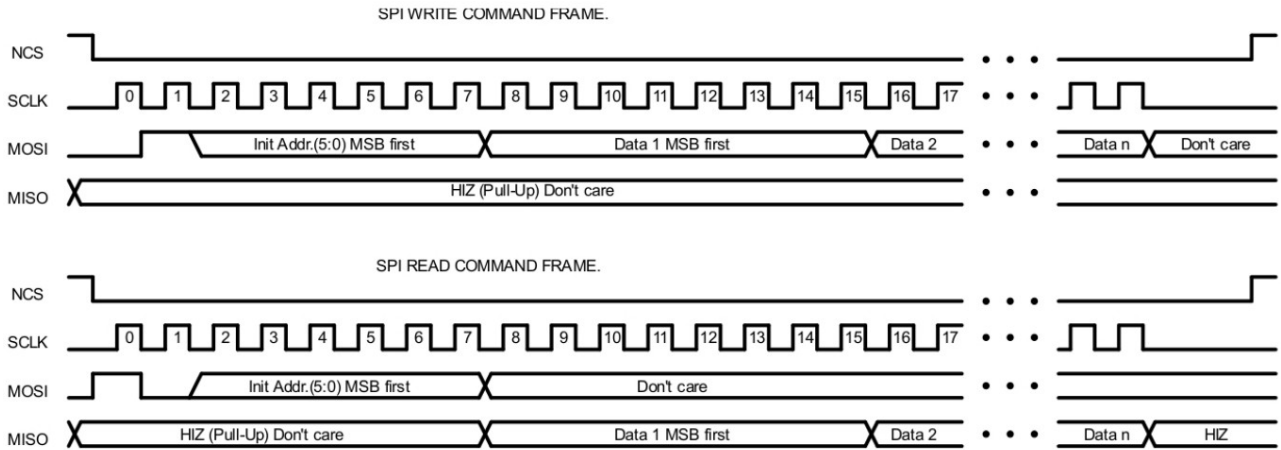


Figure 3: SPI Read and Write commands

DATA POST-PROCESSING

Background

The accuracy of **FGDOS®** is improved if the effects of operating temperature are compensated. This can be achieved by post-processing the sensor data through an external microcontroller or FPGA.

A single measurement of **FGDOS®** consists of a reference frequency (*FR*) and a sensor frequency (*FS*) pair. Both sensor and reference dependencies should be compensated to improve **FGDOS®** accuracy.

Typical values for *FS* and *FR* temperature dependence (see *El. Char. No. 209 and 302*).

Compensating for the *FS* and *FR* temperature dependence

FGDOS® has to be characterized in temperature after the sensor has been charged for the first time. This temperature characterization must be carried out under no radiation.

The relation of *FS* and *FR* is very linear with temperature variation. Assuming this linearity, the equation of a line can be extracted by measuring two pairs of *FS* and *FR* at different temperatures, T_{RT} and T_1 :

$$\begin{aligned} &FS_{RAD0}(T_{RT}), FR_{RAD0}(T_{RT}) \\ &FS_{RAD0}(T_1), FR_{RAD0}(T_1) \end{aligned}$$

where $FS_{RAD0}(T_{RT})$ is the sensor frequency with no radiation at room temperature. This line is shown in Figure 4. The resulting equation is:

$$FS_{RAD0} = m \cdot FR_{RAD0} + a \quad (1)$$

Once the FS_{RAD0} is obtained, radiation can be applied to **FGDOS®**. When radiation RAD_1 is applied to the sensor, the line relating *FS* and *FR* is modified, but it can be assumed that the slope remains constant. Figure 5 shows the effect of applying radiation. When a pair of *FR* and *FS* is

measured under radiation RAD_1 and a random temperature T_3 , the following pair is obtained:

$$FS_{RAD1}(T_3), FR_{RAD1}(T_3)$$

With $FR_{RAD1}(T_3)$ and formula (1), $FS_{RAD0}(T_3)$ can be obtained. From Figure 4 it can be seen that:

$$FS_{RAD0}(T_3) - FS_{RAD0}(T_{RT}) = FR_{RAD1}(T_3) - FR_{RAD1}(T_{RT})$$

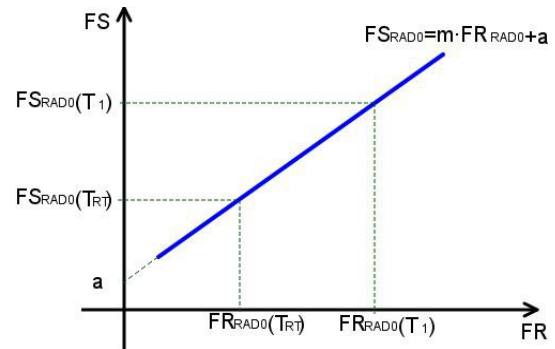


Figure 4: Variation of *FS* and *FR* with temperature

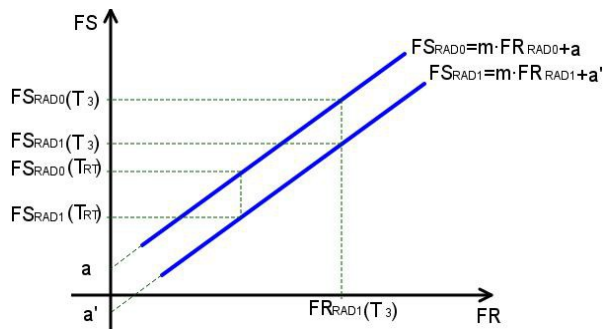


Figure 5: Effect of applying radiation

The radiation increase with respect to $FS_{RAD0}(T_{RT})$ is therefore:

$$FS_{RAD1}(T_{RT}) = FR_{RAD1}(T_3) - FS_{RAD0}(T_3)$$

This value is temperature compensated and is given in frequency. Applying the Frequency Sensitivity factor (*El. Char. No. 202*), the radiation value in Gy is obtained.

FGD-02F

Floating Gate Dosimeter (FGDOS®)



The power of small things

Target Specification. Preliminary

Rev. A0.11 Page 17/22

This compensation technique assumes linear behavior of the relation of FR and FS with temperature, as well as constant slope of this relation when radiation is applied.

assumptions are not considered and instead a look-up table is used for temperature compensation.

This is a possible approach, however **it is possible to improve even more the accuracy if these**

REGISTER DESCRIPTION

Sensor and Reference

F1S	Addr.	Bits 17:0	R 0x0000
	0x06/07/08		
0x00000	Minimum sensor counter value		
0x3FFFF	Maximum sensor counter value		

Table 2: Sensor Counter

F1R	Addr.	Bits 17:0	R 0x0000
	0x03/04/05		
0x00000h	Minimum reference counter value		
0x3FFFFh	Maximum reference counter value		

Table 3: Reference Counter

REF	Addr. 0x0B	Bits 6:4	R/W 000
000	Reference set to minimum		
111	Reference set to maximum		

Table 4: Reference frequency configuration

F1ROVF	Addr. 0x05	Bit 2	R 0
0	No Reference overflow		
1	Reference overflow		

Table 5: Reference counter overflow

Measurement Window bits

WINDOW	Addr. 0x0B	Bit 3:2	R/W 00
00	32,768 CK pulses per window		
01	16,384 CK pulses per window		
10	8,192 CK pulses per window		
11	4,096 CK pulses per window		

Table 9: Window length selection

Recharging System bits

CHMODE	Addr. 0x0D	Bits 1:0	R/W 00
00	Recharging disabled		
01	Automatic recharging mode		
10	Manual recharging controlled by FCH		
11	Manual recharging controlled by ENWR pin		

Table 11: Charge Mode Selection

ECH	Addr. 0x0D	Bit 6	R/W 0
0	Recharge not allowed		
1	Recharge allowed		

Table 12: Enable Recharging

F1SOVF	Addr. 0x08	Bit 2	R 0
0	No Sensor overflow		
1	Sensor overflow		

Table 6: Sensor counter overflow

DNEWR	Addr. 0x05	Bit 3	R 0
0	No new reference data is ready		
1	New reference data is ready		

Table 7: Reference data new value

DNEWS	Addr. 0x08	Bit 3	R 0
0	No new sensor data is ready		
1	New sensor data is ready		

Table 8: Sensor data new value

ENGATE	Addr. 0x0E	Bit 0	R/W 0
0	Meas. Window by counts at CK		
1	Meas. Window by gating at CK		

Table 10: Enable window gating

TARGET	Addr. 0x09	Bits 7:0	R/W 0x00
0x00	Minimum Frequency		
0xFF	Maximum Frequency		

Table 13: Upper level target frequency

THRES	Addr. 0x0A	Bits 7:0	R/W 0x00
0x00	Minimum Frequency		
0xFF	Maximum Frequency		

Table 14: Lower level threshold frequency

RCHEV	Addr. 0x01	Bit 7	R 0
0	Recharge not in progress		
1	Recharge in progress		

Table 15: Recharge event flag

FGD-02F

Floating Gate Dosimeter (FGDOS®)



The power of small things

Target Specification. Preliminary

Rev. A0.11 Page 19/22

RCHRQ	Addr. 0x01	Bit 6	R 0
0		Recharge is not requested	
1		Recharge is requested	

Table 16: Recharge request

RCHCNT(3:0)	Addr. 0x01	Bit 3:0	R/W 0000
0000		No recharges since last clear	
1111		At least 15 rech. since last clear	

Table 18: Recharge counter

FCH	Addr. 0x0C	Bit 7	R/W 0
0		FG charging stopped	
1		FG charging started	

Table 17: Force charge in Manual Recharging mode

Sensitivity Configuration

SENS(2:0)	Addr. 0x0C	Bit 2:0	R/W 000
xxx		Reserved	
001		High Sensitivity Selected	
xxx		Reserved	
100		Low Sensitivity Selected	
xxx		Reserved	

Table 19: Sensitivity Configuration

Interrupt request

MNREV	Addr. 0x0E	Bit 6	R/W 0
0		NIRQ signals recharge in process	
1		NIRQ signals measurement ready	

Table 20: Measurement / Recharge indicator

NIRQOC	Addr. 0x0E	Bit 1	R/W 0
0		NIRQ interruption push-pull	
1		NIRQ interruption open collector	

Table 21: Interrupt output

Power Saving and Temperature Monitor

POWER(2:0)	Addr. 0x0C	Bits 5:3	R/W 111
xxx		Reserved	
111		Normal Operation	
xxx		Reserved	
000		Power saving Mode	
xxxx		Reserved	

Table 22: Power saving

TEMP	Addr. 0x00	Bits 7:0	R 0x00
0x00		Minimum temperature value	
0xFF		Maximum temperature value	

Table 23: Temperature monitor

Serial Number and Chip Version

SN	Addr. 0x10/11/12	Bits 23:0	R 0x000000
0x000000		Minimum serial number value	
0xFFFFFFFF		Maximum serial number value	

Table 24: Serial Number

CHIPID	Addr. 0x13	Bits 7:0	R 0x01
0x01		FGD-02F version 1	

Table 25: Chip Identification Number

FGD-02F

Floating Gate Dosimeter (FGDOS®)



The power of small things

Target Specification. Preliminary

Rev. A0.11 Page 20/22

REGISTER MAP

OVERVIEW

Addr	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
0x00 R	TEMP(7:0)							
0x01 R	RECHEV	RECHRQ	0	0	RCHCNT(3:0)			
0x02	Not implemented							
0x03 R	F1R(7:0)							
0x04 R	F1R(15:8)							
0x05 R	0	1	0	1	DNEW R	F1ROVF	F1R(17:16)	
0x06 R	F1S(7:0)							
0x07 R	F1S(15:8)							
0x08 R	1	0	1	0	DNEWS	F1SOVF	F1S(17:16)	
0x09	TARGET(7:0)							
0x0A	THRESHOLD(7:0)							
0x0B	0*	REF(2:0)			WINDOW(1:0)		0*	0*
0x0C	FCH	1*	POWR(2:0)			SENS(2:0)		
0x0D	0*	ECH	0*	0*	0*	0*	CHMODE(1:0)	
0x0E	0*	MNREV	1*	1*	0*	0*	NIRQOC	ENGATE
0x0F	Not implemented							
0x10	SN(7:0)							
0x11	SN(15:8)							
0x12	SN(23:15)							
0x13 R	CHIPID(7:0)							
0x14	0	0	0	0	Reserved			

R: Read-only register

(*) : Reserved. Must be set to specified value

FGD-02F

Floating Gate Dosimeter (FGDOS®)



The power of small things

Target Specification. Preliminary

Rev. A0.11 Page 21/22

DESIGN REVIEW: Notes On Chip Functions

FGD-02F Z

No.	Function, Parameter/Code	Description and Application Notes
1	CHIPID	For FGD-02F chip releases see Table 25

DATASHEET REVISION HISTORY

Rel.	Rel. Date	Chapter	Modification	Page
A0.5		Sensitivity	LS and HS frequency ranges are typical recommended values	
A0.6		All	Minor errors on tables	
A0.7		Design Review	Added info regarding Chip release version	21/21
A0.8		Ordering Information	EVAL USB RTC	21/21
A0.9		Disclaimer		21/22
A0.10		Quick Set-up and Operation example	Addr. 0x0C = b01111001 = 0x79	8/22
A0.11	07/11/19	ELECTRICAL CHAR. Datasheet Datasheet ORDERING INFO.	004; I(VCC) and 006; I(VCCD) Changed from "Confidential" to "Preliminary" Changed contact info Removed FGD-02F_Z TC	5/22 22/22

SOLDERING CONSIDERATIONS

The temperature applied to FGD-02F throughout the soldering process can lead to charges recombination on FGDOS® sensor. Consequently,

it is recommended to trigger a new charging process after soldering.

FGD-02F

Floating Gate Dosimeter (FGDOS®)



The power of small things

Target Specification. Preliminary

Rev. A0.11 Page 22/22

DISCLAIMER

The data presented in this document is for informational purposes for engineering samples, which have not yet been qualified for production. It shall in no event be regarded as a guarantee of final specifications or characteristics. Any warranty or license of this product shall be specified and governed by the terms of a separate purchase agreement. Sealicon Microsystems conveys no patent, copyright, mask work right or other trade mark right to this product. Sealicon Microsystems assumes no liability for any patent and/or other trade mark rights of a third party resulting from processing or handling of the product an/or any other use of the product.

Sealicon Microsystems products are not designed for and must not be used in connection with any applications where the failure of such products would reasonably be expected to result in significant personal injury or death (Safety-Critical applications) without Sealicon Microsystems specific written consent. Safety-critical applications include, without limitation, life support devices and systems. Sealicon Microsystems products are not designed nor intended for use in military or aerospace applications or environments or in automotive applications unless specifically designated for such use by Sealicon Microsystems.

Sealicon Microsystems reserves the right to make changes in these specifications and features shown herein to improve reliability, function and design, or discontinue of this product, at any time without notice or obligation.

ORDERING INFORMATION

Product	Description
FGD-02F_Z	FGD-02F_Z sensor, non-characterized, QFN32
FGD-02F_Z RTC	FGD-02F_Z sensor, radiation and temperature characterized, QFN32
FGD-02F EVAL RTC	Evaluation board with FGD-02F_Z sensor, radiation and temperature characterized

Sealicon Microsystems is a trademark of Integrated Circuits Málaga S.L.

For technical support, information about prices and terms of delivery, and purchase orders please contact:

iC-Málaga s.l.
Virgen del Refugio, 5, 1ºB
07340 Alaró (Illes Balears)
Spain

Tel.: +34 971 528 527
Fax.: +34 971 518 312
Web: www.sealiconmicro.com
E-Mail: contact@sealiconmicro.com

