FGD-02F

Floating Gate Dosimeter (FGDOS®)

Target Specification. Preliminary

FEATURES

FGDOS® radiation sensor with digital output

Total radiation dose up to 250 Gy (TID)

Chip Serial Number

Interface for microcontroller applications

QFN32 with two independent sensors for redundancy

Programmable Sensitivity 3.2 kHz/Gy or to 20 kHz/Gy

Passive detection mode (zero power consumption)

Temperature monitor integrated on-chip

5V supply voltage

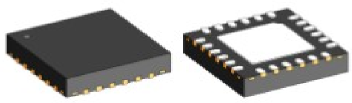
APPLICATIONS

Radiation sensor

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.

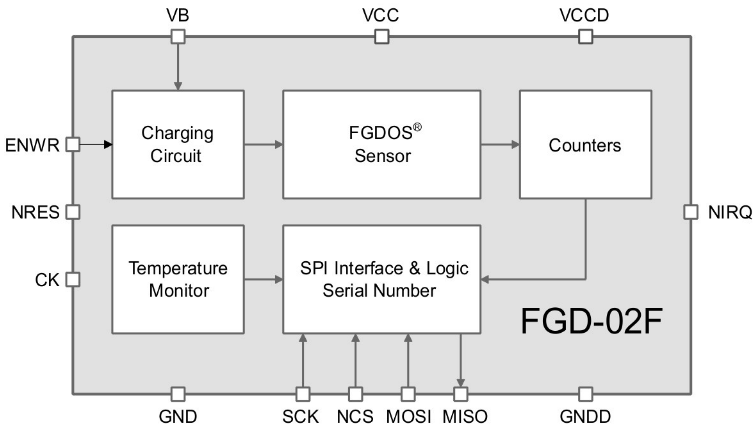
Internal counters allow radiation dose digital value to be read via SPI Interface.

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.

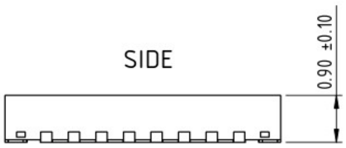
Additionally, on-chip temperature sensor and reference channel are provided for extended precision applications, via digital post-processing .

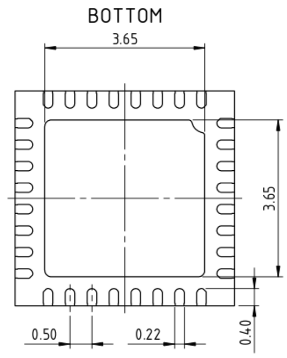


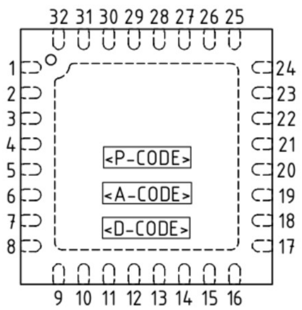
BLOCK FUNCTIONAL DIAGRAM

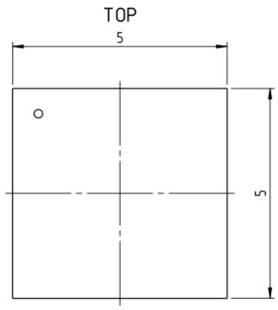
CONTENTS

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	Pin	Name	Function
1	MISO-1	Serial Data Output *SENSOR-1*	17	MISO-2	Serial Data Output *SENSOR-2*
2	NCS-1	Not Chip Select *SENSOR-1*	18	NCS-2	Not Chip Select *SENSOR-2*
3	MOSI-1	Serial Data Input *SENSOR-1*	19	MOSI-2	Serial Data Input *SENSOR-2*
4	Rsv.	***Connect to GND***	20	Rsv.	***Connect to GND***
5	N.C.	Not Connected	21	N.C.	Not Connected
6	N.C.	Not Connected	22	N.C.	Not Connected
7	NIRQ-1	Not Interrupt Req. *SENSOR-1*	23	NIRQ-2	Not Interrupt Req. *SENSOR-2*
8	VCCD-1	Dig. Power Supply *SENSOR-1*	24	VCCD-2	Dig. Power Supply *SENSOR-2*
9	GND-1	Ground *SENSOR-1*	25	GND-2	Ground *SENSOR-2*
10	VB-1	Recharge Voltage *SENSOR-1*	26	VB-2	Recharge Voltage *SENSOR-2*
11	VCC-1	Power Supply *SENSOR-1*	27	VCC-2	Power Supply *SENSOR-2*
12	GNDD-1	Digital Ground *SENSOR-1*	28	GNDD-2	Digital Ground *SENSOR-2*
13	SCK-1	*Serial Clock SENSOR-1*	29	SCK-2	*Serial Clock SENSOR-2*
14	CK-2	*Window Clock SENSOR-2*	30	CK-1	*Window Clock SENSOR-2*
15	ENWR-2	*Enable Write SENSOR-2*	31	ENWR-1	*Enable Write SENSOR-1*
16	NRES-2	*Not Reset SENSOR-2*	32	NRES-1	*Not Reset SENSOR-1*

ABSOLUTE MAXIMUM RATINGS

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

Item	Symbol	Parameter	Conditions			Unit
No.				**Min**	**Max**	
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	ºC
G005	Ts	Storage Temperature Range		-40	150	ºC

(*) 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	Symbol	Parameter	Conditions				Unit
No.				**Min**	**Typ**	**Max**	
T01	Ta	Operating Ambient Temperature Range		-40		85	ºC
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	High-sensitivity Mode Low-sensitivity Mode			10 5	mA
005	VCCD	Permissible Supply Voltage at VCCD	Referenced to GND	4.5		5.5	V
006	I(VCCD)	Supply current at VCCD				2	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, SCK, MOSI, NRES, CK		1		50	µA
107	I()pu	Pull down Current at NCS		1		50	µA
108	Fsck	Max allowed SPI clock frequency				5	MHz
109	Tncslo	Min NCS low time before first SCK pulse		3			µs
Sensor Output							
200	PSRR()	Power supply rejection Ratio	High Sensitivity Configuration		0.5		Hz/mV
201	∆Fs()R	Frequency sensitivity	(*) High Sensitivity Configuration Low Sensitivity Configuration		20 3.2		kHz / Gy
202	RGmax	Maximum Gamma Dose (TID)			250		Gy
203	RPMax	Maximum Proton Dose (TID)			200		Gy
204	∆Fs()An	Annealing Frequency variation after first recharge	(*) Measured 5 Days after		4		kHz
205	Fs()Noise	Sensor Frequency noise	Constant temperature,no radiation applied, 250ms window		+-50		Hz

206	LinG()	Gamma linearity response	Sensor within 20 kHz linear range		99		%
207	LinP()	Protons linearity response	Sensor within 20 kHz linear range		99		%
208	Fs()Temp	Frequency dependency to Temperature	High Sensitivity Configuration Low Sensitivity Configuration		130 500		Hz/ºC
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, 250ms window		+-50		Hz
302	Fr()Temp	Frequency dependency to Temperature	High Sensitivity Configuration Low Sensitivity Configuration		200 500		Hz/ºC
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	ºC
502	Tresol	Temperature Measurement Resolution			1		ºC
503	Reading	Temperature Value Ranges	Tj = 125 ºC Tj = -40 ºC	200 40		230 60	Digits

(*) Based on statistics measured with Co60 15 rad(Si) dose at 30 rad(Si)/h. Each sensor must be individually characterized

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.

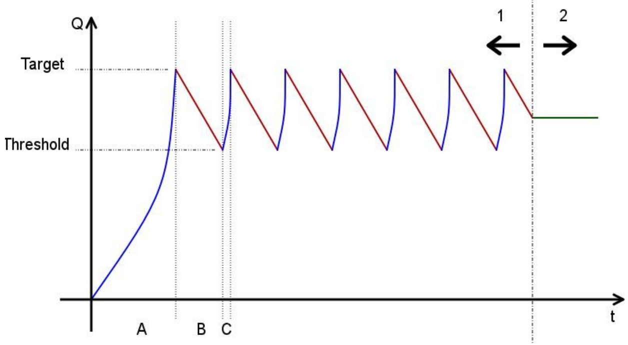


Figure 1. Working principle of **FGDOS®**

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.*

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 = b00110100 = 0x34

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

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)

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 Mea*surement 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 21). **NIRQ** is an active low signal.

DNEWR 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:

$$Sensor\ Frecuency = \frac{F1S(17:0)}{Window\ Pulses\ amount} \times f(CK) \quad \text{[Hz]}$$

Similarly, the *Reference* frequency can be calculated.

In order to minimize noise effects, in this mode it is recommended to discard measurements during SPI communication. This is achieved by setting EDIRT bit to '1' (See Table 11).

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:

$$Sensor\ Frecuency = \frac{F1S(17:0)}{CK\ pulse\ duration} \quad \text{[Hz]}$$

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, $tckl_{min}$ (***El. Char. No. 400***), between a *Sensor* and a *Reference* measurement. **DNEWS** (see Table 8) is set when *Sensor* measurement is finished, and **DNEWR** is set after a *Reference* measurement (see Table 7). If **MNREV** (see Table 21) is high, interrupt bit pin **NIRQ** will go low, signaling when the data should be read by serial communication. **DNEWS** and **DNEWR** are cleared automatically after read.

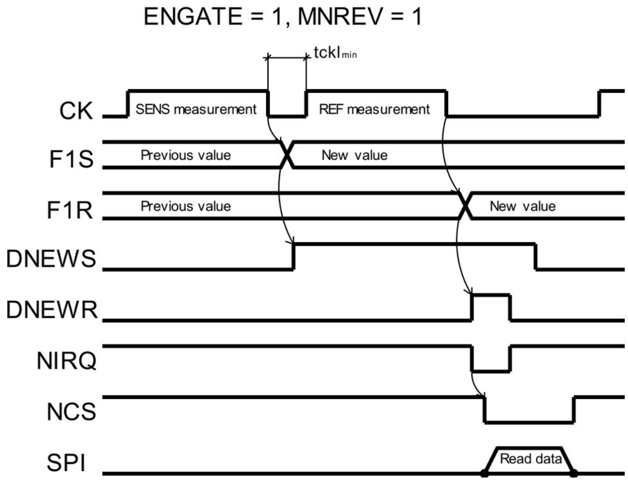


Figure 2: Sensor and Reference measurement with window gating

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 20):

- 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
High Sensitivity	20	1
Low Sensitivity	3.2	6.25

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 14). The recommended value is:
  - 50 kHz in HS
  - 130 kHz in LS
- **THRESHOLD(7:0)** defines the minimum value (see Table 15). 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 asigning 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).

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 12):

- Manual Recharge
- Automatic Recharge

Independent of the recharging mode, to enable recharges the global bit **ECH** must be set high (see Table 13).

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 21). **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 19). 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 16).

Bit **RCHRQ** goes high if **F1S(17:10)** goes below **THRESHOLD(7:0)** (see Table 17). 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 18).
- 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.

PASSIVE DETECTION

FGD-02F features a working mode for zero power consumption: Passive Detection Mode. In this mode the core of the sensor is still sensing and recording the received radiation dose.

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 (Normal Operation). 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 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 (0x3Fh), it is reset back to 0x00.

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:

$$FS_{RAD0}(T_{RT}),FR_{RAD0}(T_{RT})$$

$$FS_{RAD0}(T_1),FR_{RAD0}(T_1)$$

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:

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

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:

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

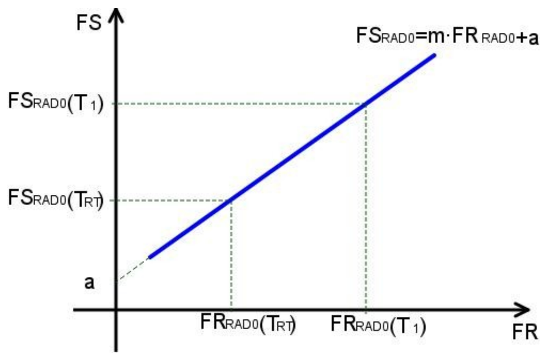


Figure 4: Variation of FS and FR with temperature

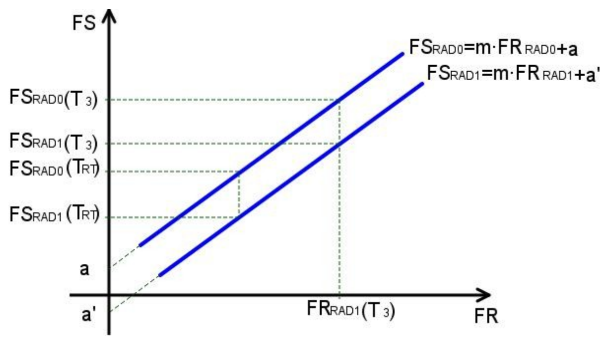


Figure 5: Effect of applying radiation

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.

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.

This is a possible approach, however **it is possible to improve even more the accuracy if these assumptions are not considered and instead a look-up table is used for temperature compensation**.

REGISTER DESCRIPTION

Sensor and Reference

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

Table 2: Sensor Counter

F1R	Addr. 0x03/04/05	Bits 17:0	R 0x0000
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

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

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

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

EDIRT	Addr. 0x0E	Bit 2	1
0	Measurements during SPI allowed		
1	Measurements during SPI discarded		

Table 11: Measurements during SPI enable bit

Recharging System bits

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

Table 12: Charge Mode Selection

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

Table 13: Enable Recharging

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

Table 14: Upper level target frequency

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

Table 15: Lower level threshold frequency

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

Table 16: Recharge event flag

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

Table 17: Recharge request

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

Table 18: Force charge in Manual Recharging mode

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 19: Recharge counter

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 20: Sensitivity Configuration

Interrupt request

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

Table 21: Measurement / Recharge indicator

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

Table 22: Interrupt output

Temperature Monitor

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
0xFFFFFF	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

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**	**DNEWR**	**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***	**1***	**1***	**1***	**SENS(2:0)**		
0x0D	**0***	**ECH**	**0***	**0***	**0***	**0***	**CHMODE(1:0)**	
0x0E	**0***	**MNREV**	**1***	**1***	**0***	**EDIRT**	**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**	**Reserved, set to 0**				

R: Read-only register
(*) : Reserved. Must be set to specified value

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	08/22
A0.11	07/11/19	ELECTRICAL CHAR. Datasheet Datasheet OREDERING INFO.	004; I(VCC) and 006; I(VCCD) Changed from “Confidential” to “Preliminary” Changed contact info Removed FGD-02F_Z TC	05/22 22/22
A0.12	06/05/20	All REGISTER MAP QUICK STARTUP AND OPERATION EXAMPLE REGISTER DESCRIPTION	Mention to Power Saving Mode removed Bit 0x0E bit 2 = EDIRT 0x0E = 0b00110100 = 0x34h EDIRT, table 11	 20/22 08/22 18/22
		ELECTRICAL CHAR.	Noise figures updated based on experimental results.	
		ELECTRICAL CHAR.	MDD figures removed.	05/22
		ELECTRICAL CHAR.	SPI requirements for NCS and SCK added	05/22
		ELECTRICAL CHAR.	Frequency sensitivity updated	05/22
A0.13		TABLES ELECTRICAL CHAR.	Table 1 updated 106 modified, 107 added	
A1.0	20/06/22	All ORDERING INFO	Radiation Sensitivity (typ.): 20kHz/Gy (HS), 3.2kHz/Gy (LS) Removed RTC products	 24/24

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.**

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ORDERING INFORMATION

Product	Description
FGD-02F_Z	FGD-02F_Z sensor, QFN32
FGD-02F EVAL	Evaluation board with FGD-02F_Z sensor

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