The Essential Telemetry (ETM) ASIC. A mixed signal, rad-hard and low-power component for direct telemetry acquisition and miniaturized RTU

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***Abstract*—The Essential Telemetry (ETM) ASIC is mixed signal, rad-hard and low-power component for direct telemetry acquisition and miniaturized RTU. The ETM is capable of autonomous analog (voltage and/or temperature) and digital data acquisition, and formatting for transmission to ground without the need of the S/C onboard computer in case of an emergency situation or to give continuous telemetry coverage during processor reconfigurations.**

In addition, it can be used as a miniaturized low power remote terminal unit for telemetry acquisition via CAN bus, thus minimizing the cabling and interface circuitry needed for data acquisition.

***Index Terms*—ETM, ASIC,RadHard,mixed signal, low power.**

I. Introduction

Essential telemetry is a critical, currently unavailable functionality in a spacecraft that involves acquiring, processing and transmitting data to earth stations at times of anomaly, when the spacecrafts CPU is not functioning. It is thus highly desirable that such an essential telemetry system is autonomous, reliable and SEE hard since there will be no easy way to configure it in flight. In this paper the ETM ASIC, a rad hard, low power, mixed signal integrated circuit is presented which performs the essential telemetry functionality. In addition, the ETM ASIC can be used as an ultra low power remote terminal unit (RTU) for nominal spacecraft housekeeping data acquisition.

The use of the ETM device in a spacecraft is shown in Fig. 1. The ETM ASIC can be used in one of the following configurations:

- Stand alone configuration (STD) where upon power up measures analog and digital inputs and forwards them them via the Packetwire (PW) interface to the S/C telemetry module (SCTMTC ASIC) for downlink to earth.
- Cascaded daisy chain(CSC/DC) configuration where multiple ETMs are used in a single PW interface to increase the number of analog and digital input channels sampled.
- Remote terminal unit (RTU) configuration where the device samples analog and digital inputs and forwards them in thr S/C processor module via the S/C CAN bus.

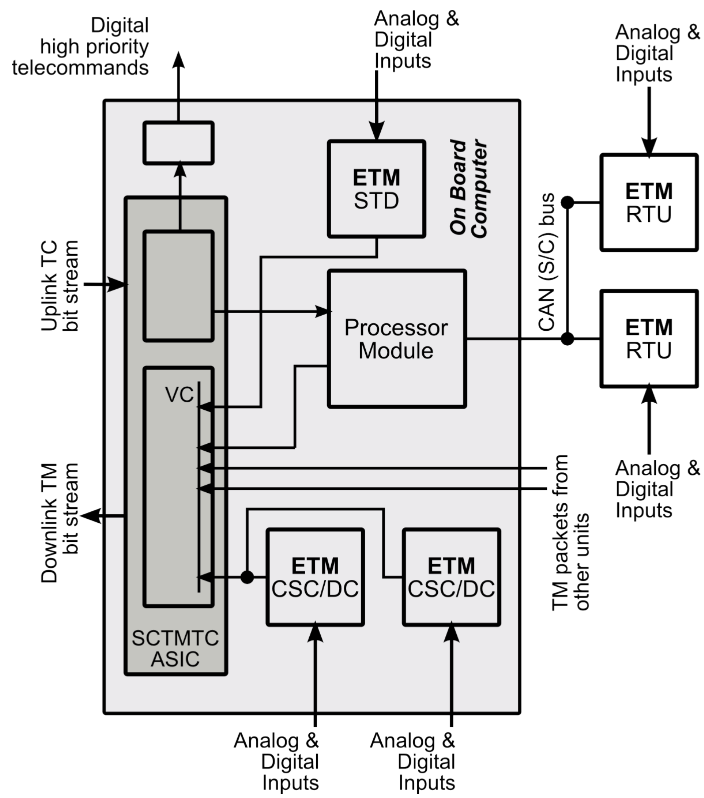


Fig. 1. ETM in possible S/C applications.

II. ETM Functionality

The ETM-ASIC autonomously performs the following tasks as soon as power is supplied:

- Sequential scanning and sampling of up to 32 differential analog (voltage or temperature) & 16 digital inputs
- Convert the analog inputs to digital values
- Format the sampled data into Space Packets
- Output the sampled formatted data either through CAN or PacketWire interface (IF).
- Receive commands when in RTU mode.

ETM has the ability to be configured with respect to the following functionalities

- number of channels that are sampled (4, 8, 16, 32)
- sample time interval ranging from 256μs up to 60sec.
- channel measurement type (voltage, temperature, 1 bit ADC-suitable for sampling digital signals through the analog channels) defined per channel group. Channel group 0 consists of the channels0-3. Channel group 1 consists of channels 4-7. Channel group2 consists of channels 8-15. Channel group 3 consists of channels 16-31.
- sample logic: nominal sampling or sampling in case of a change in a digital input or after 60 sec.
- generated packet contents (error contrlol-CRC, time of origin (TOS), etc)
- digital communication interface (PacketWire, or CAN). This configuration basically selects the essential telemetry and remote terminal functionalities.

III. Circuit Description

The block diagram of the ETM ASIC is shown in Fig. 2.

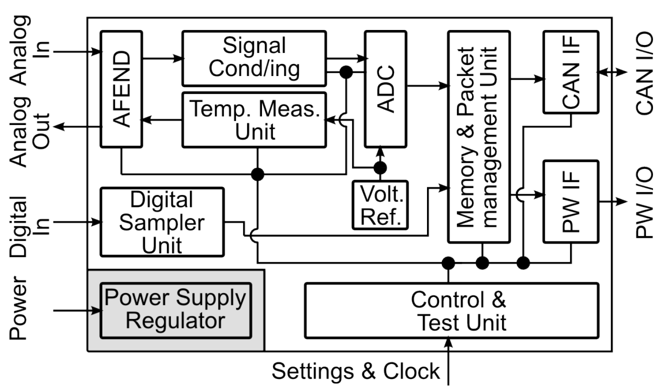


Fig. 2. Block Diagram of the ETM ASIC.

It consists of:

- an analog front end mux/demux hat directs the 32 analog inputs to the ADC and also selects the temperature sensors that will be biased by the ASIC.
- a signal Conditioning Unit
- a temperature measurement unit which directs a constant current to the external temperatures sensors
- a 12 bit digitally auto zeroed ADC
- a digital Input Sampler capable of handling differential inputs
- a voltage reference unit
- a memory unit
- a space Packet Generation unit
- a PacketWire IF
- a CAN IF
- a Control and Test unit
- a power supply regulator used to power the core of the device from the I/O power supply of 3.3V.

A. *The on chip power supply regulator*

The ETM ASIC utilizes two internal voltage regulators that produce the 2.5V core voltage (analog and digital) power supplies. The block diagram of the regulators is shown in Fig. 3. Linear regulators are used since the loads presented by the ETM core are not large 2-3mA in the analog section and 1-1.5 mA in the digital section. In addition due to special care in the digital design the transient loads are no more than 20mA thus easing the requirements

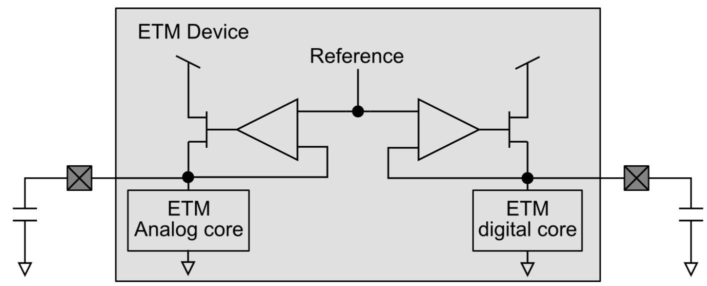


Fig. 3. Block diagram of the ETM power supply regulator unit.

B. *The Sensor Bias Unit*

The Sensor Bias Unit is utilized so that ETM can measure temperatures by sourcing a temperature and power supply independent current to a PRT or NTC temperature sensor and then by quantizing the voltage developed on the sensor [1]. The current is generated an external low temperature coefficient resistor and a current source. The block diagram of the temperature measurement unit is shown in Fig. 4.

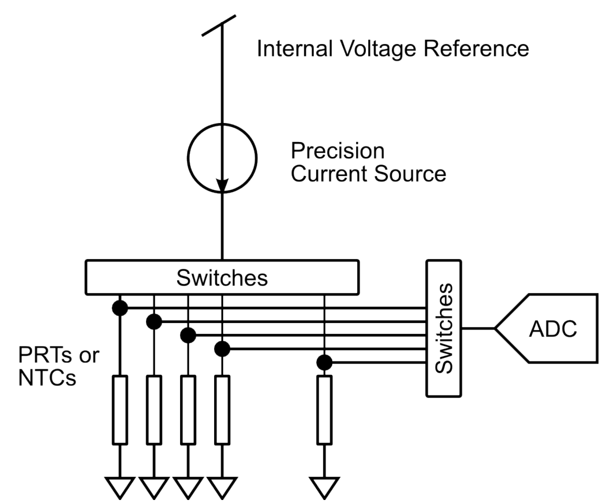


Fig. 4. Block diagram of the ETM temperature measurement unit.

C. *The ADC*

ETM uses a 12 bit digitally auto zeroed ADC based on the successive approximation topology. The ADC is capable of sampling full scale differential inputs.

D. The voltage reference

ETM uses a second order temperature compensated voltage reference.

E. The digital sampler

The digital sampler is used to sample differential digital signals. The block diagram of the digital sampler is shown in FIg. 5.

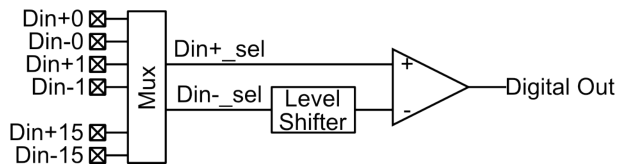


Fig. 5. Block diagram of the digital sampler used in the ETM ASIC.

F. The digital section

The digital section of the ASIC has been designed in such a manner so that low power performance and low noise interference to the analog subsystems are achieved [2]. Clock gating, guarding isolation as well as other techniques were employed to achieve these goals. In Fig. 6 a series of 1024 ADC samples at 2ms sampling time interval are presented while the device communicates through it's CAN interface. The ADC uses it's internal voltage reference.

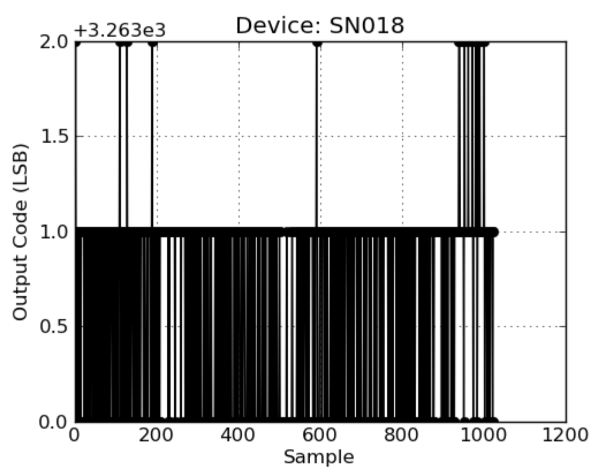


Fig. 6. 1024 consecutive ADC samples at the worst case temperature of -55°C with the device using the CAN interface for communications. The main source of noise is the quantization noise.

IV. Results

The die has a size of 5.2x5.2mm^2. The device has been fabricated in IHP SiGe 0.25μm CMOS technology through an multi project wafer (MPW) run. The resulted yield in the FM devices is 68%. A typical ADC integral non linearity (INL) curve is shown in Fig. 7.

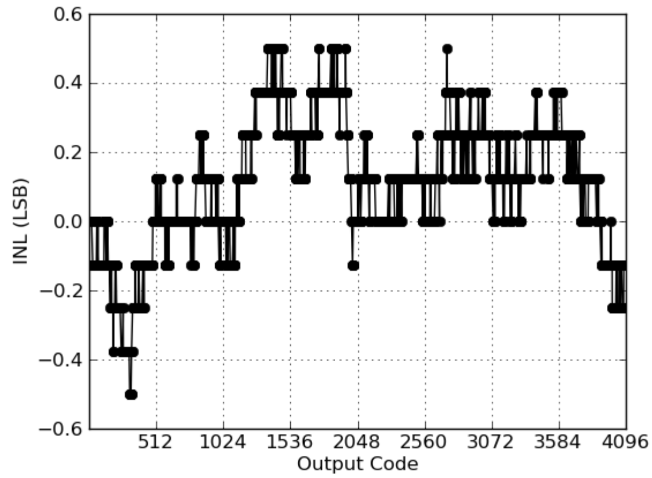


Fig. 7. Typical ADC performance

A. Power Consumption

The power consumption of the ETM device is less than 15mW under all operating conditions. In table I. As it can be seen the worst case power consumption is 14.85mW. For essential telemetry applications (STD configurations) the worst case power consumption is 10mW.

TABLE I
POWER CONSUMPTION OF THE ETM DEVICE AT VARIOUS CONFIGURATIONS. IN ALL CASES THE DEVICE IS POWERED WITH A SINGLE 3.3V POWER SUPPLY.

Oscillator Conf.	Measurement Type	Interface Conf.	Power Consumption (mW)
Ext	Voltage Only	STD	8.91
Int	Voltage Only	STD	10.56
Ext	Voltage Only	RTU	9.9
Ext	Voltage &Temperature	RTU	13.2
Int	Voltage & Temperature	RTU	14.85

B. Total Ionizing Dose-TID

Five EM and ten FM devices were irradiated up to 1MRad at the ESTEC Co-60 Facility. In this section results from the TID test campaign are presented.

1) Leakage Current variation due to TID: The leakage current increase with TID for the 10 devices irradiated is shown in Fig. 8. As it can be seen, the increase starts at 50KRad and continues up to 300-700 KRad depending on the device. From this point the leakage current starts to decrease again. At all points the increase in the leakage current did not affect the performance of the device.

2) The Voltage reference: For all ten devices tested the temperature coefficient of the voltage reference increased by 2-5 ppm/°C. However such an increase is adequate for a 12 bit ADC.

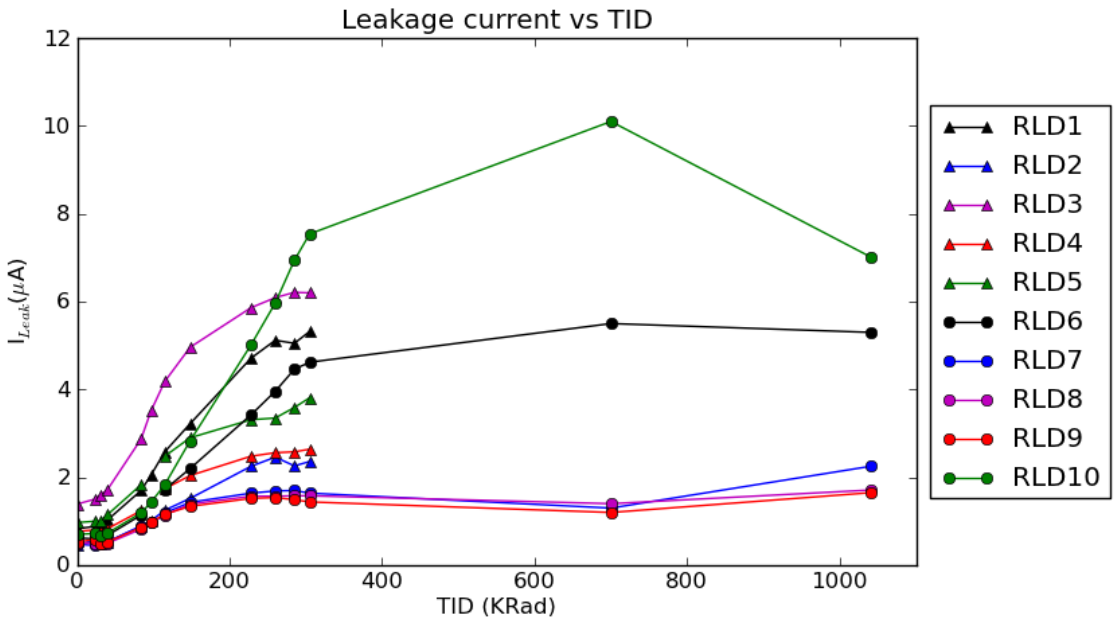


Fig. 8. Leakage Current versus TID for the 10 irradiated ETM devices.

3) The ADC: The auto zeroing function of the ADC restores the INL curve and compensates for the offset developed in the comparator. In FIg. 9 the INL of a device irradiated up to 1 MRad with no auto zeroing and with auto zeroing is presented.

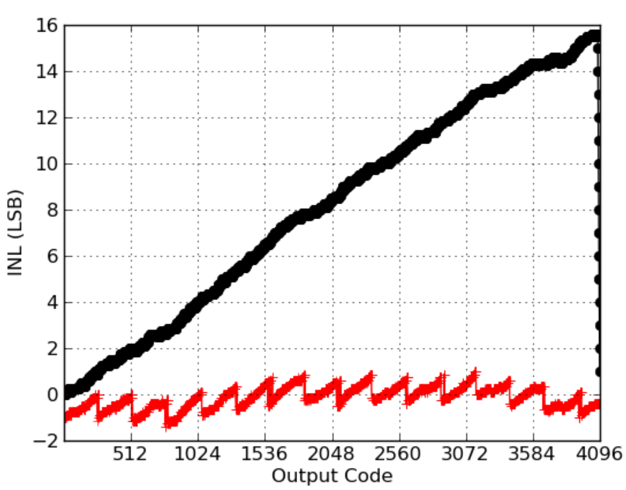


Fig. 9. INL of the ADC at 1 MRad with and without digital auto zeroing. The auto zeroing algorithm restores INL back to ±1 LSB even at 1 MRad.

4) Internal Oscillator Performance: The performance of the internal oscillator with respect to TID is shown in Fig. 10. The oscillation performance is adequate for essential telemetry applications.

5) Digital Sampler: The threshold shift of the digital sampler due to TID over the entire negative input range is shown in Fig. 11. As it can be seen the threshold variation with TID is less than 20mV, which does not affect at all the functionality of the unit. The delay of the digital sampler within 20mV from the switching point has been increased from 10 to 12ns. However, this increase does not affect the performance of the device which runs with a nominal clock of 16MHz.

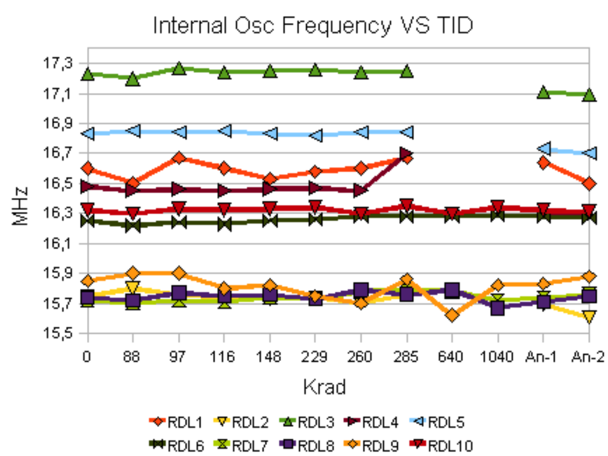
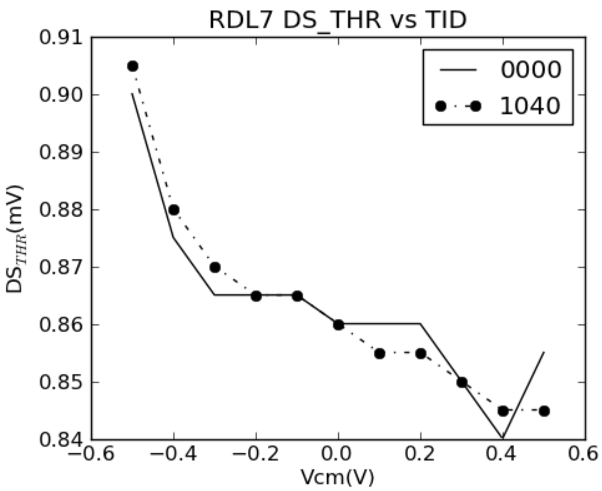
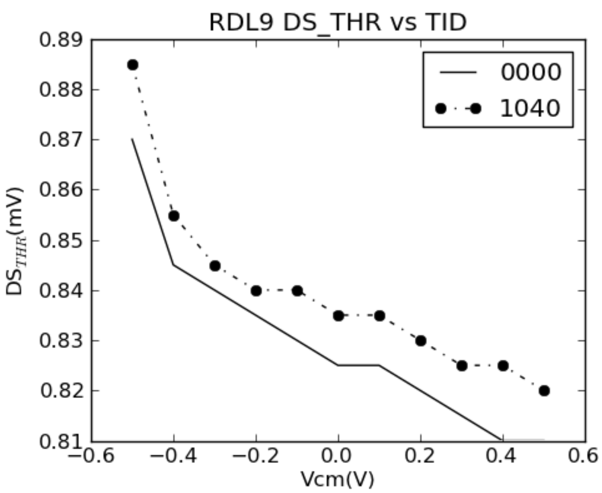


Fig. 10. Internal oscillator performance versus TID.

6) The temperature measurement unit: The most critical parameter of the temperature measurement subsystem with respect to TID is the offset of the current source amplifier. In Fig. 12 the offset drift of the current source amplifier due to TID is presented. As it can be seen, the largest drift at 1 MRad is close to 1mV. This drift would result to a temperature measurement error of less than 0.4°C at 125°C assuming a



(a) Device with normal shift



(b) Device with maximum shift

Fig. 11. Digital sampler threshold shift due to TID over the entire negative input range.

PT1000 temperature transducer. This error is the worst case error and is acceptable for most applications. It should be noted that at 300 KRad the error is not measurable.

7) The Digital section: The digital section performance was not affected by TID. The operating current per MHz was not changed by more than 0.1%. the maximum operating frequency was reduced by 5%. However, this reduction is covered through adequate margins in the design.

8) The on chip voltage regulator: The TID performance of the on chip power supply regulator is shown in Figs. 13 and 14. As it can be seen the TID developed offset of the digital power supply regulator is larger than that of the analog one. The voltage drop (synchronous with the master clock) of the digital voltage regulator was not affected by TID in a significant way. All irradiated devices exhibit a voltage drop increase of less than 1mV.

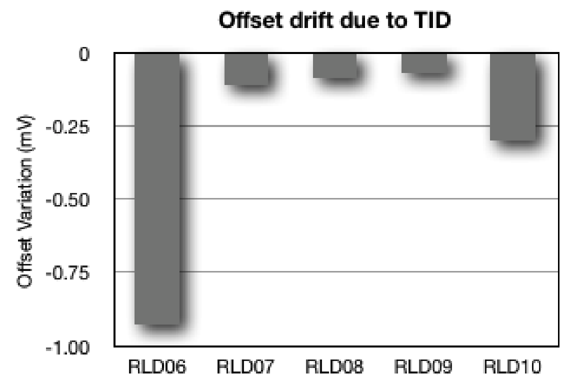


Fig. 12. Current source amplifier offset drift due to TID.

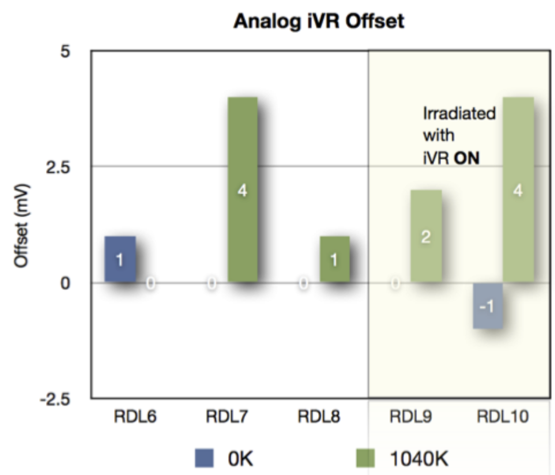


Fig. 13. TID induced offset in the amplifier of the internal analog power supply regulator.

C. SEE

Single event effects (SEE) tests have been performed on both the EM and FM models (3 devices from each run). On

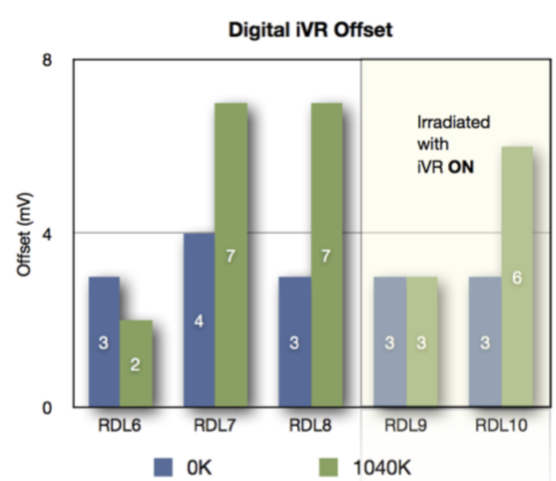


Fig. 14. TID induced offset in the amplifier of the internal digital power supply regulator.

the FM models the power supply of the device was set to 2.2V (300mV below the nominal operating voltage of 2.5V).

1) Single event latch-ups-SELs: The ETM devices was tested up to an LET level of 67 MeVcm^2/mg for SELs at a die temperature of 85°C. No SELs were observed.

2) Single event upsets-SEUs: The achieved cross section for both EM and FM devices is shown in Fig. 15. As it can be seen the LET threshold (LET$_THR$) for the power supply of 2.5V is at 57 MeVcm^2/mg while for the power supply of 2.2V is at 40 MeVcm^2/mg.

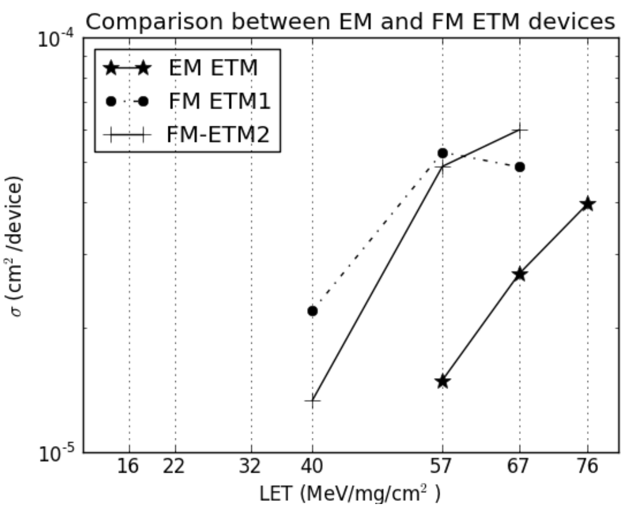


Fig. 15. Cross Section of the EM and FM ETM devices. The data from the FM device are for power supply of 2.2V.

3) Single Event Transients-SETs: The voltage reference of the device was tested for SETs. No SETs were recorded for an operating current of 200μA.

V. Conclusion

In this paper a novel telemetry acquisition ASIC that can also be used as a miniaturized RTU device has been presented. The power consumption is 15mW including the PT1000 current. This ASIC has the potential to replace discrete components in future missions, thus reducing mass, weight, power and complexity. The device can withstand 1MRad of TID and is immune to SELs up to an LET level of 67 MeVcm^2/mg. The SEU cross section is at 57 MeVcm^2/mg at the nominal core power supply of 2.5V and falls to 40 MeVcm^2/mg at the power supply of 2.2V.

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References

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