6th ESA Conference on Micro & Nano Technologies for Space Applications
ESA/ESTEC, Noordwijk, The Netherlands

Single-chip Generic Sensor Interface Mixed-Signal Platforms for Space Applications

Sergio Saponara[&], Luca Fanucci[&], Iacopo Del Corona[&], Esa Petri[*],
Marco De Marinis[^], Gianluca Casarosa[#], Bruno Sarti[#]
[&]Dept. Information Engineering, University of Pisa, Pisa, Italy
[*]Microelectronic Systems Division, Consorzio Pisa Ricerche scarl (CPR-TEAM), Pisa, Italy
[#] ESA/ESTEC/TEC-TCE, Noordwijk, The Netherlands
[^]SensorDynamics AG, Navacchio (Pisa), Italy
{s.saponara, l.fanucci, iacopo.delcorona}@iet.unipi.it, esa.petri@cpr.it,
mdm@sensordynamics.cc, {g.casarosa,b.sarti}@esa.int

Abstract- This paper discusses the new trends of sensor interfacing and acquisition for space applications. The design of a mixed-signal generic sensor interface architecture, integrated in a single chip, is proposed as a viable and suitable solution. The generic sensor interface architectural paradigm has been already assessed in the automotive scenario bringing advantages in terms of costs and flexibility with good results in terms of performance. Currently a research activity is started as a first step to extend this paradigm also to Space applications, both on-board satellite or ground spacecraft testing.

Keywords: Generic Sensor Interface (GSI), System-on-chip (SoC), Microelectronics, Mixed-signal design, on-board data handling, SpaceCraft (S/C) testing

I. INTRODUCTION

In the space scenario, a key aspect for future scientific missions is the development of low mass, low weight and low power consumption electronics, sensors and acquisition units, easily integrated in autonomous or semiautonomous exploration vehicles. On the other hand also higher levels of reliability, computational power and reusability are required for the electronic systems. These trends for on-board satellite platforms can be addressed with integrated solution, i.e. moving towards System on a Chip (SoC) mixed-signal platforms.

A miniaturization process for sensors and acquisition units shall also be of interest for on ground applications such as the testing and verification phase where a SpaceCraft (S/C) has to be interfaced with ad-hoc equipment. Conventional electromechanical sensors are not suited for such applications due to the constraints in terms of cost (mass, dimensions), power consumption and reliability. The trend is toward MEMS (Micro Electro Mechanical System) sensors, which drastically cut the area, cost and power consumption of the system. However, MEMS require a complex electronic signal conditioning chain, e.g. output filtering, amplification, linearization, modulation and input stimuli generation. To solve this issue a performing and optimized sensor acquisition interface is required. In order to reduce the development time and share the development costs on several projects the same acquisition interface should be capable to manage a wide range of sensors such as thermal sensors, accelerometers or strain gauges [1-3] based on different detection effects (e.g. capacitive, inductive, resistive)

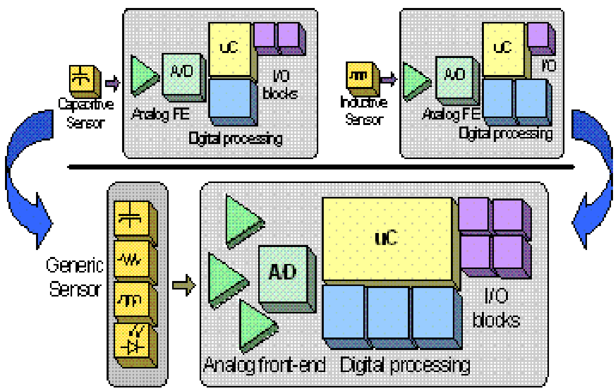

Figure 1: From Multiple Single-sensor Interface Circuits to a Generic Sensor Interface Mixed-Signal Platform

II. THE GENERIC SENSOR INTERFACE APPROACH

To solve the above issues the Dept. of Information Engineering - University of Pisa, in close collaboration with the Microelectronic Systems Division of Consorzio Pisa

Ricerche (CPR–TEAM) and SensorDynamics AG, is investigating the design of Generic Sensor Interfaces (GSI). The basic idea, as sketched in Figure 1, is the replacement of multiple interfacing and acquisition circuits, dedicated to a specific sensor, with a Generic Sensor Interface mixed-signal platform. The platform is based on the single chip integration of configurable digital and analog blocks supervised by a microcontroller.

The analog part is the front-end section of the chip, designed to be reconfigurable, and internally includes the blocks necessary for the acquisition and the conditioning of the sensor signals. The digital section comprises: a wrapper with ADC and DAC channels to communicate with the analog module; a Digital Signal Processing (DSP) hardware chain that performs basic operations of filtering and signal mixing; a microcontroller that processes software routines adapted to each specific sensor, to implement advanced DSP operations. This embedded system is completed by on-chip memory resources and peripherals for I/O interfacing. Nowadays, the electronic circuitry for on-board-processing (both payload and house-keeping operations) is typically oriented to integrated solutions, and in this context the GSI approach can help to develop a flexible, low cost and low power sensor interface. In order to achieve an easy technology scaling the GSI platform moves all signal conditioning and elaboration in the digital domain and leaves the analog domain in charge only of the basic sensor operations. Indeed digital circuitry can be scaled easier than analog circuitry in submicron low voltage supplies CMOS technologies.

In the framework of the collaboration between University of Pisa, CPR-TEAM and SensorDynamics AG the GSI paradigm has been successfully applied in the automotive field for interfacing gyro sensors, GAS sensors and magneto-resistive sensors. The results of the GSI application to the automotive fields are reported in literature [4-8].

Fig. 2 shows the GSI mixed-signal platform presented in [4,5], which features 4 analog input channels, a dedicated DSP chain for filtering, the modulation, the demodulation, a digital Phase Locked Loops (PLL) and numerical controlled oscillators (NCO), SPI and UART serial interfaces, a 32-bit non fault tolerant SPARC V8 embedded processor.

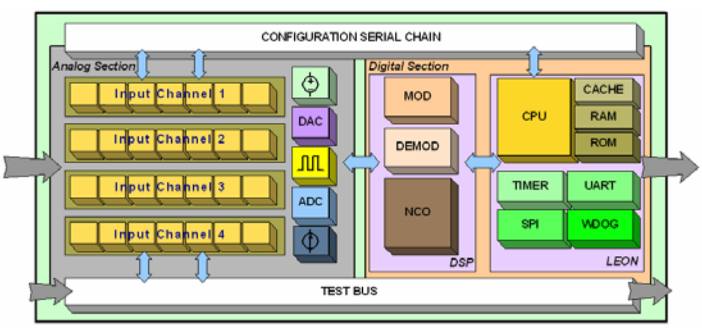

Figure 2: Mixed-signal architecture of 4 analog channels GSI platform [4].

III. THE GSI APPROACH FOR SPACE APPLICATIONS

The automotive experience related to GSI systems offered us a good basis to start from, to adapt the same approach to the needs in Space applications. Due to the different requirements of automotive applications with respect to the space field the already developed GSI solutions can not be reused and a further work is required. A list of the necessary adaptations still to be performed is reported hereafter:

The embedded processor should be based on a fault –tolerant CPU compliant with space requirements, as example the ERC32 processor or more performing macrocells such as the LEON-2 fault tolerant or the new LEON3 platform. To be noted that fault tolerant versions of the well-known ARM architecture are announced in the literature and in the future can be a suitable alternative to LEON processors.

For the on-chip memories error detection and correction (EDAC) techniques have to be adopted.

Sensors needed in space applications (on-board satellite or in ground S/C testing) are in general different from those adopted in automotive applications and hence it can occur that the mixed-signal architecture, particularly the analog front end, has to be modified.

For the communication with off-chip devices and particularly to the main host control unit (CU) space-compliant protocols and interfaces have to be adopted. Among them, the most diffused are SpaceWire interfaces/routers [9,10] for high-rate data transfers, CAN or MIL-STD 1553 for low data rates.

From the technology point of view the GSI platform has to be mapped on radiation-tolerant technologies. Indeed current implementations of the GSI for the terrestrial automotive field are integrated in CMOS or Bipolar-CMOS-DMOS technologies not space qualified. In space there are different rad-hard technologies, available with different grades of tolerance to radiation: total ionization dose (TID) or single event effects (SEE). As example there are Field Programmable Gate Arrays (FPGAs) like the RTAX anti-fuse family from Actel or reprogrammable XQ family from Xilinx, or rad-hard CMOS libraries, e.g. from ATMEL and recently also from STMicroelectronics.

Obviously the evaluation of the required tolerance to radiation effects, TID or SEE, depends on the specific project and mission. Therefore for the technology mapping of GSI platforms two scenarios have to be considered:

- mapping the architecture on a specific space technology (this scenario allows a higher rad-tolerance but also costs since the technology is not shared with other applications such as avionic or automotive).
- mapping the architecture on a commercial technology and improving the tolerance to radiation by proper architectural solutions or layout design rules or proper chip packaging (this scenario allows a radiation-tolerance that, although not maximal, can be suitable for a lot of space applications while reducing cost since the technology is shared with other applications).

Finally, from the testing point of view specific characterization phases of the space field have to be applied to the platform.

Given the above considerations on the rework to be done to implement the GSI approach in space a possible architectural modification is sketched in Figures 3 and 4 and briefly reviewed hereafter. The system is conceived to perform all signal conditioning and elaboration in the digital domain and let the analog domain in charge of the basic sensor operations. The digital section includes a LEON2 CPU (migration to LEON3 is foreseen), suitable for S/C missions, a wrapper to the analog module and a specialized DSP chain. Space-specific I/O peripherals are adopted, such as SpaceWire interfaces for high-rate data transfers. A SpaceWire router is also under development to integrate the GSI platform in complex control systems. Special care is devoted to EDAC design.

The use of the GSI platform in Space systems presents several advantages. The first one is cost reduction, because digital components are cheaper than analog ones, especially in radiation hardened technologies. Moreover the continuous scaling of CMOS technology and supply voltage offers advantages to digital circuits but represents an hard design challenge for analog circuits. Another benefit of a GSI platform is its flexibility that makes it suitable for different kind of sensors. This is achieved by integrating in the system a set of programmable function-generator blocks, easily configurable via software. Moreover, additional general purpose peripherals, such as SpW links, permit to widen the range of applications of the system.

Currently a collaboration between University of Pisa and Engineering Services Section (TEC-TCE) of the Test Centre Division of ESA/ESTEC is starting [11], focused on the implementation of microelectronic devices for environmental testing of S/C. This study aims at the development and characterization of a multi-sensor platform able to interface a whole set of sensors previously selected. The set of sensors shall be suitable for vibrations and thermal tests in harsh environment and therefore should include accelerometers, strain gauges and thermal sensors. A demonstrating breadboard based on COTS (Commercial Off-the-Shelf) Components is foreseen.

IV. Conclusion

In conclusion, the GSI architectural paradigm has been already assessed in the automotive scenario bringing advantages in terms of costs and flexibility with good results in terms of performance. Currently a research activity is started as a first step to extend the GSI paradigm for Space applications

Acknowledgment

The contribution to GSI development of M. Tonarelli, C. Rosadini, A. Gianbastiani, A. Rocchi, A. Renieri, F. Iozzi, M. Melani, F. D'Ascoli, C. Marino from Sensor Dynamics AG is gratefully acknowledged.

References

[1] MEMS Accelerometers Si-Flex-3000L and Si-Flex-1500S: See datasheet http://www.colibrys.com/e/page/337/

[2] Thermal sensors: Family Pt100 and PT1000: see http://www.temperature-sensors1.com/

[3] Strain gauges HBM SG/K series: see www.hbm.com

[4] D'Ascoli, F.; Iozzi, F.; Marino, C.; Melani, M.; Tonarelli, M.; Fanucci, L.; Giambastiani, A.; Rocchi, A.; De Marinis, M.; "Low-g Accelerometer Fast Prototyping for Automotive Applications", IEEE Design, Automation & Test in Europe Conference (DATE 07), 16-20 April 2007

[5] Iozzi, F.; Fanucci, L.; Giambastiani, A.; "Fast Prototyping Flow for Sensor Interfaces", IEEE PRIME 2006, 12-15 June 2006, pp. 393 – 396

[6] Bacciarelli, L.; Lucia, G.; Saponara, S.; Fanucci, L.; Forliti, M.; "Design, testing and prototyping of a software programmable I2C/SPI IP on AMBA bus", IEEE PRIME 2006, 12-15 June 2006, pp. 373 – 376

[7] Fanucci, L.; Giambastiani, A.; Iozzi, F.; Marino, C.; Rocchi, A.; "Platform based design for automotive sensor conditioning", IEEE Design, Automation and Test in Europe Conference, DATE 2005. pp. 186 - 191 Vol. 3

[8] De Marinis, M.; Fanucci, L.; Giambastiani, A.; Reneiri, A.; Rocchi, A.; Rosadini, C.; Sicilia, C.; Sicilia, D.; "Sensor platform design for automotive applications", IEEE Euromicro symposium on Digital System Design, 1-6 Sept. 2003, pp. 346 – 353

[9] Space engineering, "SpaceWire - Links, nodes, routers and networks", ECSS-E-50-12A, 24 Jan. 2003

[10] S. Saponara, M. Tonarelli, E. Petri, L. Fanucci, "Radiation tolerant SpaceWire Router for satellite on Board Networking", pp. 3-12, IEEE Aerospace and Systems Magazine, 2007

[11] M/E/D/2007/394/21, Statement of work "Microelectronic devices for engineering measurements and health monitoring system", Issue 1, Revision 1, September 2007

Figure 3: Possible architectural block diagram of a GSI mixed-signal platform for space applications including SpaceWire-based networking

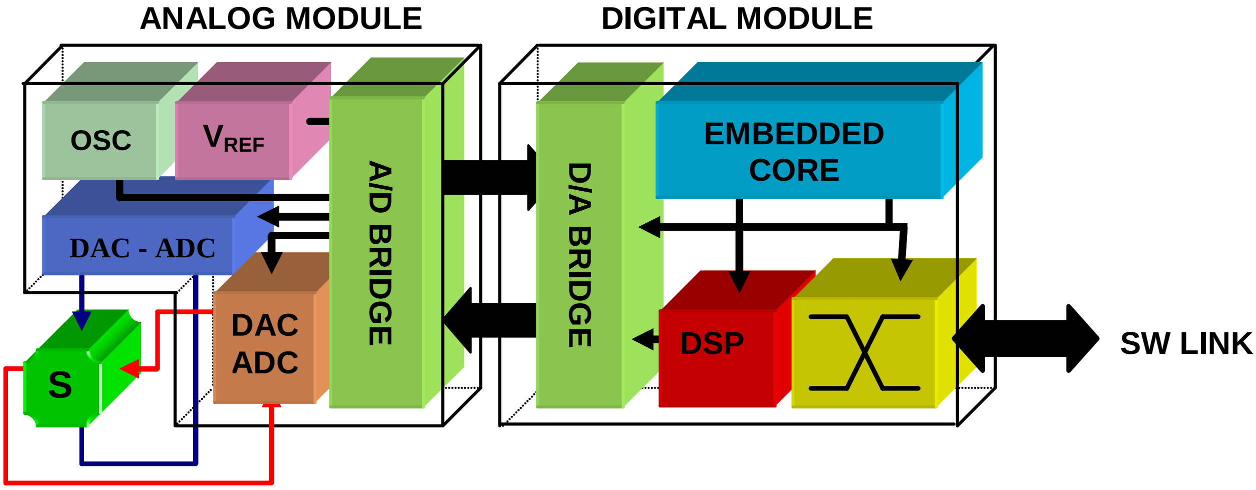

Figure 4: Focus on the digital part of a GSI mixed-signal platform for space applications including SpaceWire-based networking