Design challenges of a highly integrated SDR platform for multi-band spacecraft applications in radiation enviroments

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Abstract— **Software-Defined Radios (SDR) are already widely-used and often implemented in terrestrial Radio Frequency (RF) and wireless applications. Even the very conservative and slow changing space industry has identified the benefits of reconfigurable radio systems and uses SDRs on satellites and space vehicles. Nevertheless, those systems are mostly inapplicable for lower- and mid-class mission, or are often limited in performance, reliability and are only available for a specific frequency band. This paper presents the approach for a reliable and highly integrated Generic Software Defined-Radio (GSDR) platform design, using state-of-the-art RF transceiver devices to provide multi-band applications on spacecraft. Design challenges under radiation environments for this GSDR platform are discussed and results of a pre-evolution test under selected radiation condition on a prototype are presented.**

Index Terms—**Satellite communication, Software-Defined Radio (SDR), multi-band application, radiation-tolerant approach, radiation testing**

I. Introduction

In order to increase flexibility, data throughput and multi-band operation, Software-Defined Radios (SDRs) are becoming an important factor for Radio Frequency (RF) and wireless communication applications. The traditional definition of a SDR is the implementation of baseband algorithms into a Field Programmable Gate Arrays (FPGA) or Digital Signal Processors (DSP) to provide flexibility and opportunities in reconfiguration. The greatest advantage of SDRs is the reduction size, cost and power consumption, since data processing can be usually performed in a single devices. Unfortunately, most of those systems are limited to a specific frequency band, since the specific requirements of each application are mainly related to RF properties (down-/up conversion, RF bandwidth and signal strength) and the analog-digital conversion. The DLR Institute of Space Systems is working on this topic and has developed a first prototype for a highly integrated SDR platform with multi-band operation purposes on spacecraft. Goal of this SDR approach is to provide a reconfigurable and small platform, suitable also for lower- and mid-class spacecraft missions. An important aspect for SDR-based applications on satellite- and spacecraft missions is the reliability and accessibility, which strongly depends on the type of operated service and application. A telecommunication broadcast service or rescue application for example commonly has a high priority in accessibility and reliability, while a malfunction of experimental payloads is often acceptable. For this reason, the payload design may vary extremely in size, cost, performance and power consumption. Payloads and subsystems with a high claim of accessibility and reliability are designed with expensive Radiation Hardened (RadHard) devices and multiple redundancies, whereby experimental payloads are often designed on a Commercial Off-The-Shelf (COTS) approach and without any kind of redundancies. To achieve a Generic Software-Defined Radio (GSDR) platform with smaller dimensions, lower costs, short lead-times and higher performances, a COTS-based design seems more promising than using space qualified and RadHard devices. Moreover, for some key components, like the RF transceiver devices, specific solutions have to be found and are currently not available space qualified.

In this paper, we propose the design and its challenges for a highly integrated and reliable SDR platform for multi-band RF applications on a spacecraft. Radiation test results of a first prototype, in particular the performance of the used RF transceiver, are presented.

II. Background, Motivation and Challenges

The primary effort of these activities is to provide a generic platform, which can perform various frequency-band independent applications on a spacecraft, without a complete re-design by each mission. With the release of highly integrated RF transceivers the traditional definition of an SDR has been changed. Different manufacturers already identified the advantages and have released integrated radio systems, based on those transceivers, for development and educational markets [1]. Making the benefits of these integrated transceiver technology available for space would have a massive impact on future payload- and subsystem design, in order to configuration, flexibility, mechanical dimensions and mass properties. The biggest challenge for this technology-transaction to the space environment is to protect the system and their components against the harsh environmental conditions since such technologies are designed and qualified for the terrestrial environments. Therefore, an essential step is to characterize the potentially sensitive devices under space ambient conditions, especially ionizing radiation and high energy particles. To shape the focus of this paper, emphasis will be put on ionizing dose effects.

Particular focus is set for this publication on available highly integrated RF transceivers. The selected demonstrator for the GSDR platform approach is the AD9361, since the device itself allows the operation in a frequency range between 70MHz and 6GHz and supports many other promising features and specifications (sampling rate, RF bandwidth, low noise figure, etc.). The RF transceiver combines RF signal processing, converting, and digitization (and vice-versa) in a single device. The AD9361 uses two independent receiver and transmitter chains, whereby each transmitter chain contains two outputs and the receiver chain has three RF inputs. Thus, Multiple Input Multiple Output (MIMO) applications are also possible to operate. The in- and outputs are multiplexed and can be used to attach different, application-specific RF circuit for performance enhancement. An overview of AD9361 transceiver system is shown in Fig. 1.

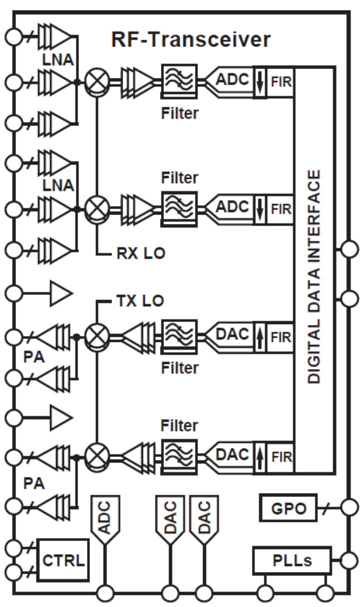

Fig. 1. AD9361 system overview in block design [2]

The AD9361 is based on a 65nm CMOS process, which makes the device sensitive to radiation effects. These conditions have been identified as one of the most critical issues in the system design, since all configurations of the RF transceiver are register-based and the major functionality of the SDR signal processing is integrated into this device.

However, plenty researches, e.g. [3], have demonstrated that a number of COTS devices are capable to withstand at least high TID. The main problem for COTS devices is that manufactures have different parts screening and qualification approaches and there is usually a non-visible process-documentation which disables the chance to identify parts of certain lots. For the AD9361, detailed information about fabrication is given by Analog Devices, as well as a notification service of process-related changes.

III. Pre-Evolution on a Prototype

To identify critical issues on selected system components and to verify the signal constraints, either on the analog, digital or RF side, a first prototype has been developed by the DLR. Fig. 2 shows a picture of the prototype before a Total Ionizing Dose (TID) test was performed.

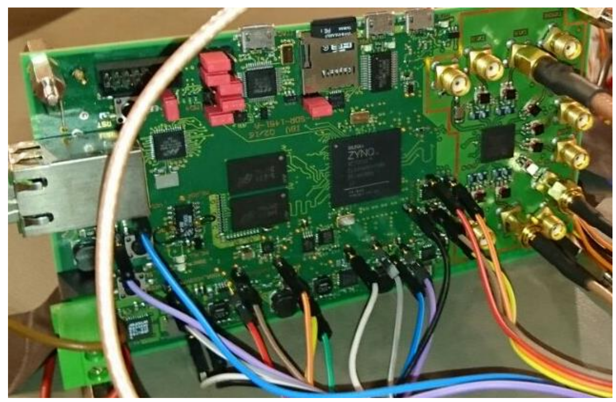

Fig. 2. GSDR Prototype board at TID test

TID degradation effects of devices are caused by gamma rays and charged particles that induce the critical ionization. To evaluate the system and components behavior under ionizing and radiation conditions, several parameters were monitored. The output voltage and applied current of the 5V DC main input voltage regulator is presented as an example in Fig. 3.

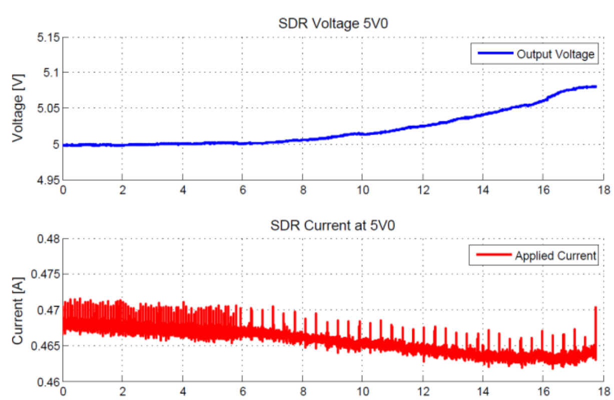

Fig. 3. Characteristic of the prototype 5V DC voltage regulator during TID test

At a total ionizing dose of 7.5kRad, the regulator output voltage starts to increase continuously until the voltage level reaches the maximum specified input voltage of the following powered devices. Other sub-voltage-regulators in the system show a similar ionization effects behavior and has been classified as medium-critical for further development activities. A deviation of other system components (e.g. memory resource, clocks etc.) specifications and functionalities during the TID test was not overserved. At a dose of 17.5kRad, the test-setup was modified with shielding-blocks for continuous irradiation only for the RF transceiver part. The AD9361 has shown good robustness against the irradiated ionizing dose. The test was performed without running a dedicated application and device-parameters were monitored at room temperature (21°C). For the receiver evaluation, a 1MHz sine-wave of 0dBm was transmitted at a carrier frequency of 900MHz, 2.4GHz and 5.5GHz, respectively, to test the complete supported frequency range of the AD9361. As an example, the receivers adjustable gain control over TID is shown in Fig. 4.

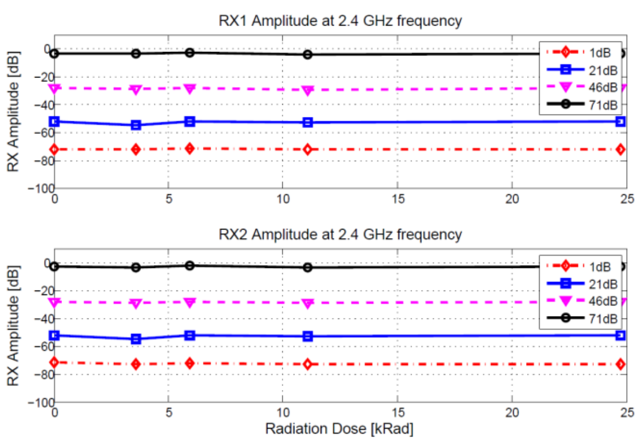

Fig. 4. RFIC adjustable gain control for 1dB, 21dB, 46dB and 71dB gain at a carrier frequency of 2.4GHz of Rx1 and Rx2

No significant gain-deviation on both receiver chains (RX1, RX2) was observed up to a total ionizing dose of 25kRad. Other receiver-related specifications like noise figure, Automatic Gain Control (AGC) performance or return loss (impedance) characteristics were also evaluated without any remarkable degradation effects. A test with modulated signals, to analyze the demodulation accuracy or receiver sensitivity was not performed during this test.

For the transmitters evaluation, similar test conditions were determined, which include the test of maximum output power stability at a 1MHz tone with a carrier frequency of 800MHz, 2.4GHz and 5GHz, the power control (adjustable attenuation) functionality and the

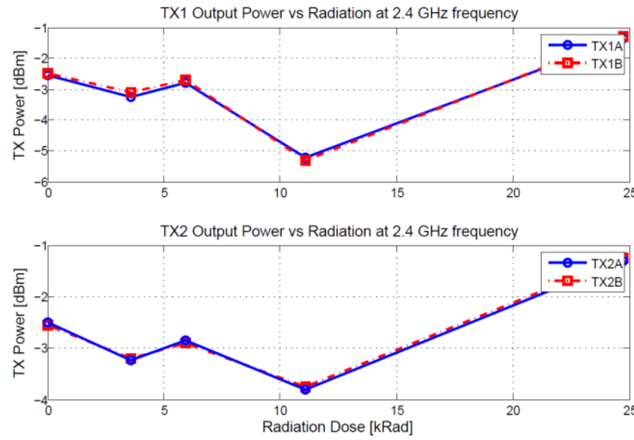

Fig. 5. RFIC maximum output power vs. TID of a 1MHz sine-wave at 2.4 GHz carrier frequency.

transmitters intermodulation distortions. In Fig. 5, the maximum output power of both transmitters, including cable-losses of ~10dB, is presented. The output power varies between -2.5dB and -3.1dB which is not assumed to be an effect of irradiation.

In Fig. 9 the results of a TX intermodulation test for different attenuation levels vs. TID is presented. The plots show the TX amplitude of the fundamental tones (1MHz and 2MHz), as well as magnitudes of the 3rd and 5th order, for three different TX attenuations (-1dB, -11dB and -21dB).

The results show that the intermodulation distortion does not change with increasing total ionizing dose, which proves that the TX amplifier linearity does not change during irradiation.

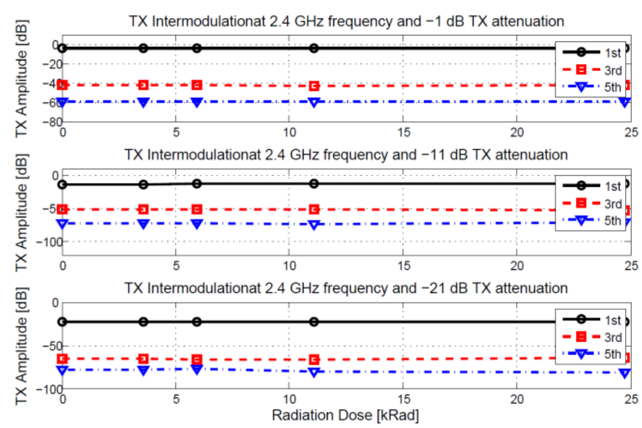

Fig. 6. RFIC TX intermodulation vs. TID for a 1MHz and 2MHz fundamental tone at 1dB, 11dB and 21dB attenuation and a carrier frequncy of 2.4 GHz.

The configuration of the RF transceiver during the irradiation to test the interfaces and general functionality of the unit, were also performed without any degradation.

IV. Conclusion

In this paper the system design of a highly integrated and generic SDR platform for multi-band RF applications on spacecraft, using state-of-the-art RF transceiver was presented. Challenges in the utilization of these RF transceivers were discussed and TID tests were performed on a prototype to characterize different selected devices under radiation conditions. In particular, the characteristics of the AD9361 as a RF transceiver demonstrator for the GSDR approach, was analysed up to a TID of 25kRad without any remarkable performance deviations.

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