A Reconfigurable, Radiation Tolerant S-Band Transponder for CubeSat Applications

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Abstract

Southwest Research Institute (SwRI) has developed a reconfigurable, radiation tolerant, communication system that addresses the needs for low-cost, quick turn spacecraft, as well as the reliability and resilience required in harsh radiation environments of higher orbit systems. The core of such a Flexible Communication Platform (FCP) centers on a Software Defined Radio (SDR) architecture providing S-Band (~2 GHz) communications. The Digital Processing Unit (DPU), complete with an onboard RF Front-end, fits in a 1U CubeSat form factor. A customizable, radiation tolerant RF front-end is available as a separate slice. The architecture of the DPU utilizes an SRAM-based FPGA with a combination of triplicated logic and Configuration Memory Scrubbing, specifically in an external RAD-Hard device, in order to mitigate the radiation susceptibility of the FPGA programming cells. The flexible design of the DPU allows rapid integration into multiple target mission architectures. When coupled with the radiation-tolerant RF front-end, the FCP is capable of communicating from LEO and MEO orbits using a variety of wideband signals and protocols.

Radiation Considerations

The functionality of SRAM-based FPGAs is defined by the bitstream loaded into its configuration memory. Both the configuration memory and the functional logic cells are susceptible to radiation effects. SEU's in the configuration memory do not necessarily result in functional errors, but they must be detected and corrected to prevent accumulation. Additionally, potential errors in the logic cells must be minimized. Ultimately, a combination of TMR and configuration memory scrubbing was used. The combination of the two techniques minimizes complexity and cost while maximizing overall mitigation strength.

Capabilities

Achievements

- Created a reference design for a radiation tolerant RF front end for an S-Band transceiver.
- Developed a reconfigurable processing unit for the S-Band transceiver which includes radiation mitigation provisions to ensure reliable operation in high radiation environments.
- Incorporated a SPA-S plug-n-play compatible interface to the processing unit.
- Implemented the FCP within a 1U CubeSat solution.

Receiver

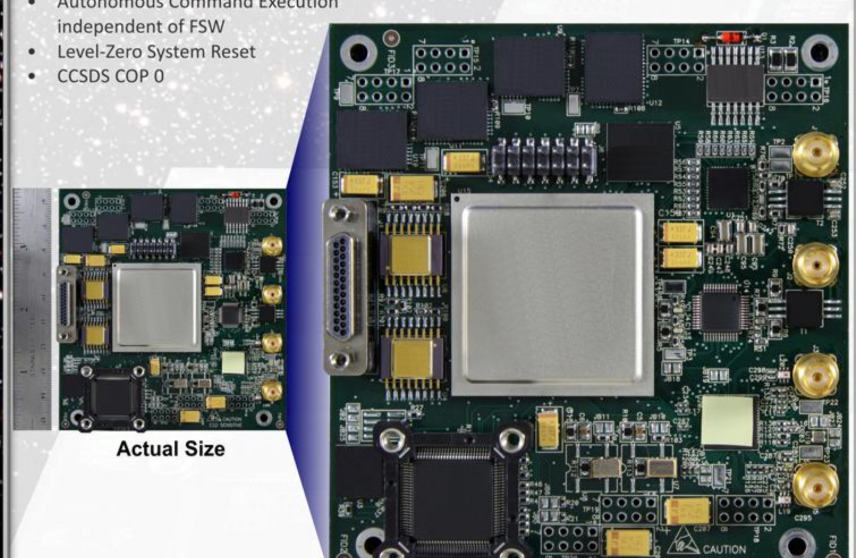
- Output Frequency: Fixed
  - 2200 to 2290 MHz
- Dynamic Range: 50 to -119 dBm
- Noise Figure: 5 dB maximum
- Input VSWR: 1.5:1, 50 ohms
- Acq Tracking Range: ± 160 kHz
- Modulation: BPSK, QPSK
- Command Data Rate: 2 to 64 Kbps
- Command Threshold (1E-7 BER): -110 dBm (max)
- Uplink rates up to 128Kbps
- Command Decode and Execution
- BCH Error Detect/Correct
- Autonomous Command Execution independent of FSW
- Level-Zero System Reset
- CCSDS COP 0

Transmitter

- Output Frequency: Fixed
  - 2025 to 2110 MHz
- Output VSWR: 1.5:1, 50 ohms
- Phase Noise: 2° RMS (max)
- Modulation: FSK
- Downlink rates up to 3Mbps
- Hardware based CADU formatting
- Autonomous Level-Zero Telemetry Collection
- Optional Convolutional Encoding

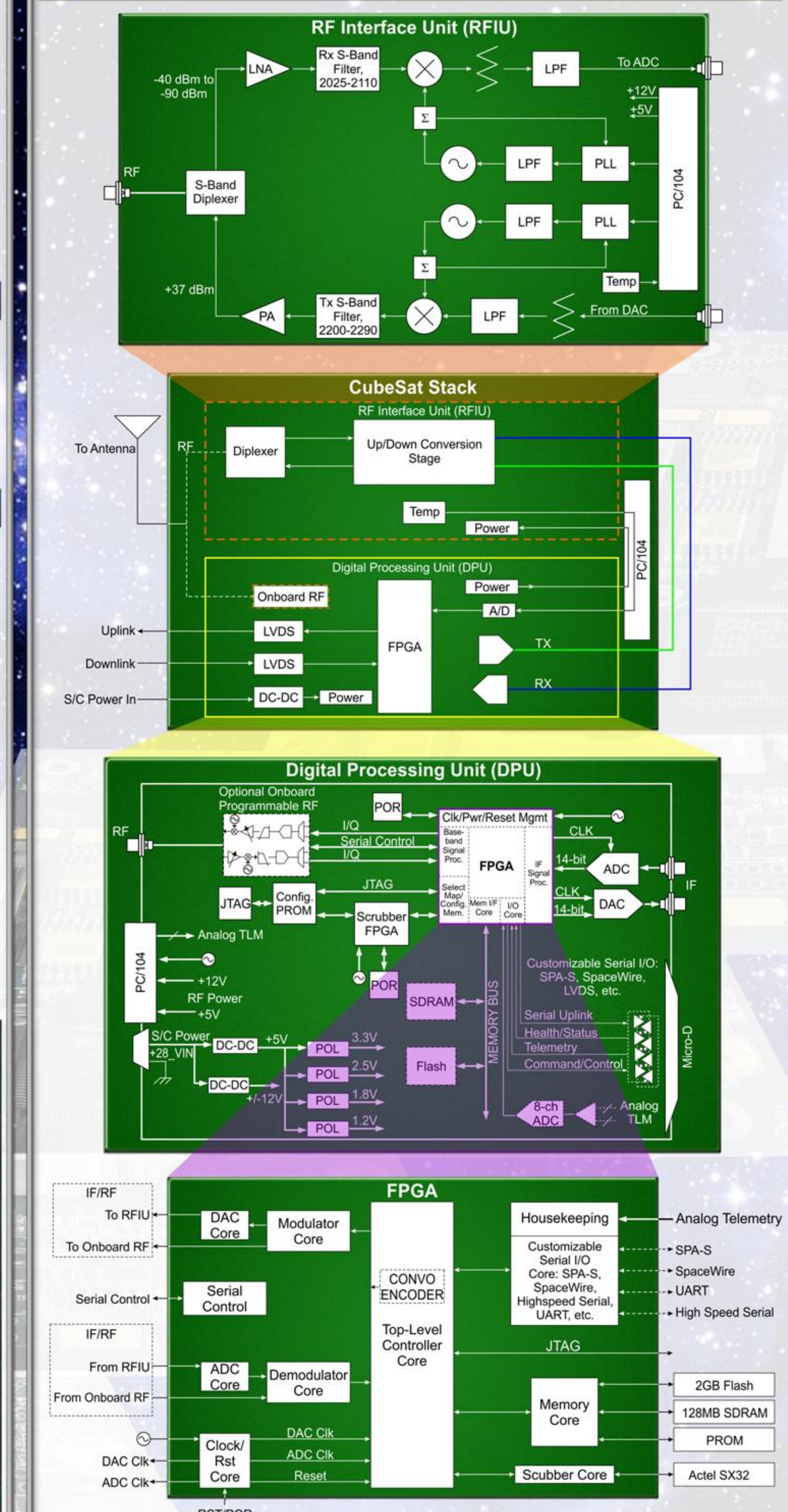
Applications

- Small Sats and CubeSats
- Intra-Observatory Communications



Actual Size

System Block Diagrams



Reconfigurable

The basic model for new low-cost, quick-turn mission classes utilizes in-advance hardware builds that have components on the shelf and available for quick deployment. To enable this development paradigm, reconfigurable components that can be rapidly developed with mission specific coding must be utilized. It is important to distinguish this capability from reconfigurable computing. Reconfiguration of the base system components in the FCP means adapting the modem and codec of the radio while maintaining a common software interface. The obvious solution for a reconfigurable radio utilizes SRAM-based FPGAs. However, these FPGAs have significant limitations in space-based systems due to possible radiation susceptibility of the FPGA programming cells. Manufacturers have recognized this limitation and are working closely with the aerospace community to develop mitigation strategies. Techniques such as automated Triple Modular Redundancy (TMR) and memory scrubbing have been studied as methods of increasing the radiation performance of the parts. To maximize radiation tolerances both mitigation methods have been implemented in the FCP.

Space Plug-n-Play Avionics (SPA)

Taking a cue from the commercial computer industry, the ORS (through AFRL) has established a Plug-n-Play standard for spacecraft to facilitate rapid integration of spacecraft components. This Space Plug-n-Play Avionics (SPA) paradigm has been implemented using the ESA SpaceWire physical protocol (referred to as SPA-S) for high bandwidth data (up to 200Mbps). The FCP will be fully SPA-S compliant. While these interfaces are being driven by the ORS, the CubeSat community will directly benefit from the inclusion of these technologies. In fact, the initial prototype SPA-S systems being developed by ORS are in a CubeSat 1U form factor. The SPA-S configured FCP will work seemlessly with SPA-S compliant systems.

Architecture

The target mission profiles chosen for the FCP drive the physical and interface requirements. Targeting CubeSat missions presents the most challenging form factor requirement. To fit within the CubeSat envelope, the FCP PCB can be no larger than 10cm x 10cm, fitting within a 1U slice. The preliminary architectural concept of the FCP is based around a multi-circuit board approach meant to fit within 1U of the CubeSat, specifically in the PC/104 form factor. All the electronics, including the DPU and an onboard RF Chip, can be included in a single board. A supplemental RFIU is available that provides customization of the RF front-end and radiation tolerance. The DPU provides spacecraft command and telemetry interfacing, available onboard RF front-end, and reconfigurable SDR algorithm resources (i.e. FPGAs, memory, embedded processing IP cores), while the RFIU provides a customizable RF front-end with oscillators, mixers, up / down conversion stages and amplifiers.

The DPU utilizes a PC/104 mechanical interface for input power. The serial data stream to the RF front-end is fully reconfigurable with a host of serial protocols, including SPA-S, standard spacewire, high speed serial, or UART, available from both an external connector and the PC/104 connector. One reason for this approach is to conform to the specification for the "CubeSat Kit Bus," established by Pumpkin, Inc. In this manner, the DPU can more readily integrate into a CubeSat Kit and receive serial I/O over the PC/104 connector. Additionally, the DPU provides all power conditioning for itself and the RFIU. In order to meet radiation requirements of higher orbits, all components were selected with drop-in, radiation-tolerant replacement parts available. Between the mitigation strategies to improve FPGA radiation immunity and a selection of radiation tolerant components, the FCP is capable of being deployed in both LEO AND MEO environments.

Conclusion

SwRI is pleased to introduce the Flexible Communication Platform (FCP) radio for LEO and MEO missions. Designed with both low-cost missions, including CubeSats and small satellites, and high-reliability missions situated in harsh radiation environments, including earth orbits above 750 km, the FCP is an ideal solution for high bandwidth downlink requirements and fast intra-satellite communication links. Based on a standard PC/104 form factor, the FCP takes full advantage of reprogrammable FPGAs to provide a host of modem and codec options and employs strategic radiation mitigation techniques, including TMR and external configuration memory scrubbing. All components have radiation-tolerant counter parts that can be used as drop-in replacements for a high-reliability platform.

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