Software Defined Radio (SDR) Payloads for Microsatellite Missions

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Abstract

The application of software defined radio (SDR) payloads on micro-satellite platforms is a recent technical innovation. The SDR approach provides a reconfiguration capability for functional flexibility and upgrade during the mission lifetime under the operational and resource constraints of the micro-space environment. An advanced SDR implementation will be flown as a payload on the CSA/DRDC Maritime Monitoring and Messaging Micro-Satellite (M3MSat) mission, and development of a second-generation SDR for future missions is underway. This paper will summarize the current status of COM DEV and industry developments in micro-satellite based SDR systems, provide a top-level technical architecture, and describe some of the potential applications for satellite wireless packet messaging communications.

Introduction

In past decades, the space industry has gone through significant changes in both services and technologies. Currently large GEO-based satellites dominate the space segment for providing FSS, MSS, DBS, and Broadband commercial services. These types of satellites are expensive (typically > $200M to build) and have long mission design life (typically 15 years).

However, both civil and military agencies have expressed increasing interests in launching smaller platforms especially LEO micro-satellites that can be flown either in single satellite mode or in form of constellations. Micro-satellites can provide operational flexibility and can be deployed much faster (from concept to launch in 12 to 24 months) and cheaper (typically less than $20M per satellite) than large satellites. To meet the high functional diversity and rich mission requirements for the LEO micro-satellites, a software defined radio payload platform is highly desirable.

One example of an SDR-based micro-satellite that COM DEV is currently working on is the M3MSat project. This satellite is the first part of a small multi-satellite constellation that will be used to collect AIS (Automatic Identification System) transmissions globally on a near real-time basis. The M3MSat, to be launched in first half of 2011, consists of an AIS Payload Electronics Module (AIS-PEM) to demonstrate the full capability of advanced spaced-based AIS technology developed by COM DEV, and a secondary communications payload to demonstrate a range of low data rate applications that can support Canadian civil needs as well as commercial requirements (the LDRS-PEM). The M3MSat configuration as shown in Figure 1 measures just 60 x 60 x 80 cm^3, and weighs only 75 kg. The M3MSat has an average DC power of 70W and allocated 15W average power consumption to either AIS-PEM or LDRS-PEM.

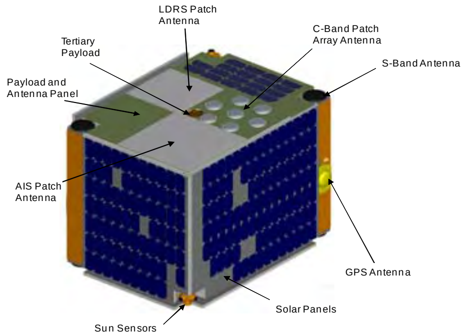

Figure 1(a): M3MSat Spacecraft

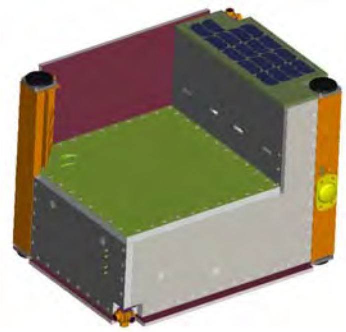

Figure 1(b) Payload Bay of M3MSat

SDR Technology in Space

This section includes a brief discussion on general SDR concepts before describing specific SDR applications for M3MSat.

A Software Defined Radio (SDR) is a radio in which some or all of the physical layer functions are software centric. In other words, the radio is implemented on a software-based re-configurable platform and can be used to support various functions and signal schemes. Such software based solutions have several very promising advantages. A reconfigurable system allows multiple missions to use the same hardware by loading different application software. The software for each system can be stored in memory and can even co-exist or execute concurrently if desired. In addition, software defined communications systems can be remotely configured or updated, allowing for inexpensive bug fixes, upgrades or optimizations. This is extremely important for a space-based system.

The growth of SDR technology is no doubt empowered by evolution of microelectronics, and continues to benefit from Moore's law. Figure 2 illustrates the exponential improvement in the key parameters of re-configurable DSP compute engines over the last 25 years in terms of cost, power, and packaging density as a function of processing power (in MIPS) – this is in general true for both FPGA and dedicated programmable digital signal processor (DSP) devices.

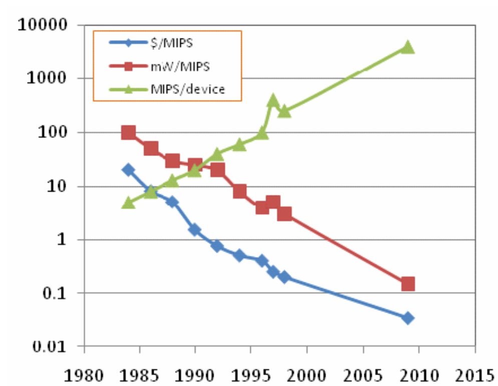

Figure 2: DSP Evolution in past 25 years

The dramatic improvement in DSP performance and cost is the key to enabling the evolution and development of SDR-based designs in future satellite systems, starting primarily in satellites with smaller platforms, especially in nano, micro, and small satellites in LEO orbits. Table 1 provides a partial list of software defined radio technology that has flown or is planned for a range of space missions, from demonstration nanosats and university smallsats to military smallsats, and even on a Mars mission, the Space Shuttle and the International Space Station. The applications supported by SDR are equally diverse and include maritime AIS signal reception, amateur radio communications, GPS reception, and surface-to-space and inter-spacecraft relay. It is expected that the utilization of SDR technology will continue to grow across spacecraft platforms and areas of application.

Table 1: Partial List of SDR Applications in Space Missions

Mission	Spacecraft	Organization	Comments
AMSAT P3E	Microsat (150 kg)	Radio Amateur Satellite Corp. (AMSAT)	SDR-based transponder (SDX/STELLA) for amateur radio communications, awaiting launch.
AprizeSat 3/4	Nanosat (12 kg)	SpaceQuest	SDR-based AIS receivers, launched July 2009.
ARISSat-1	Microsat (<100 kg)	Radio Amateur Satellite Corp. (AMSAT)	Odyssey SDR, scheduled for deployment from International Space Station in late 2010.
CANDOS	Space Shuttle (STS-107)	NASA Goddard Space Flight Centre, ITT Industries	SDR-based low power transceiver (LPT).
CHAMP	Smallsat (522 kg)	GFZ Potsdam, NASA/JPL	SDR-based Blackjack GPS receiver, launched July 2000.
CONNECT	International Space Station	NASA Glenn Research Centre	Experiments to advance SDR Space Telecommunications Radio Systems (STRS) standards.
GRACE	Smallsat (487 kg)	DLR, NASA/JPL	SDR-based Blackjack GPS receiver, launched March 2002.
Mars Reconnaissance Orbiter	Deep Space Probe (2,180 kg)	NASA/JPL, Lockheed Martin, CMC Electronics Cincinnati	Electra UHF SDR for communications relay with other Mars orbiters and landed vehicles.
SmartSat-1	Smallsat (273 kg)	Mitsubishi Heavy Industries, National Institute of Information and Communications Technology	Demonstration of Reconfigurable Communication Equipment (RCE), scheduled for launch in late 2010.
Sumbandila	Microsat (81 kg)	SunSpace, University of Stellenbosch (South Africa)	SDR-based amateur radio payload, launched September 2009.
TacSat-2	Smallsat (370 kg)	Air Force Research Laboratory, ITT Industries	SDR-based low power transceiver (LPT), launched December 2006.

With the ever-improving DSP technology, the role of SDR will continue to increase and evolve, with the line between SDR and analogue hardware moving closer to the receive and transmit antennas of the payload.

An example of this evolution can be seen in communications satellites. Historically comsat payload started with traditional bent-pipe designs and initially on-board digital processing was confined either to digital sampling, filtering and routing (Inmarsat I4, Thuraya, etc., i.e. digitally transparent designs). For these applications frequency down/up conversions were performed in the analogue domain and non-reprogrammable ASICs were developed to perform the digital functions. Some regenerative payloads have also been designed, built and operated such as SpaceWays, WorldSpace, etc. In these systems, the uplinked signals are demodulated, decoded (fixed Viterbi) and routed on a packet basis. As before frequency down/up conversions were performed in the analogue domain and non-reprogrammable ASICs were developed to perform the digital functions.

The emergence of SDR now allows for greater manipulation of the uplinked signals including; digital frequency conversions, adaptive modem/modcods, filtering, equalization, linearization; and steady improvements in the DSP ‘engine’ as described earlier allows these function to be performed over increasing processed bandwidths.

From Table 1, it is quite clear the implementation of SDR in space applications started with subsystem components in various space missions of experimental and short mission life nature, and progressed to main payloads of smaller platforms, ahead of applications on large satellites.

Microspace Constraints and M3MSat SDR Solution

One of the key requirements of smaller satellite missions is that they be built faster and cheaper than their large satellite counterparts. To a great extent this means trying to exploit building blocks that are standard and can be easily reconfigured for different applications. COM DEV sees that the re-configurability of the SDR technology over different hardware platforms, different missions, and during space missions is a highly attractive feature for micro-satellite missions and objectives

SDR payloads, while having many advantages, do face some challenges in Microsatellite payload applications:

1. Mass, power, and volume constraints for micro-satellites
2. Resource reservation is required to make SDR useful for potential update during mission or re-configurable for other missions
3. Bandwidth limit for remote software/firmware code update
4. Space radiation environment
5. What level of standardization SDR payloads should be adopted?

SDR requires a certain amount of resources to be reserved to support the potential future functionalities and flexibilities. For example, to make the SDR payload useful in supporting potential more complicated waveforms during a mission, a sizeable memory and possibly CPU/FPGA processing power, and DC power capability need to be reserved at the beginning of life (BOL) of the mission. That will directly translate to increased demands on the resources of the hosting satellite bus. With typical DC power capacity from 60W to 150W and typical mass from 10kg to 200kg for micro-satellite class, deciding the BOL margins for SDR versus costs and potential benefit is a challenging but critical task.

The flexibility inherent in SDR technology is constrained by the ability to upload new firmware to the satellite. Typically the command and control uplink to a LEO microsatellite has low bandwidth and low availability due to the limited contact time of the satellite with each ground station. Therefore the design of the firmware load structure must accommodate these constraints. Typical design choices include support of code fragments to allow “patching” of firmware, and highly optimized code frameworks.

Many re-configurable devices used to support SDR implementation, especially in micro-satellites which typically use many commercial off-the-shelf (COTS) components are sensitive to radiation in the space environment, and special considerations have to be applied, typically to include and carefully assess radiation environment for the mission, select parts using technology and processes less sensitive to radiation, design level mitigation, such as triple mode redundant (TMR) critical logics, periodic configuration scrubbing, periodic refreshing, and lastly radiation shielding.

In microspace applications, efficiency and simplicity are keys for success. Due to the different requirements and above mentioned constraints, SDR design choices in microspace do not necessarily mesh well with standard environments for SDR like Software Communications Architecture (SCA).

SCA has been a very pervasive driver for SDR development, in particular for military terrestrial applications. The goal of SCA is to standardize and create a common development platform for inter-operable military systems. The framework has considerable inherent complexity and overheads, such as vulnerability and need for large memory footprint and SEU tolerant RAM that do not lend themselves to low power, efficient and flexible satellite architectures. For example at SDR architecture level, as pointed out by NASA, a mandate to conform to POSIX (Portable Operating System Interface) diminishes its efficiency for some space applications [1]. In the long term, a space oriented SDR standard will still be beneficial. One such effort is the STRS (Software Telecommunications Radio System) being developed by NASA.

The SDR implementation for the AIS-PEM and LDR-PEM fall into Tier 2 of the five level definition by the SDR Forum [2], that is, a software defined radio with modulation and baseband processing in software, but allowing for multiple fixed-frequency/ fixed-function RF hardware. The processing power required to sample and generate RF at the antenna is not yet available. However COM DEV intends to use the knowledge gained on this development to research and consider the architectural options and pathways towards Tier-3/4 SDR solutions.

The payload consists of software configured RF front-end which features tuneable carrier frequency, and software defined digital processors for all advanced signal processing tasks. Transmitter power will be approximately 5 Watts, with limited, conservative linearization.

The digital platform consists of a CAN bus networked, high-speed DSP, implemented in a re-programmable FPGA and a 32-bit fault tolerant RISC microprocessor. Extensive memory resources are provided, including 8Gbyte of FLASH, 32 Mbyte of SDRAM and 128 kbyte of boot PROM. The two receive channels and the single transmit channel use ADC and DAC devices to sample and generate the IF signals. A selection of digital interfaces is provided to send and receive the processed data to and from the spacecraft platform and payload. These include SPI, HSDL (high speed data link), HKC (house keeping) and TTC. The SDR is capable of simultaneously processing sampled received IF signals, and generating and transmitting suitably modulated IF signals, to and from the RF/IF front end. The CPU runs RTEMS V4.8 Real Time Operating System (RTOS). This open source OS has extensive heritage on Space programs, including Mars Reconnaissance Orbiter. A Board Support Package (BSP) is provided with the SDR board to enable COM DEV to develop their own specific algorithms running on the CPU and DSP. The BSP consists of software drivers for the CPU, example SDR algorithm designs for the FPGA, and extensive documentation.

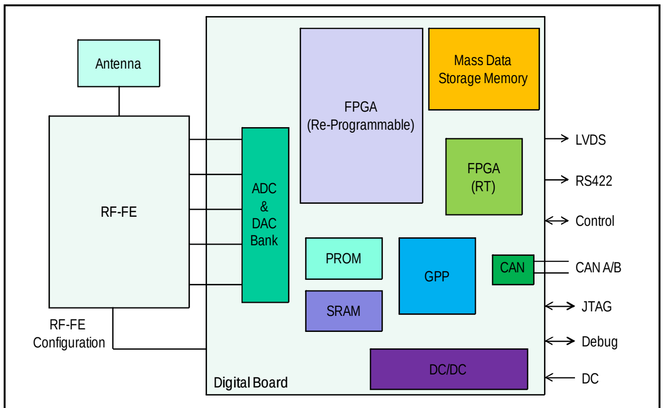

Figure 3: SDR Platform for M3MSat

SDR Applications for Microsat Missions

SDR microsatellite missions can support a wide range of communications applications in areas of Canadian and international interest. Applications envisaged for such a microsatellite communications systems should meet a number of characteristics to be well-suited to such a system,

1. data communications should be delay tolerant (non-real time, or sporadic connectivity),
2. Low amount of data required per message (bytes to 100's of bytes), (or higher for future generations and evolution of the SDR and constellation),
3. The application benefits from satellite global view and coverage, even for a single satellite,
4. The application is not well served by existing terrestrial networks and coverage.

COM DEV has studied applications for SDR microsatellites for the retrieval of data from remote (in-situ) sensor networks and other similar applications. These remote sensor networks can be cost-effectively interconnected with end-users by means of a microsatellite SDR communications payload, and low cost remote satellite data terminals.

Applications that are well-suited to the proposed COM DEV SDR approach include;

- Maritime-related
    - Vessel monitoring and safety communications systems for small and large vessels

- Remote monitoring and telemetry (remote in-situ sensor networks)
  - Resource (water (wells, streams, aquifers, quantity, flow, etc., water quality, petrochemical, such as oil and gas wells and pipelines, and resource exploitation (mining)),
  - Weather and meteorological remote sensors and weather stations,
  - Fisheries territorial and compliance monitoring and species monitoring (many options, including mammal-mounted sensors and terminals for land and sea),
- Canadian Sovereignty monitoring in the far North and in key shipping and remote locations, through a range of sensor types that are suited to remotely-collected data,
- Physical asset tracking
  - Fixed assets (high value goods, high cost/safety related infrastructure (electrical transmission and transformers, building environmental systems, facilities, security, etc,),
  - Vehicular and mobile assets,
- Personnel position tracking for remote workers and for hazardous locations and/or assignment, including emergency call capability,

It is expected that in the future, as initial applications are developed and trialed, that numerous other applications will emerge, which will undoubtedly make use of the existing capabilities of the COM DEV SDR microsatellite capability, but will further push the envelope in terms of increases in data rates, RF and DC power requirements, and shorter satellite revisit time. It is expected that these will be possible through improved microsatellite and SDR performance over time at the same or lower price. Also, it may become possible to harness the processing power and flexibility of SDR technology to reduce the complexity of the ground segment (which typically costs much more than space segment of any program, due to number of ground transceiver relative to satellite assets). Furthermore, SDR will make upgrades and improvements possible to existing satellite assets, to accommodate new air interfaces and operational modes, so that new satellites do not make older satellites obsolete (future proofing), ultimately reducing system build costs, costs to end users, and improving the business time to market and agility.

Conclusions

SDR as an attractive solution and is being applied to the payloads being developed by COM DEV for the Canadian M3MSat. The SDR-based solution will provide operational flexibility, easy bug fixes and functional enhancement during mission life for M3MSat. It can also be re-configured for other missions and applications through software configuration changes and by loading different application software. Several applications are discussed in the paper. Among these applications the AIS and LDRS applications that will be implemented for the M3MSat mission.

[1] J. C, Briones, et al. “Case Study: Using The OMG SWRADIO Profile and SDR Forum Input for NASA’s Space Telecommunications Radio System.”, NASA/TM—2009-215478, January, 2009

[2] T. A. Sturman, editor, “An Evaluation of Software Defined Radio – An Overview”, QinetiQ/D&TS/COM/PUB0603673/Version 1.0, 15th Mar 2006