

**Programmable Ultra Lightweight System Adaptable Radio (PULSAR)
Low Cost Telemetry – Access from Space
Advanced Technologies or Down the Middle**

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ABSTRACT

Software Defined Radio (SDR) technology has been proven in the commercial sector since the early 1990's. Today's rapid advancement in mobile telephone reliability and power management capabilities exemplifies the effectiveness of the SDR technology for the modern communications market. In contrast, presently qualified satellite transponder applications were developed during the early 1960's space program. Programmable Ultra Lightweight System Adaptable Radio (PULSAR, NASA-MSFC SDR) technology revolutionizes satellite transponder technology by increasing data through-put capability by, at least, an order of magnitude. PULSAR leverages existing Marshall Space Flight Center SDR designs and commercially enhanced capabilities to provide a path to a radiation tolerant SDR transponder. These innovations will (1) reduce the cost of NASA Low Earth Orbit (LEO) and Deep Space transponders, (2) decrease power requirements, and (3) a commensurate volume reduction. Also, PULSAR increases flexibility to implement multiple transponder types by utilizing the same hardware with altered logic – no analog hardware change is required – all of which can be accomplished in orbit. This provides high capability, low cost, transponders to programs of all sizes. The final project outcome would be the introduction of a Technology Readiness Level (TRL) 7 low-cost CubeSat to SmallSat telemetry system into the NASA Portfolio.

INTRODUCTION

Software Defined Radio (SDR) is an industry term describing a method of utilizing a minimum amount of radio frequency (RF) analog electronics before digitizing the signal. Upon digitization, all other functions are performed in software or firmware. There are as many different types of SDRs as there are data systems.

This paper provides information on the Marshall Space Flight Center (MSFC) SDR Low-Cost Transponder that contributes to advancing the state-of-the-art in transponder design – directly applicable to the SmallSat and CubeSat communities. The SDR, called PULSAR – Programmable Ultra Lightweight System Adaptable

Radio, can be incorporated into orbital and suborbital platforms. In doing so, PULSAR will allow project/programs to perform remote commanding capabilities, as well as real-time payload(s) and science instruments telemetry, all of which are self-supporting infrastructures requiring both component and system level work to complete. Discussions with suborbital (balloon, aircraft and sounding rockets) and orbital flight programs are currently in work. Potential partners include National Aeronautics and Space Administration (NASA) programs, commercial industry, academia/research, and other government agencies (Department of Defense (DoD), National Oceanic and Atmospheric Administration (NOAA), National Science Foundation (NSF) to name a few)

using assets associated with small satellite flights, both Low Earth Orbit (LEO) and deep space applications. Due to the SDR Technology flexibility, PULSAR can be used on any type of orbital or sub-orbital platform and tailored to each mission's requirements. PULSAR's low cost and size, weight, and power (SWaP) makes it keenly designed for small satellite (FASTSat, CubeSat. etc.) and micro satellite missions.

NASA Marshall Space Flight Center (MSFC) has an SDR transponder test-bed using "hardware-in-the-loop" methodology for:

- Evaluating and improving SDR technologies;
- Testing and assessing emerging technologies in terms of reliability, and re-configurability; and
- Achieving ever increasingly higher data through-put.

The second generation SDR, PULSAR, hardware/software design and development has been fueled using Fiscal Year (FY2013) NASA Funds for technology advancements.

TECHNICAL APPROACH

The PULSAR Project leverages the lessons learned during the prototype system (First Generation) development, which used NASA funds from FY2012. The project objective advances the PULSAR design to a sub-orbital TRL 7 qualification unit. Non-radiation tolerant (but with a path to radiation tolerance) hardware were procured in order to keep development costs low.

Technical Description

The PULSAR base design has five selectable decks – power deck, processor deck, receiver deck, and S- and X-Band telemetry transmitter decks (see Figure 1). The application determines the configuration, thus the number of decks used.

Power Deck

PULSAR operates electrically isolated from the satellite bus. PULSAR requires an external power source providing an input range of 28 ± 12 volts direct current (VDC). The power deck distributes up to 15 watts depending on configuration stack up.

The power deck contains three separate direct current (DC) power converters. One converter powers the receiver and processor decks. A second converter powers the S-band transmitter deck. The last converter powers the X-band transmitter deck. The transmitter power turns on and off with uplink commands, receiver

deck commands, or Flight Computer (FC) commands. The receiver power remains on at all times. At the introduction of power, the transmitter remains off and the receiver powers on. This design methodology allows for commanding ON/OFF, as well as warm and soft reboots from external sources.

The power deck mitigates any unintentional generation, propagation, or reception of electromagnetic energy. The PULSAR power deck design meets electromagnetic interference compatible (EMI/EMC) requirements.

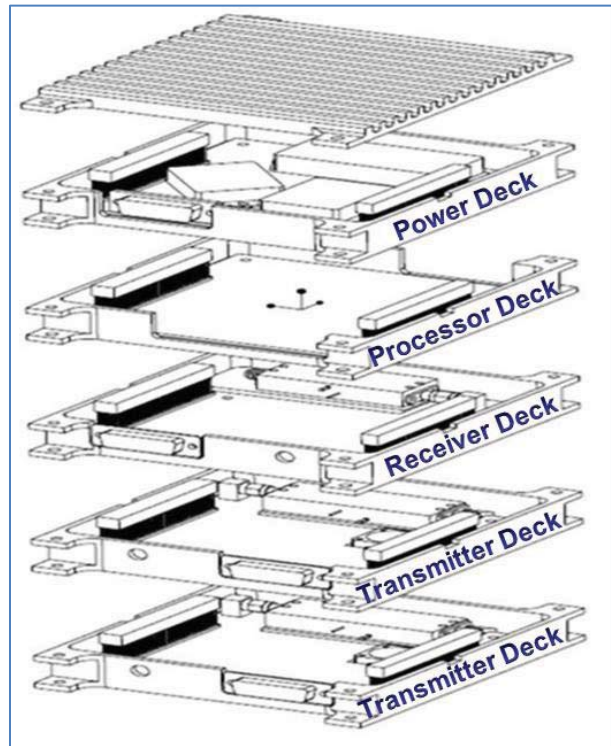


Figure 1 – PULSAR contains five main component decks.

Processor Deck

The processor deck utilizes an ARM M1 (Advanced RISC Machine) processor. The processor deck runs a field programmable gate array (FPGA) inside a radiation tolerant housing. The FPGA performs ancillary operations as dictated by mission requirements.

PULSAR utilizes VHDL rather than software. VHSIC hardware description language, VHDL, provides a logic circuit within the FPGA. The VHDL does not change throughout the life cycle of each PULSAR application.

Receiver Deck

The receiver deck uses 7 watts (W) DC input from the power deck. The receiver deck connects to two external components: the radio frequency (RF) antenna port (via sub miniature version A - SMA) and the high density DB37 flight computer (FC) interface for the uplink command stream.

The S-band receiver deck processes up to a maximum uplink data rate of 300 kilobits per second (kbps), based on ground station limitations. Therefore, the limit would increase as the ground station technology improves. The receiver deck is capable of demodulating frequency modulation (FM), binary phase-shift keying (BPSK), and quadrature phase-shift keying (QPSK).

The receiver deck technology boasts a noise figure of 0.6 dB. The receiver technology also eliminates the need for ranging tones. Instead, PULSAR uses Doppler Shift ranging.

Telemetry Transmitter Decks

The telemetry transmitter decks produces up to a 2 W radio frequency (RF) output. The RF output power tailors to any particular mission. If RF output power greater than 2 W is desired, then PULSAR simply utilizes an external Solid State Power Amplifier (SSPA) to increase the output power to the desired level. PULSAR requires 8 W input (DC) for 1 W RF output power. The telemetry transmitter decks connect to two external components: the RF antenna port (via SMA) and the high density DB37 Flight Computer (FC) interface for the downlink telemetry stream.

The telemetry transmitter decks stream data with BPSK and QPSK at a maximum data rate of 150 Mega-samples per second (Msps). Just as in the receiver deck, the ground station limits the data rate.

The transmitted data uses Low Density Parity Check (LDPC) Forward Error Correcting (FEC) coding. The improved coding gain adds an order of magnitude increase in telemetry through-put. Exemplifying flexibility, PULSAR transmits using LDPC, Reed-Solomon (223/255), or convolutional (Rate 1/2) FEC based on mission requirements.

PERFORMANCE

Table 1 shows a market analysis of industry transponders and differentiates their features compared to PULSAR. In comparison, the NASA-MSFC SDR incorporates the latest in Forward Error Correcting (FEC) codes and utilizes State-of-the-Art electronic components which give PULSAR the capability to

achieve much higher Watts-per-Bit (the industry standard benchmark showing data rate versus power).

In Table 1, there are three units listed as Satellite Communications and Navigation (SCaN). These are the SDRs recently installed on the International Space Station (ISS) as part of the SCaN test-bed. At the time of this paper, the telemetry verification was still in process and downlink data rates have not been published. The data rates listed are the telemetry classes for which the SDRs are categorized. The remaining units were gathered using the data sheets available on the company websites or published in brochures available on the internet.

Table 1: Market Analysis of typical industry telemetry transponders

Maker	Unit	Freq. Band	Downlink Data Rate, Mbps	Mass, kg	Benchmark, b/W
NASA-MSFC	PULSAR	S-, X-	150	2.1	10e6
L3 Comm ²	Cadet	S-	100	0.215	8.3e6
Innoflight ³	SCR-100	S-	4.5	0.25	3e6
L-3 TW ⁴	CTX-886	X-	400	3.85	66e6
Space Micro ⁵	μSTDN-100	S-	4	2.1	0.7e6
Harris Corporation ^{6,7}	SCaN	Ka	100	19.2	2.5e6
General Dynamics ^{6,7}	SCaN	S-	10	-	1.0e6
Jet Propulsion Laboratory ^{6,7}	SCaN	S-	10	6.6	1.0e6

PULSAR exceeds most of the other units in term of the industry benchmark. The L-3 TW CTX-886 exceeds PULSAR in data rate, but PULSAR has less mass (2.1 versus 3.85 kg) and uses less power (15 versus 75 watts – not shown in table).

ALIGNMENT

NASA is called, at the direction of the President and Congress, to maintain an enterprise of technology that aligns with missions and contributes to the Nation’s innovative economy. NASA has been and should be at the forefront of scientific and technological innovation. In response to these calls, NASA generated a plan (NASA Strategic Space Technology Investment Plan⁸) to advance technologies and nurture new innovation that will feed into future missions. PULSAR aligns primarily with the Technology Area (TA) 5 – Communication & Navigation – but has connections to other TAs in which lightweight structures, power efficiency, and communication reliability and through-put are the focus.

PULSAR development not only aligns with NASA Strategic Goals, but offers increased capabilities to commercial and academic groups. Orbital Telemetry has already expressed interest in licensing PULSAR technology. GATR, Inc. expressed a desire to merge their portable antenna system with PULSAR to create a smaller mobile system.

STATUS AND SCHEDULE

All circuit boards are printed. The power deck has all electronic components installed. Quality checkouts have been performed on the power deck and it is ready for assembly.

The X-Band transmitter deck has all electronic components installed. Quality checkouts are nearing completion (estimated at 75% completion).

The S-Band transmitter deck and receiver deck have all electronic components installed. Quality checkouts will begin after the X-Band transmitter deck is complete.

The processor deck is at the vendor for electronic components installation. The chassis is complete and awaiting the completion of all quality checkouts. Assembly commences once all decks have passed quality checkouts.

The plan is for PULSAR to go through Goddard Space Flight Center Requirements Testing at the end of July 2013. The current schedule has margin to this testing.

PULSAR will fly as a non-critical payload on the MSFC High Energy Replicated Optics to Explore the Sun (HEROES) flight in September 2013.

Table 2 lists project completions and schedule for the remainder of fiscal year (FY) 2013.

Table 2: PULSAR Schedule (as of 06/17/2013)

Done	Task	Start	Finish
✓	Print Circuit Boards	04/01/2013	05/14/2013
	Populate Circuit Boards	04/22/2013	06/19/2013
✓	Power Deck	04/22/2013	04/29/2013
✓	X-Band Trx Deck	05/03/2013	05/10/2013
✓	S-Band Rcr Deck	05/17/2013	05/28/2013
✓	S-Band Trx Deck	06/03/2013	06/10/2013
	Processor Deck	06/11/2013	06/19/2013
	Quality Checkouts	05/03/2013	07/11/2013
✓	Power Deck	05/03/2013	05/16/2013
	X-Band Trx Deck	05/13/2013	06/21/2013
	S-Band Rcr Deck	06/21/2013	07/01/2013
	S-Band Trx Deck	07/01/2013	07/09/2013
	Processor Deck	07/09/2013	07/11/2013
✓	Chassis	04/01/2013	05/09/2013
	GSFC Requirements Testing	07/22/2013	07/26/2013
	Install onto HEROES	09/02/2013	09/02/2013
	HEROES Balloon Flight	09/24/2013	10/01/2013

CONCLUSION

SDR Industry Future

Studies were performed in 2006 and 2011 to evaluate the adoption of SDR technologies in various markets.⁹ One finding shows that once the SDR technology clears the “chasm”, it will become mainstream where adopters will select it because of the successful application. PULSAR is bridging that “chasm” in the satellite telemetry realm.

PULSAR Goals Met

PULSAR leverages existing Marshall Space Flight Center SDR designs and commercially enhanced capabilities to provide a path to a radiation tolerant SDR transponder. These innovations will

- (1) Reduce the cost of NASA Low Earth Orbit (LEO) and Deep Space transponders,
- (2) Increase data through-put,
- (3) Decrease power requirements, and
- (4) Reduce volume.

Also, PULSAR increases flexibility to implement multiple transponder types by utilizing the same hardware with altered logic – no analog hardware change is required – all of which can be accomplished in orbit. The five PULSAR decks offer several permutations for capability – 14 possible combinations of processing, receiving, and transmitting. The

flexibility permits CubeSat and SmallSat programs to select only what they need for their mission.

PULSAR project team achieved a targeted cost of less than \$100,000 for the SDR. The actual cost will be determined after licensing and commercialization.

PULSAR provides high capability, low cost, transponders to programs of all sizes. The final project outcome will be the introduction of a low-cost CubeSat to SmallSat telemetry system into the NASA Portfolio.

PULSAR Future

PULSAR will obtain a Technology Readiness Level (TRL) 7 – suborbital – with the balloon flight in September 2013. PULSAR Project Team is pursuing flight opportunities to advance the technology to a TRL 8 or 9.

At the writing of this paper, PULSAR is successfully competing in a secondary payload call for the Green Propellant Infusion Mission. NASA Game Changing Directors have asked for a New Start Package for the proposal that combines the PULSAR technology and two other NASA-MSFC advancing technologies. If selected, the flight opportunity will advance PULSAR to a TRL 9.

NASA Johnson Space Center (JSC) will use a PULSAR to validate a ground-based SDR Lab. JSC is building the capability to perform “hardware-in-the-loop” testing of SDRs.

The PULSAR Roadmap includes adaptation into a ground based system and upgrading the receiver from S-Band to X-Band. These technologies are planned for FY2014 development.

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