Tactically Extensible and Modular Communications - X-Band

TEMCOM-X

William Herbert Sims
National Aeronautics and Space Administration
NASA / MSFC / ES63
Huntsville, USA
Herb.sims@nasa.gov

Kosta A. Varnavas
National Aeronautics and Space Administration
NASA / MSFC / ES33
Huntsville, USA
Kosta.A.Varnavas@nasa.gov

Joseph Casas
Science and Space Technology Projects Office
NASA Marshall Space Flight Center
Huntsville, USA
joseph.casas@nasa.gov

Stephen L. Spehn
Deputy Science Advisor
U.S. European Command
Stuttgart, Germany
stephen.l.spehn.civ@mail.mil

Neal Kendrick
Dynetics, Inc.
Huntsville, USA
Neal.Kendrick@dynetics.com

Stephen Cross
Dynetics, Inc.
Huntsville, USA
Steve.Cross@dynetics.com

Paul Sanderson
Dynetics, Inc.
Huntsville, USA
Paul.Sanderson@dynetics.com

Janice C. Booth
U.S. Army Aviation and Missile Research,
Development, and Engineering Center (AMRDEC)
Huntsville, USA

***Abstract*— This paper will discuss a proposed CubeSat size (3U) telemetry system concept being developed at Marshall Space Flight Center (MSFC) in cooperation with the U.S. Department of the Army and Dynetics Corporation. This telemetry system incorporates efficient, high-bandwidth communications by developing flight-ready, low-cost, Proto-flight software defined radio (SDR) and Electronically Steerable Patch Array (ESPA) antenna subsystems for use on platforms as small as CubeSats and unmanned aircraft systems (UASs). The current telemetry system is slightly larger in dimension of footprint than required to fit within a 0.5U CubeSat volume. Extensible and modular communications for CubeSat technologies will partially mitigate current capability gaps between traditional strategic space platforms and lower-cost small satellite solutions. Higher bandwidth capacity will enable high-volume, low error-rate data transfer to and from tactical forces or sensors operating in austere locations (e.g., direct imagery download, unattended ground sensor data exfiltration, interlink communications), while also providing additional bandwidth and error correction margin to accommodate more complex encryption algorithms and higher user volume.**

Keywords-Software Defined Radio, Tactically Extensible, Electronically Steerable Phased Array, unattended ground sensors.

I. INTRODUCTION

This paper provides information on the Marshall Space Flight Center (MSFC) SDR Low-Cost Transponder as well as the Army/Dynetics Electronically Steerable Phased Array - X-Band (ESPA-X) that contributes to advancing the state-of-the-art in telemetry system design – directly applicable to the SmallSat and CubeSat communities. The SDR, called PULSAR – Programmable Ultra Lightweight System Adaptable Radio – as well as the ESPA-X can be incorporated into orbital and suborbital platforms. In doing so, Tactically Extensible and Modular Communications - X-Band (TEMCOM-X) 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.

Current CubeSats do not have sufficient bandwidth for transmit and receive to support innovative payload designs and complex encryption schemes being developed by the CubeSat community (academic, military, civil, industry) to support increasing bandwidth with low error-rate demands on the tactical edge[1]. The leap ahead technology is the low-cost space / high-altitude qualified reconfigurable SDR transponder for simultaneous X-band transmit and receive communications at a minimum of 110 Mbps. In addition, the SDR has a highly efficient SWaP (less than 50% of traditional Size, Weight and supply Power), which achieves higher bits per input supply watt (at ~10 Mbits per input

 ISBN: 978-1-61208-397-1

watt) than traditional communication SDR systems (at ~300Kbits per input watt). [2]

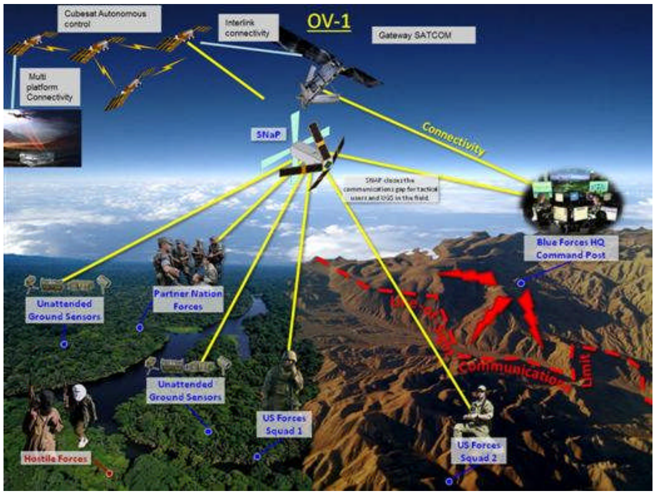

Figure 1. Tactically Extensible and Modular Communications - X-Band (TEMCOM-X)

Due to the SDR technology flexibility, TEMCOM-X can be used on any type of aircraft, UAV, orbital, or sub-orbital platforms and tailored to each mission's requirements. TEMCOM-X low cost and size, weight, and power (SWaP) makes it attractive for CubeSat and micro satellite missions.

The matched low profile form factor electronically steerable array antenna provides mission adaptive beam forming for optimizing signal to noise ratios with extensibility in the design approach for future multiple independently steerable beams from the same antenna array.[3]

This paper will discuss the technical approach being proposed showing the extensibility of the system. Further the performance of the overall system will be discussed. TEMCOM-X will be shown to align with current NASA Strategic Space Technology Investment Plan.[4] The discussion will then migrate to the Electronically Steerable Patch Array – X-Band (ESPA-X). The final area of discussion will show one possible operational scenario.

II. Technical Approach

The proposed TEMCOM-X Project leverages the lessons learned during the PULSAR telemetry system (First Generation) development, which used NASA funds from FY2012-13. The project objective is to advance the TEMCOM-X design to a proto-flight unit, which will be accomplished by reducing the overall size of PULSAR to fit within a 1U form factor. PULSAR currently uses non-radiation tolerant hardware to keep costs low, with a clearly defined path to radiation tolerance.

The TEMCOM-X base design will have up to four selectable decks – power deck, processor deck, X-Band receiver deck, and X-Band telemetry transmitter deck. The application determines the configuration, thus the number of decks used.

The current PULSAR power deck will be reduced in overall footprint to meet the 1U CubeSat dimensions. The operating voltage of TEMCOM-X is proposed to be from 16VDC to 50VDC (the same as PULSAR).

The current PULSAR Processor deck has been proposed to provide beam-forming control for the ESPA-X antenna. Having a processor deck dedicated to a transponder communication system was a first in industry.

The proposed X-Band Receiver deck will leverage the IP and lessons learned from the PULSAR S-Band Receiver. Command and Data (uplink) capabilities will be on the order of 150Mbps.

The transmitter deck will produce up to 2 W of radio frequency (RF) output. The RF output power can be tailored to any particular mission. The telemetry transmitter deck streams data with OQPSK modulation at a maximum data rate of 110 Mega-bits per second (Mbps).

Exemplifying flexibility, PULSAR currently transmits using Reed-Solomon (223/255) Forward Error Correction (FEC). Future enhancements will include Low Density Parity Check (LDPC, rate 7/8), or convolutional (Rate ½) based on mission requirements. Currently the LDPC encoding algorithm has been verified in simulation at MSFC as well as in independent external testing. TEMOCOM-X can incorporate other error correction algorithms, as necessary.

The antenna array (front-end) will incorporate a planar design consisting of multiple board layers with integrated array circuitry to reduce the array depth.

III. Performance

Table shows a market analysis of industry transponders and differentiates their features compared to PULSAR.[5] 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 Bits-per-Watt (the industry standard benchmark showing data rate versus power).

TABLE I. 2012 MARKET ANALYSIS OF TYPICAL INDUSTRY TELEMETRY TRANSPONDERS

Maker	Unit	Freq. Band	Downlink Data Rate, Mbps	Mass, kg	Bench-mark, b/W
NASA-MSFC	PULSAR	S-, X-	150	2.1	10e6
L3 Comm	Cadet	S-	100	0.215	8.3e6
Innoflight	SCR-100	S-	4.5	0.25	3e6
L-3 TW	CTX-886	X-	400	3.85	5.3e6
Space Micro	µSTDN-100	S-	4	2.1	0.7e6
Harris Corporation	SCaN	Ka	100	19.2	2.5e6
General Dynamics	SCaN	S-	10	-	1.0e6
Jet Propulsion Laboratory	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).

The system contains sufficient RF link capacity to achieve the desired performance while maintaining the goal Bit Error Probability (BEP) assuming that the design goal gain (19.76dBi) can be met.

Table 2 lists the RF link margin assumptions. The calculation was performed using the IRIG 119 method.

$$SNR = P_T - L_{C(T)} + G_T - L_P - L_M - L_{Pol} - L_A + G/T - kB$$

P_T = Transmitter Power
$L_{C(T)}$ = Transmitter Cable Loss
G_T = Transmitter Antenna Gain
L_P = Path Loss
L_M = Multipath Loss
L_{Pol} = Polarization Mismatch Loss
L_A = Atmospheric Attenuation
G/T = Receiving System Figure of Merit
kB = Boltzmann's constant x Bandwidth

Results were correlated using an Error Bit/Noise calculation method.

TABLE II. LINK MARGIN ASSUMPTIONS/CALCULATIONS

	Uplink		Downlink	
Frequency		8.2GHz		8.2GHz
P_T	50W	47dBm	1W	30dBm
$L_{C(T)}$		1dB		1dB
G_T		43.9dBi[1]		19.76dBi[2]
L_P	2448km[3]	178.5dB	2448km[3]	178.5dB
L_M		0dB		0dB
L_{Pol}		0.25dB		0.25dB
L_A		1.0dB		1.0dB
G/T		-4.91dB/K[4]		22.5dB/K[1]
Data Rate		150Mbps		150Mbps
kB		-116.84dB		-116.84
SNR		22.08dB		8.35dB
Threshold	No FEC	12.0dB[5]	FEC	5.0dB[6]
Margin		**+10.08dB**		**+3.35dB**

1 – Documented performance of GATR 2.4m X-band antenna system.

2 – Design goal performance of Dynetics Phased Array Antenna.

3 – Max slant range calculated from satellite to ground station for 650km orbit and 5° elevation.

4 – Calculated assuming design goal Gain with low loss feed system and LNA noise figure of 2.5dB maximum.

5 – Required SNR for BEP of $1x10^{-5}$

6 – Required SNR for BEP of $1x10^{-12}$ using LDPC FEC

IV. 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 Plan) 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 throughput are the focus.[6]

V. ESPA-X

The current proposed design of the ESPA-X includes a radiating element that is a circularly polarized patch antenna with +8dBi gain with a maximum 11 dB return loss (1.78 VSWR) in the band of interest. The T/R module will transmit in horizontal polarization and receive in vertical. This design decision prevents the need for a second circulator adjacent to the antenna element, and it should provide sufficient isolation between the two paths.

In order to achieve the desired 100 W (+50dBm) Effective Radiative Power (ERP) on transmit, each of the 15 patch antenna elements' input power must be approximately 18.5 dBm. The transmit gain profile assumes that the +36 dBm from the diplexer will arrive at each element after a series of four two-way power dividers, with each divider incurring an approximate loss of 4 dB (hence the +20 dBm input power to the TR module transmit chain.) The transmit chain is quite simple, with a phase shifter (nominal 7 dB loss), an amplifier, and a harmonic reject filter (nominal 1.5 dB loss).

The receive chain gain distribution assumes a 0.4 dB loss through the patch antenna and a 1.2 dB loss through the front-end bandpass filter. The LNA's noise figure of 0.6 dB is sufficient to insure that the overall transmit chain's noise figure will remain below the required 2.5 dB.

VI. OPERATIONAL SCENARIO

The operational scenario in the graphic shown in the Introduction depicts U.S. and Partner nation (PN) small-unit forces operating beyond line-of-sight communications with their command center, and in close proximity to hostile forces. The U.S. and PN units have deployed unattended ground sensors (UGS) in key location for remote reconnaissance, and are supported by low-earth-orbit (LEO) assets that incorporate both PULSAR and ESPA-X. The communications requirements of the U.S. and PN forces include:

– Encrypted voice between the small units and the command center;

– Imagery and other map-based data between the small units and the command center;

– Frequent, periodic polling of UGS with forwarding of trigger information from the UGS to the small units and the command center; and

– Relay of imagery, full-motion video (FMV), and other near-real-time data from airborne and orbital sensor platforms to the small units and the command center.

These communications requirements are individually serviceable through existing systems, and collectively serviceable through combinations of existing systems, but TEMCOM-X provides unique advantages, to include:

– Increased bandwidth to service larger data demands with fewer assets;

– Multiple beam-forming to provide simultaneous access to frequency bands with reduced error rates;

– Provides high rate bandwidth for satellite interlink communications;

– Full duplex transmit and receive for maximizing communication opportunities;

– Tailored spot beams for prioritized service to critical assets; and

– Dynamically adaptable waveforms to support multiple disparate systems simultaneously.

VII. CONCLUSION

The TEMCOM-X concept is currently in the late formulation stages and has been proposed for full implementation to develop and test a protoflight unit of the integrated PULSAR-X and ESPA-X technologies to support X band communication systems for cubesat and small aircraft platform compatibility.

TEMCOM-X leverages existing Marshall Space Flight Center SDR designs and commercially enhanced capabilities. Innovations will

(1) Reduce the cost of Low Earth Orbit (LEO) and Deep Space transponders,

(2) Increase data through-put,

(3) Decrease power requirements, and

(4) Reduce volume.

Also, TEMCOM-X concept increases flexibility to implement multiple transponder types by utilizing the same hardware with altered logic – no hardware change required – all of which will eventually be accomplished in orbit. The flexibility permits CubeSat and SmallSat programs to select only what they need for their mission.

TEMCOM-X offers 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.

The potential future TEMCOM-X Roadmap includes adaptation into options such as C-Band and Ka-Band. These technologies are proposed for continued development.

ACKNOWLEDGEMENTS

I cannot express enough thanks to my supervisors for their continued support and encouragement: Mr. Mark James and Mr. Tim Ezell. To Maegan and Maeson – thank you for allowing me time away from you to complete the research and writing of this paper. Thanks to my parents as well, Mr. and Mrs. William H. Sims, who instilled the work ethics that I have today – it has not gone unnoticed, and is very much appreciated. Finally, to my caring, loving, and supportive wife, Beverly, your encouragement when the research and writing times got rough is much appreciated. It was a great comfort and relief to know that you were willing to provide management of our household activities while I completed this work.

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 ISBN: 978-1-61208-397-1