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SPA-Based Emergency Micro Black Box Transponder for Space Vehicles

Kevin J. Lynaugh[1], Scott Dossey [2], Matthew Davis[3], and Richard Middlestead[4]
Vulcan Wireless Inc. Carlsbad CA, 92008, USA

and

James Lyke[5], James Crane[6], John Demello[7], and Calvin Roman[8]
Air Force Research Laboratory, Kirtland Air Force Base, Albuquerque NM 87117, USA

This paper describes a space flight experiment that demonstrated a space vehicle emergency black box transponder messaging system. The system utilized the Tracking and Data Relay Satellite System-Multiple Access (TDRSS-MA) for emergency messaging to ground controllers. The space vehicle Space Plug-n-Play Avionics or SPA interface supplies the telemetry data to the micro black box transponder. The micro black box transponder transmits the message from the space vehicle to the TDRSS-MA Geosynchronous Satellite. The NASA White Sands Complex receives the signal from the TDRSS-MA satellite and demodulates the message, then routes it to the controllers. Rapid response to system anomalies are now possible and can speed recovery and reduce the down time of complex space vehicles. This system is capable of hosting hundreds of users.

The flight demonstration flew on May 4th 2010 from Space Port America. The experiment was carried aloft by the UpAerospace Space Loft XL4 to an altitude of greater than 114km while transmitting messages to the TDRSS-MA network and a secondary telemetry station hosted by the Space Development Test Wing (SDTW) at Kirtland Air Force Base in Albuquerque, New Mexico over 200km away. The payload was developed by Vulcan Wireless Inc. in cooperation with Air Force Research Lab-Responsive Space Vehicles Directorate and partially funded by the Operational Responsive Space Office. The flight was supported by NASA, Space Development Test Wing, and ITT Corporation.

The Micro Black Box Transponder or MBT is a miniaturized software defined radio capable of hosting a variety of space communications waveforms, frequencies and protocols. The added flexibility of the software defined radio was highlighted in the mission by conducting two simultaneous missions during the flight. The SPA interface on the MBT allows for rapid integration onto a wide variety of space platforms. Satellite manufactures can integrate the functionality of the MBT into the spacecraft design with minimal costs and complexities.

I. Nomenclature

CCSDS = *The Consultative Committee for Space Data Systems*

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[1] President, Vulcan Wireless Inc., 1935 Camino Vida Roble, Suite 150A Carlsbad, CA 92008..
[2] Senior Software Engineer, Vulcan Wireless Inc., 1935 Camino Vida Roble, Suite 150A Carlsbad, CA 92008.
[3] Principal Engineer, Wireless Inc., 1935 Camino Vida Roble, Suite 150A Carlsbad, CA 92008..
[4] Director of Communications, Vulcan Wireless Inc., 1935 Camino Vida Roble, Suite 150A Carlsbad, CA 92008..
[5] Technology Advisor, U.S. Air Force, Principal Electronics Engineer, Space Vehicles Directorate, 3550 Aberdeen Avenue SE, Associate Fellow, AIAA.
[6] Electronics Engineer, Space Vehicles Directorate, 3550 Aberdeen Avenue SE
[7] Electronics Engineer, Space Vehicles Directorate, 3550 Aberdeen Avenue SE
[8] Electronics Engineer, Space Vehicles Directorate, 3550 Aberdeen Avenue SE

GEO = Geosynchronous Earth Orbit
LEO = *Low Earth Orbit*
MBT = Micro Black Box Transponder
SDTW = Space Development Test Wing
TDRSS-MA = Tracking, Data and Relay Satellite System-Multiple Access
xTEDS = eXtensible Transducer Electronic Data Sheet
ZOE = Zone of Exclusion

II. Introduction

Increased space weather events and rouge orbital debris are necessitating backup communication systems for complex space craft. Currently backup communication systems required dedicated ground terminals to be within view of the space vehicle to establish communications. In the case of a low earth orbit satellites having many geographically dispersed ground terminals can be an impractical constraint. Having ground terminals available all over the planet is costly and resource intensive. The goal of the Micro Black Box Transponder system is to provide a ubiquitous communications link without the constraint of dedicated ground terminals. The transponder also needs to have low mass, reduced footprint, and minimal DC power to operate with a goal of hosting it on a CubeSat.

III. Micro Black Box Transponder Project

The motivation for the Micro Black Box Transponder Project is to develop a messaging channel that can be used as a backup to primary communications links for high value LEO space vehicles. Further goals would be to produce a communications device with a CubeSat footprint in mind that has a Plug-n-Play interface. The ultimate goal is to provide a generic messaging service utilizing existing infrastructure that is not tethered to a fixed ground terminal. Not being tied to a fixed ground station allows for constant communications and the shortest latency to the user. Plug-n-Play hardware interface will allow for rapid integration onto a larger system with minimal software development and integration time.

IV. System Overview

For the first implementation of this system we selected the NASA Tracking Data and Relay Space System (TDRSS). TDRSS is a geosynchronous based satellite network system developed to support the space shuttle and a variety of space missions. It is comprised of three operational space craft located at 41W, 174W and 275W(ZOE) longitude slots and are in inclined orbits of up to 7 degrees. Each TDRSS vehicle has a series of phased array antennas which view the earth and can communicate with space vehicles in low earth orbits. The TDRS system is particularly well suited for the Micro Black Box Transponder application because at least one TDRSS-MA is in view of any given LEO space vehicle due to the spacing of the TDRSS constellation. A TDRSS vehicle is depicted in figure 1. Note the location of the multiple access antennas.

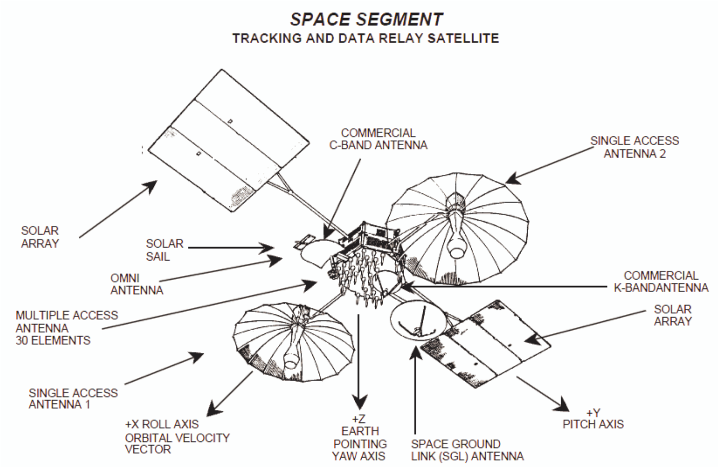

Figure 1. Tracking and Data Relay Satellite Configuration (F1-F7 Shown). *The multiple access antennas, which are comprised of a 30 element phased array, are shown mounted to the nadir deck of the space craft. [1]*

Advanced TDRSS array capability was also demonstrated and enabled reception of some of the signals in this experiment.

The communications element mounted to the small space craft consists of a CSR-SDR-S software defined radio with the S-Band transmitter enabled. The CSR-SDR-S also has an integrated SPA-U and SPA-1 Plug-n-Play interface. The CSR-SDR-S is 82mm by 82mm by 17mm and requires a single antenna. The radio and antenna were integrated into the Space Loft XL4 flight vehicle.

V. Flight Experiment

The sounding rocket platform was used to demonstrate a compact space vehicle communications payload on a space borne platform. Using the sounding rocket introduced some communications link issues. Two issues arose from the sounding rocket configuration, the first being the high spin rate of greater than 5 revolutions per second and the second was a low gain antenna. Waveform design overcame the effects of the high spin rate and the advanced capabilities of TDRSS array overcame the low antenna gain.

VI. Payload Configuration

The Space Loft XL4 sounding rocket is a cost effective suborbital flight vehicle which can carry a variety of payloads. Payloads are integrated into independent canisters, which are stacked into the upper stage of the vehicle. For this project a PTS-4 payload canister was utilized and all systems needed to be integrated into this volume. The payload is required to function completely autonomously for the duration of the flight. The payload needed to provide an on-off power switch, battery system, transmitter, power amplifier, launch detection and antenna system. The requirements for this project were to transmit a short message through the TDRSS-MA system to simulate an emergency message from a small space vehicle in distress. The dynamics of the sounding rocket certainly exhibited worst case impairments.

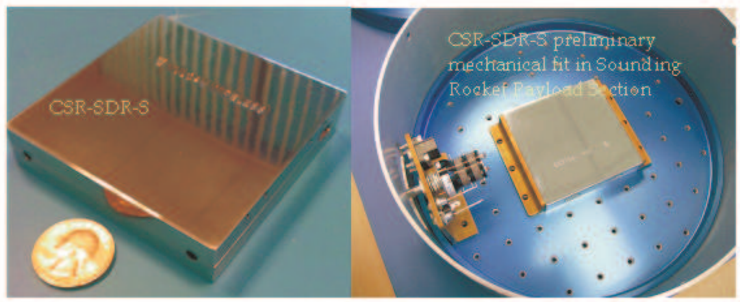

Figure 2. CSR-SDR-S TDRSS-MA Software Defined Radio and PTS-4 Payload Configuration. *The view on the left shows the CSR-SDR-S CubeSat radio and the view on the right shows the CSR-SDR-S mounted into the PTS-4 payload housing. Picture by Vulcan Wireless Inc.*

Due to extreme launch loads, in excess of 18g's, and high rotational rates all components and harnessing are required to be very robust. The CSR-SDR-S CubeSat software defined radio and the preliminary payload configuration is displayed in figure2. The CSR-SDR-S is configured with an S-Band spread spectrum modulator compatible with the TDRSS-MA system. The CSR-SDR is capable of multi-band operation, but was not used in this flight experiment. The CSR-SDR formatted the message using CCSDS communication frames.

The antenna system needed to be exposed to the hypersonic air flow and needed to be constructed to withstand this environment. In figure 3 the configuration of the antenna are shown as well as the booster section. A secondary mission was also conducted concurrently by transmitting payload telemetry, in real-time, to the launch facility via a second modulation and frequency. The

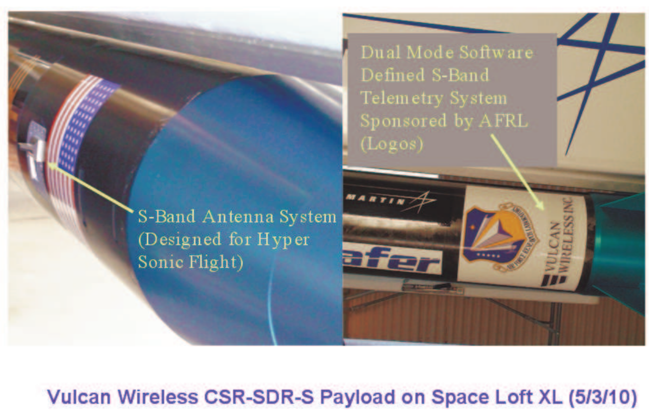

Figure 3. External Antenna Mounting and Vehicle Configuration. *The flight antenna can be seen in the figure to the left. Picture by Vulcan Wireless Inc.*

secondary signal gave real-time state of health information verifying proper payload operation in flight. A software defined radio receiver was used at the launch complex to demodulate and record the payload data.

Farther away from the launch pad the Space Development Test Wing tracked the flight with a 12 foot tracking antenna located on Kirtland Air Force base (250km to the north of the launch pad). Thus, data was being received from two ground based antennas and three TDRSS satellites.

VII. Sounding Rocket Flight

The sounding rocket was launched from Space Port America's PAD-1 on May 4th, 2010 at 6:45am. The vehicle achieved and altitude of over 114km. The launch is shown in figure 4. The Micro Black Box Transponder was received on all TDRSS-MA satellites that were configured and the real time data was also received at the launch pad.

Figure 4. Space Loft XL4 Launch *Picture by Bob Martin KRQE News Channel 13*

The following is an excerpt from a prepared statement for media, cleared by AFRL PA office, "…As we know, all aircraft carry black box units that offer valuable insights when a plane crashes or is lost. Such insights are critical in reducing future accidents. Unfortunately, no spacecraft have such black boxes, but we think they can, and that is what today's experiment is about. The "Genesis black box", like an aircraft black box sends out signals that can be picked up on the ground, in this case through the NASA Tracking and Data Relay Satellite System (TDRSS). Doing the test on a sounding rocket is possibly more challenging than doing it from space, due to the dynamic motion and rotation of the sounding rocket. NASA's interest and support of our project was critical. AFRL and NASA are interested in the implications of this test, which paves the way for putting such black boxes on launch vehicles and satellites in the future, serving both for emergency as well as routine transmissions of small amounts of mission data, pretty much from anywhere in space."

VIII. Post Flight

The sounding rocket suborbital flight path reached apogee, and jettisoned the booster stage and deployed a series of parachutes. The payload section returned to the surface of the earth and was successfully recovered. The payload continued to operate even when the vehicle was on the ground. The vehicle performed as expected and landed within the predetermined recovery area. The representatives from UpAerospace flew on a US Army UH-1 helicopter to immediate recover the payload section. A video of the launch and payload is available on our web site at www.vulcanwireless.com. Once the payload was flown back to the launch pad the payload canisters were removed from the recovered section. The CSR-SDR-S was undamaged and still operational with plenty of battery charge left. Heating damage can be seen on the exterior of the payload, but no noticeable damage was detected within the payload canister. The post flight payload is shown in figure 5. The CSR-SDR-S can be seen in the center of the bottom portion of the

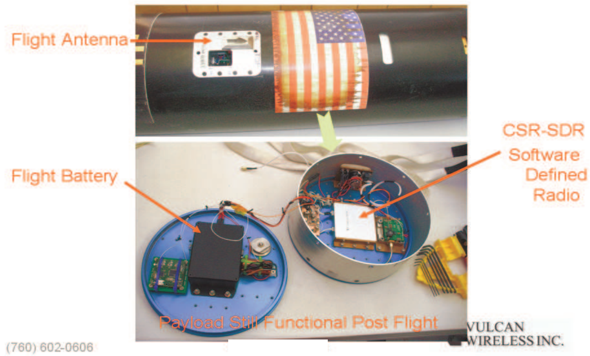

Figure 5. Post Flight Payload Recovery. *The flight antenna can be seen in the figure on top and the payload is shown on the bottom. Picture by Lt. Matthew Leines*

flight canister. Support circuits such as the launch detection circuitry and the external user interface can be seen.

IX. Conclusion

This flight experiment demonstrated the functionality and utility of using the existing TDRSS-MA system for a low power emergency messaging channel for small space vehicles. The system can provide continuous communication capability for small space craft any where on orbit. The Micro Black Box Transponder capability was demonstrated using the CSR-SDR-S software defined radio, and is also capable of multiple frequencies and multiple waveforms. This flight experiment demonstrated the flexibility of the software defined radio to achieve multiple missions using a compact radio increasing the functionality of small space vehicles. The CSR-SDR-S also has SPA-U and SPA-1 interfaces built into the radio to support rapid integration to complex space vehicles.

X. Acknowledgements

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References

[1] "2nd TDRSS Workshop" Sponsored by NASA Headquarters' Office of Space Communications and Goddard Space Flight Center's Mission Operations and Data Systems Directorate,