SPECTRUM RELOCATION FUND
TRANSITION AGILITY CHALLENGE

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ABSTRACT

Due to Auction 97 frequency sell off and anticipated higher usage of C-Band, space time code (STC) and low-density parity-check (LDPC) code were evaluated for latency, characterization, and performance during flight. The benefit of an STC path can be observed by measuring the channel power of a dual antenna and comparing it to the contributions from each antenna independently. The STC provides a benefit only when both antennas are visible to a receiver and when the combined result of a dual antenna system would destructively add. The Eglin Spectrum Reallocation Fund (SRF) Project transitions the United States Air Force (USAF) aeronautical mobile telemetry (AMT) from operations in frequencies auctioned by the Department of Commerce (DOC) as part of Auction 97. This paper describes the AMT test methods used and upgrades accomplished by the 96th Test Wing in order to meet requirements of Auction 97.

INTRODUCTION

The SRF requirement was two-fold, provide for a frequency agile and spectral efficient telemetry system; secondly assess the benefits to mission effectiveness of space-time code (STC) and low-density parity check (LDPC). In order to assess the impact of integrating STC and LDPC systems on Eglin, AFB, the latency overhead of the transmitter and receiver were evaluated. Historically, Eglin AFB has been primarily an L/S band range. To meet requirements of Auction 97, various tri-band antennas were surveyed for suitability. To assess the utility of STC on Eglin AFB an aircraft was modified with both an STC/LDPC capable transmitter and a baseline unencoded transmitter. Channel power measurements were taken of the aircraft in J-PRIMES using either a signal generator to provide dBi or the transmitter to provide effective isotropic radiated power (EIRP). Traditional telemetry systems are configured prior to flight. A requirement of SRF is to allow for the frequencies and/or modulation codes to be dynamically changed based on airborne real-time requirements. Finally a real-time software tool was developed to assess the utility of STC. This paper describes the test methods and resultant upgrades accomplished by the 96th Test Wing (96 TW) in order to meet requirements of Auction 97.

STC AND LDPC MEASUREMENTS AND TEST METHOD

Critical to the modernization of telemetry systems is the evaluation of latency overhead due to new encoding schemes (STC and LDPC). The STC and LDPC are not new coding technologies, the 96 TW had to come up with a standard method of evaluating transmitters from different manufacturers. A major constraint of the 96 TW was to stay within a millisecond latency. The use of STC and LDPC require overhead consisting of framing and parity information which introduce latency; the user data rate is accelerated to allow additional information, Figure 1 - Overhead Bits. Measuring latency was accomplished by generating a pattern of zeros or ones then inserting a short burst of a different pattern, see Figure 2 - Measuring Latency.

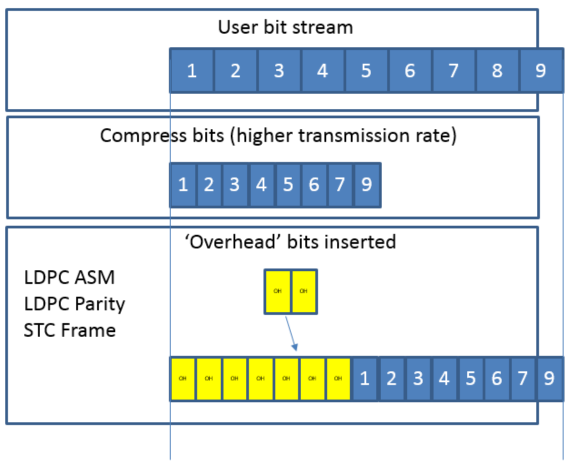

Figure 1 - Overhead Bits

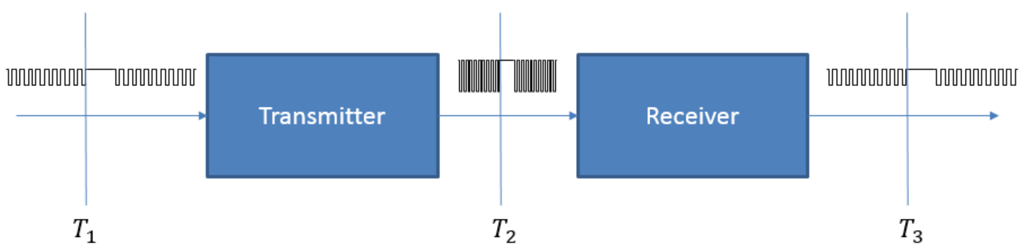

Figure 2 - Measuring Latency

System Latency L_s is given by: $L_S = T_3 - T_1$

Transmitter Latency L_t is given by: $L_T = T_2 - T_1$

A simulator was used to create a bit stream and a discrete trigger coincident with a burst of different data. A Mixed Domain Oscilloscope (MDO) was used to measure transmitter coding latencies shown below in Figure 3.

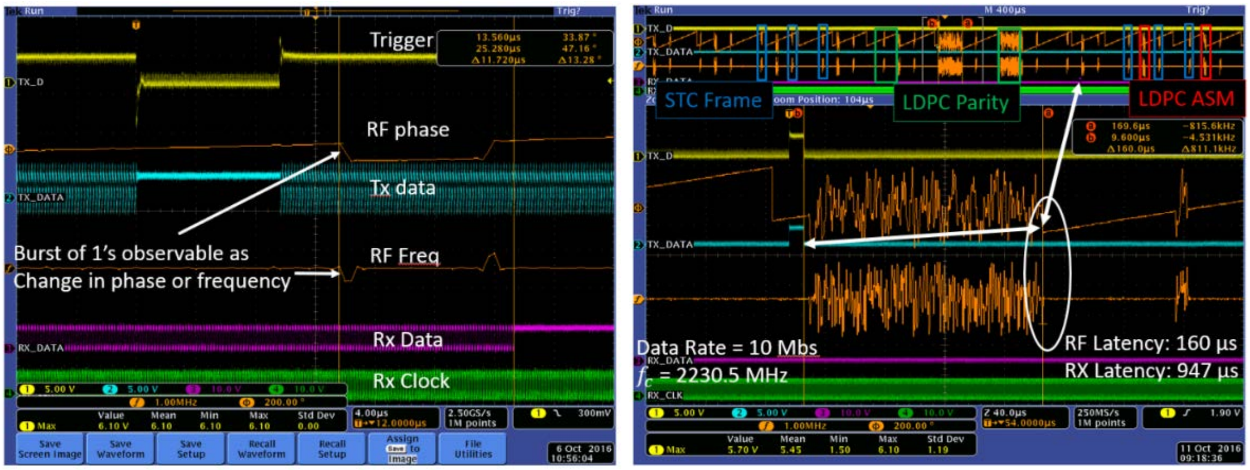

Figure 3 – Mixed Domain Oscilloscope RF Latency Measurements

The transmitter latency varied depending on where in the frame (STC or LDPC) the burst occurred. For a data rate of 10 megabits per second (Mbps), transmitter latencies at the start of the frame were 14 microseconds (µs) while at the end of the frame they approached 160 µs. From a system perspective latency the contribution of LDPC and STC coding is fixed as the receiver compensates for the transmitter packet 'jitter'. Contributing factors include data rate, coding formats, block size, and vendor implementation.

JOINT-PREFLIGHT INTEGRATION OF MUNITIONS AND ELECTRONIC SYSTEMS (J-PRIMES) TESTING

As part of the aircraft modification tri-band antennas were assessed for suitability. Antenna patterns were taken on a 3-foot diameter radial ground plane and are shown in Figure 4. Testing reflects that prior to Military Aircraft Temporary Class 2 Modification (T2), antennas should be measured to verify vendor antenna patterns across all bands.

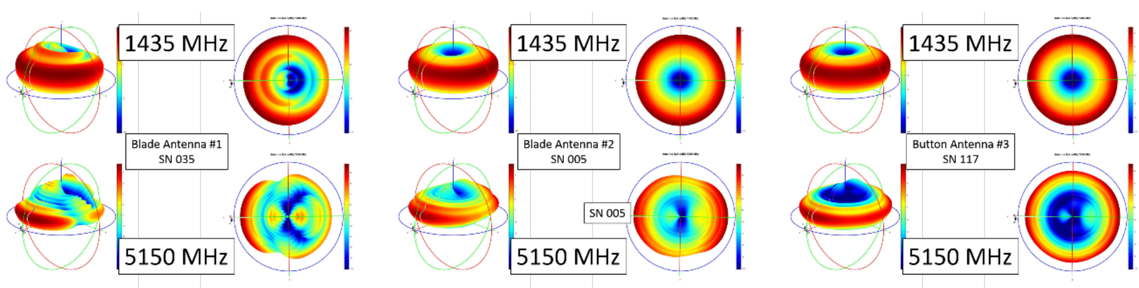

Figure 4 - Antenna Patterns

The test aircraft was placed in the J-PRIMES anechoic chamber (Figure 5) and mapped EIRP. Signal strength, polar, and azimuth readings were recorded creating vector (r, θ, φ) from the center of the rotating antenna. Aircraft measurements were taken with signal generators as well as transmitters. Figure 6 Left shows the diversity combined benefit of an STC signal; it should be noted that the power measurement for the non-STC signal is lower than anticipated by ~6 dB due to test setup. Since the two signals are orthogonal, the non-combined benefit of STC can be observed with a signal generator by first mapping the dual antenna configuration and then the upper and lower antenna independently as shown in Figure 6 – Diversity Combined STC benefit (left) and Non-Combined benefit (right).

Figure 5 - Test Aircraft in J-PRIMES

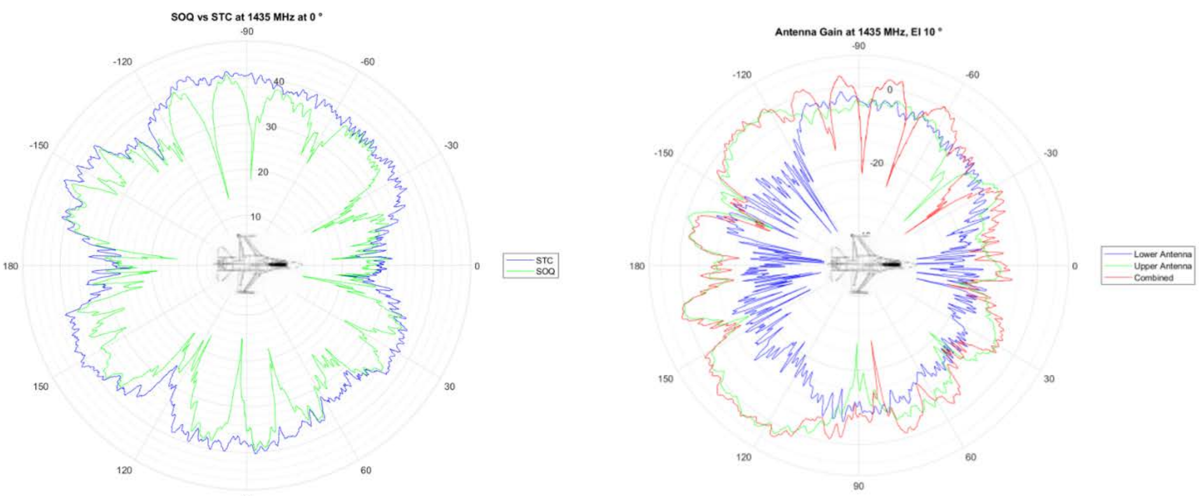

Figure 6 – Diversity Combined STC benefit (left) and Non-Combined benefit (right)

T2 MODIFICATION

The 96 TW addressed challenges to provide for spectral agility and mission effectiveness: allow the transmitter frequency to be changed in flight, resolve the "dual antenna problem" [1, 2], and increase the link margin of the system without increasing power. The airborne configuration consisted of the installation of new Cockpit Control Display Unit (CCDU), Ethernet Serial Instrumentation Remote (eSIR), low-loss cables, tri-band antennas, and instrumentation tray. The SRF instrumentation tray consisted of two transmitters: a Baseline, and an STC/LDPC Spectrally Efficient Airborne Transmitter (SEAT) as shown in Figure 7. The Baseline and SEAT transmitter signals were combined so the performance could be evaluated from the same set of antennas [3]. A third transmitter, labeled Legacy, was used to provide for aircraft time-space position information (TSPI) and command and control status. Power measurements were lower for the baseline transmitter than expected due to the absence of isolators between the baseline splitter and combiners.

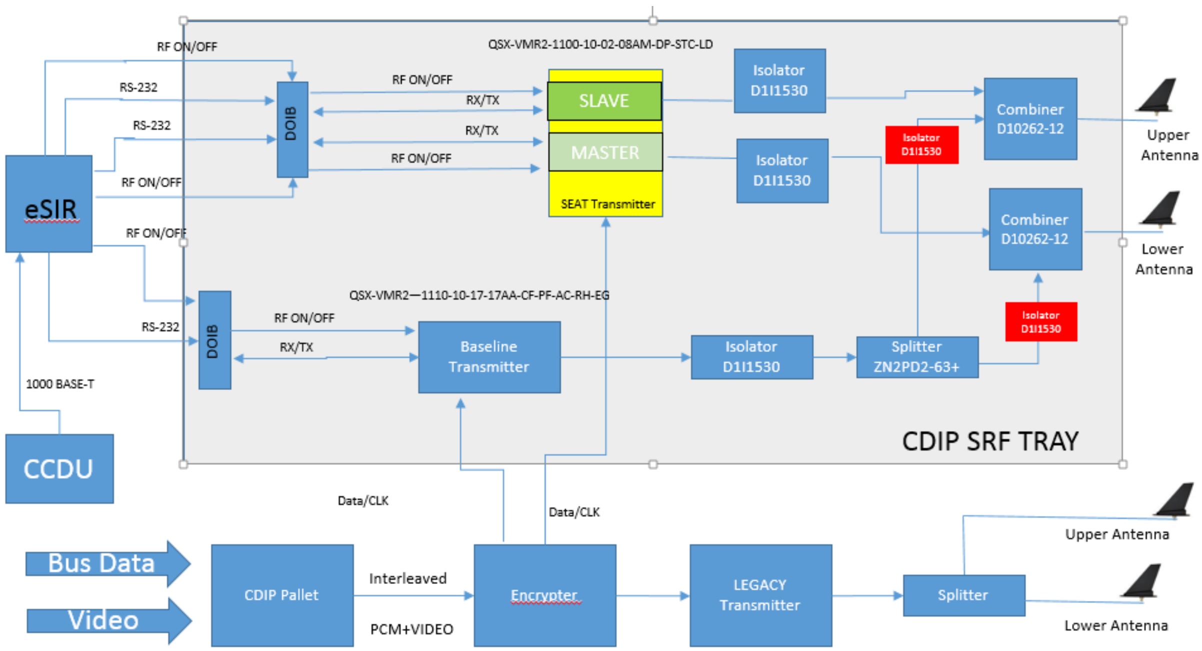

Figure 7 - SRF Instrumentation Tray

The CCDU was used to control the transmitters using a combination of serial commands and discrete inputs from the eSIR. The eSIR maintained an internal resource state for each transmitter, using periodic serial polling to guarantee that its state was accurate. The Cockpit CCDU interacted with the resource state in the eSIR via Constrained Application Protocol (CoAP) packets. Changes made to the internal resource state of the eSIR were translated into the appropriate serial commands and discrete inputs to the transmitters. To maintain simplicity of implementation and troubleshooting, CoAP payloads were limited to text strings. Resource definitions which returned multiple parameters packaged the data using JavaScript object notation (JSON). In this manner, a single CoAP GET request would return all the state data in one packet, rather than using multiple packets to query each individual resource. The master and slave transmitters were logically presented as a single transmitter in the eSIR. For the flight test, a transmitter's state was represented by the parameters in Figure 8:

Resource	Example
Name	"Legacy"
RF	"ON" or "OFF"
Frequency	"2450.5"
Bit_Rate	"10"
Modulation	"SOQPSK"
STC	"ON" or "OFF"
LDPC	"ON" or "OFF"
Differential_Encoding	"ON" or "OFF"
Source	"Internal" or "External"
Power_Amp	"10"
Temp	"45.4"
Fault	"FAULT"

Figure 8 – Transmitter State Representation

A simple "Config" resource was also defined to allow for predetermining configuration profiles for different combinations of transmitter parameters. By sending a configuration number to the eSIR via a CoAP POST to that resource, each transmitter would be configured with all the parameters required for a specific test. This configuration number, transmit enable (RF), and the frequency selections for the transmitters represented the parameters available for command from the CCDU. Multiple CCDUs could be used simultaneously with no complication, as each would query the eSIR for information independently. The eSIR, acting as a CoAP server, did not need to maintain any knowledge of how many clients were interested in its state. The nature of CoAP as a lightweight UDP protocol kept network bandwidth and processing overhead to a minimum, with no noticeable degradation in performance as multiple CCDUs were added to the network switch. Using this control system, the transmitters were configured to generate internal pseudorandom (PRN)-15 data, as well as transmit aircraft data. When transmitting PRN-15 data, a direct single bit comparison of STC and STC/LDPC could be accomplished between the legacy and SRF transmitter. Both the transmitters under test were provided with variable power and max power of 20 Watts. Bit rates of 10, 20, 30, and 40 Mbps were tested.

FLIGHT TEST AND REAL TIME DATA

A bit error analysis software application was developed for use with both real time and post mission data reduction. Transmitter performance as a bit error rate over one second was blended with TSPI. Flight testing included the use of one receiving site on the Eglin AFB land range, one on the flightline and one 100 nautical miles to the east. Each receiving site simultaneously provided two PRN-15 pattern signals, one from the Baseline transmitter and from the SEAT. The real-time TSPI was provided from either instrumentation on the jet, from the legacy stream, or and Advance Range Data System II (ARDS II) pod. As shown in Figure 9, all six telemetry streams throughout a 4g right-hand turn, each ribbons indicates the bit error rate (BER) over a second. White vectors are shown indicating range and bearing to each telemetry site. Coloring of the ribbon trails were configured for a yellow, at a BER of 10^{-7}, and red, for a BER of 10^{-6}.

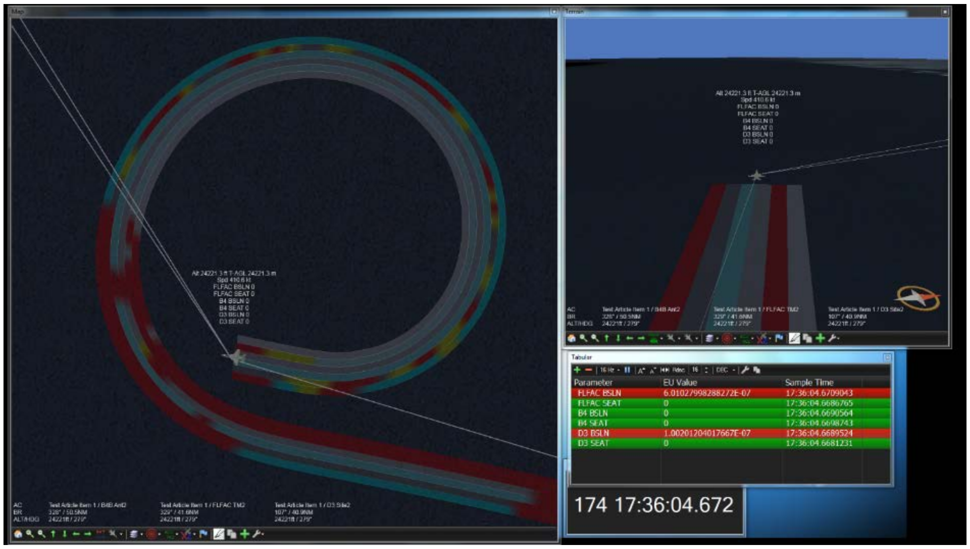

Figure 9 - NetView Bit Error Rate (BER) versus time-space position information (TSPI)

Each receiver site was instrumented with an IRIG 106-17 Chapter 10 [4] recorder capturing combiner outputs from the baseline, SEAT, and TSPI on the legacy channel. Spectrum analyzers and a camera were installed to capture the channel power measurements and front panel display from each receiver. To demonstrate the utility of STC, the power was significantly reduced by 11 dB from operational levels so that the uuencoded SOQPSK-TG would exhibit errors. Conceptually this can be viewed as a circle that approaches the EIRP as link margin is consumed in free-space path loss as shown in Figure 10. Additionally, testing was performed with both systems, Baseline and SEAT, at full power. The flight plan included left and right orbits at 60 and 100 NM with aileron rolls in sets of three to accommodate both test points.

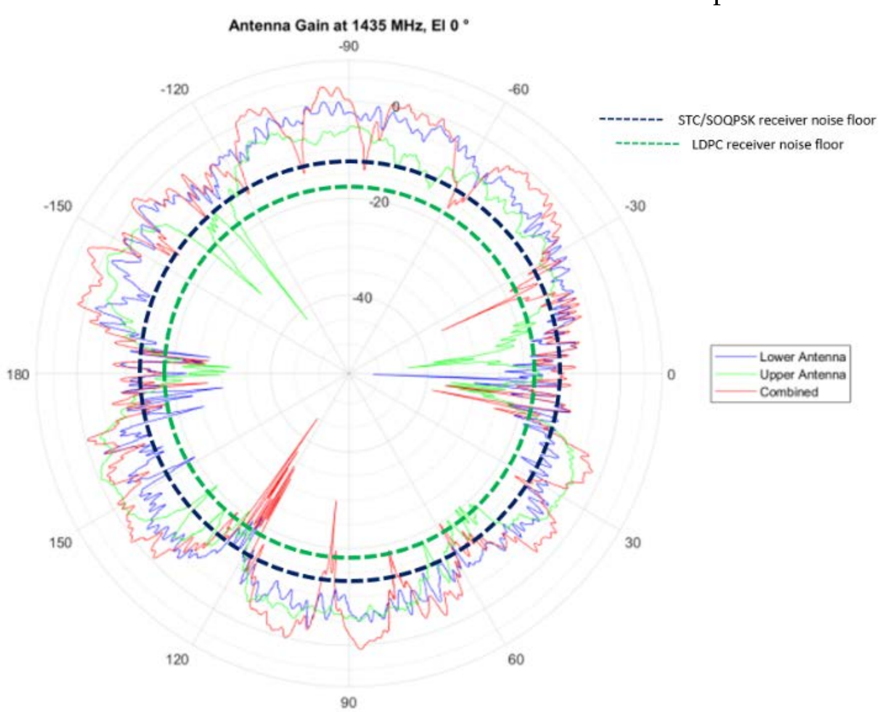

Figure 10 - Arbitrary Rx sensitivity floors of STC and LDPC

FLIGHT TEST RESULTS

In general, improvements were seen while using STC with occasional unexpected anomalies. For the purposes of this paper, we will discuss performance of the SEAT configured for STC and Baseline configured for SOQPSK-TG at 10 Mbps configured for low power and short range. Data for the left hand orbit taken at 55 NM is shown in Figure 11. Numerical and graphical results are shown in Table 1, Figure 12 - Cumulative Errors, and Figure 13 – Bit Error Rate. Anomalous combiner performance was periodically observed on the STC receiver which degraded the overall performance in every segment of flight as shown in Figure 14 - Left Orbit 55 NM segment zoom. At the time of this paper, the cause of the anomalies was not known. However, the reduction or elimination of the anomalies would greatly improve performance. Some of these anomalies are more apparent and impactful than others.

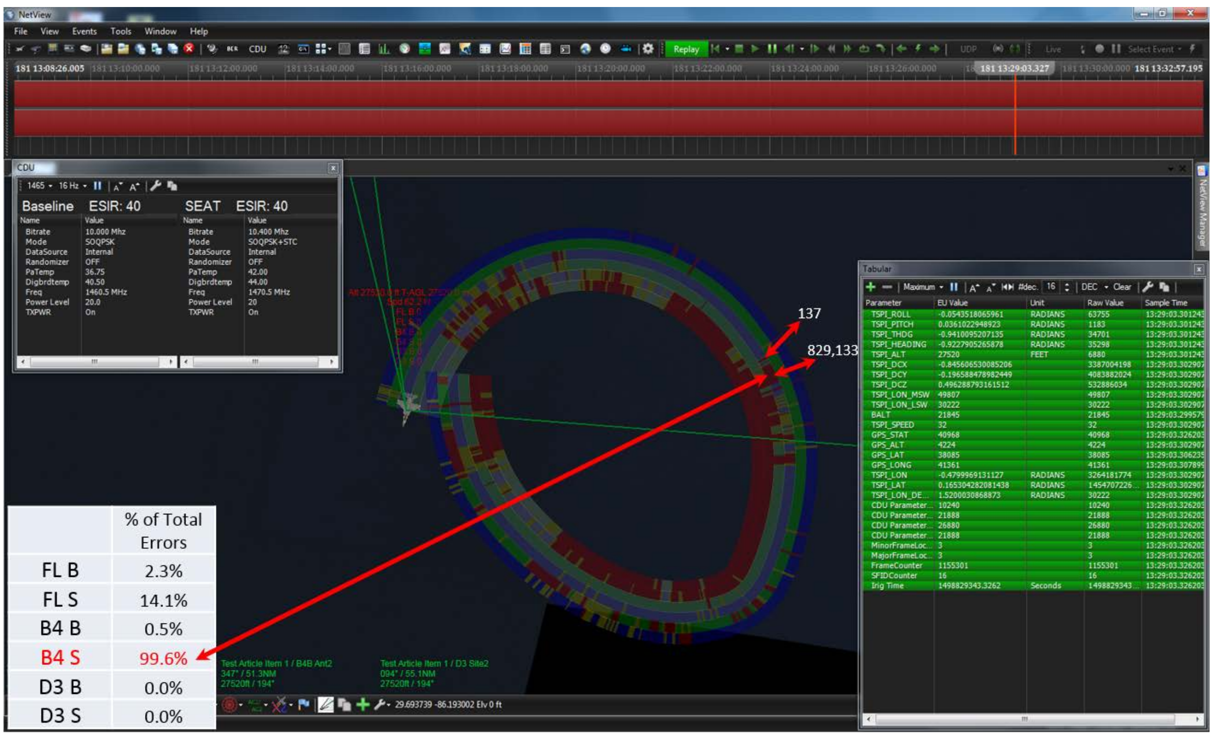

Figure 11 - Left Orbit 55 NM

Link AvailabilityL_A is given by: $L_A = \frac{T_{bits}-T_{err}}{T_{bits}}$

Where $B_t$the total are bits over an interval and B_e are the bits in error over the same interval.

The percentage of baseline errors $\%B_{err}$ given by: $\%B_{err} = \frac{Seat\ T_{err}}{Baseline\ T_{Err}}$

Table 1 - Left Hand Orbit 55 NM

	T_{Errors}	T_{Bits}	T_{BER}	$\%B_{err}$	L_A
FL Baseline	*55,412,497*	*5,908,842,880*	*9.38E0-3*		*99.0622%*
FL Seat	*8,706,875*	*5,908,833,152*	*1.47E-03*	*15.7128%*	*99.8526%*
B4 Baseline	*58,918*	*5,908,833,152*	*9.9 E-06*		*99.9990%*
B4 Seat	*831,951*	*5,908,833,152*	*1.41E-04*	*1412.05%*	*99.9859%*
D3 Baseline	*2,299,874*	*5,908,408,416*	*3.89E-04*		*99.9611%*
D3 Seat	*85,023*	*5,908,833,152*	*1.44E-04*	*3.70%*	*99.9986%*

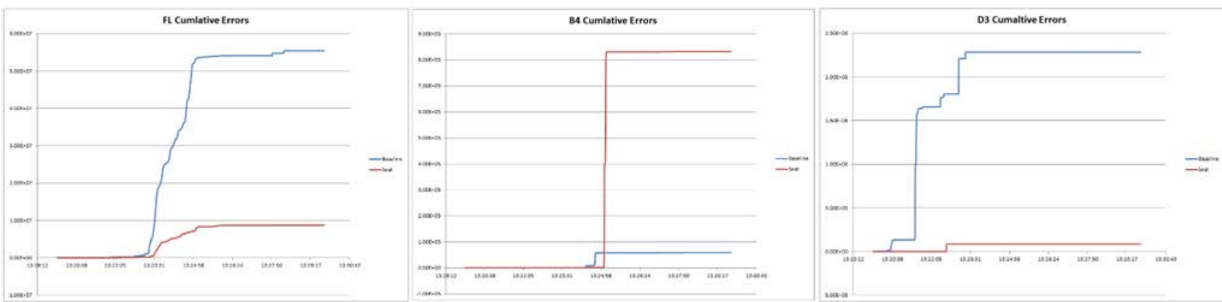

Figure 12 - Cumulative Errors

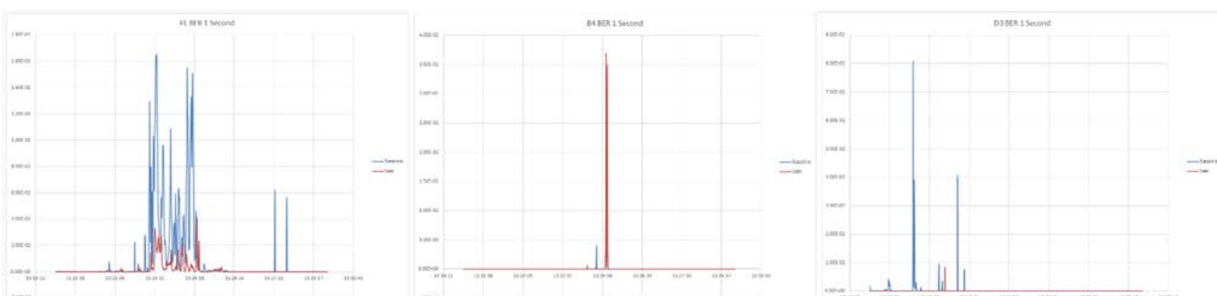

Figure 13 – Bit Error Rate

Figure 14 - Left Orbit 55 NM segment zoom

A test comparison between STC and LDPC was performed which clearly demonstrated the benefit of LDPC; see Figure 8 Arbitrary Rx sensitivity floors of STC and LDPC. Dedicated testing of LDPC was not accomplished due to other higher priority testing requirements supported by the test aircraft. Additional testing is planned as resources become available.

CONCLUSION

In this paper, we identified methods to measure the latency of a STC/LDPC coded system, accounting for both transmit and receive components. Demonstrated the measurement of an STC channel power providing comparison with a dual antenna system. Developed a TSPI/BER tool for which ranges can use free of charge to evaluate dynamic link performance in real-time and post mission. Validated that benefit of STC is heavily dependent on the airframe and antenna placement. Revealed from J-PRIMES plots that it was evident that the ‘dual antenna’ problem may be addressed with power offsets between the two antennas. The LDPC showed positive results; additional testing is required to assess the degree of benefit in range operations.

REFERENCES

[1] M. Jensen, M. Rice, and A. Anderson. Aeronautical telemetry using multiple-antenna transmitters. *IEEE Transactions on Aerospace and Electronic Systems*, 43(1):262–272, Jan 2007.

[2] M. Rice, “Space-Time Coding for Aeronautical Telemetry: Part I – System Description,” in *Proceedings of the International Telemetering Conference*, Las Vegas, NV, October 2011.

[3] M. Rice and K. Temple. Space-time coding for aeronautical telemetry: Part II — Experimental Results in *Proceedings of the ITC*, Las Vegas, NV, October 2011.

[4] Range Commanders Council Telemetry Group, Range Commanders Council, White Sands Missile Range, New Mexico, IRIG Standard 106-17: Telemetry Standards, 2017. (Available on-line at http://www.wsmr.army.mil/RCCSite/Pages/default.aspx).