CAN SPACE TIME ENCODING AND ADAPTIVE EQUALIZATION BENEFIT ROTARY-WING MISSIONS AT THE YUMA PROVING GROUND?

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ABSTRACT

The US Army Yuma Proving Ground (YPG) utilizes telemetry in several critical ways. Data, video, and voice from test aircraft provides YPG the information necessary to effectively execute missions. This information must be displayed real-time for efficient use of available flight time, making a robust telemetry link vital. In seeking an increased telemetry downlink capability, YPG considered three new technologies: Space Time Coding (STC), Adaptive Equalization (EQ), and Low Density Parity Check (LDPC). These technologies have shown reduced multipath and increased datalink reliability on fixed-wing aircraft; however, YPG's concern was the technology's benefits on rotary wing aircraft tested here. To assess potential benefits of these technologies, YPG conducted flight tests using representative flight profiles and vendor-supplied equipment to collect quantitative and qualitative data.

KEYWORDS

1. Space Time Coding
2. Adaptive Equalization
3. Low Density Parity Check

INTRODUCTION

YPG is a subordinate command of the Army Test and Evaluation Command and is one of the largest military installations in the world. Located in southwestern Arizona, it encompasses 1,308 square miles. YPG personnel conduct tests on nearly every weapon system or piece of military equipment in the ground combat arsenal. With a mission to provide premier test services to the U.S. Government and her allies, YPG conducts, reports, and supports developmental tests, experiments, production tests, integrated developmental/operational tests, as well as provides training support. In 2014, YPG fired over 287,000 rounds of artillery, mortar, missile, and small arms munitions, flew over 2,400 aircraft sorties, drove over 484,000 test miles, and conducted over 1,200 airdrops. These numbers more than double when events conducted in support of training are counted, and for the last 5 years YPG was the busiest Army proving ground.

The Aviation Systems and Electronic Test Division at YPG is responsible for testing of aviation ballistic weapons and missiles, unmanned aerial systems, aircraft systems, precision guided and unguided air delivered systems, personnel parachutes, sensors and surveillance systems, and electronic warfare systems. As a developmental test activity, the goal is to help the developer field their systems and provide the Soldier with the safest, most lethal equipment. Instrumentation is a critical part of meeting this goal, and is used to either capture the reported information from the item under test or capture the "true" performance of the system. In either case, it is critical that the instrumentation accurately capture the necessary data.

Regardless of the test mission being conducted, the ability to display critical information from the system under test real-time in Mission Control greatly benefits the test team. The ability to make decisions based on current and relevant data allows the test team to maximize their efforts and ensure that necessary data is being collected. If the data from the system under test can be combined with truth data from range instrumentation, then system performance can be assessed. Flight time is not cheap, so the ability to quickly and efficiently assess flight test objectives is critical to mission success.

The best way to achieve this is a robust data delivery system. Range instrumentation is generally ground based and utilize the range fiber backbone to transport data where it needs to be. Transmitting radio frequency (RF) data from aircraft is more complex and susceptible to RF interference, multipath, or other losses. The key components of YPG's RF infrastructure are the same as other ranges, but the aircraft are different. YPG primarily tracks rotary-wing aircraft rather than fixed-wing planes, which presents unique challenges that are not realized in some other test communities.

The transmitters, receivers, and antennas that make up a telemetry link are only part of the data delivery system—the performance of the RF link is critical. A robust telemetry link can greatly enhance the overall performance of the data delivery system. At the 2014 International Telemetering Conference (ITC), YPG researched new technologies not currently in use on the range in an effort to increase the RF link reliability during typical missions at YPG.

New technologies and hardware were identified at ITC and a plan was developed to test them at YPG. Those technologies were STC, Adaptive EQ, and LDPC. YPG put a plan together to test those capabilities with loaner hardware and a rotary-wing aircraft that belonged to the range.

DEMONSTRATION SETUP

YPG partnered with the members of Range Commanders Council (RCC) Telemetry Group and the Telemetry community in a mutually beneficial effort to make the demonstration a reality. YPG did not have the either the hardware or trained personnel available to conduct the demonstration. Conversely, our partners had no data from rotary-wing aircraft, despite a plethora of data from fixed-wing systems. The people helping YPG are acknowledged by name at the end of this paper.

One of the long-standing issues with any helicopter testing conducted at YPG is aircraft orientations that masks the transmitting antenna. There are multiple reasons for this, including antenna placement on the aircraft and the rotary-wing aircraft's typically low flight altitude. Perhaps the most significant issue is that helicopters can remain in a masked orientation for an extended period of time while hovering. Based on prior experience, YPG's usual approach is to locate antennas on the top and bottom of the aircraft and use a power divider to split the transmitter output to feed both antennas. This configuration minimizes the chance that both antennas will be masked at the same time in flight. This 2-antenna configuration was the baseline that YPG would use to during the demonstration to compare the various technologies.

The original plan was to execute demonstration flights using only the video output from a stabilized camera. This is a common configuration for many support missions flown at YPG and it could be easily implemented on the UH-1H. After discussion with colleagues, it was decided use bit error rate test set (BERT) as the data source for a portion of the demonstration, since it could be used to quantify the quality of the telemetry links. Two days of flight testing were planned, with BERT being the primary data source on the first day and video output being the primary data source on the second day. Results from the first day would be used to determine any configuration changes for the second day. The other important outcome of the discussion with our colleagues was the configuration is shown in figure 1.

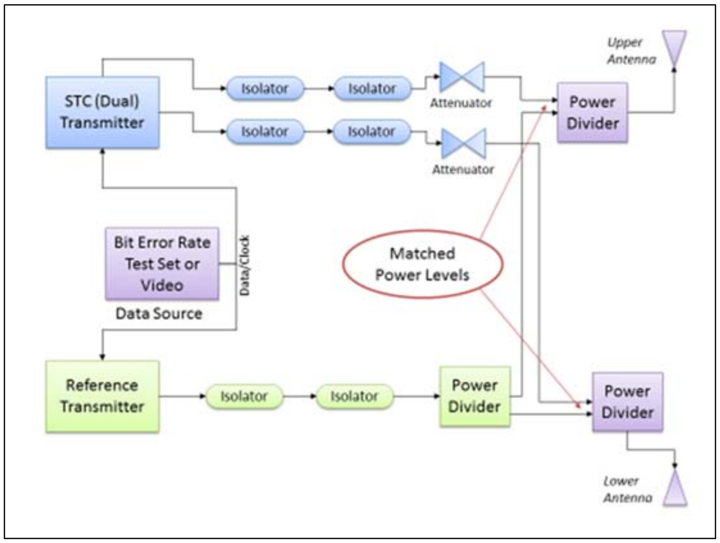

Figure 1. Demonstration Configuration

This configuration for the demonstration would allow us to maximize the amount of data gather during a particular flight, and would allow for direct comparison for the two technologies being utilized on a particular flight. In addition, the STC Transmitter and the Reference transmitter could be configured in multiple ways, which allowed the various configurations required for the Demonstration to be enabled without any hardware changes other than cabling. Our partners agreed to provide all the components shown in figure 1 except for the transmitting antennas and the video data source. YPG would provide the transmitting antennas, the video data source, and a helicopter. Other equipment to receive the signal would also be provided as need by various partners.

A UH-1H helicopter was used as a test platform and, to emulate other helicopter testing at YPG, an antenna was mounted on the upper wire strike protection assembly of the UH-1H. The second antenna was mounted on the lower aft portion of the aircraft belly. This configuration minimized the chance of masking both antennas at the same time in flight. In addition, the upper antenna location produced some very interesting results during the demonstration. Figure 2 shows the 2-antenna configuration utilized for this demonstration and figure 3 shows the actual installation of the upper antenna for the demonstration.

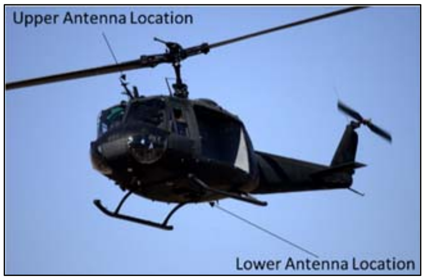

Figure 2. UH-1H Antenna Configuration

Figure 3. Upper Antenna

Two equipment racks were installed on the aircraft. The instrumentation rack (shown in figure 4) had the following equipment: loaned instrumentation pallet that contained transmitters, power splitters, BERT source, and instrumentation recorder. The other rack contained the sensor interface hardware (shown in figure 5).

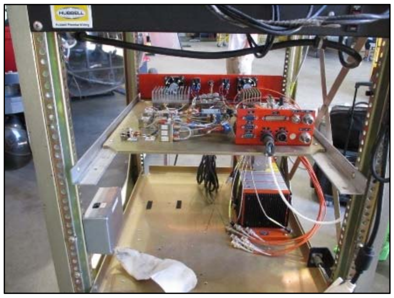

Figure 4. Instrumentation Rack

Figure 5. Sensor Interface Rack

The V14 sensor (shown in figure 6) was used during Flights 4 and 5.

Figure 6. V14 Sensor

YPG Test Officers with experience conducting helicopter testing on the range were asked to determine a flight path for the demonstration. The flight path was chosen to utilize areas on the range where helicopter testing is commonly performed and to emphasize profiles that have caused telemetry dropouts in the past. In order to make the best use of the available flight time, no hover flights were included and one flight pattern was used for all test flights. The flight profile is as follows and an aerial map is shown in figure 7. In order to maintain consistency, all test flight profiles were monitored by a Mission Controller on a real-time vector map.

a. UH-1H flew north along Rocket Alley at 1,000 ft above ground level (AGL), 328 degrees (deg) magnetic (mag).
b. Turned NE at center of LA drop zone; descended to 300 ft AGL, 023 deg mag.
c. Flew from Met 10 to Target 23 on 328 deg mag at 300 ft AGL, 328 deg mag.
d. Climbed to 5,000 ft mean sea level (MSL) and orbited at CM-1 (could orbit while in the climb) - right hand orbit.
e. Descended to 1,000 ft MSL fly NW to abeam Red Hill, 328 deg mag.
f. Turned left and arced back to CM-4, then flew toward Site 14 at 300 ft AGL, 020 deg mag.
g. Continued through Site 14 on same heading to vic NE corner P. Square at 300 ft AGL.
h. Turned left and arced back to western edge of Prospect Square.
i. Flew south along west edge of Prospect Square direct to Site 14 at 300 ft AGL, 169 deg mag.
j. Turned 90 deg east and flew along Target Boundary Road to East Target Road at 300 ft AGL, 079 deg mag.
k. Diverted through Indian Wash, climbing to 1,500 ft MSL to North Pad, 121 deg mag.
l. Made one orbit at North Pad at 1,500 ft MSL - left hand turn.
m. Returned west through Indian Wash to Middle Mountain Road descending to 500 ft AGL.
n. Returned to Laguna Airfield southbound along Middle Mountain Road at 500 ft AGL.

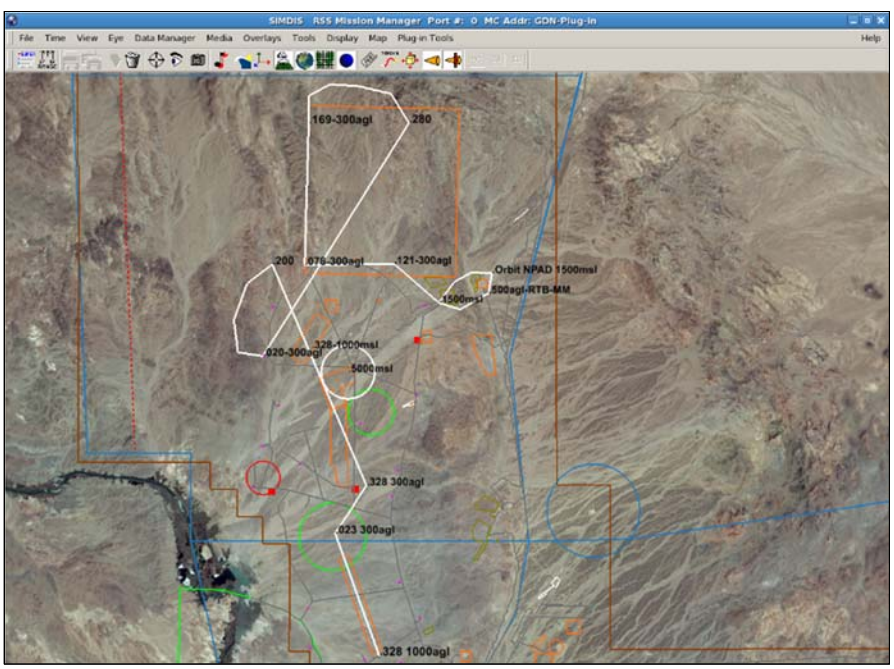

Figure 7. Vector Map Display

A total of 5 flights were conducted on June 4-5, 2015. Each of the flights was flown in a different configurations with respect to transmitter and receiver set-up; however, the same flight profile was used for each flight. For Flight 4, the aircraft did not complete the entire flight profile due to poor performance of the configuration for that particular flight. The vendor supplied both the transmitters and receivers, and was responsible for implementing to desired configuration. For configurations designed to emulate YPG's traditional configurations, the transmitter(s) were set-up to transmit in either PCMFM or SOQPSK only modes. A 50/50 power divider was used on the reference transmitter to feed both antennas on several flights, which is also part of YPG's traditional configuration. YPG's 6-foot diameter tracking antenna and associated hardware located at Telemetry Site-4, Cibola Range was used to track the aircraft for all flights. The RF feed from this tracking antenna was provided as input into the vendor's reference. The demonstration flight configurations are listed in tables 1 through 5.

Flight 1 was designed to be a direct comparison of the new Space Time Encoding technology to YPG's traditional (legacy) PCMFM/SOQPSK downlink. For this flight, both the reference and STC/Dual transmitters were utilized, and the data source was a BERT with pseudorandom binary sequence 15 data.

Table 1. Demonstration Flight 1 Configuration, PN15 Data

Transmitter			Receivers	
Legacy	SOQPSK Frequency = F2 Antenna = Top & Bottom Power Divider = Yes		R1	Channel 1 = F1, SOQPSK-STC Channel 2 = F2, SOQPSK-STC Equalization = No
Demo	SOQPSK - STC Frequency = F1 Antenna = A&B		R2	Channel 1 = F2, SOQPSK-EQ Channel 2 = F2, SOQPSK-STC Equalization = Yes CH 1

The second flight was flown in YPG's most common form of TM transmission, PCMFM, but employed frequency diversity by transmitting the same BERT data on two different frequencies. The top antenna was configured to transmit on F1 while the bottom antenna was configured to transmit on F2. For this flight, the vendor utilized the STC/Dual transmitter as two separate transmitters while the receivers were set-up with and without adaptive equalization. Although there was no difference in the transmitted signal for this flight, this configuration was interesting because it could be implemented almost immediately at YPG with existing equipment (minus adaptive equalization). Frequency diversity had been tried at YPG many years before but had fallen out of favor due to logistics and spectrum availability concerns. Although the concerns are still valid, the advantages from frequency diversity may outweigh these concerns in certain applications; hence, the interest in this configuration.

Table 2. Demonstration Flight 2 Configuration, PN15 Data				
Transmitter			Receivers	
Legacy	PCMFM Frequency =F1 Antenna = Top		R1	Channel 1 = PCMFM F1 Channel 2 = PCMFM F2 Equalization = No
Legacy	PCMFM Frequency =F2 Antenna = Bottom		R2	Channel 1 = WB F1+F2 Channel 2 = PCMFM F2-EQ Equalization = Yes CH 2

The remaining flights (3, 4, and 5) were conducted on the second day of flight testing and video from the stabilized camera was used as the data source. The configurations flown on the second day incorporated lessons learned on the first day.

Flight 3 configuration was very similar to the configuration flown on Flight 1. For this flight, both the reference and STC/Dual transmitters were utilized. The STC technology was employed again but for this flight the LDPC mode was also enabled. The reference transmitter was set-up for PCMFM. Both of these transmission modes were chosen to minimize drop outs in the video transmission. The decision for these configurations was based both on the demonstrated flights conducted the previous day and the team's observation of an actual test program video transmission. Although the set-up for this test program was different than the set-up that was being used for the Demonstration, the video encoding and transmission portions were similar. The team observed during this flight that small RF dropouts tended to result in a significantly longer loss of video signal in Mission Control.

Table 3. Demonstration Flight 3 Configuration				
Transmitter			Receivers	
Legacy	PCMFM Frequency = F1 Antenna = Top & Bottom Power Divider = Yes		R1	Channel 1 = PCMFM1 Channel 2 = SOQPSK-STC/LDPC Equalization = No
Demo	SOQPSK-STC/LDPC Frequency = F2 Antenna = Top & Bottom		R2	Channel 1 = PCMFM-EQ Channel 2 = SOQPSK-STC/LDPC Equalization = Yes CH 1

Flight 4 configuration was similar to Flight 2 as frequency diversity and PCMFM were once again used. For this flight, the vendor again utilized the STC/Dual transmitter as two separate transmitters, with the receivers' set-up with and without adaptive equalization. Once the flight began, however it became immediately apparent that this flight would not produce any usable results. The quality of the video data from the top antenna was so poor because of its proximity to the main rotor caused RF signal losses, which in turn required the video to resynchronize. Due to the amount of time required for the video to resynchronize and the frequency of RF signal losses, there was no usable video data being displayed from the top antenna. Consequently, the only usable data was collected from the bottom antenna, which was a configuration (video/PCMFM/single antenna) that was already commonly used at YPG. The flight was quickly terminated and a 5th ad hoc flight was added to the day's events.

Table 4. Demonstration Flight 4 Configuration				
Transmitter			Receivers	
Demo	PCMFM Frequency =F1 Antenna =Top Power Divider = No		R1	Channel 1 = PCMFM1 Channel 2 = PCMFM2 Equalization = No
Demo	PCMFM Frequency =F2 Antenna = Bottom		R2	Channel 1 = WB F1+F2 Channel 2 = PCMFM F2 Equalization = Yes

For Flight 5, the stabilized camera video remained as the data source but only the bottom antenna was utilized. The team quickly decided on a configuration that allowed a comparison of SOQPSK and SOQPSK-LDPC for the transmitted signal. The receivers were configured to also compare the effect of the adaptive equalization on only the SOQPSK signal.

Table 5. Demonstration Flight 5 Configuration				
Transmitter			Receivers	
Legacy	SOQPSK-LDPC Frequency = F2 Antenna =Lower Power Divider = No		R1	Channel 1 = SOQPSK-LDPC Channel 2 = SOQPSK Equalization = No
Demo	SOQPSK Frequency =F2 Antenna = Lower		R2	Channel 1 = SOQPSK-LDPC Channel 2 = SOQPSK-EQ Equalization = Yes CH 2

RESULTS

Since the flight test occurred in early June, and the deadline for ITC paper submission followed shortly thereafter, no quantifiable results were available at press time. Analysis of the available data is ongoing and will be presented at ITC in 2015.

This demonstration was conducted to look at some new telemetry technologies in an effort to improve the quality of the data on display to our customer in Mission Control. Throughout the demonstration, there was much discussion amongst the team about the results, but all agreed that there were more factors involved than just the new transmitters and receivers. However, there was an attempt to drill down and look only at the new equipment and the following are some qualitative observations made during the demonstration:

a. There was improvement seen when using STC capability.
b. There was improvement seen when using LDPC capability.
c. Further investigation is required to determine if Adaptive EQ improved the data link reliability.

From an overall view of improvement to the data displayed in Mission, Flight 4 and 5 were the most informative. In Flight 4 we saw that in trying to prevent antenna masking by including a top antenna, we ended up with an overall configuration (video compression/decompression and TM equipment) that produced no usable data in Mission Control. In fact, since a power divider was used to split the transmitted signal, a case could be made that because the 2-antenna configuration reduced the power to the lower antenna that it was actually worse to have an upper antenna.

Flight 5 was performed to see if this was indeed the case and for much of the flight, the video was available and of sufficient quality for use in Mission Control. During this flight, improvements provided from LDPC were also apparent as it seemed to provide more usable video data than the SOQPSK only link. There was, however, an extended period of time when the helicopter entered a specific portion of the flight profile where there was no usable video in Mission Control due to lower antenna masking. Since the flight profile flown was a composite of many common flight profiles flown antenna, masking remains a real issue. With no other changes, the new transmitter/receivers cannot overcome the issues.

Based on these flights, Flight 3 results became very interesting. Flight 4 showed how unfavorable the upper antenna location on the UH-1H was for video transmitted as PCMFM. Similar to Flight 4, both upper and lower antennas were used, but STC/LPDC was enabled, which produced more periods of usable video data in Mission Control. A qualitative estimate is that the video was available 50% of the time during this flight. A quantitative assessment will be made in the future but the observed results show a dramatic improvement with STC/LPDC.

The actual upper antenna location on the UH-1H was chosen largely because it was available for the demonstration. There were likely better locations on the UH-1H, but whether a better location is truly available for use is always an issue since other RF devices that are part of the aircraft's mission equipment package usually end up in these locations. For example, the top of the tail rotor on an Apache would be an excellent location for the TM antenna because it would be located outside of the path of the main rotor and offer good visibility; unfortunately, the GPS antenna for the aircraft navigation systems is located there. The Demonstration showed that masking is still an issue, and past instrumentation efforts have shown the availability of good antenna locations can be challenging; however, for instrumentation efforts that require a 2-antenna configuration, STC/LDPC could provide some noticeable improvements in performance.

The biggest non-TM related factor that impacted the video data quality was the video compression/decompression robustness. There are two areas of concern based on this Demonstration. The first is the ability to absorb small RF dropouts and remain synchronized. The second is the amount of time required to resynchronize after synchronization is lost. Further analysis of the data and perhaps some follow on lab characterizations will be needed to characterize the impact of either of these areas; however, the results from the demonstration led the team to believe that the amount of time to reacquire a usable video signal after a loss was too long, which is detrimental to the mission. YPG will address this issue with the video decoder vendor to see if reacquisition delay can be reduced. This may be a bigger issue if the test requires the data link to be encrypted.

Analysis of the data collected still needs to be performed to verify that our observations match the actual results. Initial efforts will focus on the last 3 flights as these configurations most closely emulate the typical test programs conducted at YPG. Additional input from the rest of the team will also be solicited to help ensure that the best pathway can be planned as we go forward.

CONCLUSION

Whether or not to implement some or all of the technologies tested is the ultimate question. New technology comes with additional cost. Some of these capabilities are more costly than others since they require both a new transmitter and receiver, like STC, while others only need a new receiver as existing transmitters are sufficient, like Adaptive EQ. Still others, like the use of frequency diversity during missions, can be implemented at virtually no cost by utilizing existing equipment; however, to get the full benefits of right and left hand circular polarization, more receivers and combiners will be required to receive polarizations and frequencies off test aircraft.

Although not available at the time of the Demonstration, YPG has been working towards being able to track a test aircraft from multiple antenna locations on the test range. The tracking antennas located in geographically different locations are at different elevations and separated by at least several miles. This spatial diversity should help in many ways, especially with respect to antenna masking. The plan is to utilize antenna pointing and some type of best source selector with this implementation to maximize the benefits. Similar to the frequency diversity, more receivers would be needed. Combine both frequency and spatial diversity on a test program and the requirement for equipment grows rapidly.

Regardless of the path taken, it will take years in this current fiscal climate to implement all of the desired improvements. Demonstrations like this provide a tremendous amount of data for a small cost when compared to equipment cost plus the help from the community.

ACKNOWLEDGEMENTS

YPG would like to thank our RCC and vendor partners for making this demonstration a reality. Without their support, this demonstration would never have left the ground: Kenneth “Kip” Temple, RCC Telemetry Group & Edwards Air Force Base, and Mark Geoghegan and Bob Schumacher, Quasonix.

REFERENCES

1. Telemetry Group, Telemetry Standards, IRIG Standard 118–12 (Vol 2), Test Methods for Telemetry RF Subsystems, Secretariat, Range Commanders Council, US Army White Sands Missile Range (WSMR), New Mexico, September 2012.

2. Telemetry Group, Telemetry Standards, IRIG Standard 106–13 (Part 1), Chapter 10, Secretariat, Range Commanders Council, WSMR, New Mexico, June 2013.