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Transitioning to C-band

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Abstract: With the sell-off of the standard telemetry frequency bands, the transition to C-band in the USA has been slow in adopting the new requirement. Several flight test ranges have moved to C-band but most of the USA has not. As a result, all three frequency bands, L, S, and C, are still being used for flight test despite the government ruling. To address the multiband utilization, several transmitter suppliers have developed a tri-band transmitter to support the frequency allocation on demand approach. This paper reviews the Curtiss Wright's tri-band transmitter development, performance results and the support for space-time processing, forward error correction, and thermal management.

1. Transitioning to C-band

The government auction of airwaves for use in mobile broadband to support the demand for internet access by smart phones and tablets effects the standard telemetry frequency bands, the transition to C-band in the USA has been slow in adopting the new requirement.

With the Government auction and sell-off of the telemetry frequency bands the everyday operation of the flight test community is drastically affected with reduced operational availability to increased frequency crowding. The Government responded with new standards for bandwidth efficient modulation schemes to "pack" more data bandwidth in the remaining telemetry workspace, allowing the private sector to develop hardware in the new C-band allocations for telemetry.

The vendor telemetry community responded first with the spectrum efficient hardware for both air and ground applications while the requirements for C-band applications evolved from initial experiments to actual orders.

The ground segment in the USA has upgraded to be C-band capable across the country. Of interest, the commercial occupation of their new ownership of the L and S-bands (D and E bands) is regional with local test ranges still using L and S-band due to the current availability. Areas of the country where frequency crowding exists, C-band is widely used with equal activity in L-band as well. With the wide variation of frequency bands availability, tri-band transmitters are the focus for flight test operations.

Figure 1: A tri-band transmitter can support S, L and C-bands

2. Developing a Tri-band Transmitter

Curtiss-Wright developed a tri-band transmitter to provide a multiband solution in a single unit to help engineers avoid having to replace units to change band between test flights or when flying from range to range. The transmitter provides lower and upper L(D) band, full S (E) band and C-band in a form factor designed to replace many existing units in the field.

The unit also includes the latest technology as defined in the IRIG-106-19 standard for advanced range telemetry (ARTM) compliant modulation, forward error correction (FEC) and space time compensation (STC) as well as providing independently control dual RF outputs. The unit went through a full series of in house testing as a design verification as well as many tests by the USA Government to both validate the hardware performance and to become familiar with the new features in a real telemetry environment.

Through these tests, there were several modifications and enhancements that include customization as many of the ranges did not agree on the list useful features based on their test objectives. As a result, four variants of the tri-band now exist to address the desire feature list.

During the test campaigns, several undesirable performance issues were observed and corrected using active compensation. The linearity response of the IQ modulator device (where I is the in-phase component, and Q the 90 degree phase difference), across the three frequency bands did not match the manufacture's performance data. Unfortunately, the selected part had the highest performance device currently available amongst the leading suppliers.

The corrective action was to incorporate active band linearization compensation using a micro controller to activity monitor temperature and apply compensation factors across with wide bandwidth of the three frequency bands. Similarly, the RF power leveling across the three bands was also a challenge and was enhanced with a second micro controller compensation circuitry to level the RF output power across the three bands. Temperature control, being a challenge and further discussed in the following a paragraph, was implemented to control the overall temperature of the transmitter to prevent over-heating and component damage.

2.1 Interoperability Testing

Much of the funding gained by the sell-off of the telemetry bands was spent on a modern upgrade to the range receiver offering with DSP based receiver designs from several manufactures addressing the multiband, the STC and the IRIG 106 chapter 7 standards.

Where they failed as interoperability testing amongst the vendor's products was to assure compatibility and operability. The community did come together to perform an operability test session at the 2019 International Telemetry Conference in Las Vegas to where the transmitter vendors could test against the many vendor's receiver products allowing, them to record the waveforms for future development. Curtiss-Wright was the only transmitter vendor with an IRIG-106-19 compatible transmitter.

As a testament to the accuracy of the IRIG-106 standard, the tri-band transmitter performed well based on demonstrating the functionality of the many vendor's receiver products to demodulate the tri-band waveforms at various data rates and modulation schemes. This test confirms the stated modulation formulas, the LDPC and STC coding schema in the IRIG-106-19 Standard.

2.2 Performance of Space Time Processing (STP)

There was a need for STP to eliminate interference between an upper and lower antenna interference. Time delays between the upper and lower antennas is typically caused by cable length differences. Typical propagation delay in coaxial cables can vary from 1.2 to 1.6 nanoseconds per foot, depending on the material. Ordinarily with a short cable this has minimal impact. Due to the nature of telemetry equipment being added after the air vehicle is built, long cable(s) are generally used as they are routed through vehicle causing the difference in the propagation delays.

The author has discovered that most implementations measure and match the cable delays to minimize the effect. The tri-band transmitter provides a feature to delay the STC data pattern from none to one clock period increments of 1,024 steps, independently of the two RF outputs to match the delay of each RF path. Tests performed with a STC enabled receiver (STC-ER) has determined that when a timing mismatch of one clock period or less, the STC-ER performs as expected. Larger mismatches than one clock period results in a significant loss of lock and no data. The vendor of the STC-ER provided a metered representation of the miss-match that provides the user with a visual indication of the balanced time delay with the air system to make the adjustment of the tri-band transmitter delay feature simple and repeatable.

2.3 Forward Error Correction (FEC)

The author has been a telemetry supplier of RF hardware for close to 40 years and has used FEC in several forms (Convolutional & Reed-Solomon primarily) over this long career. Today, with the adoption of LDPC forward error correction, IRIG-106-19 standardizes six varying coding schemes for improved link margin. The improved noise performance is not for free as it increases the bandwidth with the FEC data overhead.

The expansion factor (EF) as described in the IRIG-106-19 standard, states regardless of the block length the EF for ½ rate is 33/16, 2/3 rate is 25/16, and the 4/5 rate to be 21/16 to include the FEC as well as the alternate synchronization method (ASM). The six coding schemes, and their information block length (IBL), are as follows:

- 1 = Code Rate 1/2, IBL 1024
- 2 = Code Rate 1/2, IBL 4096
- 3 = Code Rate 2/3, IBL 1024
- 4 = Code Rate 2/3, IBL 4096
- 5 = Code Rate 4/5, IBL 1024
- 6 = Code Rate 4/5, IBL 4096

As an example of the EF for a 4 Mbps NRZ-L stream with LDPC 4 (2/3 rate; block 4096) would result in a data rate of 6.25 Mbps. The same 4 Mbps NRZ-L stream when encoder with LDPC 5 would result in a rate of 5.25 Mbps, and at the LDPC 1 code rate, the 4 Mbps would result to be 8.25 Mbps. The equation is as follows, where R is rate and F is factor:

$$R_{Transmitter} = R_{NRZ-L} \times F_{code\ rate\ expansion}$$

Experimenting in a lab environment with this FEC determined that the performance of the encoding is well behaved. The algorithm performs as described in the IRIG standard. BER performance without and with FEC can be seen in Figure 2 and Figure 3.

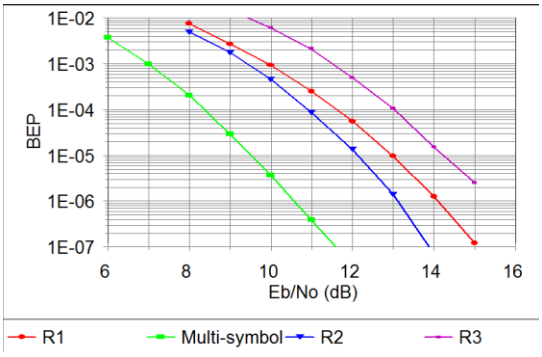

Figure 2: BER performance with no FEC

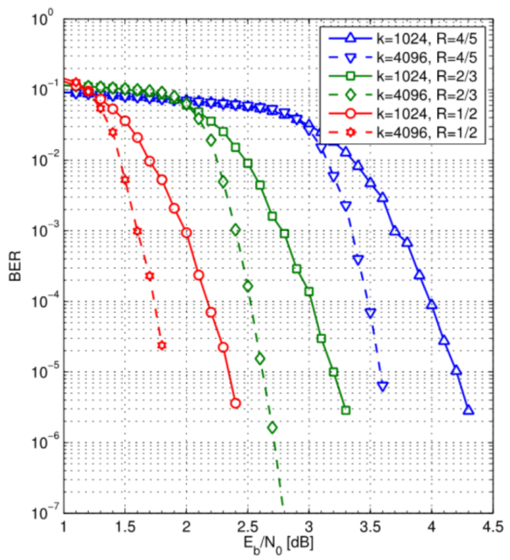

Figure 3: BER performance with FEC

Be advised that the operational region for repeatable performance narrows as the coding gain increased to a point where using the maximum gain with the ½ coding rate, the operation region is somewhat limited down to several dB.

The use of FEC is not useful for all applications and special consideration should be made before deciding to use this tool to obtain your telemetry data. From the tri-band transmitter perspective, switching the LDPC on and off is quite easy by sending a transmitter command of "FE1" to "FE6" to enable your desired code rate or a "FE0" to disable it.

Depending on your ground state receiver of choice the change over from no FEC to FEC being enabled may take several seconds to reconfigure. Planning of when to change over in flight will take scheduling to avoid longer loss of data. Certainly though, FEC works and has been the method of improving link margins for many years.

2.4 Thermal Management

The "drop in replacement" approach for the tri-band transmitter resulted in thermal management issues with the initial prototype of the new transmitter.

The primary heat sink path for transmitters is the bottom-mounting surface. With the thermal dissipation equally distributed, the modules that are farther away from the bottom-mounting surface have a higher temperature rise over the lower modules. Temperature rise of 20°C was measured between the bottom baseplate and the internal temperature of the top module.

2.5 Mitigation of the thermal rise

Decreased the thermal resistance between the module sections with over lapping mechanical joints combined with increased wall thickness on the center (power supply mode) reduced the thermal rise from the 20°C to 15°C. The increased the RF efficiency with optimized RF tuning through the RF chain gained a reduction in current draw and a temperature rise decrease of an addition 3°C.

Thermal protection was implemented with a micro-controller in the transmitter that monitors keys areas in the transmitter to control the dissipation by regulating the output RF power. This control, when activated, would throttle back the RF output power when temperature rises above a preset temperature (typically 75°C) to eliminate the risk of exposing the devices in the top module to excessive temperatures.

The thermal protection is enabled by the end user. To reduce the risk of damage, to the user would set the desired temperature threshold and then enable the control through the transmitter communication port. This feature was found to work well and is an easy safe guard against hardware damage when in the field.

3. Summary:

Every development includes new features, problem resolution, manufacturing maturity, and well as surprising results and the tri-band development was no different.

The complete control over the RF output power with independent control of the RF power going to the upper and lower antenna was evidently a useful tool for lab testing. No longer does the test engineer need to carry the variety of RF attenuators to match the RF levels driving the test equipment to perform BER tests.

A simple commanded adjustment of the RF power allows a smooth RF level adjustment rather than the manual step attenuator. This eases performance testing. The author of this paper historically did not support the 1 dB step adjustment in RF power but after completing this development, the advantage of this feature is obvious and the credit goes to the telemetry community for this advance.

The ease of responding to both the 106-15 programming protocol and the 106-19 command protocol was a surprise. From a transmitter vendor perspective, the transmitter command listing between the various versions of the IRIG standard have evolved to now well over 60 commands. For the user, remember the appropriate protocol for that transmitter causes delays and inappropriate programming. The tri-band acknowledges the previous command structure as well as the latest IRIG standard command structure, which saves time and increased typing accuracy for the test engineer.

Temperature protection to throttle back the RF power to limit the high temperature of the tri-band saves hardware damage. For some applications it is desirable for the transmitter to “die trying” and continue to transmit through high temperature events. This is not true for flight test where there are long preflight and flight times where the temperature limiting function will save the hardware from damage. This is certainly an advance feature and welcome for the flight test community not to have to turn the transmitter off to allow it to cool down.

Thumbwheel and serial port programming is still required for these flight test transmitters and the author found that to be easy to use and very few difficulties in communicating to the tri-band transmitter. The take away here is the simpler the better and it all works. The friend of this interface is the ”?” command, where the tri-band prints out the many command structures to guide the test engineer on the proper command structure.

Cable delay matching between the upper and lower antennas providing delay matching between the cables lengths is now quite easy in using the STC balance displays on some of the vendor’s receivers. The delay matching to within 1-bit time is require for STC demodulation performance as the interoperability testing results provided.

The tri-band transmitter requirements will continue to evolve as user gain experience in using this modern transmitter tool to assure the data is received successfully in the current and future frequency bands.

4. References

Note 1: Range Commanders Council IRIG-106-19 Telemetry Standard, Chapter 2 and Appendix (performance data provide from the standard for clarity)