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Alternate benefit of Forward Error Correction

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Abstract

The use of Forward Error Correction not only increases the link performance in a high noise environment but also provides an alternate solution for thermal management. A paper was presented in 2020 on a tri-band transmitter that briefly discussed thermal management. It was not obvious then that the use of forward error correction could be used to manage the thermal heating of the unit while still maintaining the RF link margin. This concept of using the benefit of coding gain to reduce the RF dissipation is applicable to many use cases that are prone to overheating. This paper explores the practicality around transmitter thermal management and some test results of using FEC as a possible alternate thermal control mechanism.

Keywords
Forward Error Correction, thermal management, LDPC, Transmitter, Link margin

Introduction

Forward Error Correction has been used in telemetry applications for many years. With the publication of the latest technology in the IRIG-106 standard, provided the opportunity to implement and test the algorithm over a number of transmitter products that Teletronics Technology (TTC-CW) produces. Throughout the many bit error rate tests over the months of performance corner cases with good and consistent results, the question arose, what else could we use LDPC for?

Background information

It’s becoming problematic for end user to deal with the dissipation requirements for modern transmitters with all of the features that the industry has developed. The features require high speed FPGA implementations to obtain the performance and spectral purity required to compete in this industry. These devices operate at higher speeds dissipating greater heat, raising the transmitter temperature. If heat transfer properties are ignored by the end user, it will create a good chance of overheating the transmitter. Thermal management for the high performance transmitter of today is a concerned when used on aircraft, missile, and hypersonic vehicles based on the availability of adequate mounting surfaces as well as the overall environmental conditions that these platforms operate in.

Heat flow in transmitters

As a rule for many years, the highest heat dissipator is the power amplifier section with the modulator section being smaller of the two. Typical modulators dissipate 5 watts where the PA section dissipates 20 watts or more depending on the RF power rating of the transmitter. The modern transmitter provides efficient RF conversion percentages with the modulator taking 12-14% of the overall power use; the PA is a healthy 58-60%, and the remaining 28% of power is transferred out the RF connector to the antenna as radiated energy.

The transmitter is normally configured with the PA section close to the mounting surface to allow the heat to be transferred efficiently through the bottom cover to the chassis of the system. This has worked well for many years until lately with the modern vehicles using structures with reduce thermal properties with limited heat transfer characteristics.

As the technology has advanced in the RF product requirements and product offering the percentage of power usage is increasing. The modern FPGAs and DSPs operate at a much higher clock rate with many features that are required today to stay competitive with the advancing feature list. Most or all of the modern modulator designs, use the higher dissipation FPGAs resulting in a shift in a higher percentage of power, or dissipation in the modulator section. Since all of the transmitter vendors box configuration for packaging has the modulator on top and the PA on the bottom, the increased heat in the modulator now impacts the temperature rise of the transmitter increasing the risk of overheating.

Dissipation techniques

Some of the RF Vendors use a fan accessory to create airflow to remove the heat the new transmitter dissipates. Airflow works well and TTC-CW has provided several telemetry products with integrated heat sinks to assist in the removal the excess heat. Unfortunately airflow is good for ground applications but in practice, there is rarely enough airflow to make it the solution for all use cases. Other systems use a cold plate which work very well with high power dissipating systems. Not all aircraft have the facility to support a cold plate to keep their electronics cool to within its rated temperature which ultimately leads to early failure and reduced reliability.

Over-heating protection

There have been several occasions where overheating events have happened in the past with fielded TTC-CW Transmitters. The damage was caused by exceeding the chassis rated temperature of 85^0C. TTC-CW also provide a temperature sensor on the side of the Transmitter to indicate a maximum chassis temperature exposure. Case temperatures above 93^0C typically degrades functionality of several RF devices within the transmitter. This happens when the end user does not understand the heat flow characteristics of these modern transmitters and their required installation. Over-heating protection varies by application and the priority of the data over the hardware. Meaning, in some applications the Transmitter should be allowed to over-heat if the data that it is transmitting is more important than turning the unit off when temperature exceeds its maximum safe level. But on the other hand, there are applications where, saving the hardware when in a over heating condition is more important than the data. For these various applications, modern transmitters offer a temperature control function that when enabled will automatically reduce the RF output level when the internal temperature exceeds a preset value in an attempt to regulate the chassis temperature. This control mechanism saves the hardware but results in a potential link margin risk with the reducing RF output levels and is warranted for application where loosing the link is not critical to the success of the test.

Additional over-heating mitigation include external cooling whether forced air or a cold plate which have been successfully implemented on many programs when available on the test platforms and in lab test applications. Unfortunately this is not the case for all applications most missile, launch, long range weapon systems still suffer the risk of over heating when there is poor heat flow or insufficient heat sinking.

The ultimate solution is reducing the self-heating of the transmitter and until the chip manufacturers can increase the RF efficiency over what the RF devices provide today, there is not much came done on the electrical design, to reduce the dissipation requirements for the Telemetry Transmitter for the near term.

RF link margin background

Telemetry link margins are calculated based on the maximum transmission distances that involves counting the system losses from the transmitter output, through the cabling, filters, isolators, and other devices the system engineers add in line with the transmitter to be compliant to the local transmission standards. Unfortunately the RF loss of those items incur reduces the RF energy that propagates through the air to the dish antenna on the ground to complete the link. Forward Error Correction provides coding gain which adds to the link margin when used in the operational range of the receiving equipment. FEC increases the data rate and resulting modulation bandwidth by the “overhead” or the additional data that the FEC algorithm requires. The increased bandwidth has always been a debate over using FEC and the value it provides. In fact the ½ rate LDPC algorithm increased the data rate by 2.0625 times which equates to a loss of 3dB of link margin. Due to the high coding gain of the ½ rate LDPC, the 3dB is only a fraction (20%) of the overall link improvement that the LDPC ½ rate provides.

$$\mathbf{IFBWdb=20*(Log(2*data\ rate))} \quad (1)$$

Forward Error Correction (FEC) Types, performance, and correction

Convolutional Encoding has been used for many years in Telemetry and much of the earlier Bit Synchronizers had an option for a Viterbi™ decoder. This coding scheme provided several dB of coding gain and was standardized almost 40 years ago for use in flight test telemetry. Developments in Turbo codes lead to the most current variant in the IRIG-106 standard Low Density Parity Check or LDPC and offers higher coding gains than some of the earlier version of FEC used in streaming telemetry.

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The practical performance of these LDPC algorithms is very much dependent on the receiver, de-modulator, and decoder performance was well as the test setup to include high isolation of the transmitting device and the LDPC receiver. The author has tested four of the leading vendor's receiving equipment and found very good consistency in the test results with all of the vendors products

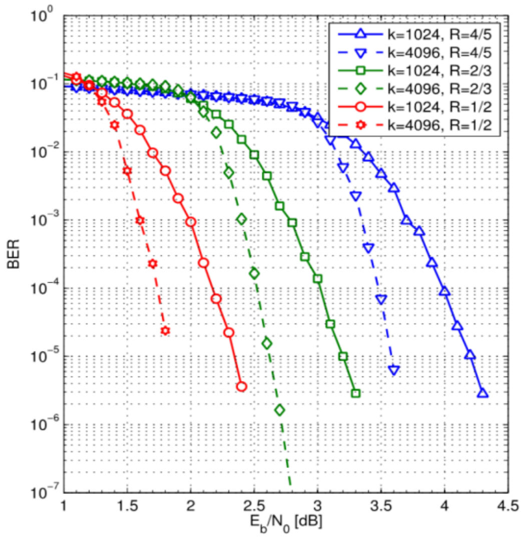

Figure 1 **IRIG-1060029 Figure D-11. LDPC Detection Performance with Symbol-by-Symbol Demodulator [1]**

when performed in a lab environment in use of a noise interference test set. The combination of the receiver sensitivity and coding gains may the higher gain algorithms more of a test challenge for consistent results when varying the RF power into the receiver over adding noise to the IF path using the noise interference test set.

Why would we consider using FEC to reduce the transmitter dissipation?

Reducing the level of RF output power of a transmitter reduces its dissipation. The gains provided with the new FEC algorithms allows for the link to be closed with lower RF Transmitter power. As an example, a typical 10 watt transmitter outputs 40 dBm and draws 1.25 amperes and dissipates 25 watts that is required to be properly heat sunk to maintain its case temperature below the absolute maximum of +85^{0}C. Applying 4/5th LDPC provides a minimum of 8 dB of coding gain. A 5 watt transmitter output is 37 dBm, draws 0.9 amperes, and dissipates 20 watts, 20% less than the 10 watt transmitter. Applying the 4/5th LDPC FEC to the 5 watt transmitter, the resulting BER performance equates to the non-FEC 10 watt transmitter but at a lower dissipation.

- 10 watt transmitter, outputs 40 dBm, Eb/N_0 level for 1E-6 BER is measured at 13 dB and dissipates 25 watts.
- 5 watt transmitter, outputs 37 dBm, $Eb./N_0$ level for 1E-6 BER in using 4.5th LDPC now at 11 dB and dissipates 20 watt or 20% less.
- Note the increased BW of the 4/5th LDPC FEC contributes 3 dB more noise.

Test results and conclusions

Testing this concept in a lab environment resulted in several surprises. The test configuration is critical to obtain reliable results. Using today's highly sensitive receivers combined with coding gains that are achieved in using LDPC creates a challenge to provide enough isolation between the receiver to the RF cabling to avoid having the cable leakage mask the true algorithm performance. The use of a Noise Interference Test set that operates at the IF level into the receiver and avoids much of the complexity of attempting to measure the combined gains.

Testing the coding gains provide a pleasant surprise with consistent improved BER performance with all three variants of the LDPC algorithms. The results measured in the lab setup were with in a 1 dB of the Eb/No plots provided above. In additional the increased coding gains of 2/3 and 1/2 rates over the 4/5^{ths} rate operated at Eb/No performances below 3 dB demonstrating the algorithm performance. The tests demonstrated BER rates of approximately 1E-6 rate at very low signal to noise levels consistency across all of the FEC variants.

Table 1 4/5th FEC BER 10vs5 watts

LDPC	RF Watts	I total amps	Eb/No	BER
None	10	1.25	13	1.2e-6
¾ 1024	5	0.9	7	1.8e-6
¾ 4096	5	0.9	5	1e-6

The Transmitter included in the tests offers variable RF output power, and performed closely to the expected results were the reduction of the RF output to reduce the power dissipation and used the coding gain to restore the BER performance back to the Non-FEC rate at 1E-6.

Between the three variants though, the recovery time from a significant fade from the receiver perspective indicated the higher gain algorithms (2/3 and 1/2 rates) were slower to respond than the lower gain from that 4/5ths algorithm demonstrated good response to deep fades.

Summary.

The use of FEC for reducing the dissipation of the transmitter was proven with the evaluation and test process described here in. The result of using the 4/5ths algorithm as the best performer over the two higher coding gain variant to reduce the dissipation with consistent results. The use of Forward Error Correction is not design for all applications but certain does provide an unique solution to reduce a transmitters dissipation and maybe consider when the traditional methods of heat sinking is not enough to keep the product from overheating.

References:

[1] IRIG-106-20, Range Commanders Council, IRIG-1050029 Figure D-11