

Clause 192 7.5 Gb/s PAM3 Signaling Considerations

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Ad hoc

Scott Muma, Microchip

Overview

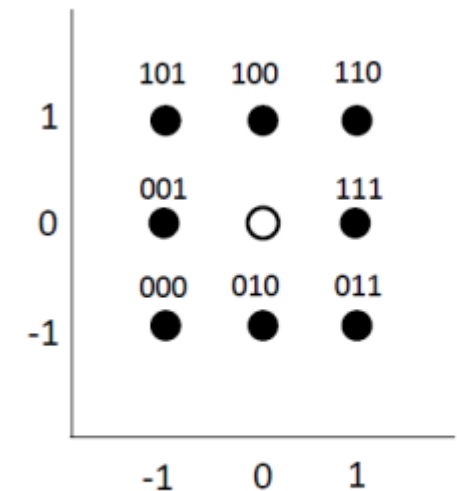
- ❑ **The PAM3 signaling proposed for Clause 192 in https://www.ieee802.org/3/dm/public/0326/gorshe_3dm_02a_0326.pdf has low impact on the camera transmit complexity and allows many tradeoffs in receiver implementation.**
- ❑ **While not optimal from a FEC perspective, the post-FEC decoder BER impact is minor which seems favorable for simplicity and compatibility with other rates.**
 - ❑ 3B2T mapping is one of the simplest ternary mappings to implement.
 - ❑ Since the Clause 192 7.5 Gb/s proposal uses 3-way interleaved FEC codewords the number of bits in a burst are divisible by 3 so no padding/adjustments are necessary.
 - ❑ While a single PAM3 symbol error could result in bit errors in 2 FEC symbols, there are several mitigating factors that reduce the probability of error multiplication in the 3B2T decoder.
 - ❑ For a receiver using a 1D slicer the reduction in FEC coding gain is less than 0.05dB

3B2T mapping

- ❑ IEEE 802.3-2022 Table 97-2 maps a set of 3 bits (3B) to a pair of ternary symbols (2T) or trits
- ❑ This can be visualized as a 2D constellation as per:
https://www.ieee802.org/3/bp/public/jul14/shen_3bp_01_0714.pdf
(3B2T figure copied here for reference)
- ❑ Trit pair {0,0} is not transmitted and may be handled several ways at the receiver
- ❑ Assuming a 1D receive slicer then symbol errors may result in trit pair {0,0} at the PMA service interface, however the PCS can take advantage of this:
 - ❑ By decoding trit pair {0,0} to 000 then 3 adjacent decoded values [001, 010, 100] are single-bit errors, only one [111] is a 3-bit error.
 - ❑ Given a random transmitted trit pair which then has a single, 1-level PAM3 symbol error, there are 20 possible error cases in the constellation. Assuming equal probability of any symbol being errored, there is a 1/20 chance that the error was the transmitted trit pair {0,+1} being errored to become {0,0}. There is a 1/20 chance of error multiplication.
 - ❑ If a trit pair has two, 1-level PAM3 symbol errors the decoded hamming distance is 2, meaning there is no error multiplication, so that is not further analyzed.
 - ❑ Erasure decoding is not guaranteed to improve these results so not analyzed here.
 - ❑ A 2D receive slicer is not analyzed here since it would never present {0,0} at the PMA service interface. Any error multiplication is unlikely.

Table 97-2—3B2T Mapping to PAM3

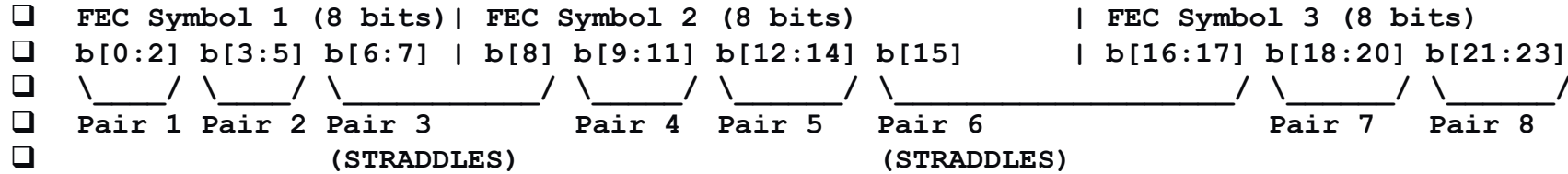
B[2], B[1], B[0]	T[1], T[0]
000	-1,-1
001	0,-1
010	-1,0
011	-1,+1
100	+1,0
101	+1,-1
110	+1,+1
111	0,+1



3B2T (3bit to 2 ternary)

FEC codeword alignment benefits

❑ In Clause 192 the FEC symbols are 8 bits, so in a 24-bit sequence the 3B2T decoded alignment is straddling FEC symbols in 2 out of 8 places:



❑ Since only 2 of every 8 trit pairs can straddle FEC symbols, the probability of a multi-FEC-symbol error is further reduced by a factor of $\frac{1}{4}$.

❑ Total probability of multiple FEC-symbol errors is then $\frac{1}{20} * \frac{1}{4} * \text{PAM3_SER}$ which gives a total FEC symbol error rate of $\frac{81}{80} * \text{PAM3_SER}$ (1.25% increase to pre-FEC BER due to the 3B2T coding scheme).

FEC codeword interleaving benefits

- ❑ Since the FEC codewords are L-interleaved and $L=3$ for 7.5G, a PAM3 symbol error that causes 2 FEC symbol errors will result in errors in 2 different FEC codewords.
- ❑ The RS-FEC(128, 122, 8) code can correct up to 3 FEC symbol errors, so if there are 2 or fewer other symbol errors in the same FEC codeword the errors are correctable.

Conclusions

- ❑ Due to the properties of the 3B2T mapping algorithm, Clause 192 FEC codeword interleaving, and Clause 192 FEC symbol alignment to ternary symbol boundaries the impact of 3B2T mapping on FEC coding gain is limited (<0.05dB reduction) with a simple 1D slicer receiver.
- ❑ Moving from PAM4 to PAM3 increases the SNR at the receiver by significantly more than 0.05dB, even when the transmit voltage swing is reduced. This SNR should be quantified based on the proposed specifications.
- ❑ More sophisticated receivers might provide additional SNR improvements and can mitigate the noted FEC impact.
- ❑ Other ternary coding schemes might provide additional benefits, so this analysis provides a basis for comparison.

Thank You