Performance analysis of coded 16-PAM scheme for GEPOF. BER, MTBE, MTTFPA, PER

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Objectives

- This presentation provides a performance analysis in terms of BER, MTBE, MTTFPA and PER for the coded modulation scheme defined in [2]

Coded 16-PAM - BER, MTBE, MTTFPA, PER

- **BER:** Bit Error Ratio: is the ratio between the number of received errored information bits and the total number of received information bits (correct and errored ones) in average.

- **Errors arrival:** because the communication system integrates a FEC (Forward Error Correction) the errors at the information sink (i.e. GMII RX) are going to arrive in bursts, when noise in the channel produces the error correction capability of the FEC decoder is exhausted for a code-word (typically just one code-word). As higher the error correction capability is, larger are the bursts when correction capability is overpassed.

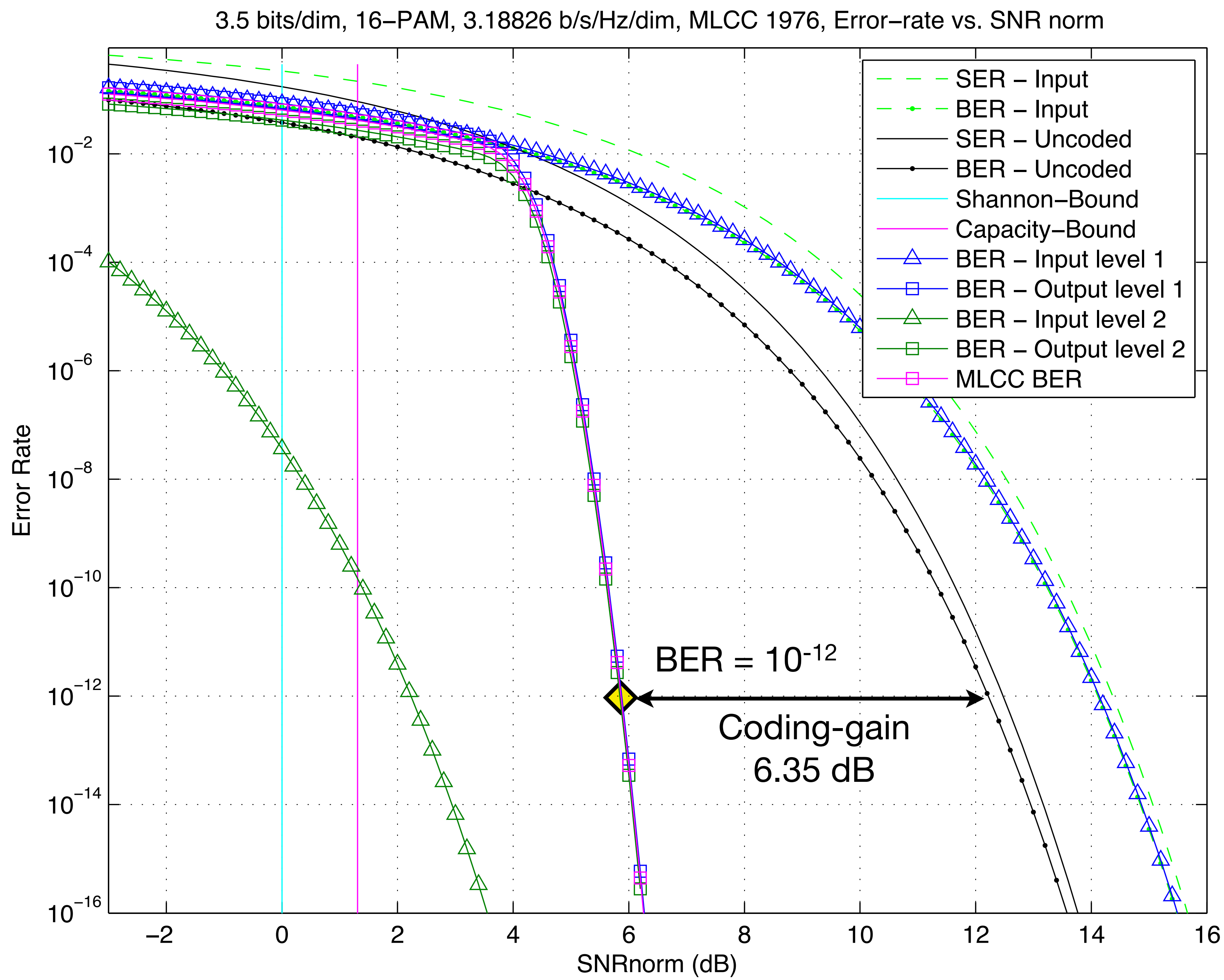
- **MTBE:** Mean Time Between Errors: for a system with FEC, this is defined as the mean time between bursts, which corresponds with the magnitude that is measurable in the lab.

Coded 16-PAM - BER, MTBE, MTTFPA, PER

- **MTTFPA:** Mean Time To False Packet Acceptance:
  - Also known as Undetected Error Rate (UER), is a basic requirement of 802.3 standard, and provides a figure of merit of the absolute mean time to an errored packed being accepted as valid.
  - Normally MTTFPA is a number of years larger than the age of universe!!
  - Any Ethernet PHY for automotive should be designed with MTTFPA in mind: MTTFPA is the only figure of merit to guarantee safety in the communication link
  - In general, 802.3 CRC does not suffice to guarantee large MTTFPA values for i.e. gigabit speed links, and some grade of error detection is necessary to be implemented in i.e. line coding and/or FEC
  - Error correction and error detection capabilities of the FEC as well as the scramblers, framing signaling and 802.3 CRC are going to have important impact into MTTFPA

- **PER:** Packet Error Ratio: is the ratio between the number of received errored Ethernet packets and the total number of received Ethernet packets (correct and errored ones) in average. In general, PER depends on the size of the Ethernet frame and how the errors are produced in bursts (i.e. MTBE).

Coded 16-PAM - Performance



See [1] for discussion about capacity bound in THP channel as well as for definition of SNR_{norm}

Coded 16-PAM - Performance analysis

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-- BER analysis: --
Channel: THP
Level 1: BCH(1976, 1668, 28) m = 11
Spect. Eff.: 3.18826 b/s/Hz/dim
Shannon gap (BER = 1e-12):              5.87 dB
Capacity bound gap (BER = 1e-12):       4.56 dB
SNR (BER = 1e-12):                      25.01 dB
Uncoded gap (BER = 1e-12):              12.2 dB
Coding gain (BER = 1e-12):              6.35 dB
Input SER (BER = 1e-12):                0.0132918
Input BER (BER = 1e-12):                0.00291155
Input BER MLC level 1 (BER = 1e-12):    0.00332296
Input BER MLC level 2 (BER = 1e-12):    2.06509e-27

-- MTTFPA analysis: --
MLC level 1:
   MTBE (BER = 1e-12):                           09 h:31 m:44 s
   MTTFPA with FCS detect (BER = 1e-12):         4.7e+06 y
   MTTFPA with BCH detect (BER = 1e-12):         1.1e+27 y
   MTTFPA with BCH & FCS detect (BER = 1e-12):   4.7e+36 y
MLC level 2:
   MTBE (BER = 1e-12):                           3.3e+10 y
   MTTFPA with FCS detect (BER = 1e-12):         1.4e+20 y

MLC as a whole:
   MTBE (BER = 1e-12):   09 h:31 m:44 s
   MTTFPA -PHY & FCS- (BER = 1e-12): 1.4e+20 y
   MTTFPA -just PHY-  (BER = 1e-12): 3.3e+10 y

-- PER analysis: --
   Eth Frame Size = 64 bytes,   PER = 1.1e-10 (BER = 1e-12)
   Eth Frame Size = 256 bytes,  PER = 1.6e-10 (BER = 1e-12)
   Eth Frame Size = 512 bytes,  PER = 1.9e-10 (BER = 1e-12)
   Eth Frame Size = 1024 bytes, PER = 3.7e-10 (BER = 1e-12)
   Eth Frame Size = 1522 bytes, PER = 5.4e-10 (BER = 1e-12)
```

High coding gain. Basically, it is responsible of 6 dBo of link budget, considering that the TIA has to implement an AGC based on trans-impedance control

High input BER to Level 1.This is good for an implementation of Link Monitor able to determine the link quality accurately and fast. Bit errors corrected by the BCH decoder per codeword may be a good estimate of the received signal quality.

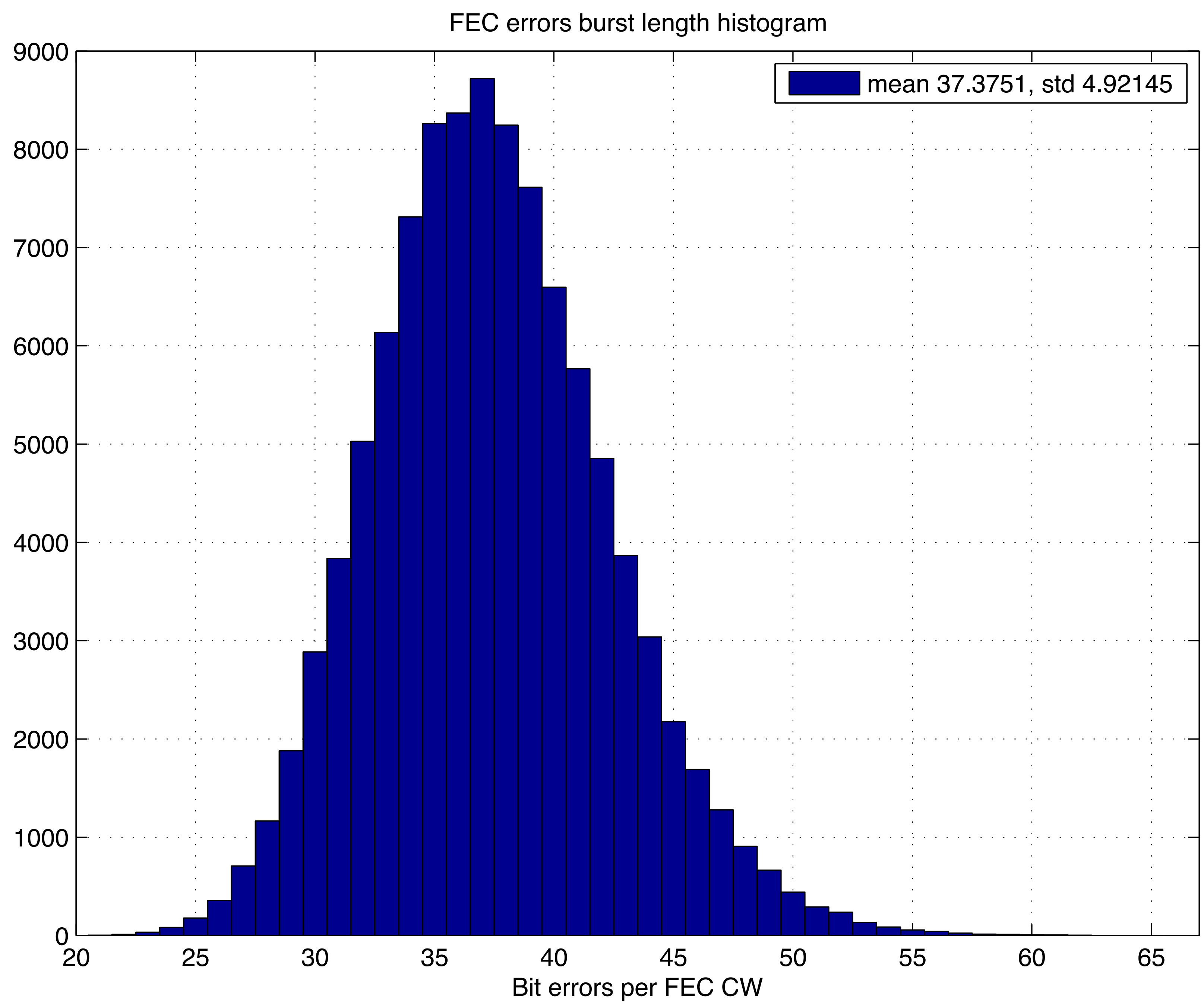
FCS does not suffice to provide MTTFPA > age of universe. Error detection capability of BCH is needed. Error detection capability will also avoid error propagation in Ethernet frames encapsulation due to bad frame delimiters detection.

MAC FCS is not required for MTTFPA. BCH suffices to detect packet errors, and the MTBE of second level is > age of universe. The MTTFPA is determined by the second level, which is the minimum.

Low PER. Because the error arrives in bursts from FEC decoder and BCH error detection capability is used.
PER < BER*PktSz/10

Coded 16-PAM - Performance analysis

- Errors burst length statistics for an erroneous code-word event (MC simulation):



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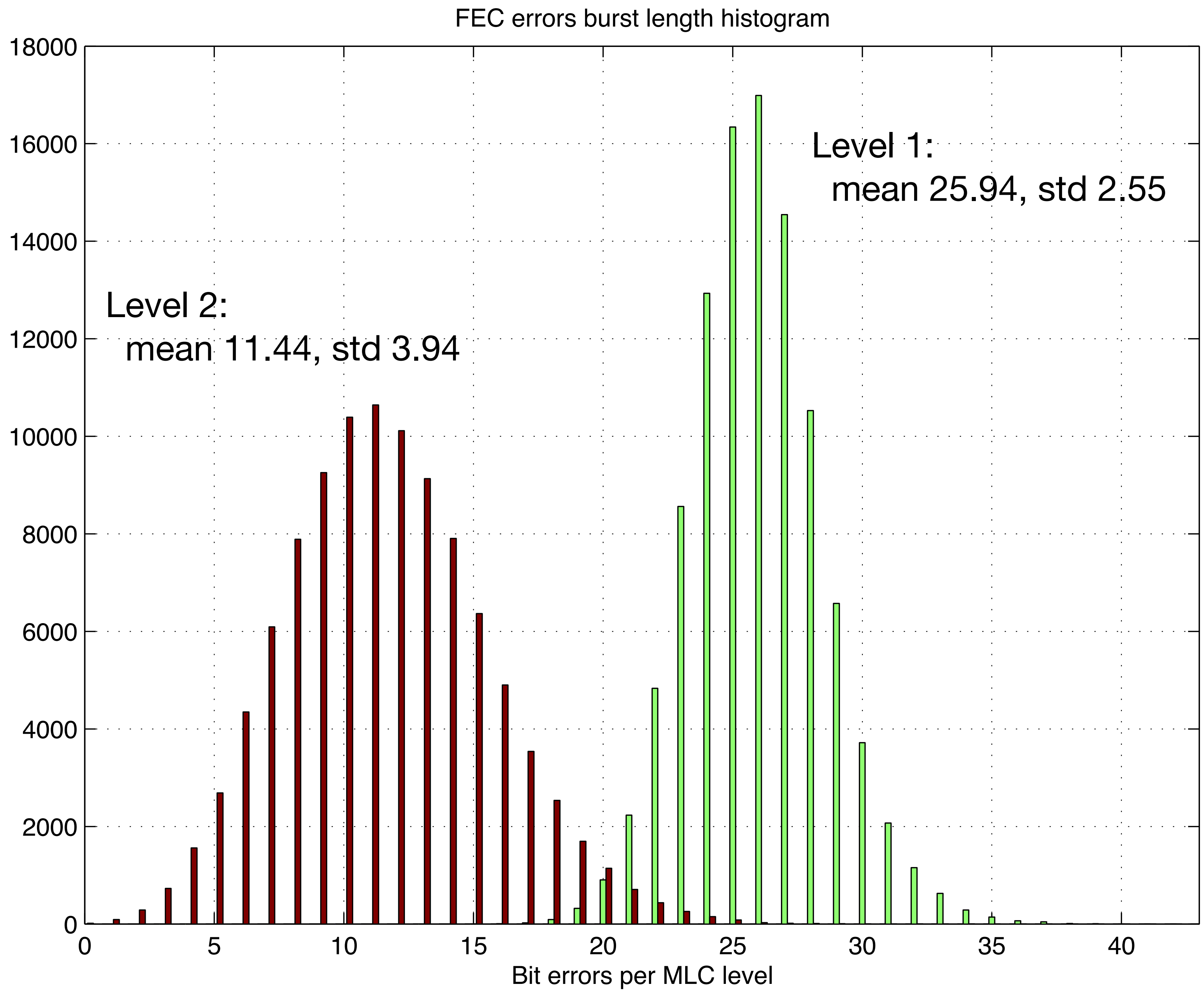

Coded 16-PAM - Performance analysis

- Link budget, MTBE and MTTFPA as a function of BER:

	BER ≤ 10^{-10}	**BER ≤ 10^{-11}**	**BER ≤ 10^{-12}**	**BER ≤ 10^{-13}**	**BER ≤ 10^{-14}**
Relative link budget (dBo)	0,13	0,05	-0,03	-0,12	-0,19
MTBE	5m:45s	57m:28s	9h:32m	4 days	39 days
MTTFPA -PHY + FCS- (years)	$6{,}9 \cdot 10^{18}$	$3{,}2 \cdot 10^{19}$	$1{,}4 \cdot 10^{20}$	$6{,}0 \cdot 10^{20}$	$2{,}4 \cdot 10^{21}$
MTTFPA -only PHY- (years)	$1{,}6 \cdot 10^{9}$	$7{,}4 \cdot 10^{9}$	$3{,}3 \cdot 10^{10}$	$1{,}4 \cdot 10^{10}$	$5{,}7 \cdot 10^{11}$

Age of universe ≃ $13.8 \cdot 10^{9}$ years

Coded 16-PAM - Discussion about BER specification

- What is the right specification point of BER from the operation point of view?
  - BER ≤ 10^{-12} is in the objectives, and it seems technically feasible from implementation point of view
- Which is the MTBE specification required by the automotive industry, taking into account the MTTFPA is > age of universe?
- Should the BER specification be measurable in the lab?
- Should the specified operation point of the system be different of the qualification point (= measurable point)?
- Is the BER the right figure of merit that has to be specified? PER or MTBE is more related to safety applications as automotive.
- Some numbers:
  - Because the typical errors burst length is 37.4 bits per CW for the proposed FEC, we would typically wait for at least 3 CW error events to be able to collect ≥ 100 bits required for a good BER statistic
  - Then, to measure a BER ≤ 10^{-10}, we need ~18 minutes in average
  - For BER ≤ 10^{-11}, we need ~3 hours
  - For BER ≤ 10^{-12}, we need ~1 day!!
  - For BER ≤ 10^{-13}, we need ~12 days!!
  - For BER ≤ 10^{-14}, we need ~4 months!!

Coded 16-PAM - Discussion about BER specification

- The GEPOF PHY will implement the Link Monitor as part of the PMA RX, qualifying in real time the link quality (e.g. BER ≤ 10^{-12}) in a very short time interval
- Link monitor is not implemented based on real BER measurement because:
  - The PHY would need infinite time to establish the link
  - The user data information transported by the PHY is not a priori known
- How to measure the link quality in a short time? The idea is to measure how many bits are corrected by the FEC per code-word and based on that calculate the output BER, which is the target of the specification
- With this method an accurate output BER estimate can be reported in less than 1ms, once the timing recovery and equalization are ready, indeed for an output BER ≤ 10^{-14}
- Moreover, the PHY could estimate a link margin based on bit error corrected by the 1^{st} level BCH.
  - Link margin measures (in dB) how much can be increased the attenuation before the link is lost because the BER > specification point
  - Link margin also measures how much can be increased the noise before lose the link
- Therefore, <u>the operation BER can be guaranteed by a PHY independently of feasibility to measure it</u>

References

- [1] *Rubén Pérez-Aranda, "High spectrally efficient coded modulation schemes for GEPOF technical feasibility", GEPOF SG, Plenary Meeting, July 2014*

- [2] *Rubén Pérez-Aranda, et al., " High spectrally efficient coded 16-PAM scheme for GEPOF based on MLCC and BCH", 802.3bv TF, Interim Meeting, Jan 2015*

Questions?