Proposed changes to 178A.1.11

(comment #327)

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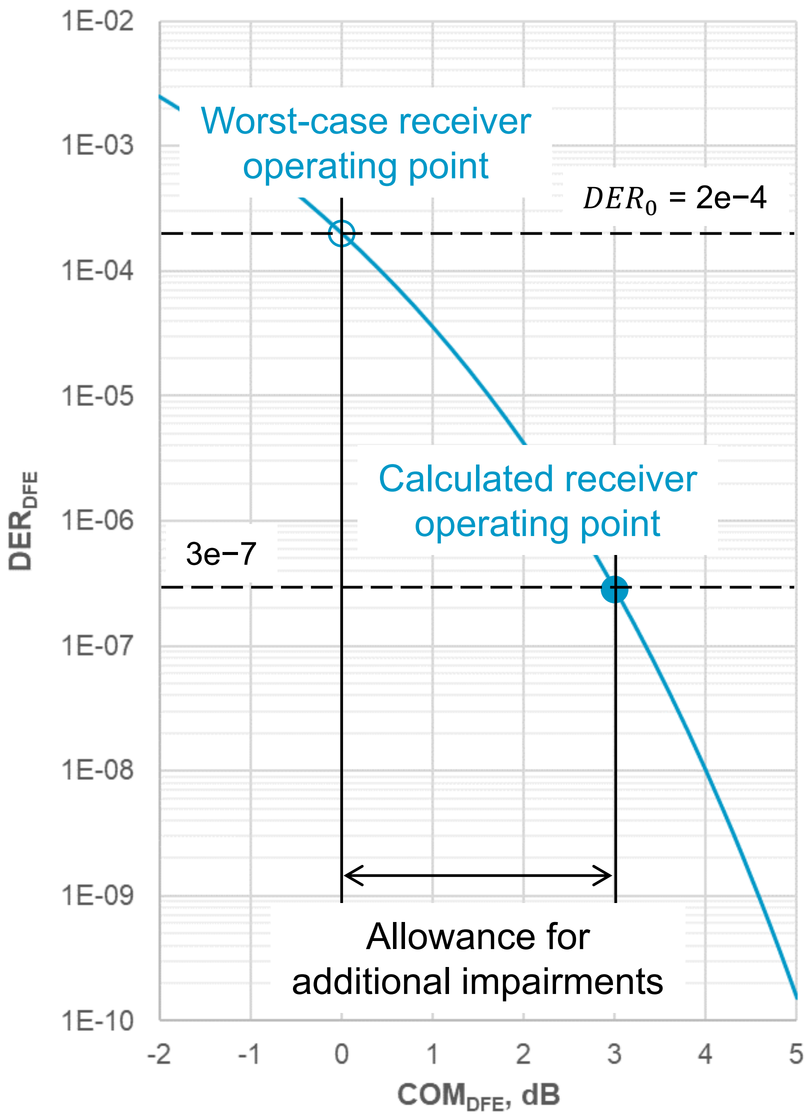
Introduction

- Channel Operating Margin (COM) for a reference receiver based on maximum-likelihood sequence detection (MLSD) is computed using the following expression

$$COM = COM_{DFE} + 20\log_{10}(-P^{-1}(DER_{MLSD})/A_s) = COM_{DFE} + \Delta COM_{MLSD}$$

- The first term, COM_{DFE}, is the COM for a reference receiver based on decision feedback equalization (DFE)
- The second term is a “gain” for the MLSD-based reference receiver relative to the DFE-based reference receiver
- It was observed in healey_3dj_01a_2407 that the MLSD gain may be over-estimated
- This contribution provides further explanation of the issue and a proposal for changes to the draft

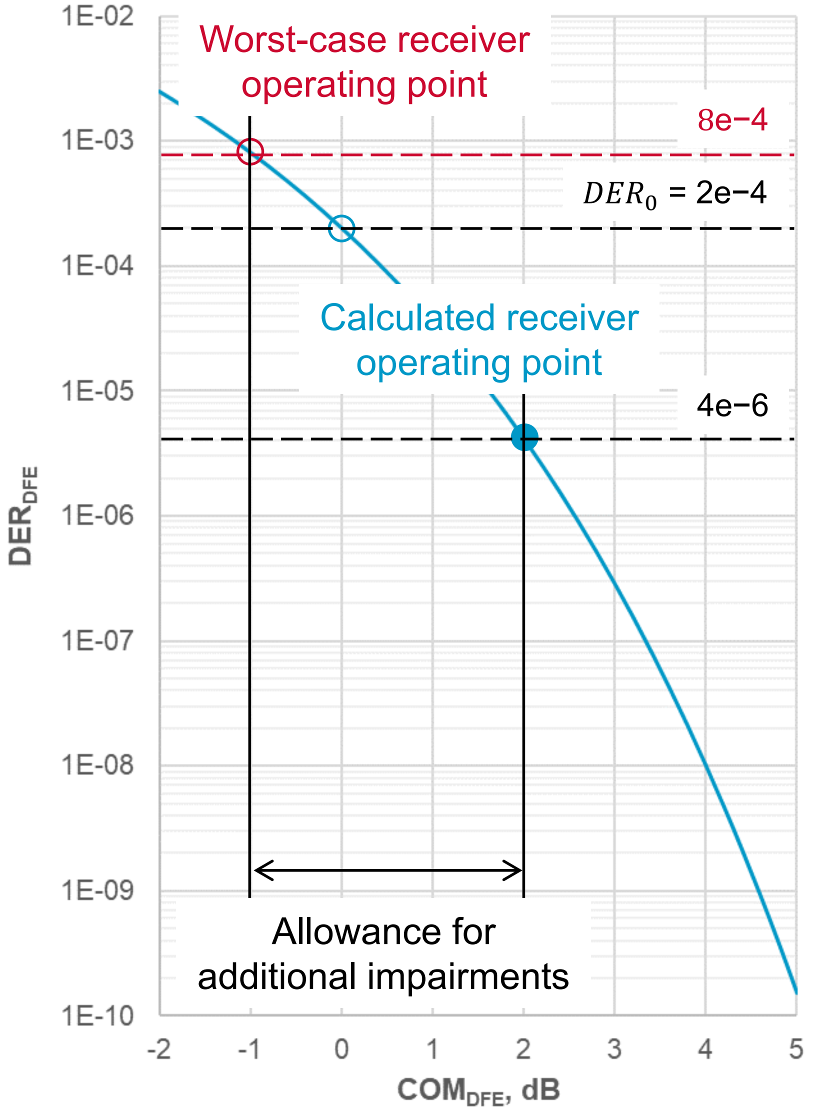
Review of COM for a DFE-based reference receiver



- Within the COM framework, receiver performance is measured in terms of detector error ratio (DER)
- COM is computed relative to a detector error ratio limit DER_0
- When COM is 0 dB, the receiver DER is equal to DER_0
- A compliant channel is required have at least 3 dB COM which suggests that DER is much better than DER_0
- A compliant receiver DER may be as high as DER_0 over a compliant channel
- This suggests that the 3 dB limit is an allowance for additional impairments that were not included in the calculation of COM

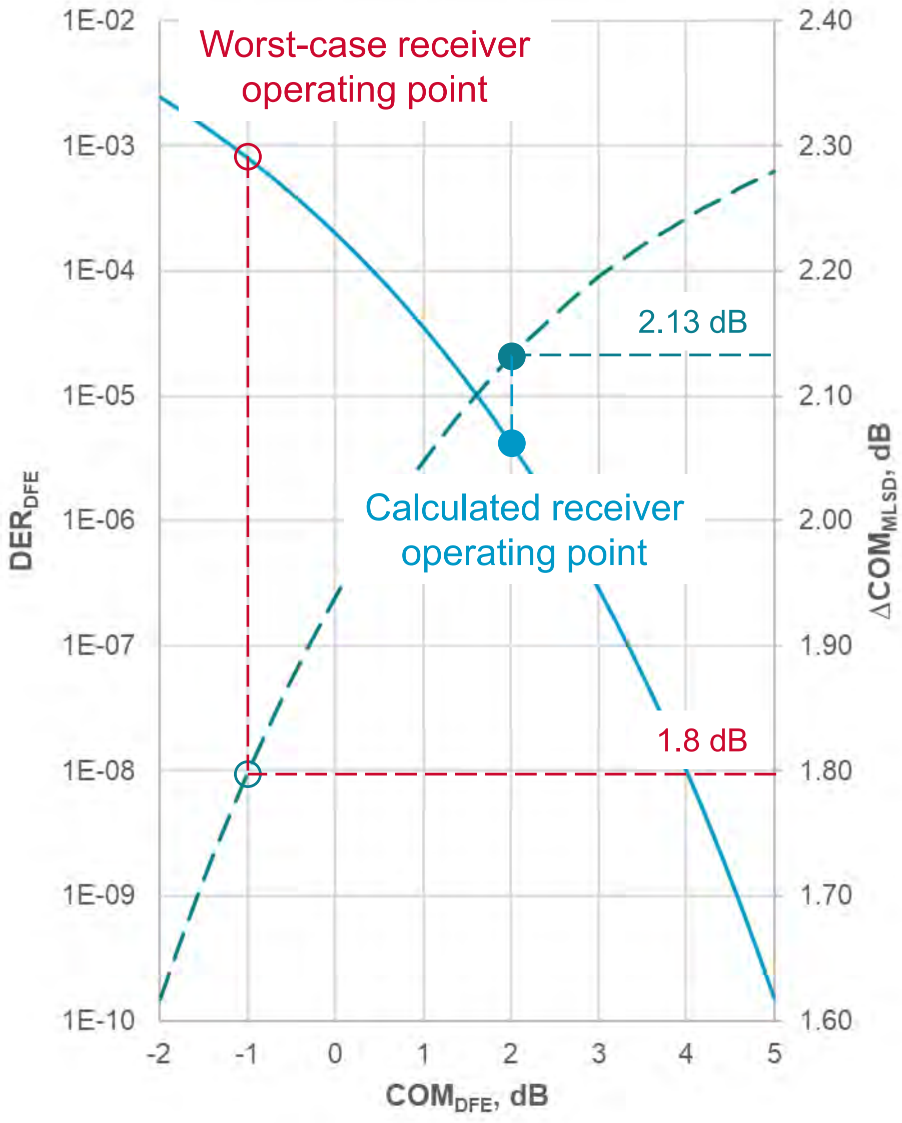
NOTE – Examples shown are for additive white Gaussian noise and use the channel model 1 + 0.85D.

Motivation for an MLSD-based reference receiver



- Any value of COM greater than 0 corresponds to a DER below the limit
- When COM is below 3 dB, the concern is that a receiver that uses the full impairment allowance will yield a DER above the limit
- In other words, the calculated margin is less than the assumed impairment allowance
- For these channels, the MLSD-based reference receiver can be used to improve the calculated receiver operating point and possibly achieve the desired 3 dB margin

MLSD gain is a function of the calculated operating point



- The effective gain of the MLSD-based reference receiver is related to COM_{DFE}
- In the region of interest, the MLSD gain tends to increase with increasing COM_{DFE}
- This MLSD gain is currently computed using the calculated receiver operating point
- However, the calculated receiver operating point is optimistic
- It enforces margin to allow for impairments that are not included in the calculation
- The MLSD gain should be calculated based on the worst-case operating point which accounts for the consumption of this margin

July 2024 straw polls (refer to motions_3dj_2407)

Straw Poll #E-2

I would support the direction of modifying the calculation of COM for an MLSD reference receiver to add a method of receiver impairments per healey_3dj_01a_2407

(choose one)

Results (all): Y: 36, , N: 7 , A: 15

Straw Poll #E-3

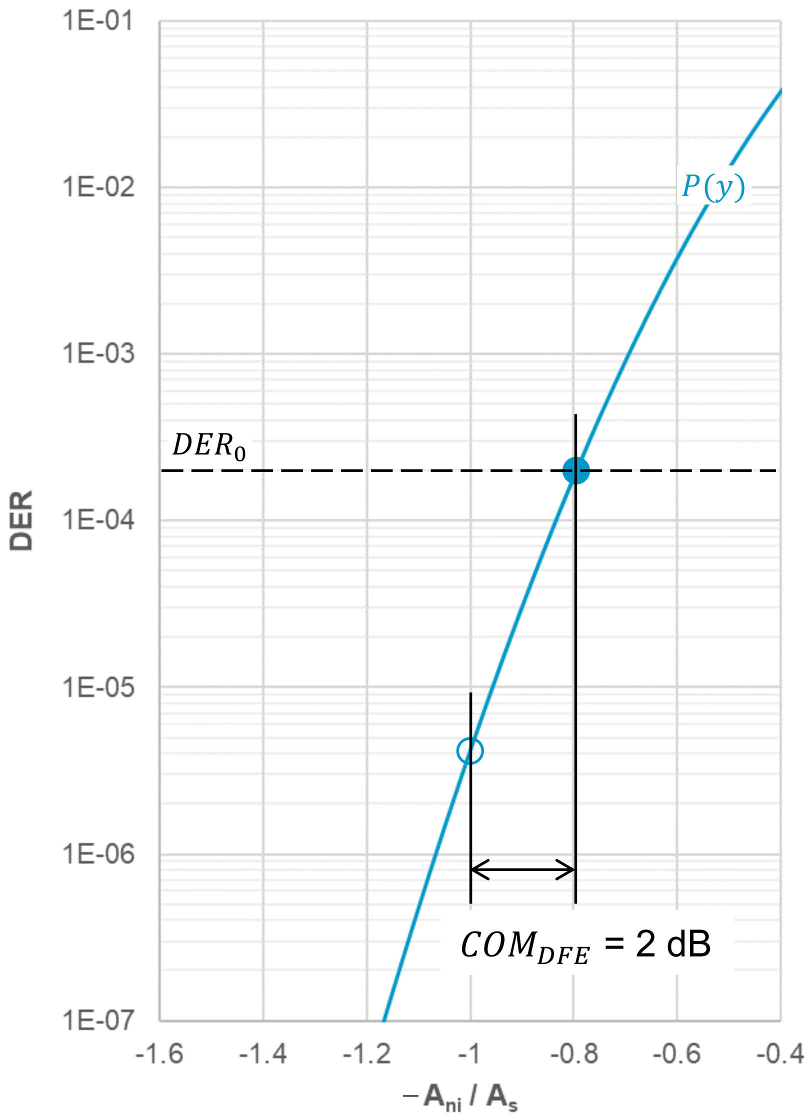
When approximating the impact of pre-MLSD receiver impairments in the COM calculation, I prefer the approach of:

- Option A: scale the receiver noise (e.g. healey_3dj_01a_2407, slide 4)
- Option B: define a MLSD implementation allowance Q that is a function of COM_DFE (e.g. healey_3dj_01a_2407, slide 6)
- Option C: Need more information
- Option D: Abstain

Results (all): A: 15, , B: 0 , C: 28 , D: 10

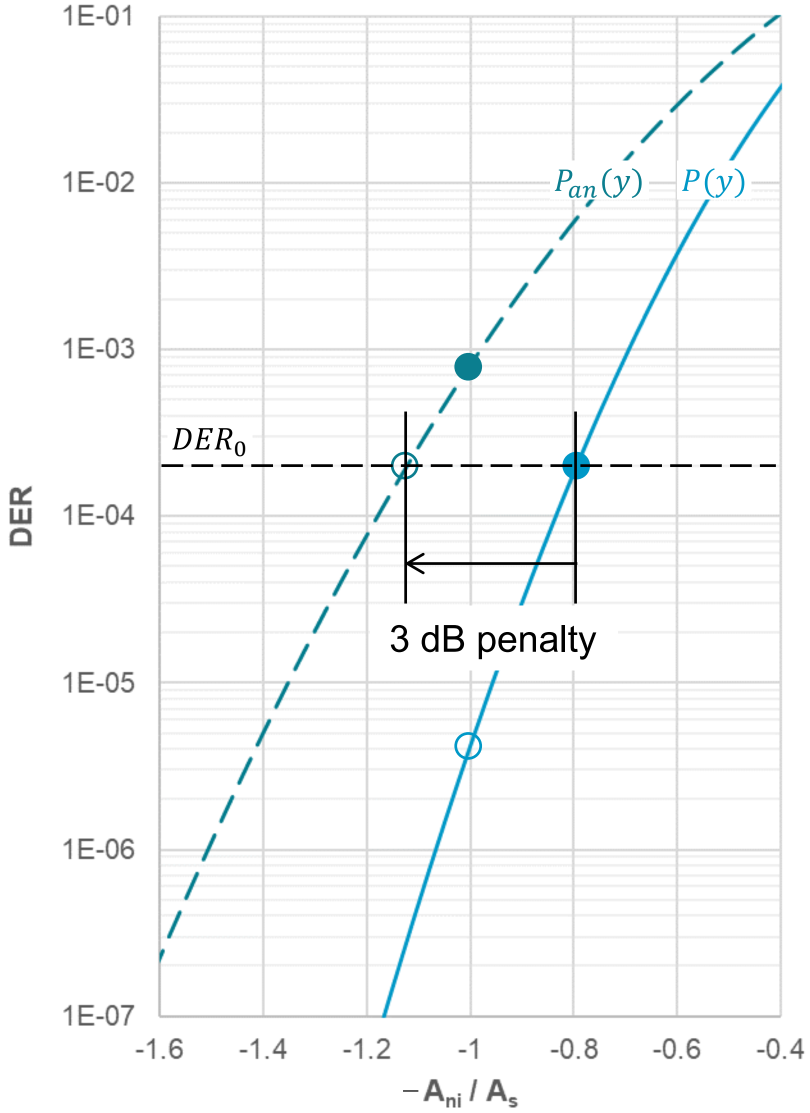
- General agreement that something should be done
- Some preference for “Option A” (scale the receiver noise)
- This contribution provides the set of changes corresponding to “Option A”

Overview of the proposed changes, 1 of 4



- Compute COM_{DFE} from the cumulative distribution function of noise and interference amplitude $P(y)$ as currently defined in the draft

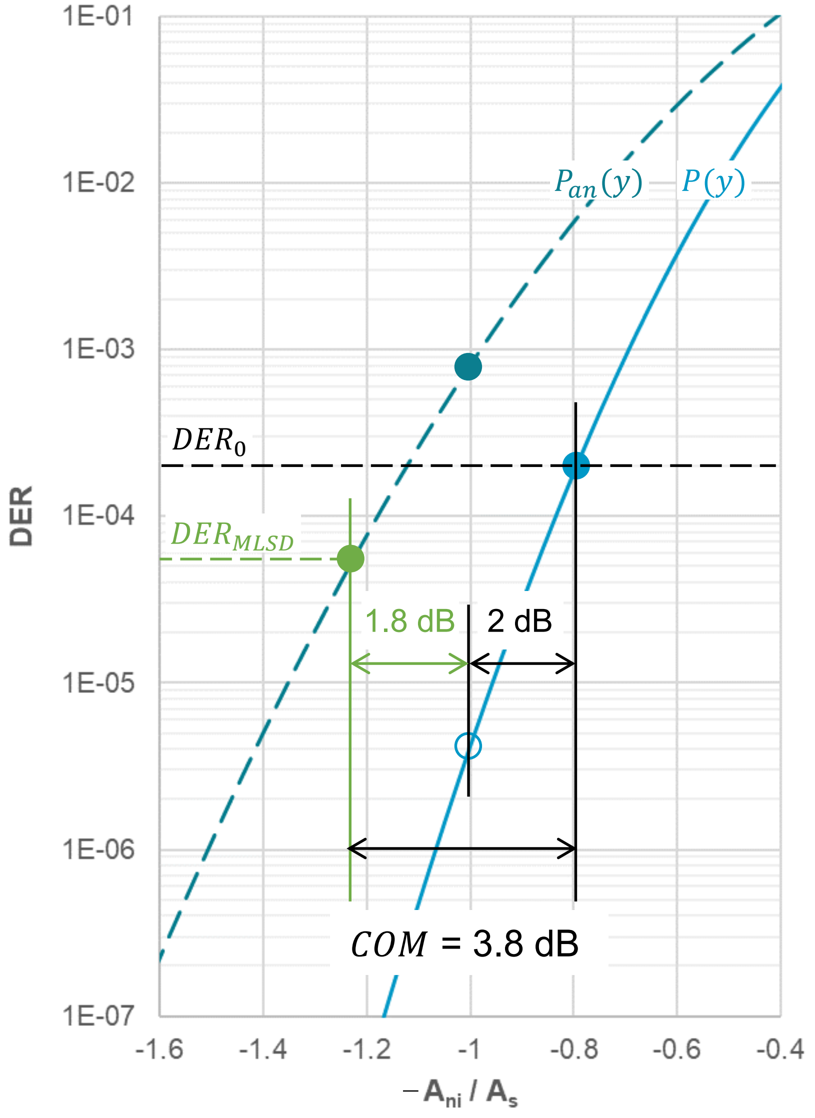
Overview of the proposed changes, 2 of 4



- Define a new cumulative distribution function $P_{an}(y)$ that is $P(y)$ with additional noise
- The additional noise represents impairments allowed by the minimum COM limit but not explicitly included in the calculation of $P(y)$
- This is not an "implementation penalty" for MLSD
- It is included so that the MLSD gain is calculated in the correct context

- Note that a corresponding adjustment must also be made to the power spectral density of the noise and interference
- This is addressed in the list of detailed changes

Overview of the proposed changes, 3 of 4



- Compute DER_{MLSD} using $P_{an}(y)$ instead of $P(y)$
- Compute the corresponding MLSD gain

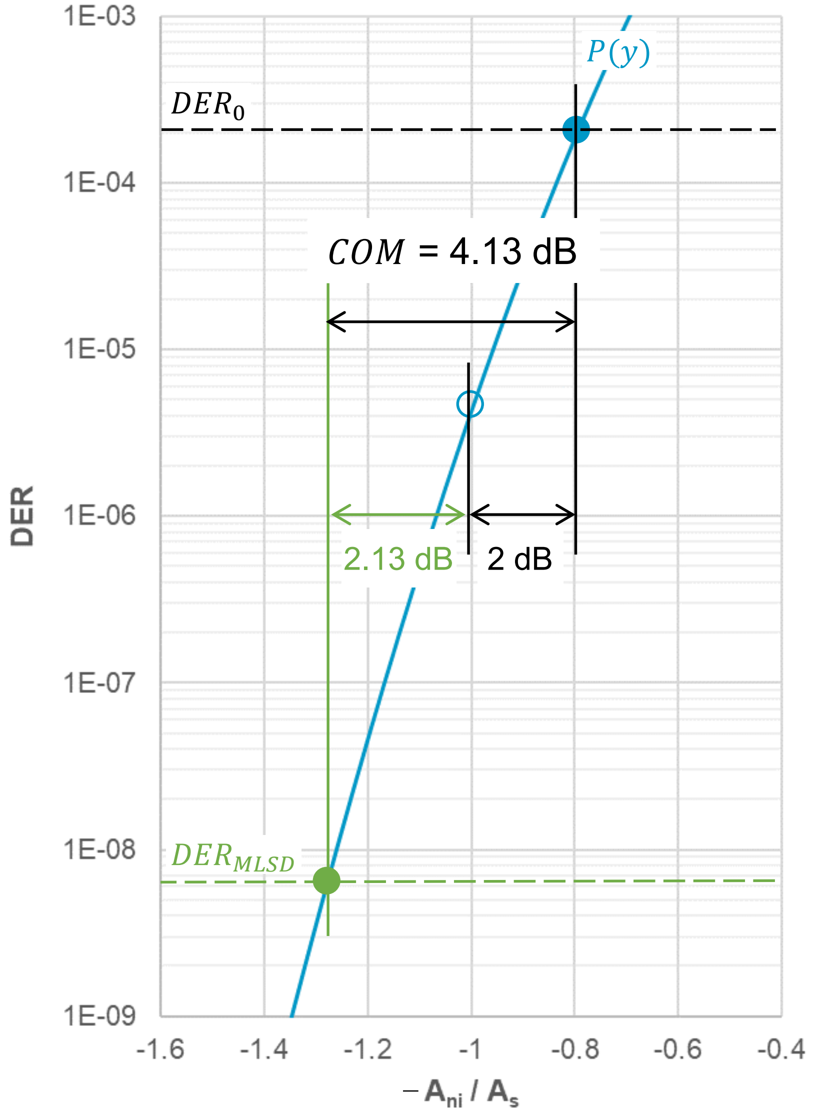
$$\Delta COM_{MLSD} = 20\log_{10}(-P_{an}^{-1}(DER_{MLSD})/A_s)$$

- Apply the gain to COM_{DFE} to yield COM for the MLSD-based receiver

$$COM = COM_{DFE} + \Delta COM_{MLSD}$$

- The resulting value of COM provides the same allowance for additional impairments as COM_{DFE}
- If needed, the COM limit could be increased to allow for additional MLSD-specific impairments

Overview of the proposed changes, 4 of 4



- When DER_{MLSD} is computed using $P(y)$, the MLSD gain is over-estimated by more than 0.3 dB
- The additional gain due to this over-estimation will tend to “disappear” as the impairment allowance is consumed
- This effectively reduces the impairment allowance by more than 0.3 dB

Proposed changes, 1 of 5

Change 178A.1.11 as follows.

178A.1.11 Maximum likelihood sequence detection

[...] This modification is defined by Equation (178A–36).

$$COM = COM_{DFE} + 20\log_{10}(-P_{an}^{-1}(DER_{MLSD})/A_s) \cancel{- Q} \quad (178A–36)$$

where $P_{an}(y)$ is defined in 178A.1.11.1 and DER_{MLSD} is defined by Equation (178A–37) ~~and Q is a specified MLSD implementation allowance~~.

NOTE—Subtracting Q from COM is no different than specifying that the minimum COM limit is a larger number (e.g., 3 dB + Q). It is proposed that we remove Q and specify a minimum COM limit that can accommodate all remaining receiver impairments including MLSD implementation penalties. This change is unrelated to the rest of the proposal and does not need to be included if an explicit accounting of Q is desired.

Proposed changes, 2 of 5

Insert a new subclause before 178A.1.11.1 and renumber the subsequent subclauses accordingly.

178A.1.11.1 Additional receiver noise

The receiver noise is increased before COM for the MLSD reference receiver is computed. The increased noise represents additional receiver impairments allowed by the minimum COM limit but not explicitly included in the calculation of COM_{DFE}. Let $S_{an}(\theta)$ be the power spectral density of the additional noise as defined by Equation (178A–X).

$$S_{an}(\theta) = g_{an} S_{rn}(\theta) \left| H_{rxffe}(\theta) \right|^2 \tag{178A–X}$$

where g_{an} is a scale factor for the added noise with a value greater than or equal to 0.

Let $p_{an}(y)$ be the probability distribution function of noise and interference amplitude that includes the added noise. It is computed as defined in 178A.1.10.2, using the same parameter values that were used to compute COM_{DFE}, but replacing σ_G with σ_{an} where σ_{an} is defined by Equation (178A–Y).

$$\sigma_{an}^2 = \sigma_G^2 + f_b \int_{-\pi}^{\pi} S_{an}(\theta) d\theta \tag{178A–Y}$$

The corresponding cumulative distribution function $P_{an}(y)$ is defined by Equation (178A–35) substituting $p_{an}(y)$ for $p(y)$.

Proposed changes, 3 of 5

178A.1.11.1 Additional receiver noise [continued]

The value of g_{an} that is used to calculate COM for the MLSD reference receiver is the value that makes the quantity $20\log_{10}[P_{an}^{-1}(DER_0)/P^{-1}\,(DER_0)]$ equal to the specified value of ΔCOM_{an}.

NOTE—The intent is for ΔCOM_{an} to equal the minimum COM limit (e.g., 3 dB) but it is also possible to specify a smaller value.

Proposed changes, 4 of 5

Change the beginning of 178A.1.11.2 (formerly 178A.1.11.1) as follows.

178A.1.11.~~1~~2 Sequence noise distribution function

The probability distribution function of the noise corresponding to a sequence of length j is denoted $p_j(y)$. ~~The value of~~Given $p_{an}(y)$ defined in 178A.1.11.1, $p_j(y)$ is initialized to $\mathrm{conv}[p_{an}(y), p_{an}(y/b_{\cancel{1}lim}(1))/|b_{\cancel{1}lim}(1)|]$, where $\mathrm{conv}[u, v]$ denotes the convolution of u and v.

~~The value is~~It is then iteratively updated by repeating the assignment defined by Equation (178A–39) $j-1$ times.

$$p_j(y) = \mathrm{conv}\left[p_j(y), \frac{1}{|1-b_{\cancel{1}lim}(1)|}p_{an}\left(\frac{y}{1-b_{\cancel{1}lim}(1)}\right)\right] \quad (178A\text{–}39)$$

NOTE—The proposed changes include corrections to the notation used to represent the first feedback coefficient (which is also used as the channel model by the MLSD reference receiver).

Proposed changes, 5 of 5

Change the beginning of 178A.1.11.3 (formerly 178A.1.11.2) as follows.

178A.1.11.~~2~~3 Inter-symbol interference and noise autocorrelation function

The power spectral density of the noise and residual inter-symbol interference at the output of the feed-forward filter is defined by Equation (178A–40).

$$S_{ni}(\theta) = S_n(\theta)\left|H_{rxffe}(\theta)\right|^2 + S_{an}(\theta) + \sigma_X^2 |\mathrm{DFT}[h_{ISI}(n)]|^2 / f_b \quad (178A–40)$$

where $S_{an}(\theta)$ is defined in 178A.1.11.1.

Summary and conclusions

- The calculated gain for an MLSD-based reference receiver is over-estimated because it does not account for the margin allocated for additional impairments
- This optimism can be removed by the inclusion of an additional noise term before the MLSD gain is calculated
- Detailed changes to the draft that address this issue have been provided