Modulation Schemes Link Budget Analysis under BCI Interference for RTPGE

January 2014
IEEE Reduced Twisted Pair Gigabit Ethernet

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Outline

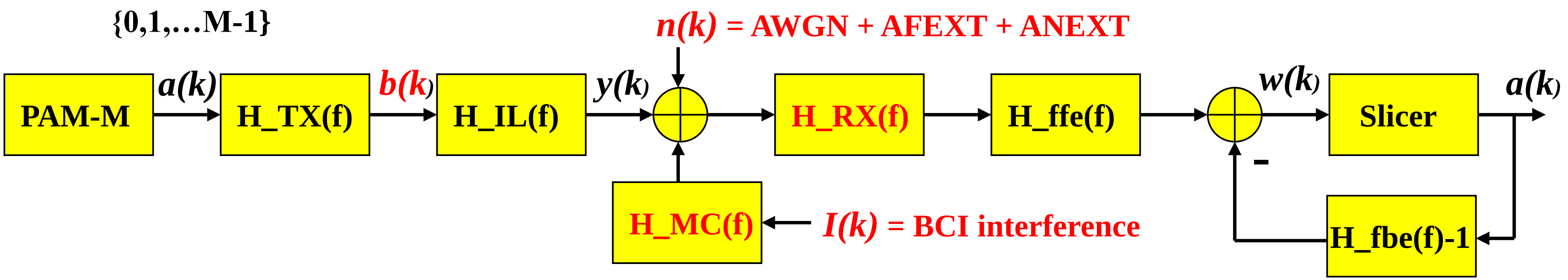
- SNR Calculation and Channel Model
- BCI Analysis Method
  - Simulation Example
- System Design Considerations
  - Filter Cut-off Frequency Constraint
- Link Budget Discussion
- Summary

SNR Calculation and Channel Model

- SNR calculation is referred from "huang_01_0512.pdf"
  - Transmission PSD = Latest proposed TX PSD MASK (max transmitting power). [PSD Mask from "EMCnoise_ad_hoc_f2f_3bp_01_0716"]
  - 15 meter Cable model (IL, AFEXT, ANEXT) from "ch_ad_hoc_3bp_01_1113.pdf"
  - –140dBm/Hz AWGN
  - RX AFE second order Butterworth filter
  - Calculating *Decision-point SNR* with infinite FFE and finite length FBE(50taps)
    - Frequency domain analysis model
  - Target SNR = *Uncoded SNR* (at BER = 10^{-10}) – *Coding gain*
  - Define *SNR_margin* = *Decision-point SNR* – Target SNR
  - Perfect ECHO cancellation
- Mode conversion [H_MC(f)] is from "EMCnoise_ad_hoc_3bp_01_1113.pdf " (15 meter cable)
- Assume 10% overhead for channel coding.

BCI Analysis Method

- Analysis method is modified from "bliss 03bp_01_1113.pdf"

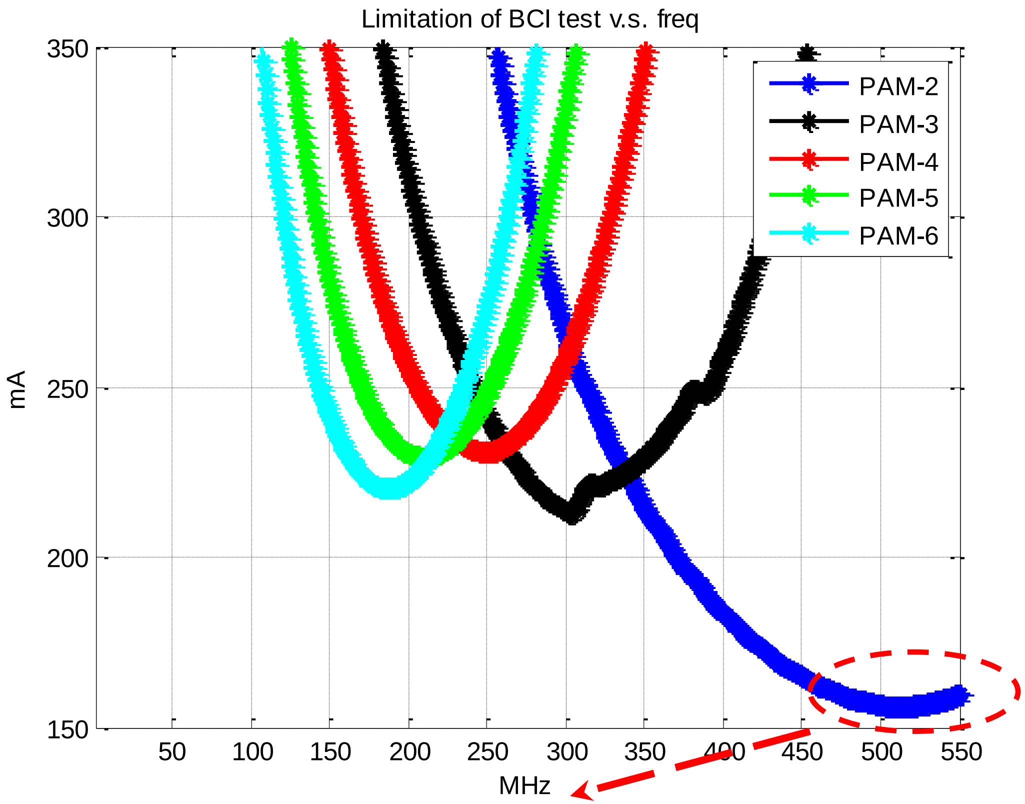


- The PSD of *b(k)* = TX PSD MASK (max transmitting power)
- Narrow-band sine wave interference (BCI-test) is attenuated by RX filter [H_RX(f)] and boosted by FFE [H_ffe(f)]. Thus, BCI-test limitation will vary among different test frequency.
  - Solve for the min amplitude sine wave at *w(k)* to make a decision error.
  - This amplitude divides by the frequency response of H_RX(f), H_ffe(f), and mode conversion ratio [H_MC(f)].

In the end, we can calculate the limitation of BCI-test refer to the *I(k)* among different frequency.

Simulation Example

- Simulation shows that BCI-test limitation will vary among different test frequency.
  - Assume the coefficients of FFE and FBE are fixed under BCI-test.

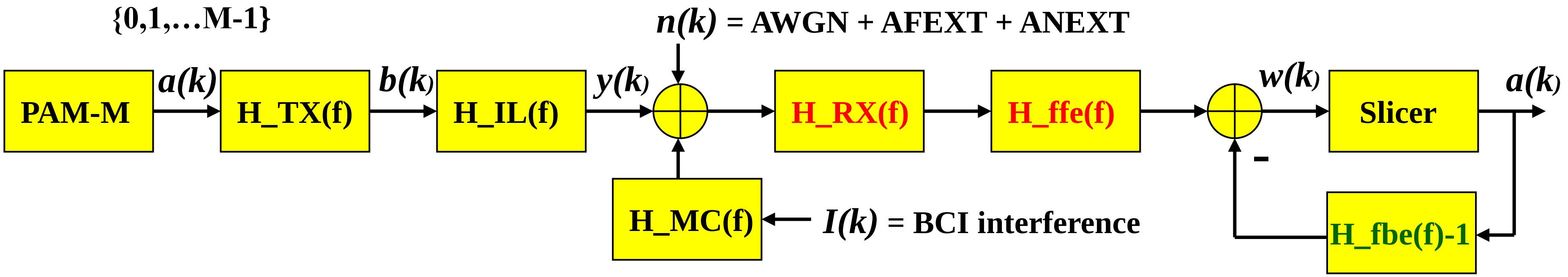


PAM	Nyquist frequency (MHz)
2	550
3	347
4	275
5	237
6	213

RX filter cut-off freq = 0.45*bard rate

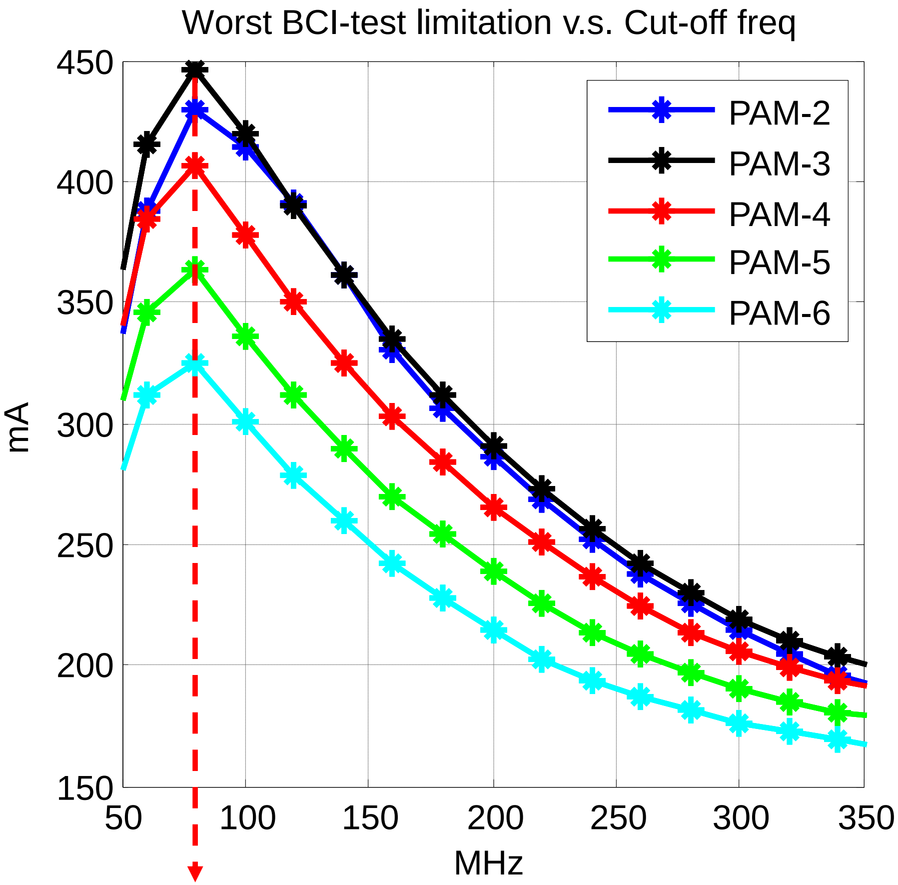
- *Worst BCI-test limitation* occurs around Nyquist frequency for all modulation schemes.

System Design Considerations

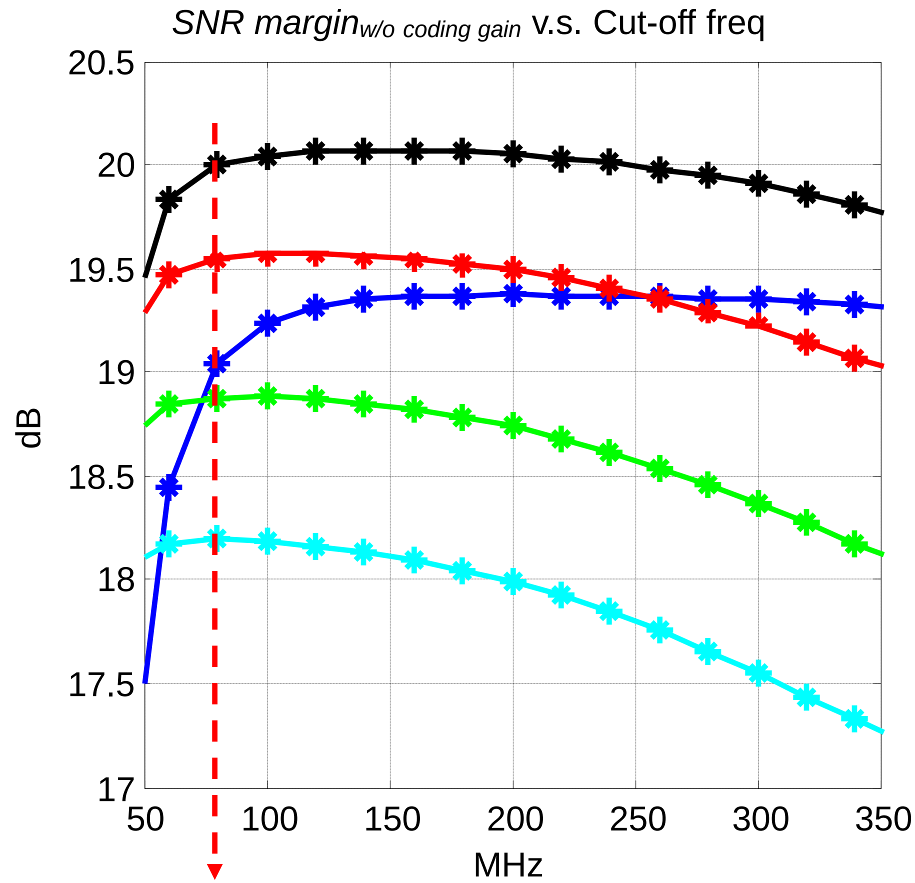


- Some considerations of receiver design.
  - Received signal *y(t)* is equalized by *RX AFE filter*, *FFE*, and *FBE*.
  - Received noises *n(k)* and *I(k)* are equalized by *RX AFE filter*, and *FFE*.
  - ***The weight of equalization among RX AFE filter, FFE, and FBE will strongly affect the limitation of BCI-test, especially in high frequency test tone .***
    - Better performance for BCI-test: *RX AFE filter* and *FFE* are LPF, and *FBE* is HPF.
    - Worse performance for BCI-test: *RX AFE filter* and *FFE* are HPF, and *FBE* is LPF.
- General design rules of equalization constraint in our simulation.
  - *FFE* and *FBE* are solved from *Decision-point SNR* in best sampling phase.
  - The cut-off frequency of *RX AFE second order Butterworth filter* should slightly degrade the SNR and highly improve the BCI-test limitation.

Filter Cut-off Frequency Constraint



PAM-3 > PAM-2 > PAM-4



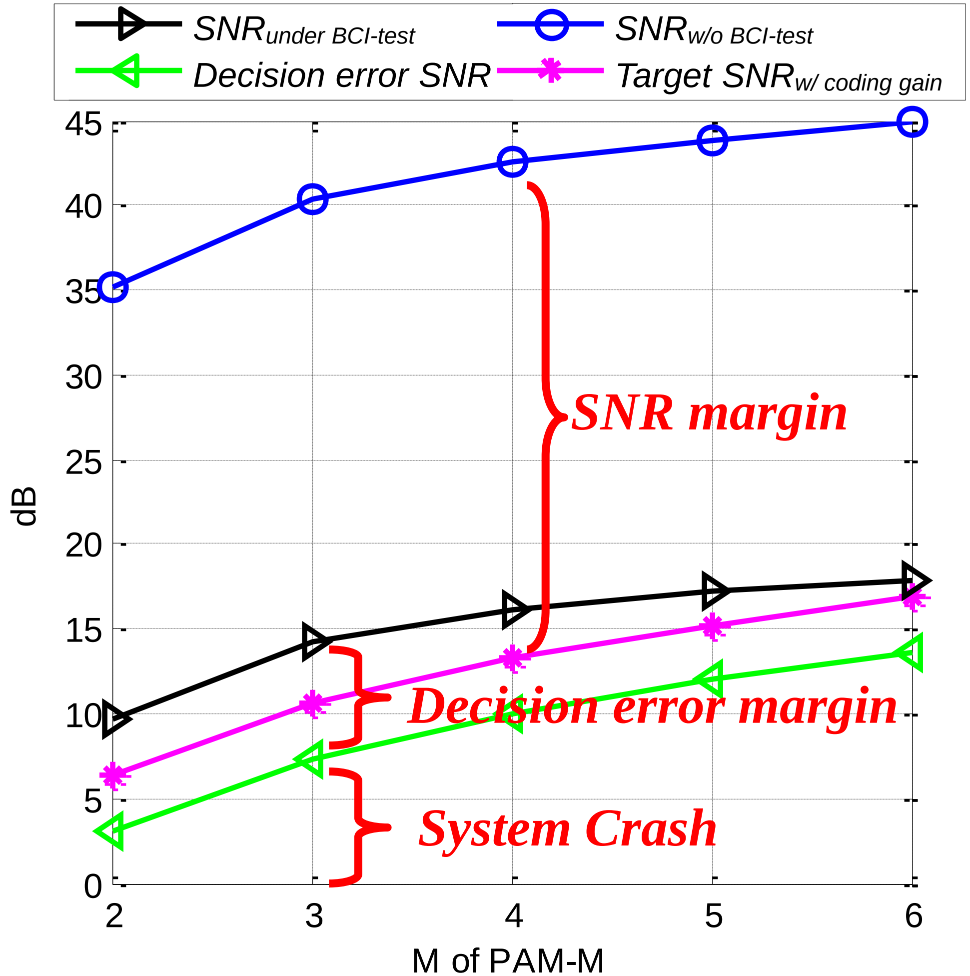
PAM-3 > PAM-4 > PAM-2

- Choose the proper cut-of frequency of *RX AFE filter*:

PAM	2	3	4	5	6
Cut-off freq (MHz)	80	80	80	80	80

Link Budget Discussion (15 meter)

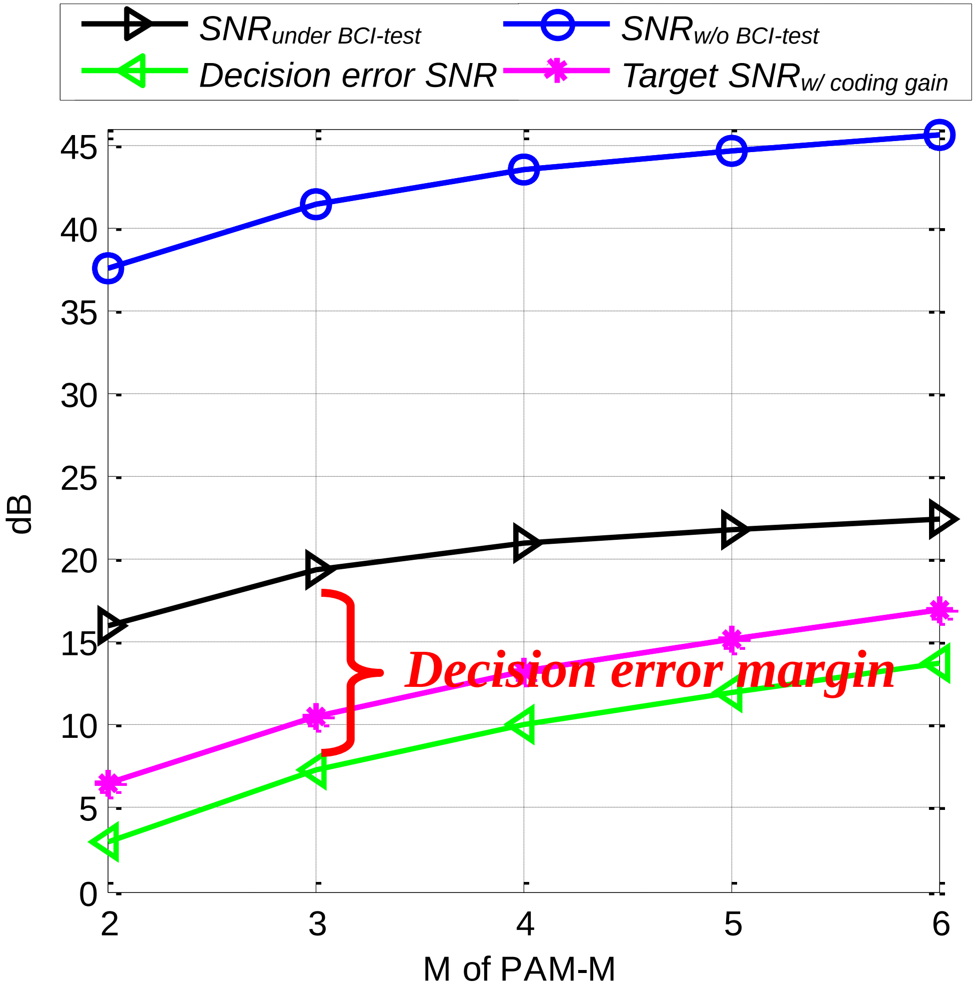
- Link budget calculation
  - Assume LDPC coding gain (~9.75dB) .
    - Calculate *Target SNR$_{w/\ coding\ gain}$*
  - Assume flat 200mA BCI noise level
    - Calculate *SNR$_{under\ BCI\text{-}test}$*
  - *Decision error SNR* is the signal to sine wave power ratio, that min amplitude sine wave can make a decision error (slicer error).
- PAM-3 have the best BCI performance with *Decision error margin*. (7dB)



- The simulation shows the RTPGE passing the BCI-test with BER =10^{-10} is theoretical feasible.
  - The coding gain comes from Gaussian noise analysis. One concern is that whether FEC can still keep the same coding gain under BCI-test (color noise)?

Link Budget Discussion (2 meter)

- 2 meter cable for BCI-test condition.
  - 2 meter cable model from "hermann_3bp_01_0913.pdf"
    - 23 AWG with 4 connectors.
    - Temperature = 125º
- Brief summary :
  - PAM-2 have the best BCI performance with *Decision error margin* (12.9dB).
  - All modulation schemes have at least 8.7dB *Decision error margin*.
- The simulation shows that all modulation schemes can pass the BCI-test of 2 meter cable.



- The spec of coding gain can be released under 2 meter cable condition.

Summary

- Worst BCI-test limitation occurs around the Nyquist frequency.
- Receiver design is highly correlated to the BCI-test limitation, such as RX filter and equalizer design.
- The simulation shows the RTPGE passing the BCI-test with BER $=10^{-10}$ is theoretical feasible.
  - Need to further verify the coding gain under BCI-test.
- Considering BCI-test of *Decision error margin*
  - PAM-3 would be the better candidate for 15 meter cable.
  - All modulation schemes would be fine for 2 meter cable.
- Future work
  - Figure out TX shaping filter, transmission power, and implementation lose.
  - Solution should be trade-off among *SNR margin*, *equalization constraints*, and *complexity* which will imply the best modulation and channel coding.
    - Lower baud rate means lower complexity and power, but lower margin.

This presentation is not a baseline proposal. However, the performance of this solution can be used as a baseline for future evaluation.

Thank you

Any questions?

Backup

Link Budget Discussion (15 meter)

- Details of link budget Calculation (page 8)

PAM	Decision error margin (under BCI-test)	SNR Gap	SNR margin (w/o BCI-test)
2	6.6dB	3.2dB	28.8dB
3	7.0dB	3.7dB	29.7dB
4	6.1dB	2.9dB	29.3dB
5	5.2dB	2.0dB	28.6dB
6	4.2dB	1.0dB	28.0dB

- *SNR Gap* $= SNR_{\text{under BCI-test}} - \text{Target } SNR_{\text{w/ coding gain}}$
- *SNR_margin* $= \text{Decision-point } SNR - \text{Target } SNR_{\text{w/ coding gain}}$
- *Decision error margin* $= SNR_{\text{under BCI-test}} - \text{Decision error } SNR$

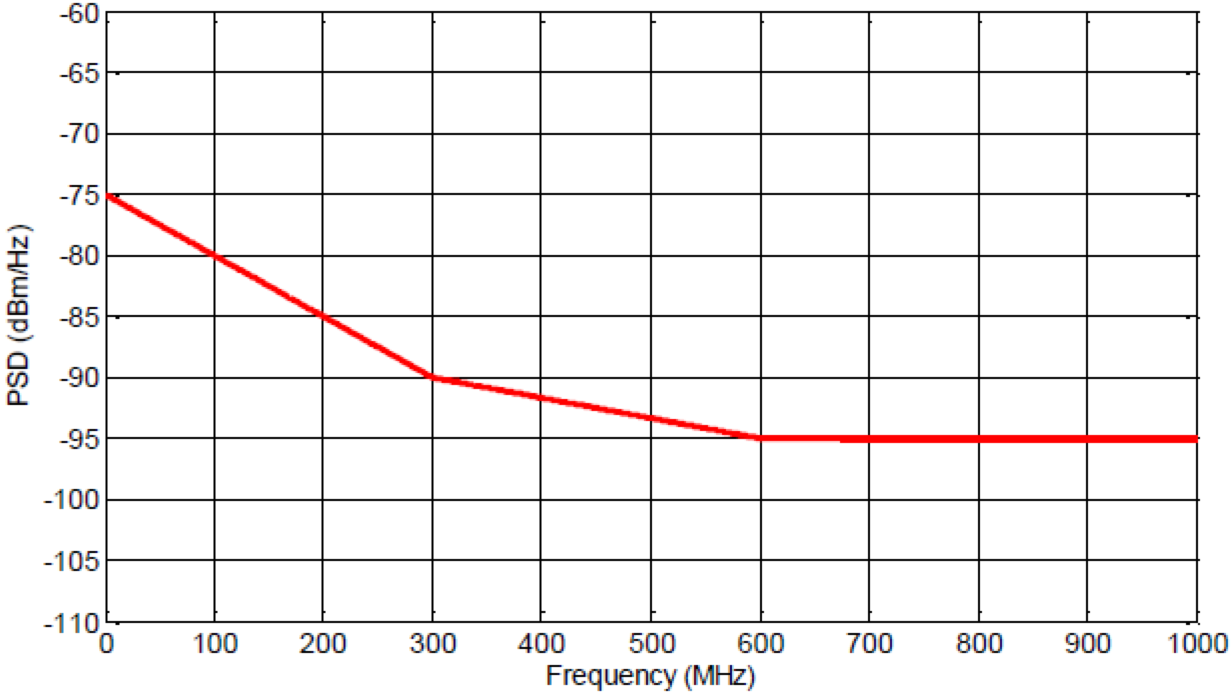
Link Budget Discussion (2 meter)

- Details of link budget Calculation (page 9)

PAM	Decision error margin (under BCI-test)	SNR Gap	SNR margin (w/o BCI-test)
2	12.9dB	9.5dB	31.1dB
3	12.2dB	8.9dB	30.9dB
4	11.0dB	7.7dB	30.2dB
5	9.8dB	6.6dB	28.6dB
6	8.7dB	5.4dB	28.0dB

- *SNR Gap* = $SNR_{under\ BCI\text{-}test}$ – $Target\ SNR_{w/\ coding\ gain}$
- *SNR_margin* = *Decision-point SNR* – $Target\ SNR_{w/\ coding\ gain}$
- *Decision error margin* = $SNR_{under\ BCI\text{-}test}$ - *Decision error SNR*

TX PSD MASK



$[-f/20 - 75]_{\text{dBm/Hz}}$	$0 < f < 300\text{MHz}$
$[-f/60 - 85]_{\text{dBm/Hz}}$	$300\text{MHz} < f < 600\text{MHz}$
$-95_{\text{dBm/Hz}}$	$600\text{MHz} < f < 1000\text{MHz}$

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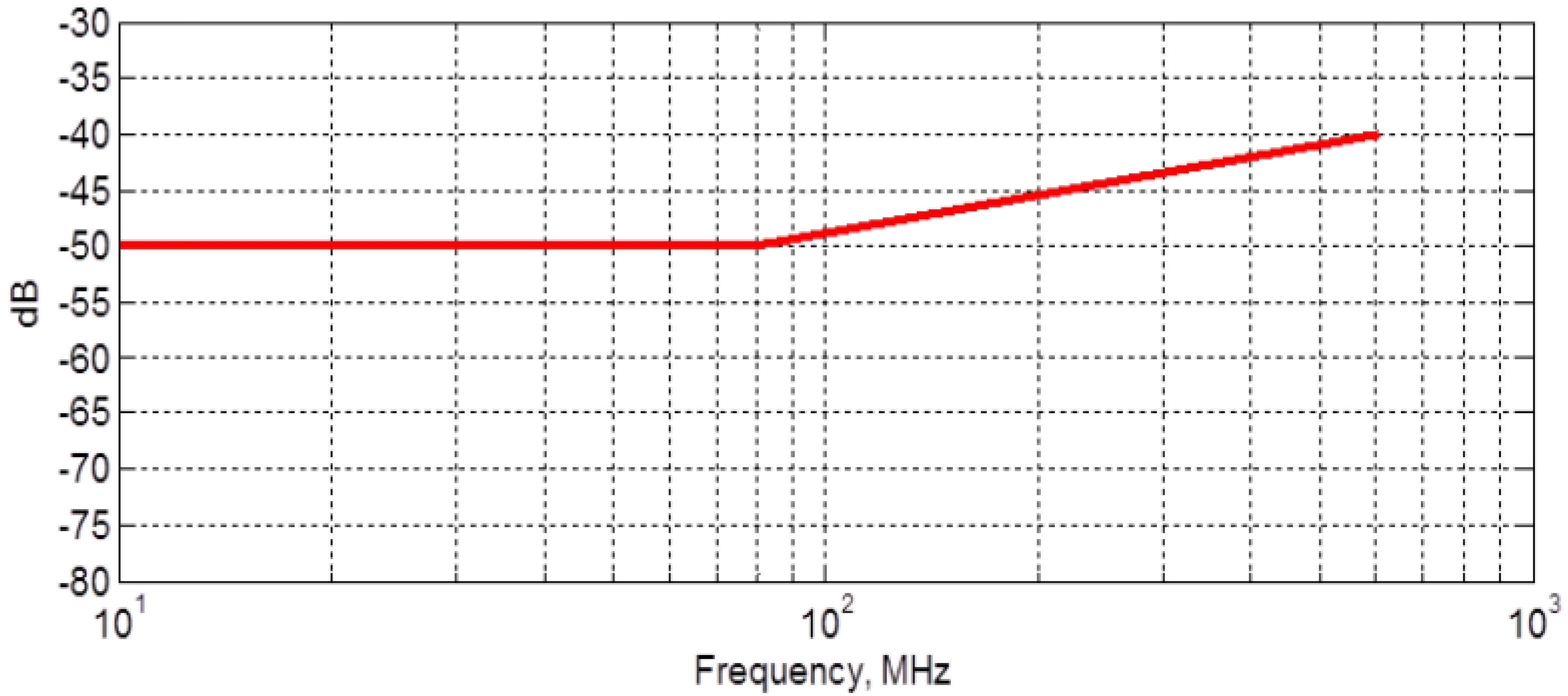
Mode conversion H_MC(f)

- The <u>mode conversion limit line</u> is proposed for a <u>15m UTP link segment with 4-inline connectors</u>



-50_{dB}	$10 < f_{MHz} < 80$
$[5 \log_n (f_{MHz}) - 72]_{dB}$	$80 < f_{MHz} < 600$

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