Electro-Magnetic Emissions and Susceptibility for RTPGE with PAM-M & DFE

Will Bliss, Broadcom

IEEE P802.3bp RTPGE Task Force

Orlando, FL

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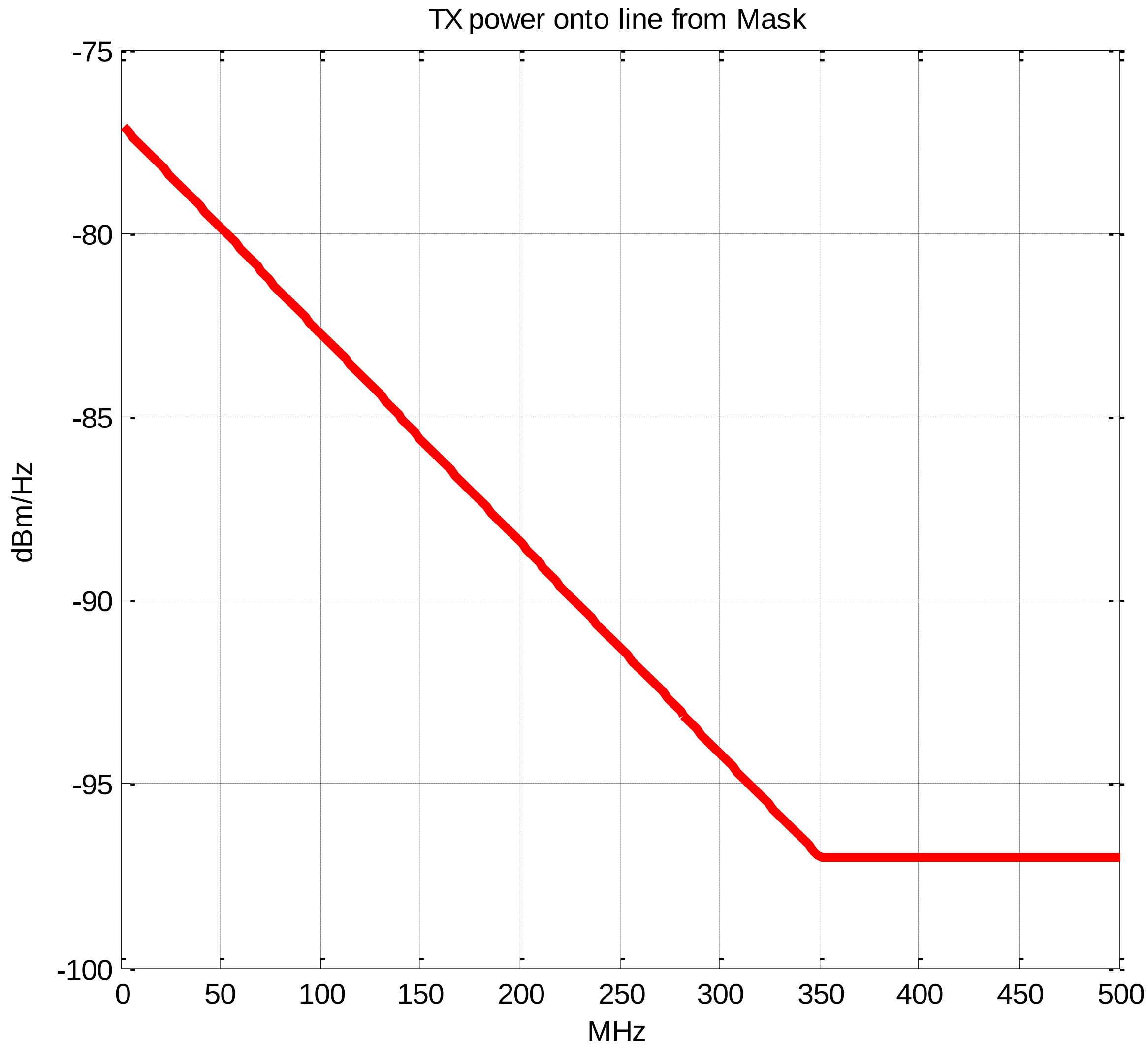
Overview

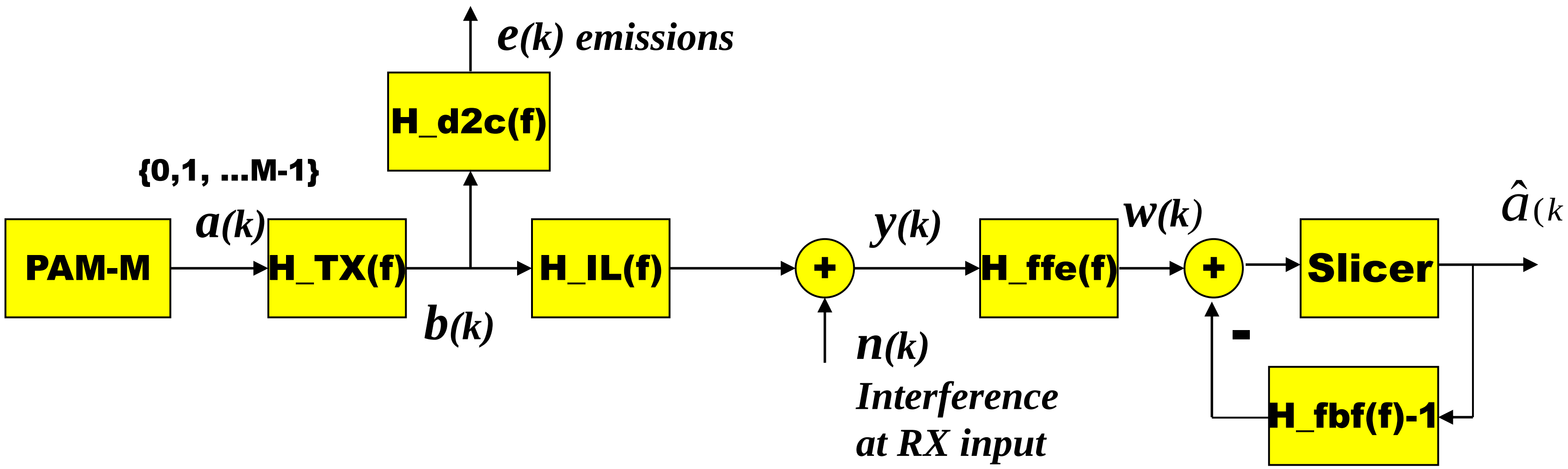
- Use the ‘strip-line’ measurement of a ‘CAT6a-like’ TP in [Tazebay_3bp_01_0113]
  - Use the TX PSD mask proposed, which was based on the measurement and the emissions criteria of 15 uV ‘peak’ in 100KHz BW
- Assume a PAM-M transmitter with a TX filter that exactly achieves this ‘mask’
  - This is a type of bound, as practical TXs won’t exactly achieve the TX PSD mask
- Allot 13% overhead for FEC (short block for low latency & modest gain)
- Solve for the performance of a DFE RX optimized for white noise at the RX input with this ‘TX mask’ and 15m of ‘CAT6a-like’ IL
  - The ‘TX PSD mask’ and the IL combine to create an ‘effective IL’ that defines pefformance
  - Solve for sine wave ‘interference’ amplitude at the RX input that causes errors
  - Is this reasonable margin against EMI for a product?
- Using the emissions transfer function measurement in the citation, compute the susceptibility to interference ‘impressed on common mode strip-line’ for this RX
  - How much ‘interference in space’ can be tolerated with this RX?

TX PSD Mask to meet Emissions



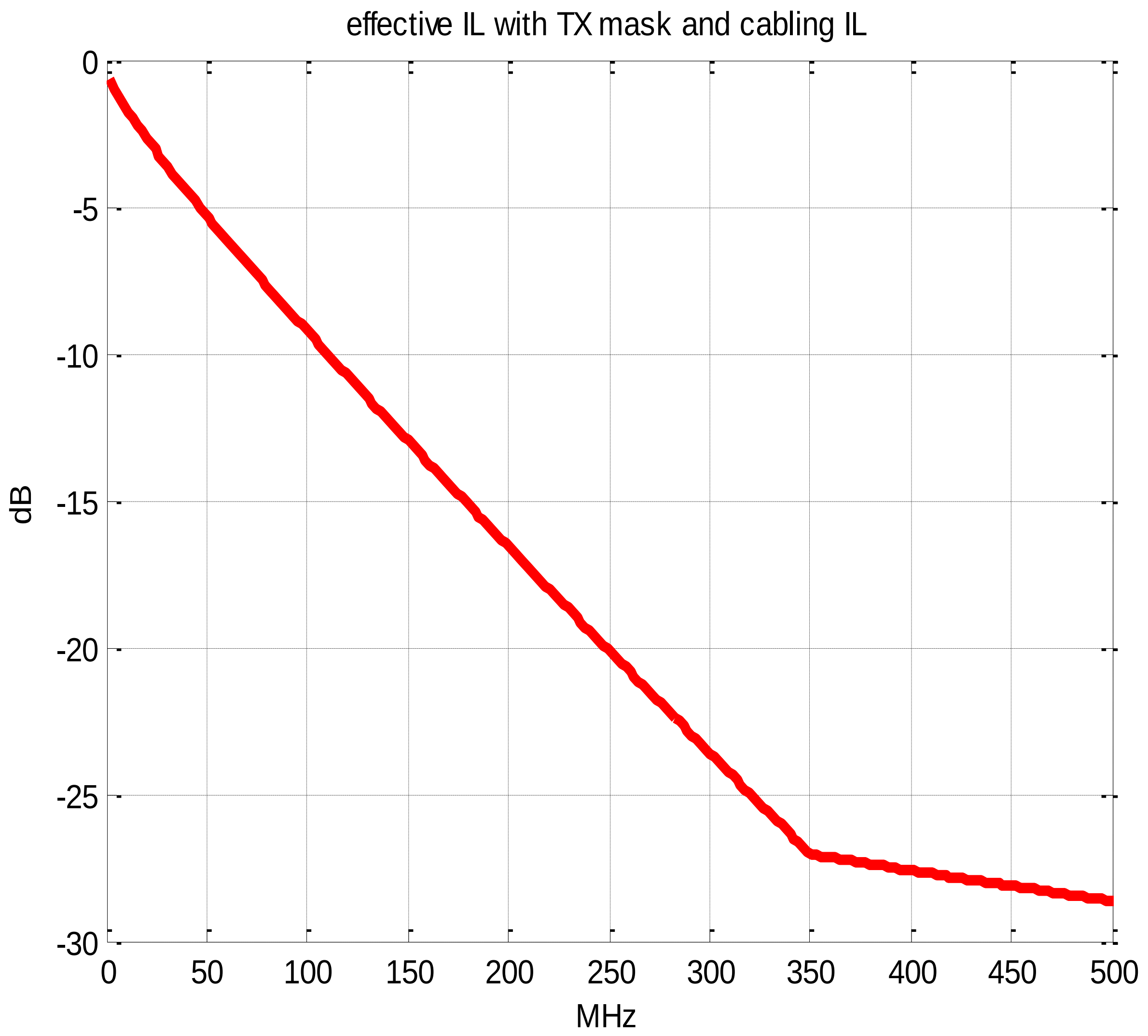
- Taken from [Tazebay_3bp_01_0113]
- Which was derived from strip line measurements of cable only
- May be improved for cable only
- But will need some margin for connectors, …
- Note that total transmitted power allowed increases with the Band Width used
- For simplicity, here use spectrum up to the Nyquist frequency (1/2 the Baud frequency)

EMC model for RTPGE w/ PAM & DFE



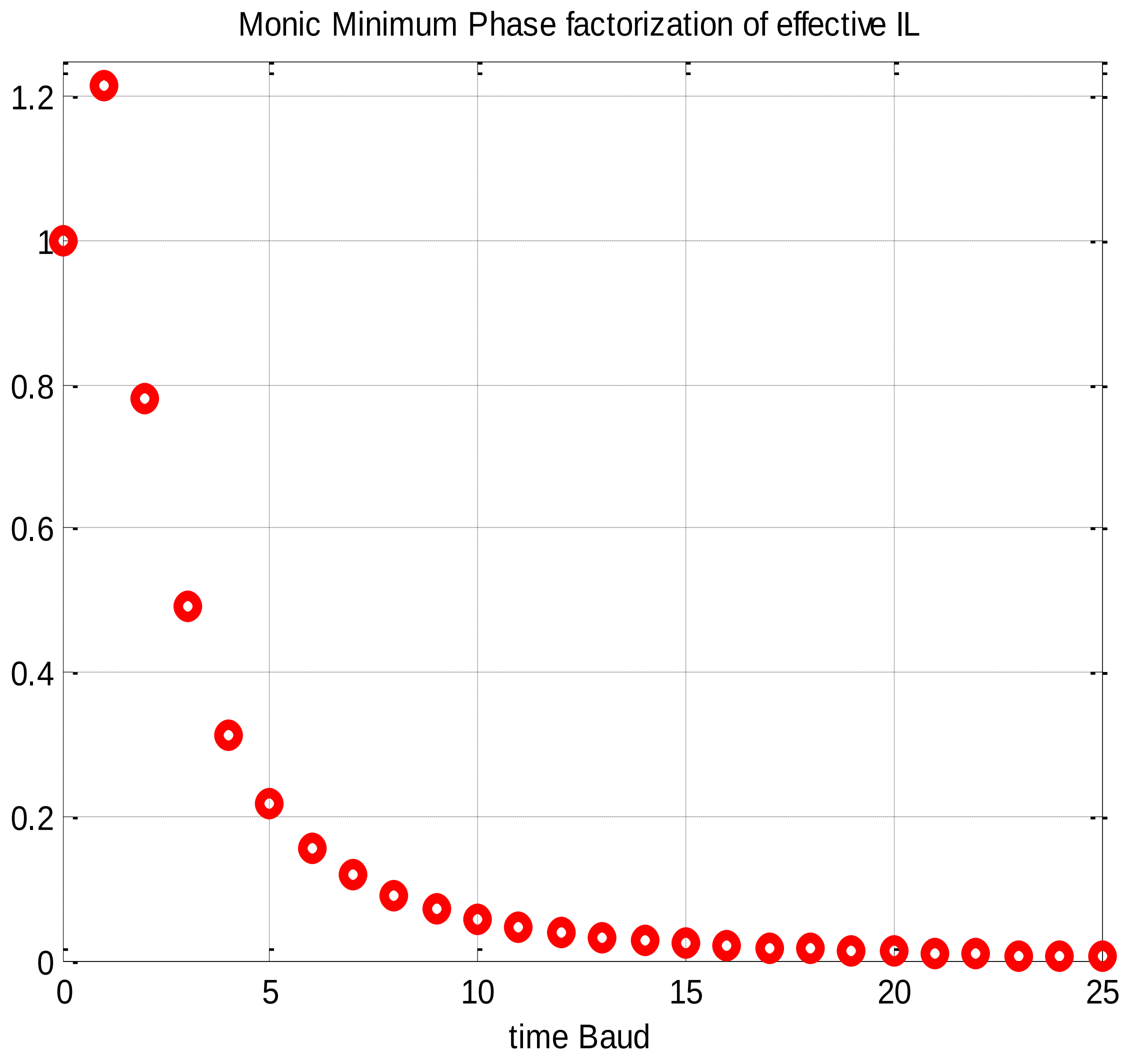
- The transmitter must be limited by LPF H_TX(f) such that the emissions *e(k)* meet the criteria set by the industry and regulation
- In other words, the signal at *b(k)* must meet the TX PSD mask
- The differential signal put on the line is filtered by the emissions transfer function H_d2dc(f), which gives *e(k),* the 'common mode' emissions output of the strip line
- The transmit signal is further low passed by the Insertion Loss of the cabling and connectors, H_IL(f)
- Assuming *n(k)* is 'white' and the SNR(f) is nowhere low, H_ffe(f) will be all-pass, creating a minimum phase signal at *w(k)*
  - Solve for the min amplitude sine wave at *n(k)* to create a slicer error
  - Sine waves at *n(k)* will fail at the same amplitude for all frequencies

‘Effective IL’ from net TX Mask and cabling IL



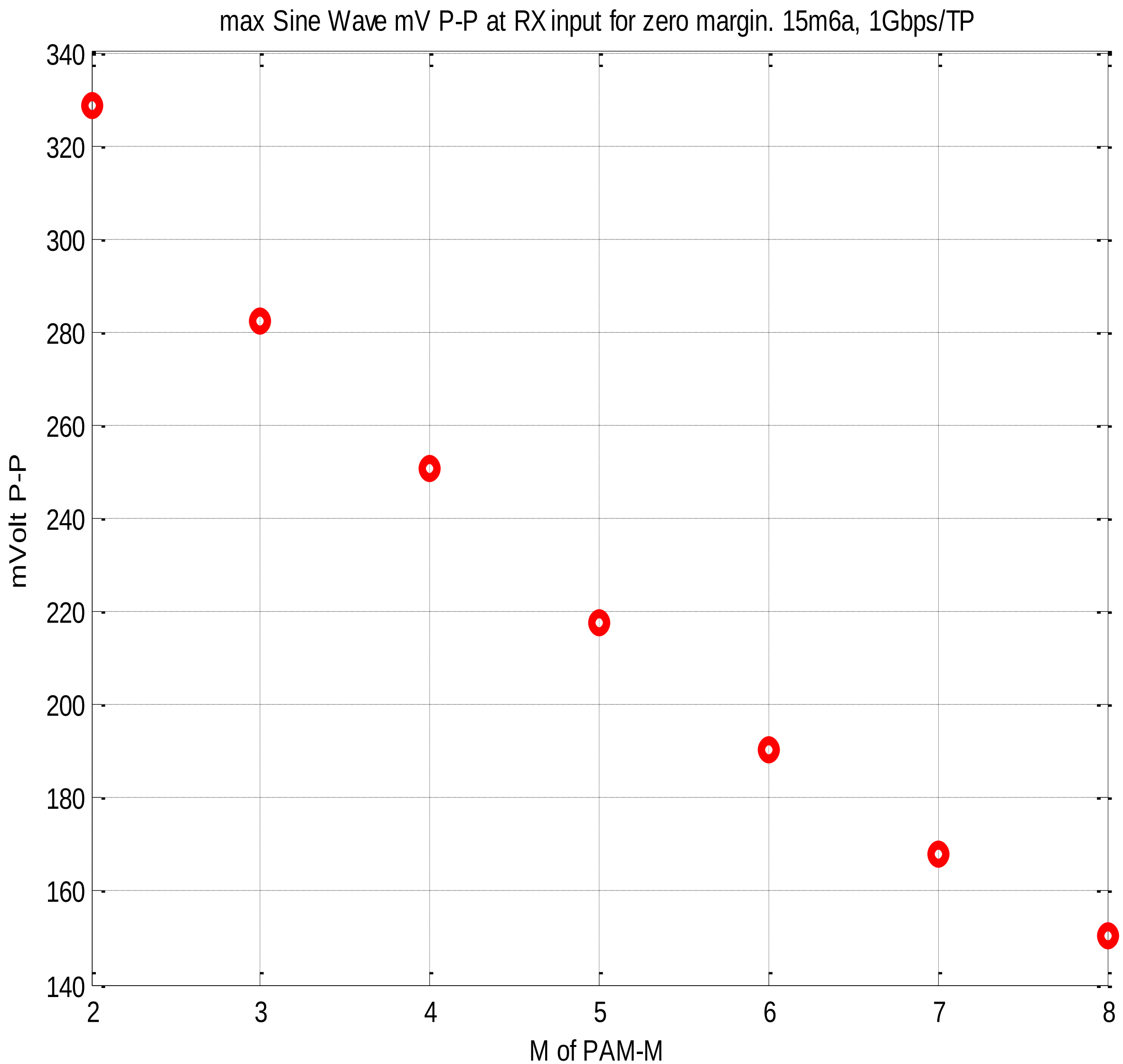
- The net effect of the TX PSD mask and the cabling IL creates an ‘effective IL’
- Shown here out to 500MHz, as needed for the actual system band width
- From RX design of DFE perspective, this ‘looks like’ a channel with much higher IL than the cabling system

DFE Response for M=3



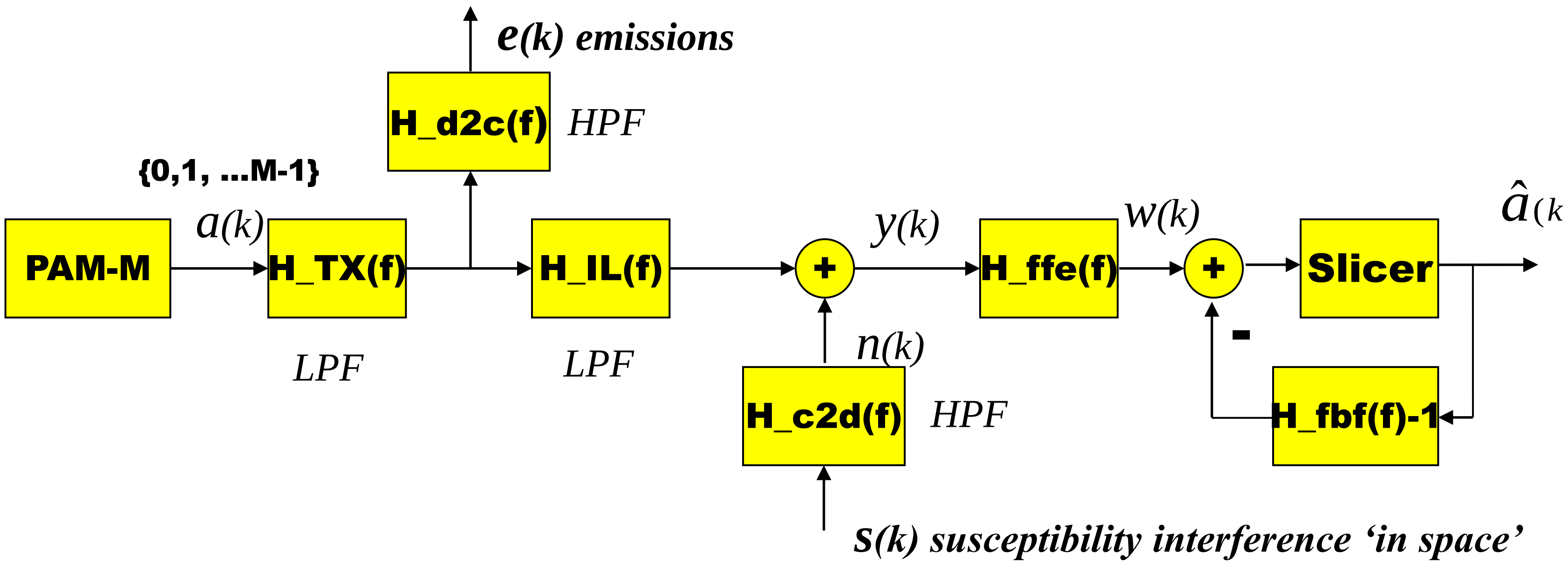
- DFE designed for white noise at the RX input with moderately high SNR(f)
- Example shown for PAM-3, where the Nyquist frequency with 13% overhead for FEC = 356 MHz
- The monic term *h(0)=1* is dropped from the actual feedback circuit
- This response is consistent with that of channels with 27dB IL

Maximum Sine Wave at RX input for Zero Margin



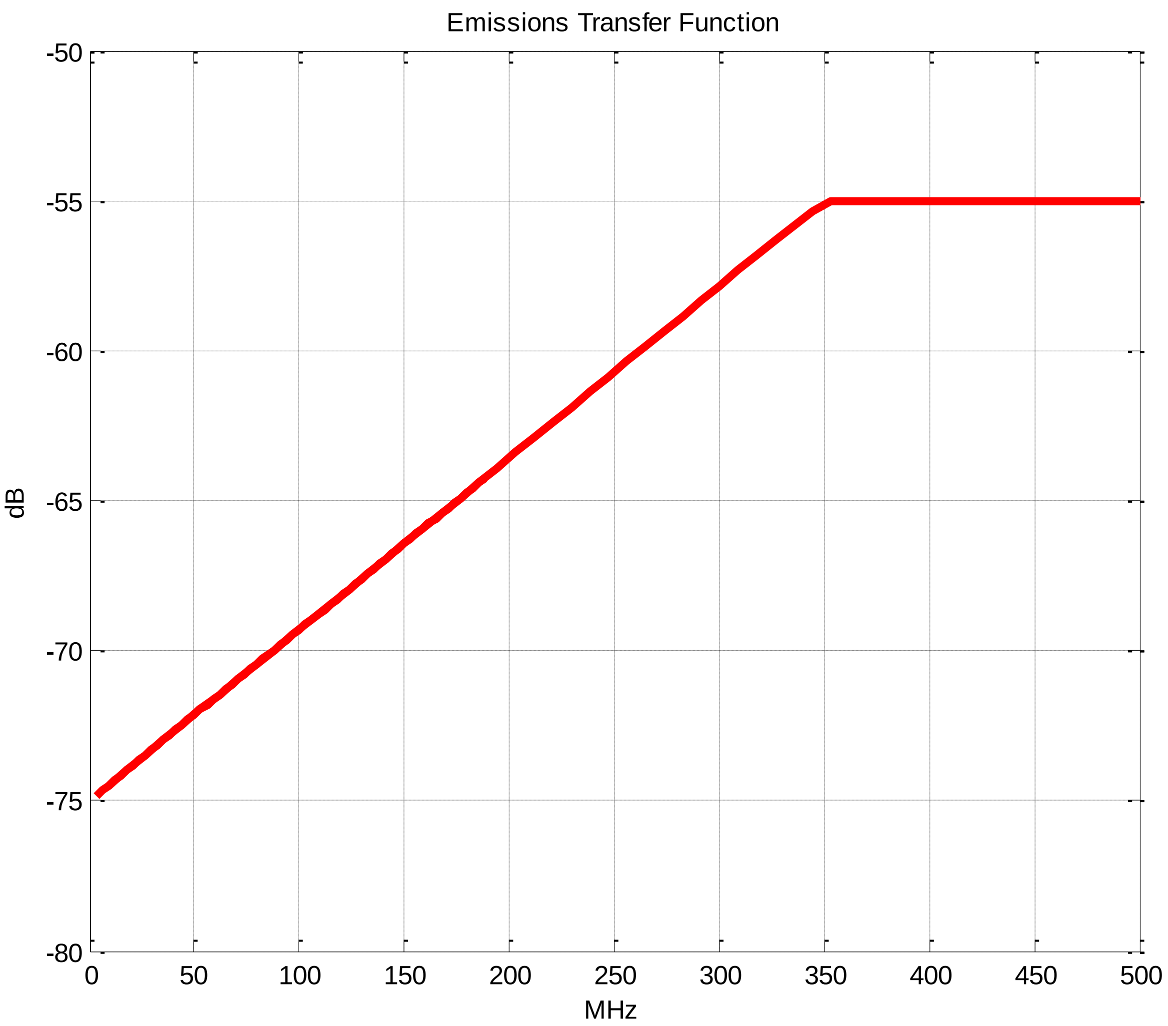
- Lower PAM-M is inherently more resistant to sine wave interference at the RX input
- Reduce 9dB to change from Peak-to-Peak to rms
- E.g., reduce another 6dB to keep the 'vertical eye half open' rather than completely closed
- So 15dB reduction for RMS measure with '6dB sine wave margin'
- E.g., PAM-4 tolerates 45mV rms w/ 6dB margin
- This is not the 'No Problem Ever' region of EMI pickup on cabling?

EMC model for Susceptibility 'in Space'



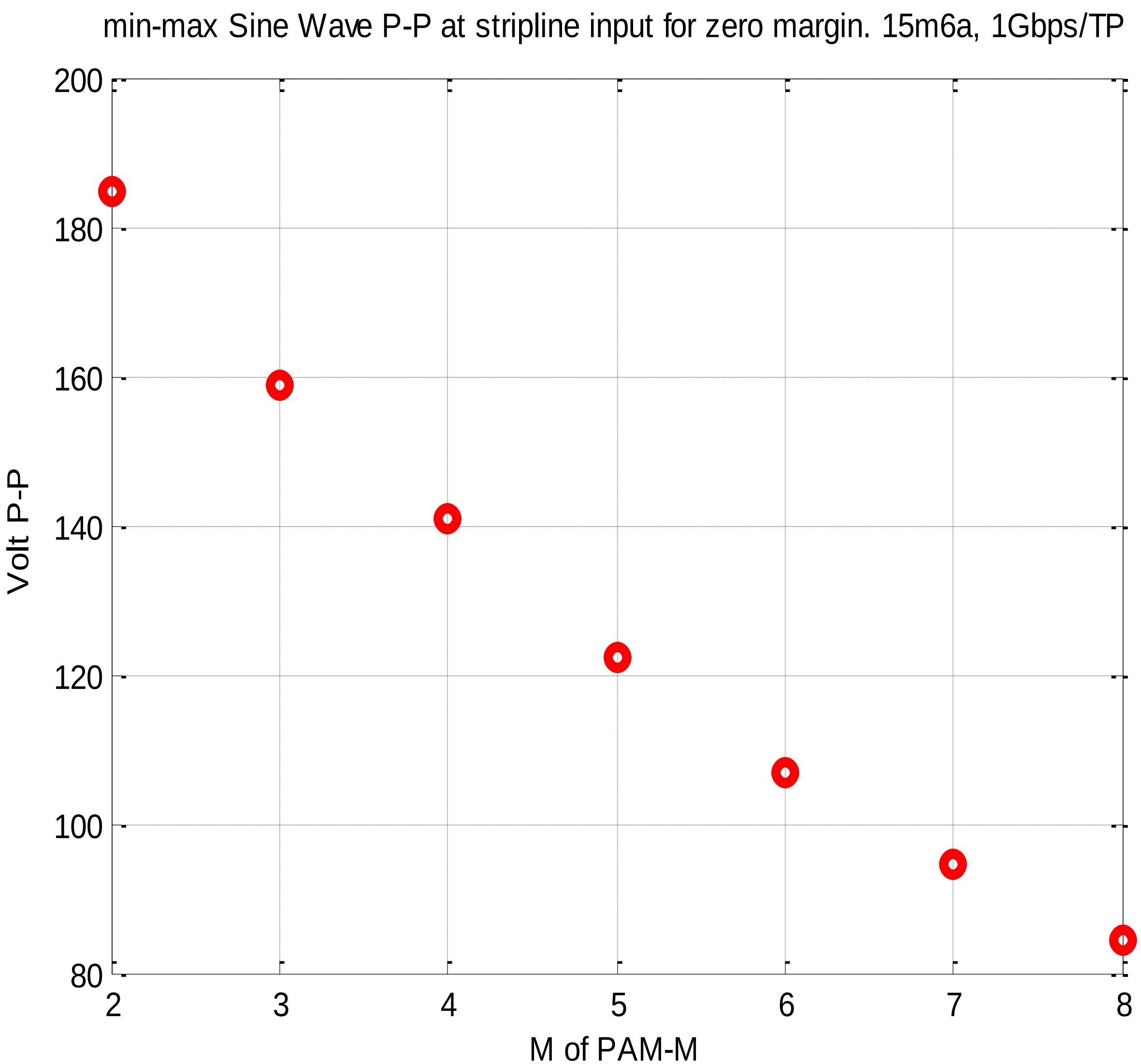
- Denote a common mode signal driving the strip line as *s(k),* the stand in for the EM susceptibility interfering signal coming from 'space'. It produces the differential signal on the line of n(k) after passing through transfer function H_c2d(f)
- By reciprocity and symmetry we have H_c2d(f) = H_d2c(f)
- Analyze the allowed sine wave interference at *s(k)* for the zero margin case
  - Worst case will be at high frequencies where the H_c2d(f) is largest

Emissions Transfer function



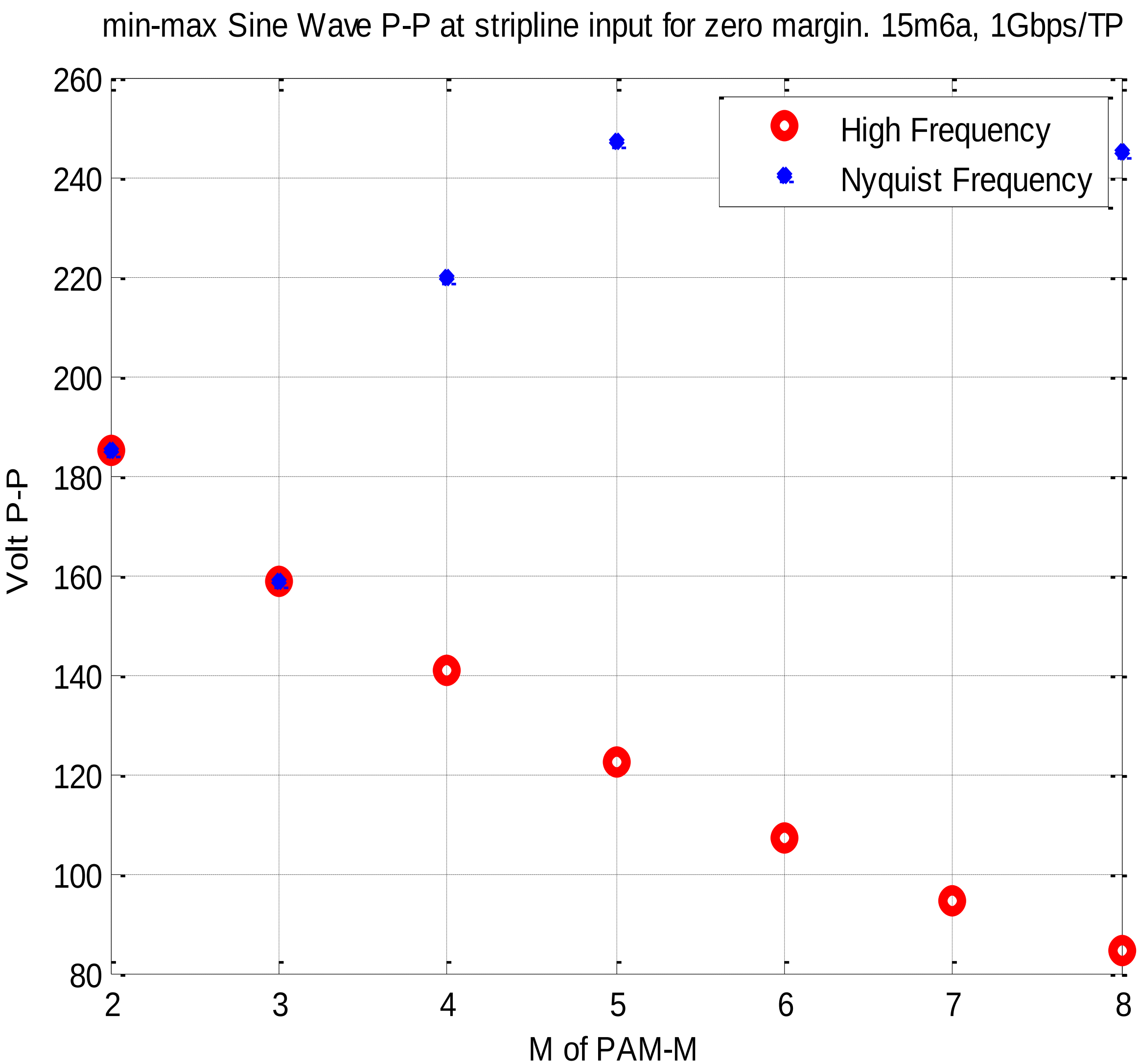
- The emissions transfer function from the cited measurements
- By reciprocity and symmetry used for the susceptibility transfer function

Maximum Sine Wave at CM Strip Line for Zero Margin



- Here assuming no anti-aliasing, so worst case is always at interference frequencies >= 350MHz
- This is pessimistic for PAM-4 and higher
- Again reduce by 9dB to translate from Peak-to-Peak to RMS
- Again, this may not indicate 'No Problem Ever' from EMI

Maximum Sine Wave at CM Strip Line for Zero Margin



- Blue points assume a brick wall band-limiting (perfect anti-aliasing), so the worst case interference tone is at the Nyquist frequency
- This is overly optimistic for anti-aliasing
- Actual anti-aliasing performance will be between these 'bounds,' and performance vs. M-level will become flatter

Summary and Conclusions

- A class of PAM-M transmitters with low pass TX filters was designed to exactly hit a proposed TX PSD mask
- A class of DFE RXs was designed for white noise at their inputs
- The Low Pass TX PSD mask was shown to create an 'Effective' channel with significantly higher IL
- The performance against sine wave interference at the RX input was calculated and shown to be maximized by choosing smaller 'M' PAM-M, even though it requires higher band widths
- Even for PAM-2 (NRZ), the interference tolerance does not appear to be larger than the 'worst imaginable' EMI pickup for a cabling system
- The measured emissions transfer function was used to solve for the susceptibility at the common mode of the strip line jig
  - Actual performance will strongly depend on the quality of analog anti-aliasing filter implemented
  - Again, interference tolerance does not appear better than the 'worst imaginable' EMI

Future Work

- How close to the TX PSD mask can we afford to implement?
  - Electronic power dissipation increases as we get closer to the mask
- Relate tolerated interference levels to measures of Radiated Immunity (RI in Volts/meter) and to Bulk Current Injection (BCI in Amps)
- Extend performance analysis to 'Impulsive type Noises'
  - Which in the automotive environment appear to be much longer than a single Baud, and more like enveloped and chirped Sine waves
- Consider other architecture performance issues with interference, including timing recovery and equalization
- Refine customer requirements for Electro-Magnetic Emissions and Susceptibility and determine if any PAM systems with unshielded cables and connectors can be expected to performs adequately

Thank you

Backup; Insertion Loss Specifications, 15m