25Gbps Communication over 10GBASE-KR Channels

Will Bliss
Broadcom Corp.

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Outline

- The 10GBASE-KR channel specifications for Insertion Loss to Cross Talk Ratio (ICR) and Insertion Loss (IL)
- Is it possible to send 25Gbps over these channels, which were defined for 10Gbps?
- Is it practical to send 25Gbps over these channels?

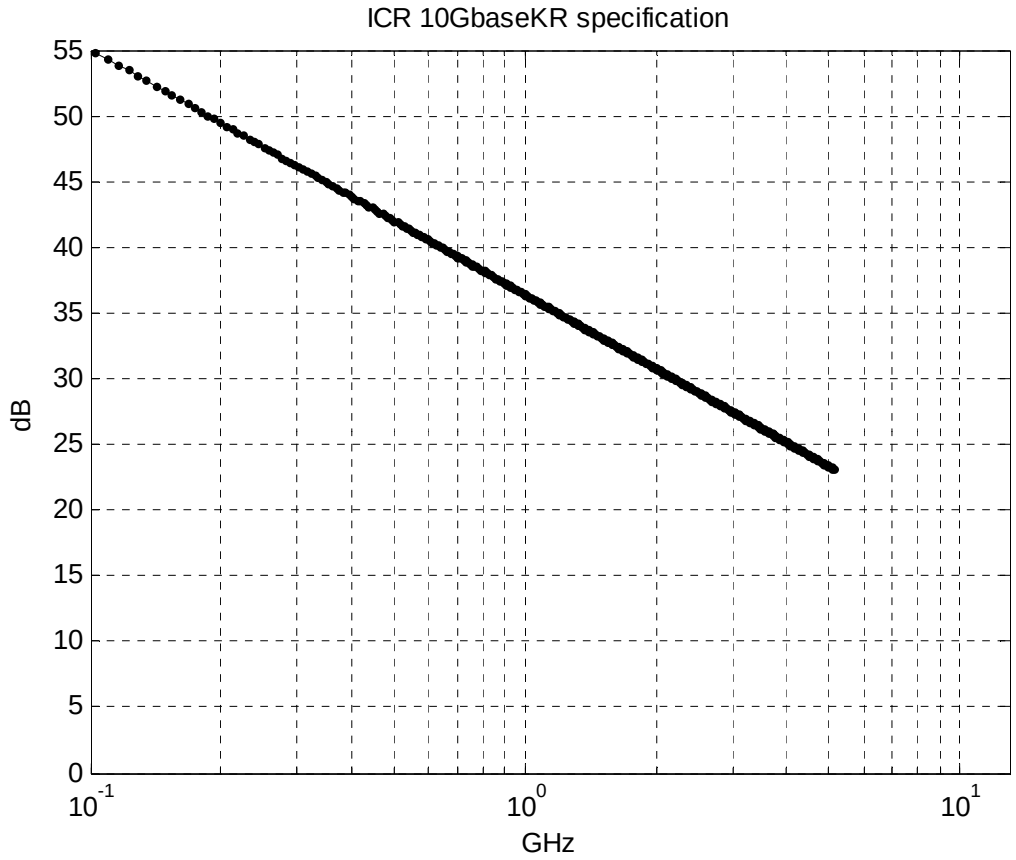
A channel specification for 100GBASE-KR4?

- The 10GBASE-KR channel specification already exists
  - The vast majority of the industry is using the Informative 10GBASE-KR channel characteristics as a specification
  - Doesn't need to be negotiated
    - So potentially faster standard development
    - And faster real deployment
- The 10GBASE-KR channel specification is known to be met with low cost boards and connectors
  - It had been thought very tough to meet the informative channel characteristics, but it has turned out to be an easy to meet specification
  - Including long reaches, to 38"
  - Already a large installed base of compliant channels
    - So faster and more accurate development of real PHYs
- But does the 10GBASE-KR channel support 25 Gbps?

The 10GBASE-KR channel specification

- The Insertion loss to Cross talk Ratio (ICR) is the SNR bound of the channel
  - Other impairments are self-inflicted circuit and signal processing non-optimal implementations
- The 10GBASE-KR *ICRmin(f)=23.3 -18.7*log10(f / 5GHz)*
  - For 100 MHz < ***f*** < 5.15625 GHz
  - "Accounts for worst-case differences in characteristics (e.g., amplitude, transition times) between the victim and aggressor transmitters"
  - "It also assumes a 3dB signal-to-noise ratio penalty related to insertion loss deviation"
  - "It is recommended that *ICRfit(f)* be greater than or equal to *ICRmin(f) …"*
  - So as normal, some margin is already in the specification
- The 10GBASE-KR Insertion Loss (IL) specification is approximately
  - A modest 4.3dB/GHz slope for 1 < *f* < 6 GHz
  - A steep 14.5 dB/GHz slope for 6 < *f* < 15 GHz
    - Which is very discouraging for using Baud rates much greater than 14 GBaud/sec

10GBASE-KR Insertion loss to Cross-talk Ratio (ICR) specification



- The ICR specification is an SNR bound
- The 10GBASE-KR ICR specification stops at 5.15.. GHz
- Shannon Capacity *C = 52.2 Gbps*

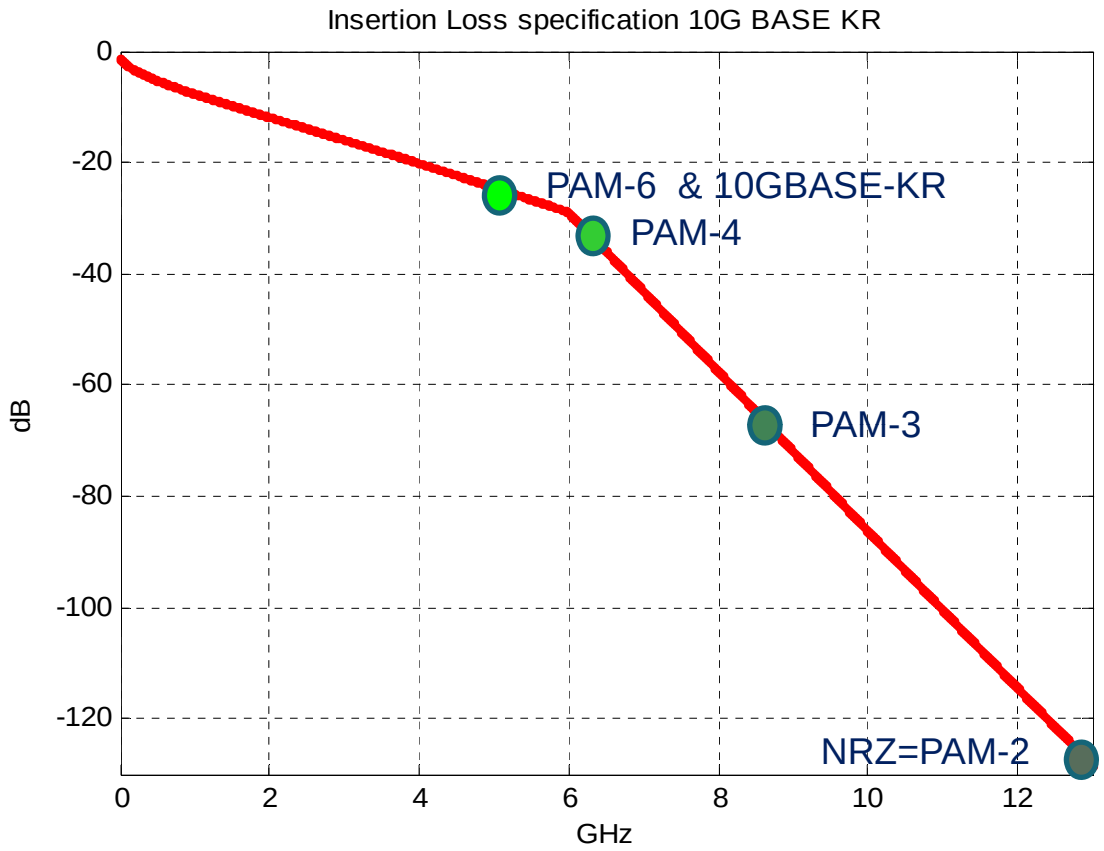
Shannon Capacity of the 10GBASE-KR Channel

- The Shannon Capacity of a narrow spectral segment of width *W* Hz in additive Gaussian noise is
  - *W * log2(1 + Signal/Noise)* in bits/sec
- Ignoring the non-Gaussian nature of Cross-Talk, and integrating over *f*
  - Shannon Capacity of 10GBASE-KR ICR spec. is *C = 52.2 Gbps*
  - More than double our target of 25Gbps per link
- This is encouraging, even though its only a bound
  - The Shannon bound gives no overt directions on how to accomplish such capacity
    - What 'modulation' and/or FEC coding to use
  - Many practical communication systems now operate within 10% of capacity
    - But they typically require FECs and modulation systems more complex than has been considered for KR

Salz DFE Bounds of the 10GBASE-KR channel

- What performance is possible with very simple modulation (line codes) and very simple FEC codes?
  - Consider only PAM-M, for NRZ (M=2) up to PAM-8
    - PAM-M is the simplest possible 'advanced' modulation choice
    - This isn't new, as many prior contributors (not listed here) have proposed PAM-M as the next step for back plane communications
  - Consider only a simple single error event correcting FEC
    - Similar to current Fire code performance
- The Salz SNR upper bounds the SNR possible with a Decision Feedback Equalizer (DFE)
  - DFE is one of the simplest possible 'advanced' receivers possible
    - Patented in the 19th century!
  - No limit on accuracy (length) of Feed Forward Equalizer (FFE) in bound
  - No limit on length of Feed Back Filter (FBF) in bound
  - No SNR penalty for decision errors in bound

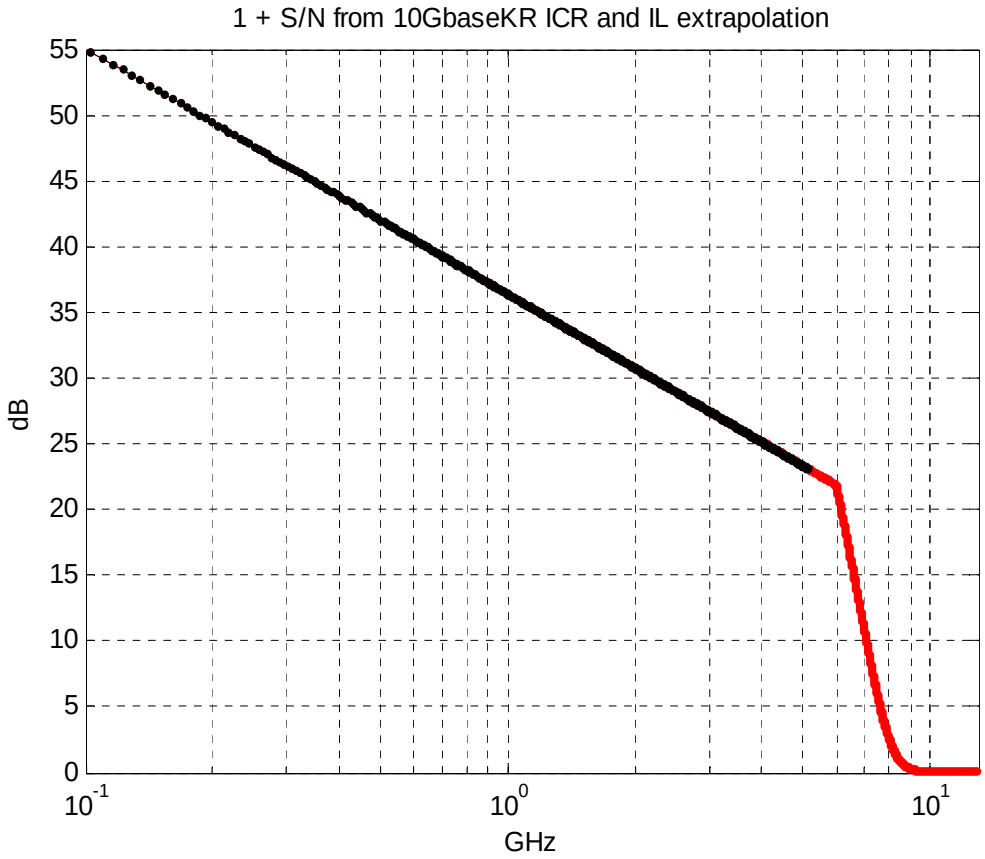
10GBASE-KR Insertion Loss Specification with 25Gbps PAM-M



- Slope of IL changes at 6GHz
- 4.3 dB/GHz below,
- 14.5 dB/GHz above
- An increase in slope of 10.2 dB/GHz
- 25Gbps Nyquist IL;
- NRZ = 126.8 dB
- PAM-3 = 66.3 dB
- PAM-4 = 35.4 dB
- PAM-6 and 10GBASE-KR Nyquist IL = 25.2 dB

- The NRZ Nyquist IL of 126.8 dB is not close to feasible
- The PAM-3 Nyquist IL of 66.3dB is much more difficult than prior channels, and not feasible
- The PAM-4 Nyquist IL of 35.4dB is more difficult than prior channels, but is feasible

{1+ Signal/Noise} from 10GBASE-KR ICR and IL extrapolation



- Black = the 10GBASE-KR ICR specification
- Red = the extrapolation of ICR above 5.15 GHZ
- The ICR equation is extrapolated, and
- The change in IL Slope is applied above 6GHz
- As if the cross talk noise followed the ICR specification, but the signal followed the IL specification

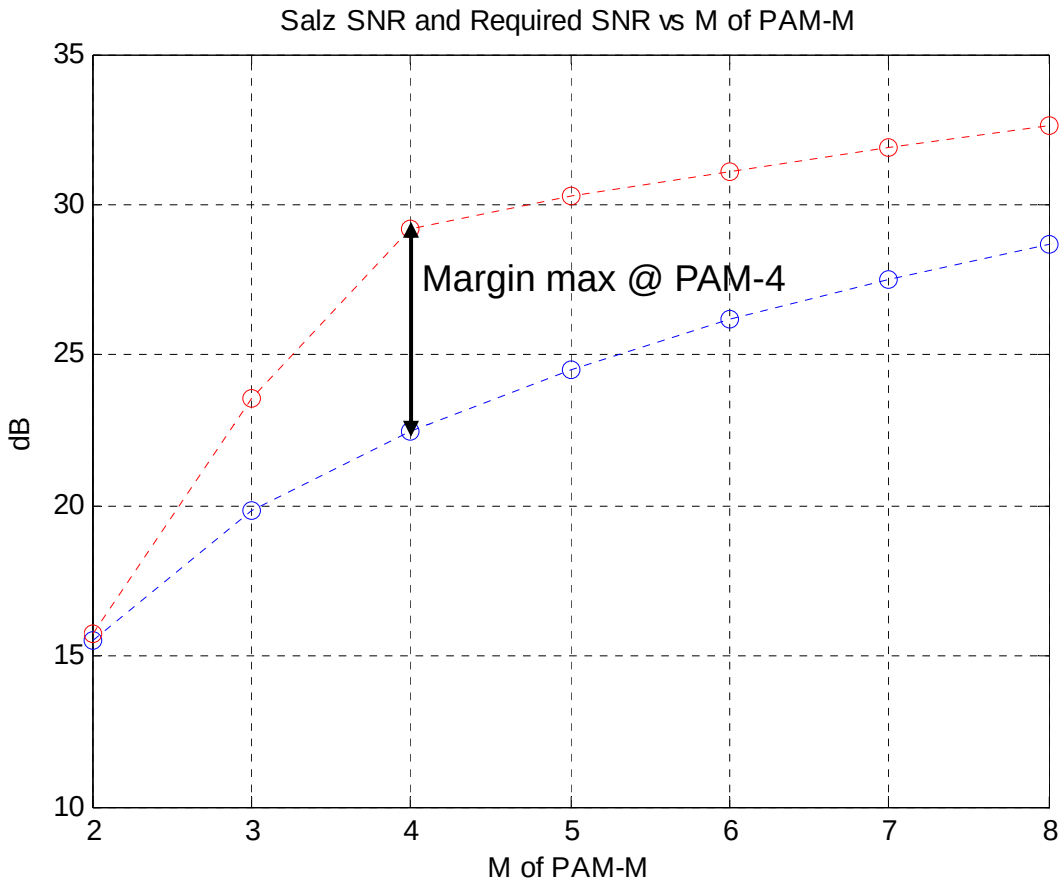
- Salz SNR_dB = mean(10*log10{1 + Signal(f)/Noise(f)})
- Because minimum mean squared error solutions de-weight poor SNR 'bins' to a minimum of 0dB

25Gbps PAM-M with 10GBASE-KR ICR and IL Specification

10Gbps NRZ		25Gbps NRZ	25Gbps PAM-3	25Gbps PAM-4	25Gbps PAM-5	25Gbps PAM-6	25Gbps PAM-7	25Gbps PAM-8
1	bits/Baud modulation	1	3/2	2	9/4	5/2	11/4	3
10.3125	Baud Freq GHz	25.7813	17.1875	12.8906	11.4583	10.3125	9.3750	8.5938
31.1	Salz bound dB	15.8	23.6	29.2	30.3	31.1	31.9	32.6
15.5	Req. SNR for 1e-15 w/ single event FEC	15.5	19.8	22.5	24.5	26.2	27.5	28.7
15.6	Margin=Salz – Req'd dB	0.3	3.8	6.7	5.8	5.9	4.5	3.9

- Margin is maximized with PAM-4
  - It is feasible to build a practical communication systems with this margin
  - But a different experience than with10G BASE KR, which has high margin
- Note that NRZ and PAM-3 bounds at 25Gbps are not practically feasible
  - The huge loss of signal above 7GHz is impractical with real DFE systems

Salz SNR and Required SNR vs. Modulation Index M (PAM-M)



- Red = Salz SNR using 10GBASE-KR ICR and IL specification
- Blue = Required SNR for 1e-15 error rate with single error event correcting FEC
- The margin is maximized with PAM-4
- The PAM-3 and NRZ Salz bounds are not feasible due to the severe Insertion Loss above 7 GHz

Next Steps for 25Gbps over 10GBASE-KR channels

- Increase library of measured channels that were designed for 10GBASE-KR
  - Presumably all were designed for and meet the 10GBASE-KR normative characteristics
  - Compare the real IL and real ICR to the specification and extrapolation
  - Calculate real RX performance on the real ICR and real IL for various PAM-M choices
  - Consider practical implementation issues for higher PAM-M
  - Choose the most practical PAM-M
- Consider more powerful FEC (independent of channel model)
  - Code in at least the 25 Gbps streams, but best in the100 Gbps stream
    - Too much extra latency from coding in the virtual 5 Gbps streams
  - Consider maximum latency acceptable
  - Consider increased PHY Baud rate to allow increased code redundancy
    - Transparency to higher Ethernet layers is possible