Channel Selection Tradeoffs for Automotive 2.5G/5.0G/10Gbps

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Overview

This presentation studies the minimum cable bandwidth requirements for 2.5G/5.0G/10Gbps Automotive Ethernet PHY

- First part discusses the tradeoffs of channel excess BW and PHY complexity

- Second part discusses what is the maximum cable BW that is required for 10Gbps PHY

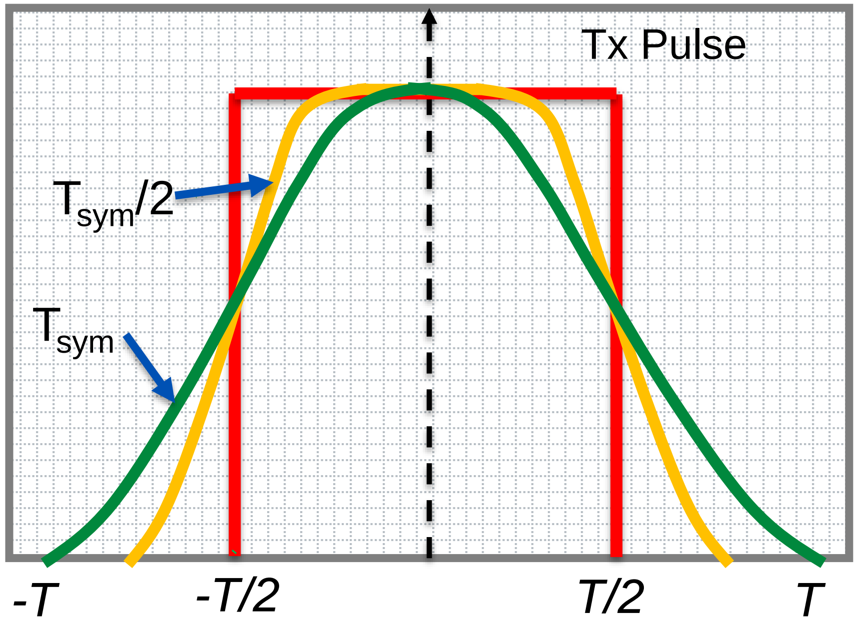
Channel BW Requirement and PHY Complexity

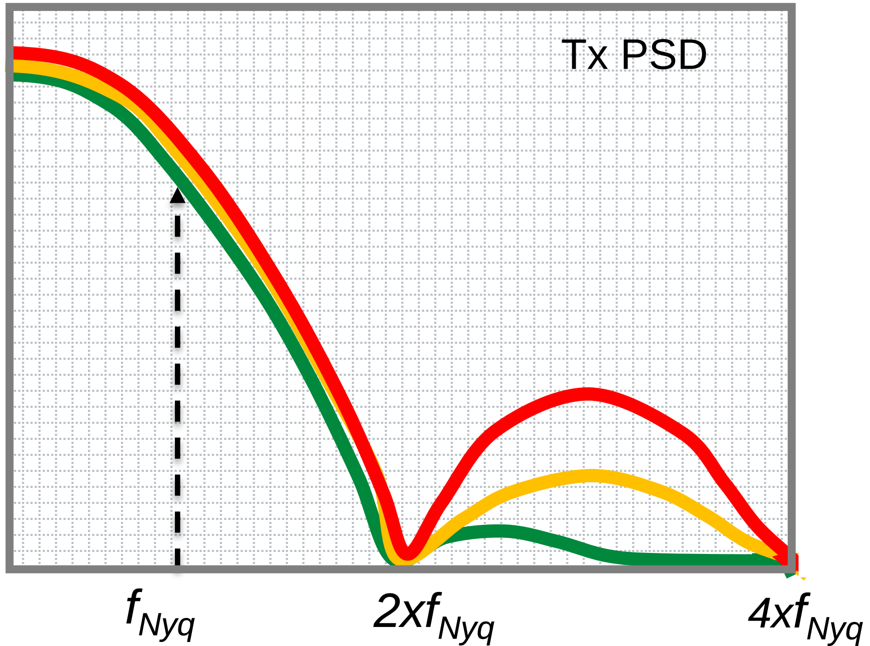
- The absolute minimum required channel BW for a PHY to successfully transmit a baseband signal is half signal baud rate or Nyquist frequency (f_{Nyq})
- Although power spectrum of a baseband signal always stretches beyond its f_{Nyq}
  - Therefore, for successful transmission, the signal power in Nyquist excess BW must be properly characterized or adequately suppressed
  - if channels are specified only up to f_{Nyq}, PHY needs additional complexity to adequately suppress any signal power above f_{Nyq}.
  - Extending channel limit lines to cover excess BW above f_{Nyq} of a signaling scheme allows PHYs to reduce complexity

➔ The tradeoffs between PHY complexity and cabling BW must be carefully considered in specifying channel requirements

Signal Beyond Defined Channel BW

- Links with smooth/well-behaved channel response up to $1.25xf_{Nyq}$ can simplify PHYs receiver signal processing complexity
  - Idea Tx pulse with zero rise/fall time ➔ Signal Power (f >$1.25xf_{Nyq}$) = ~11%
  - Typical Tx pulse with $T_{sym}/2$ rise/fall time ➔ Signal Power (f >$1.25xf_{Nyq}$) = ~7%
- Signal power > f_{Nyq} can be further reduced by PHY Tx pulse shaping
  - Tx pulse shaped with T_{sym} rise/fall time ➔ Signal Power (f >$1.25xf_{Nyq}$) < 3%





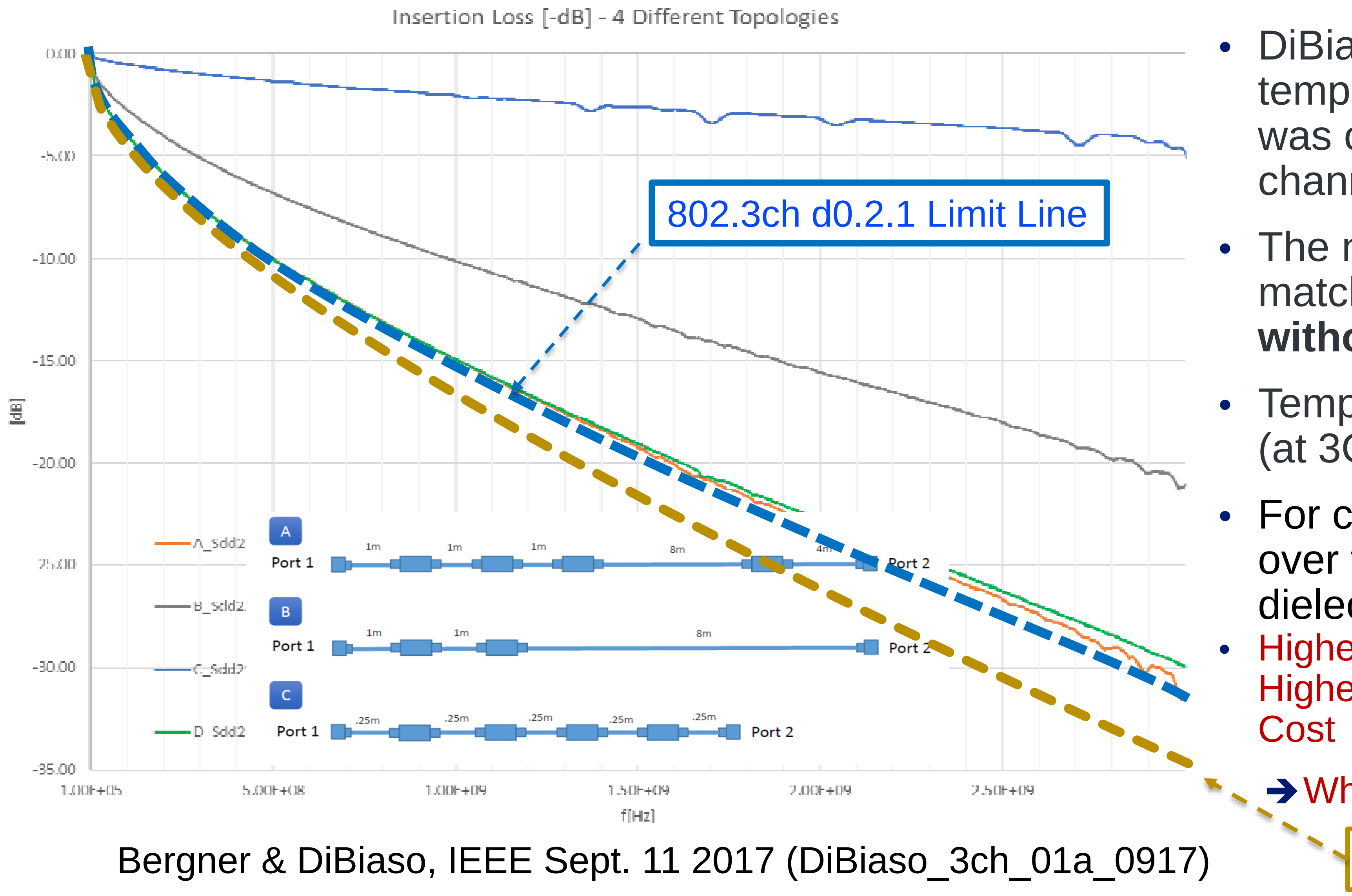
How Much Excess BW is Enough?

- Signal power > f_{Nyq} can also be reduced by adding PHY receiver filtering
  - Tx pulse shaped with T_{sym} rise/fall time ➔ Signal Power (f >1.25xf_{Nyq}) < 3%
  - Tx pulse shaped with T_{sym} rise/fall time ➔ Signal Power (f >1.10xf_{Nyq}) = ~7%

- An additional 1st-order LP filter relaxes excess BW requirement from 25% → 10%
  - Tx pulse with T_{sym} rise/fall & LP filter ➔ Signal Power (f >1.10xf_{Nyq}) < 3%

➔ With moderate complexity, pulse shaping/filtering, PHYs can be designed to reliably operate over channels defined only up to 10% excess BW

Channel Insertion Loss Target



Bergner & DiBiaso, IEEE Sept. 11 2017 (DiBiaso_3ch_01a_0917)

- DiBiaso-Bergner Channel A plus 105C temperature effect (~20% higher IL) was originally considered as the worst channel in our analysis
- The new channel model closely matches DiBiaso Channel A, **but without temperature effect**
- Temperature effect adds about 4-5dB (at 3GHz) to cable loss
- For cables to meet new IL limit line over temperature, their gauge & dielectric quality must improve
- Higher BW Cables/Connectors Lead to Higher Cost of Cabling, thus Total Solution Cost

➔ What's relative cost between the two?

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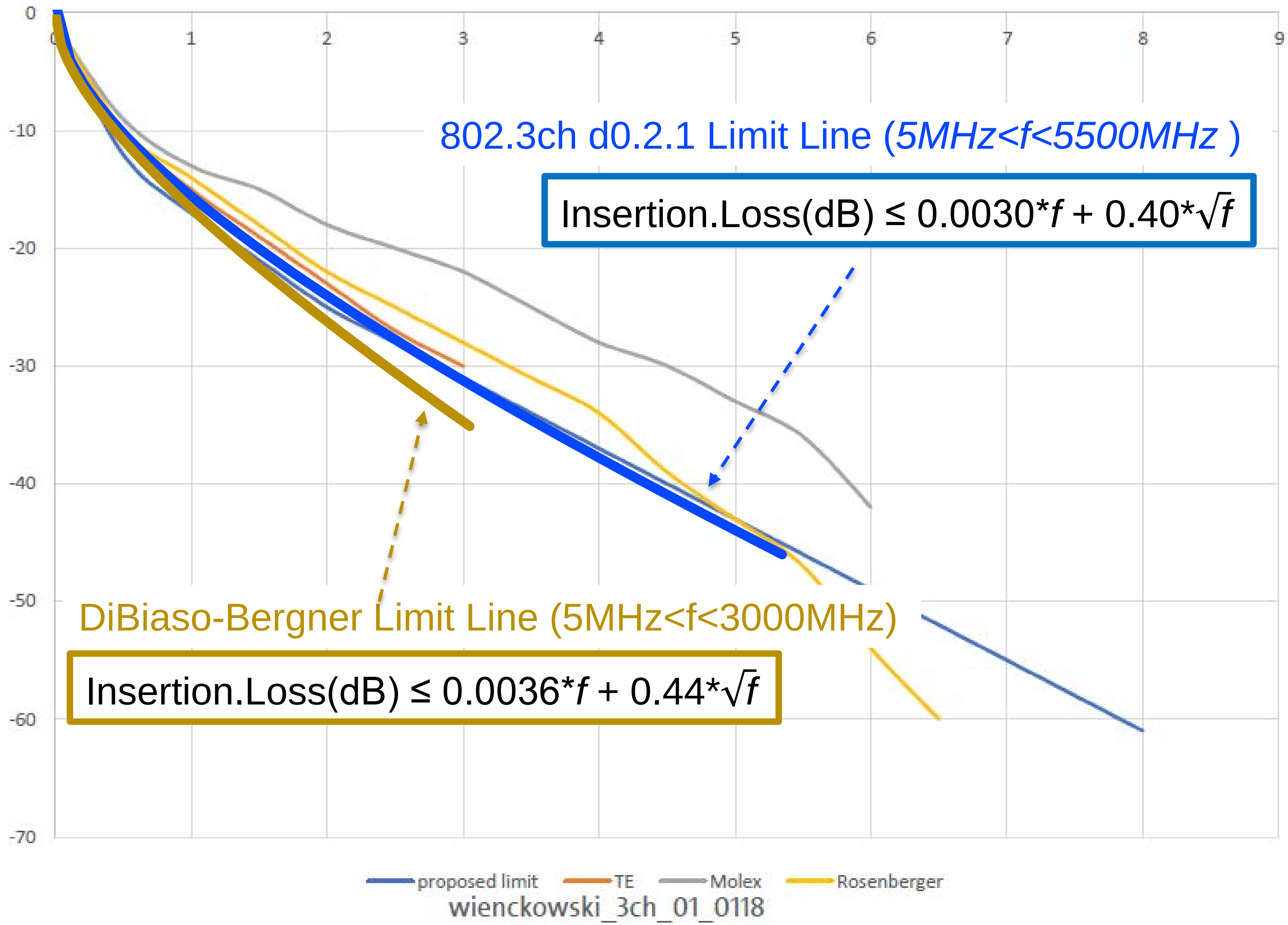
Insertion Loss Limit Line Update



- Difference Summary
  - IL relaxed by 4dB@3GHz
  - Top Freq. extended to 5.5GHz
- The IL limit line is also defined for data rates of 2.5Gbps-10Gbps, while such IL limit is a total overkill for 2.5Gbps, and even 5Gbps
  - Creates a totally unnecessary requirement for 2.5G/5G cables that only adds to the cabling costs
- Cost difference between 3GHz and 5.5GHZ cables is not clear yet (no data presented)
  - At minimum all certification/qualification devices/equipment must be upgraded from existing 3GHz to 8GHz

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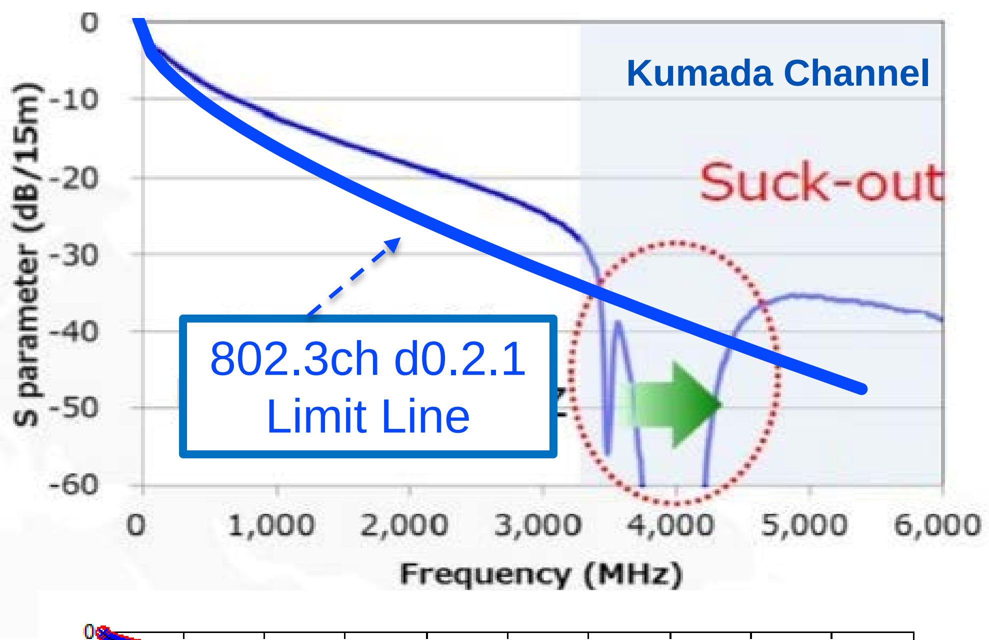
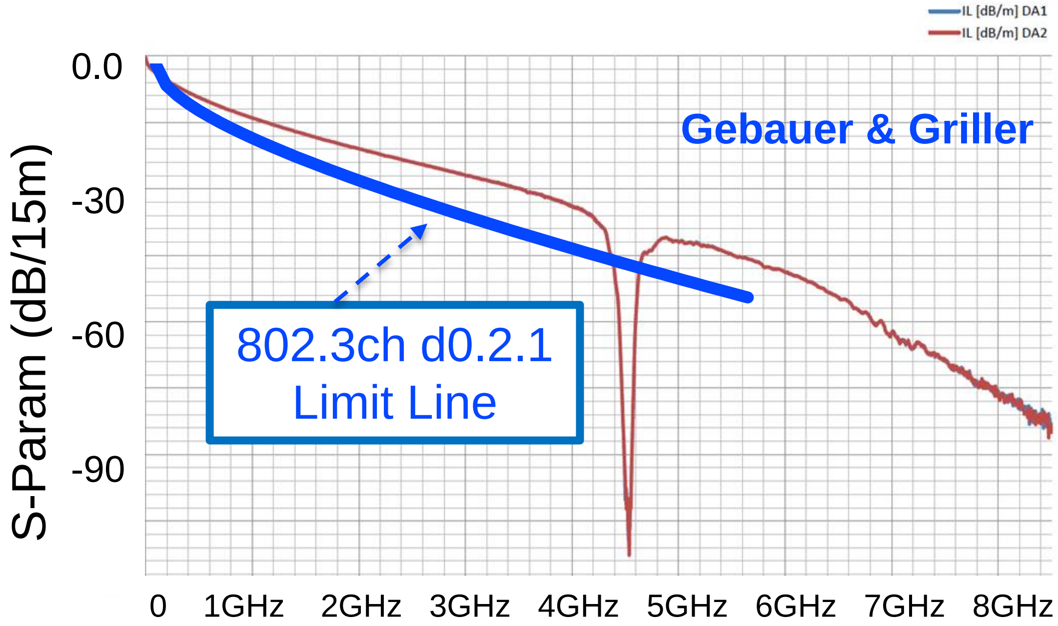
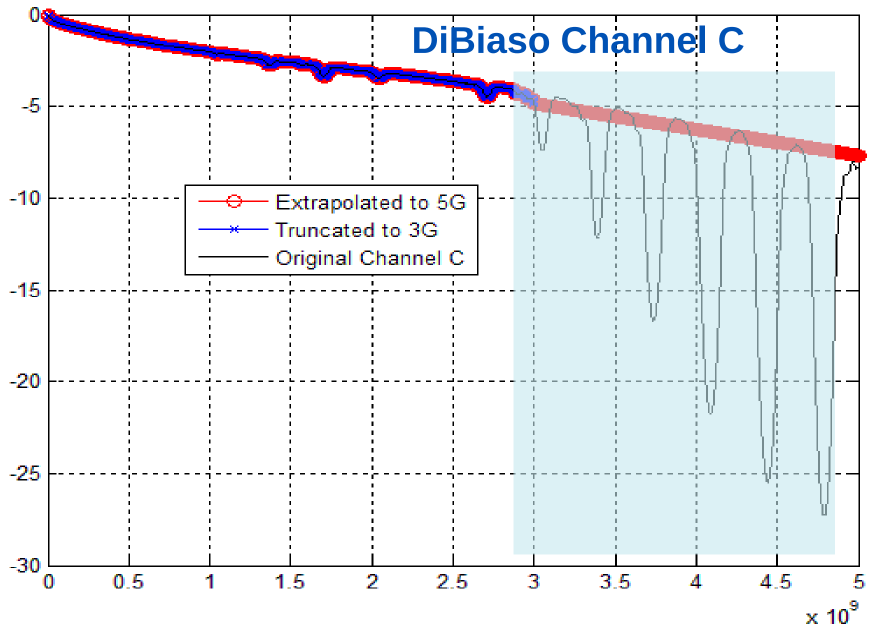
Mature Automotive Cabling in Volume Production







- Existing automotive cable assemblies in production and installed in large volume show solid performance up to BWs 3GHz-3.2GHz
- These cables are more mature with lower cost compared to newer cables with 5.5GHz bandwidth requirement
- If PHY can transmit net data rate of 10Gbps over these cables under 3GHz, we can define one IL/RL limit line for 2.5G-10Gbps that most existing 3GHz cable assemblies can meet

Salz SNR Analysis over DiBiaso Channel A@105C: 2.5G/5G/10Gbps

2.5Gbps	PAM2	PAM4	PAM8
Baud rate (10% FEC Overhead) [GBaud]	2.75	1.38	0.92
Nyquist BW (FEC Overhead) [GHz]	1.38	0.69	0.46
10% Excess BW [GHz]	1.52	0.76	0.51
IL @Nyquist [dB]	20.97	13.61	10.77
Ideal Salz SNR margin [dB]	28.16	24.25	19.06

10Gbps	PAM2	PAM3	PAM4	DSQ32	PAM8
Baud rate (10% FEC Overhead) [GBaud]	11.0	1.74	5.50	4.40	3.67
Nyquist BW (FEC Overhead) [GHz]	5.50	3.67	2.75	2.2	1.83
10% Excess BW [GHz]	6.04	4.04	3.02	2.42	2.01
IL @Nyquist [dB]	63.8	47.84	32.73	27.82	24.89
Ideal Salz SNR margin [dB]	9.3	11.45	10.78	9.42	8.52

5.0Gbps	PAM2	PAM4	PAM8
Baud rate (10% FEC Overhead) [GBaud]	5.50	2.75	1.83
Nyquist BW (FEC Overhead) [GHz]	2.75	1.38	0.92
10% Excess BW [GHz]	3.02	1.52	1.01
IL @Nyquist [dB]	32.73	20.97	16.12
Ideal Salz SNR margin [dB]	19.83	18.94	15.02

- Ideal Salz SNR margin → Received SNR assuming ideal PHY or no Alien/RF Interference
- AWGN: -150dBm/Hz, Tx Amplitude: 1.0V+/-10%

- Assuming PHY additional filter to suppress signal power beyond 10% Excess BW:
  → 2.5Gbps & 5.0Gbps don't need cables with BW>3GHz
  → 10Gbps in PAM4 and possibly other higher-level PAMs (with f_{Nyq}+10% within 3GHz) operate with reasonable SNR margin to overcome unaccounted noise sources

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Salz SNR Analysis over 802.3 d0.2.1 Limit Line: 2.5G/5G/10Gbps

2.5Gbps	PAM2	PAM4	PAM8
Baud rate (10% FEC Overhead) [GBaud]	2.75	1.38	0.92
Nyquist BW (FEC Overhead) [GHz]	1.38	0.69	0.46
10% Excess BW [GHz]	1.52	0.76	0.51
IL @Nyquist [dB]	19.00	12.58	9.96
Ideal Salz SNR margin [dB]	31.49	26.62	20.46

10Gbps	PAM2	PAM3	PAM4	DSQ32	PAM8
Baud rate (10% FEC Overhead) [GBaud]	11.0	1.74	5.50	4.40	3.67
Nyquist BW (FEC Overhead) [GHz]	5.50	3.67	2.75	2.2	1.83
10% Excess BW [GHz]	6.04	4.04	3.02	2.42	2.01
IL @Nyquist [dB]	46.16	35.24	29.23	25.36	22.64
Ideal Salz SNR margin [dB]	14.42	14.68	12.62	10.95	9.97

5.0Gbps	PAM2	PAM4	PAM8
Baud rate (10% FEC Overhead) [GBaud]	5.50	2.75	1.83
Nyquist BW (FEC Overhead) [GHz]	2.75	1.38	0.92
10% Excess BW [GHz]	3.02	1.52	1.01
IL @Nyquist [dB]	29.23	19.00	14.89
Ideal Salz SNR margin [dB]	21.80	20.23	16.22

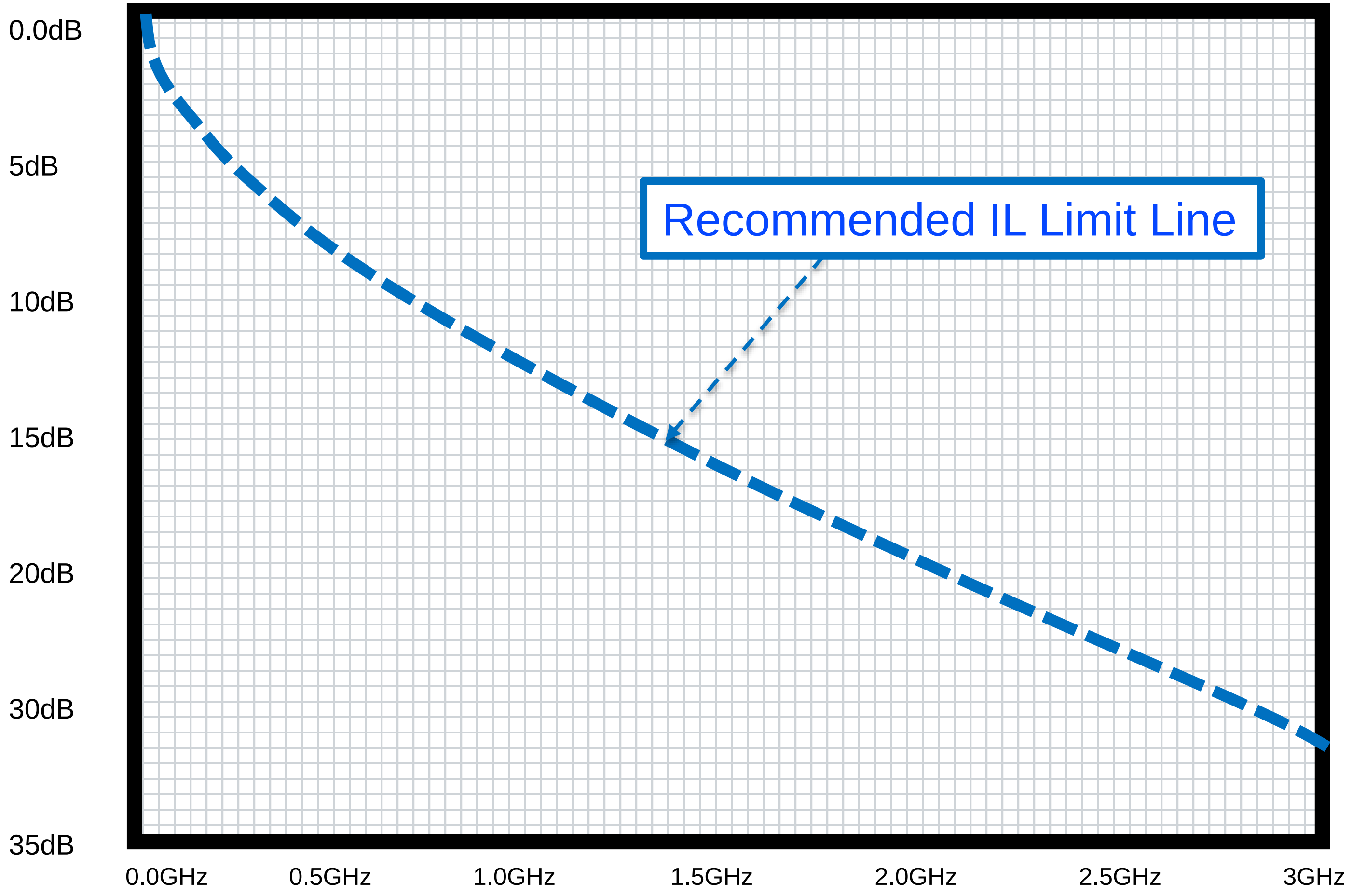
- Similar analysis with 802.3 d0.2.1 IL limit line for PAM4 and higher modulations (with f_{Nyq}+10% within 3GHz) show even higher SNR margin for 10Gbps
- PAM3/PAM2 schemes with f_{Nyq} >3GHz excluding existing cabling minimally improves an already strong SNR margin
- Alternative is to use relaxed 802.3 d0.2.1 IL limit line up to 3GHz, which simply means using lower loss (lower gauge) cables but stay with existing cable/connector technology

Conclusion

- f_{Nyq} is absolute minimum frequency range to define channel specs
  - Defining channel specs over 25% excess BW is preferred but not necessary, since PHYs can utilize additional filters to operate over channels specified only up to f_{Nyq}.
  - Defining channel specs over 10% excess BW reduces the PHY complexity for required filtering
- The latest proposed channel limits uses max frequency of 5.5GHz, disqualifying most (if not all) existing 3GHz automotive cables
  - 3GHz cables provide more than enough BW for 2.5Gbps/5.0Gbps and have enough BW for 10Gbps robust transmission at PAM4 and higher modulations
  - There are no technical reasons presented yet that dictate higher than 3GHz BW requirement, which lead to higher costs of cabling, and thus higher cost of final system.

- Recommendation: Define the cable BW to up to 3GHz. This BW is enough for all PHY speeds from 2.5Gbps to 10Gbps, and minimizes the total system cost.

Recommended Insertion Loss Limit Line

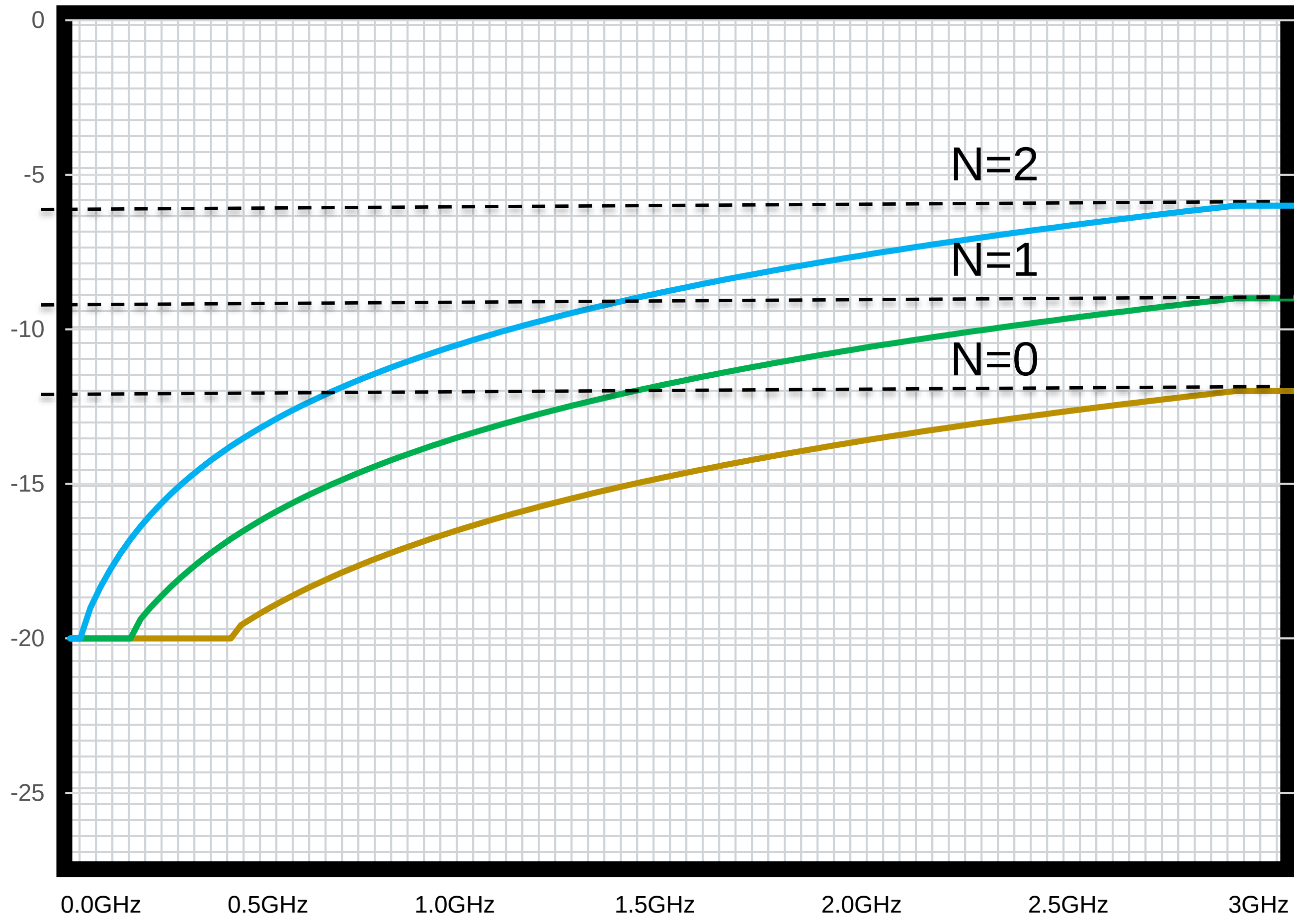


- Keep the same limit line equations as agreed upon per Geneva meeting, but change the maximum bandwidth to 3GHz

$$\text{Insertion.Loss(dB)} \leq 0.0030*f + 0.40*\sqrt{f}$$

5MHz<f<3000MHz
(Frequency in MHz)

Recommended Return Loss Limit Line



Return.Loss(dB) > (*f in MHz*)

$$\begin{cases} 20\text{dB} & 5 \le f < 500/2^N \\ 12-3N - 10\log(f/3000) & 500/2^N \le f < 3000 \end{cases}$$

- IL_{3GHz} > 20dB → N=0
- 10dB< IL_{3GHz} < 20dB → N=1
- IL_{3GHz} < 10dB → N=2

L_{3GHz} → Channel IL at 3GHz

Thank you.

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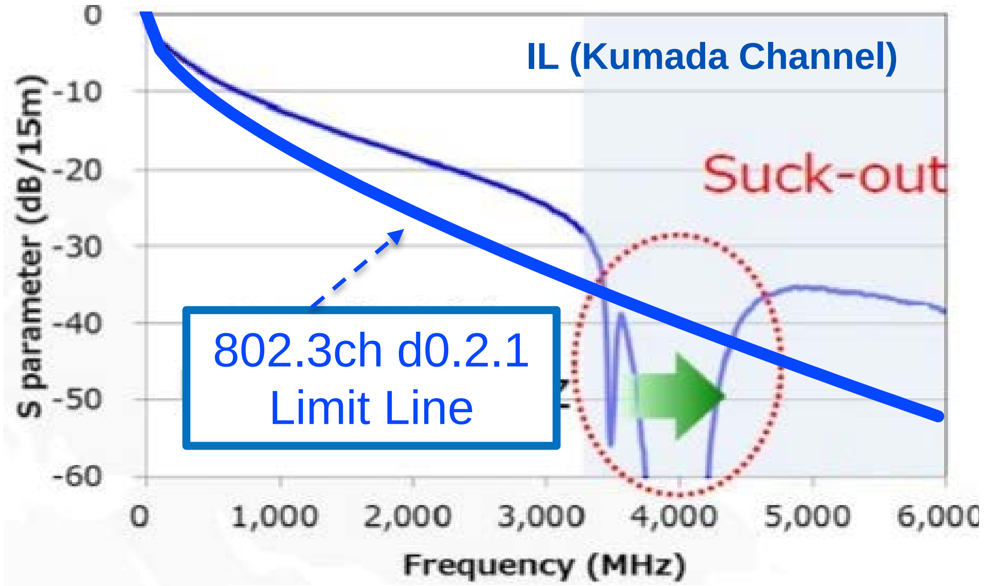
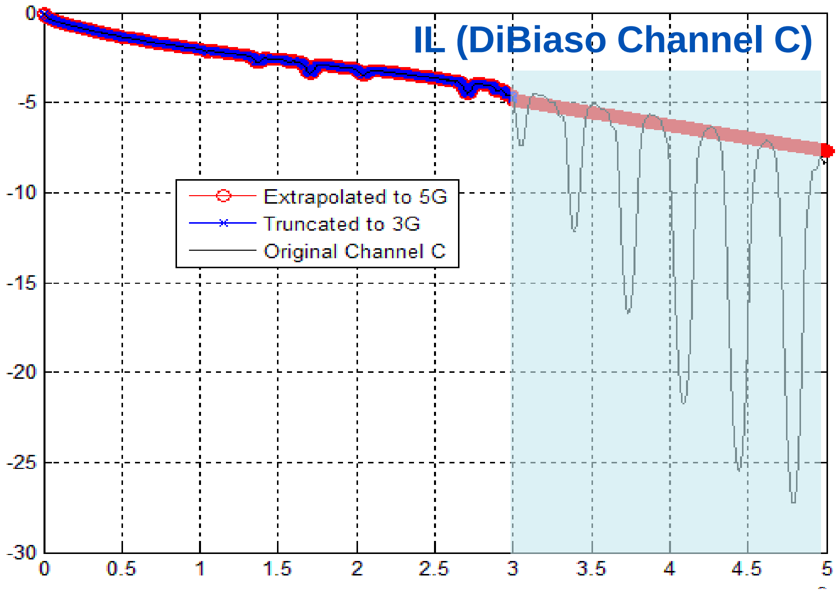
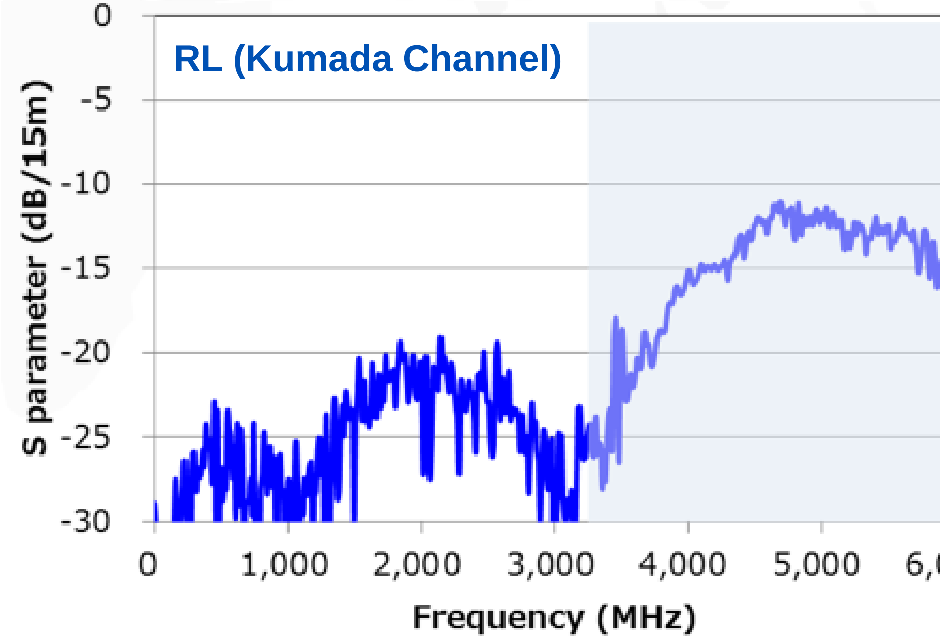
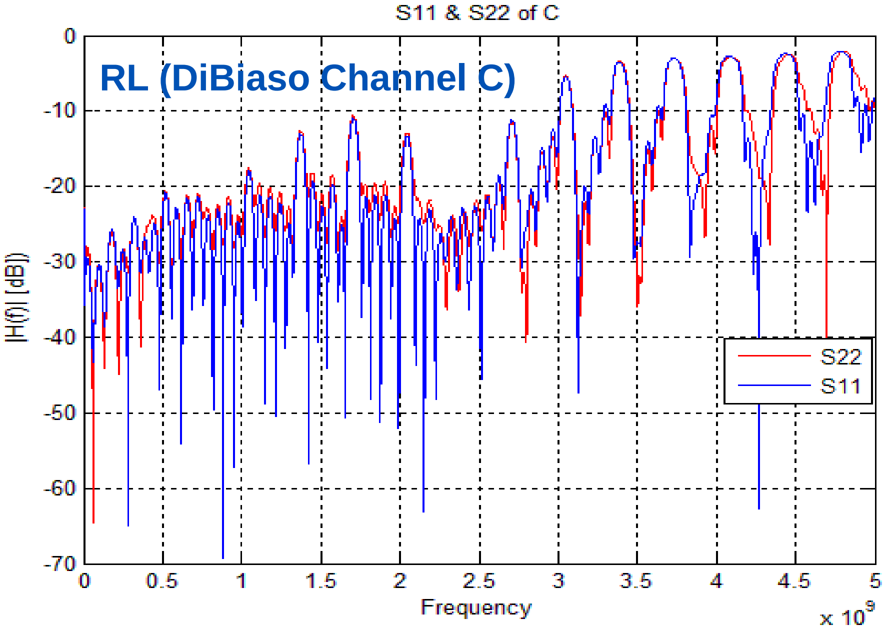
Examples of Mature Automotive Cabling in Production









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