A Feasibility Study of One Twisted Pair Gigabit Ethernet

May 2012

IEEE Reduced Twisted Pair Gigabit Ethernet

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The Purpose

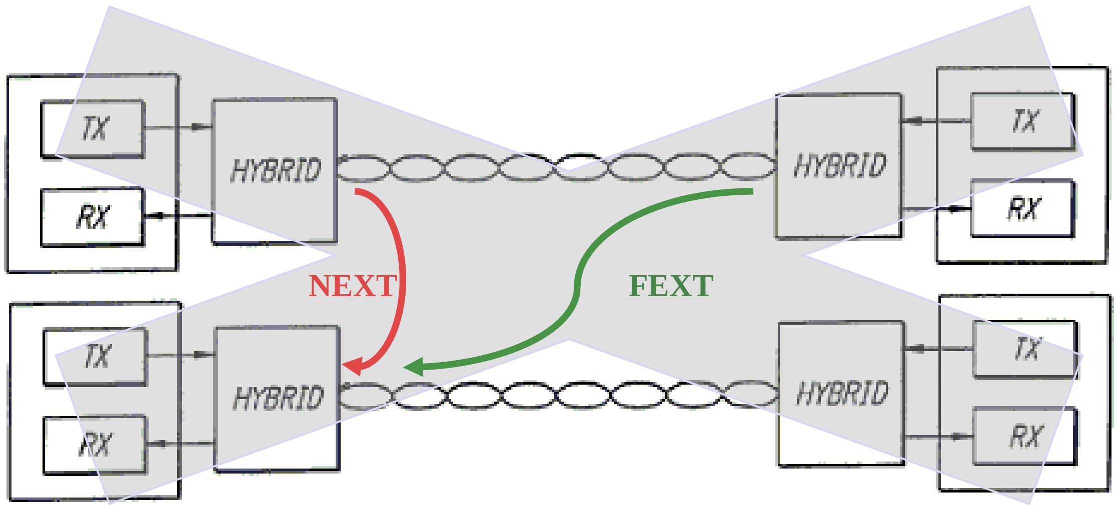
- This presentation attempts to demonstrate a methodology for the technical feasibility of one pair RTPGE using the existing 1000BASE-T MAC, PCS, and 10GBASE-T channels.
- It is an exemplary case using various SNR for performance evaluation and does not try to prove or debate if it is the best solution. It also does not compare with other potential solutions.
- It highlights additional functions required like auto-negotiation and EEE which will be addressed separately.

Outline

- The Advantages of One Twisted Pair Gigabit Ethernet Solution
- Cable Model
- Performance Analysis
  - Frequency domain Model
  - Time domain Model
  - Simulation Result
- PCS, Channel Coding, and EEE
- Auto-negotiation
- Summary

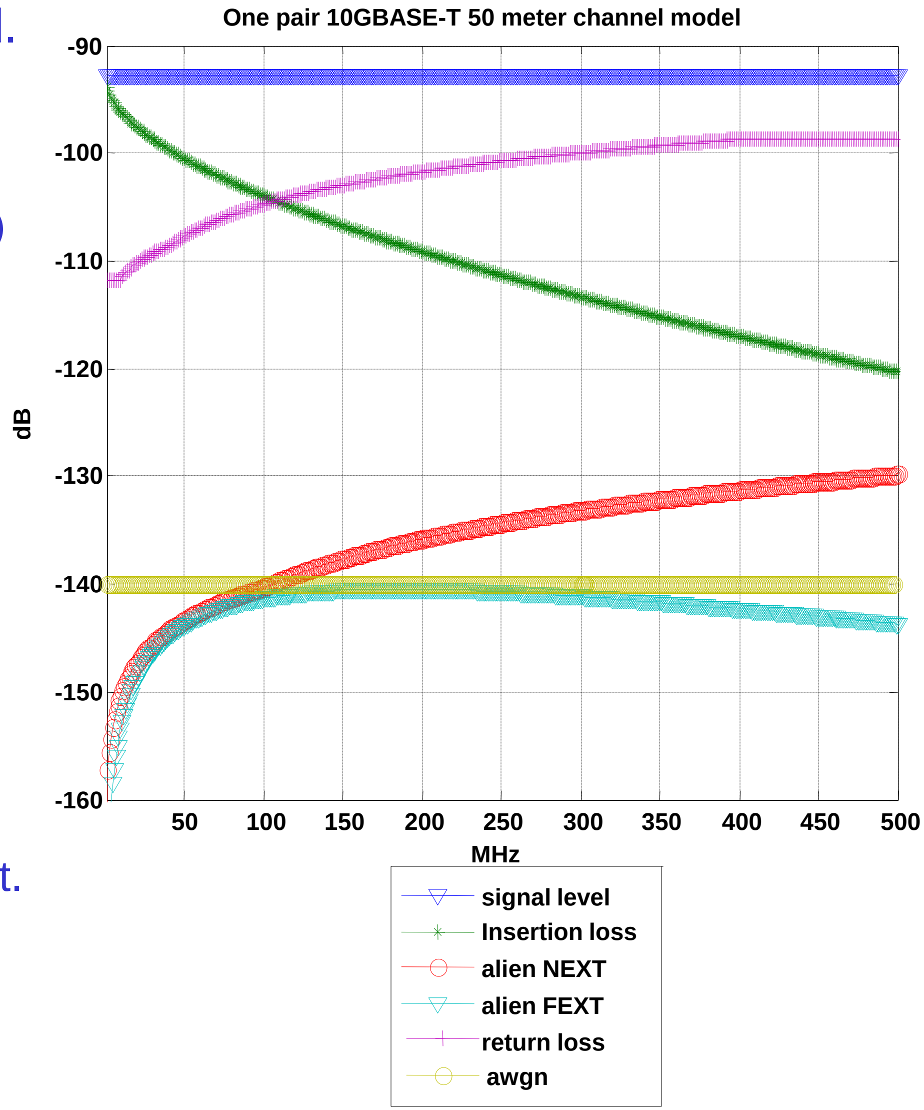
The Advantages of One Twisted Pair Gigabit Ethernet Solution

- Cost: Two pair cable costs double.
- Weight: Better fuel economy.
- Simplicity: No need of additional FEXT and NEXT cancellations.
  - FEXT and NEXT are dominant interference in two pair cable
  - Shorter cable has higher FEXT (automotive environment)



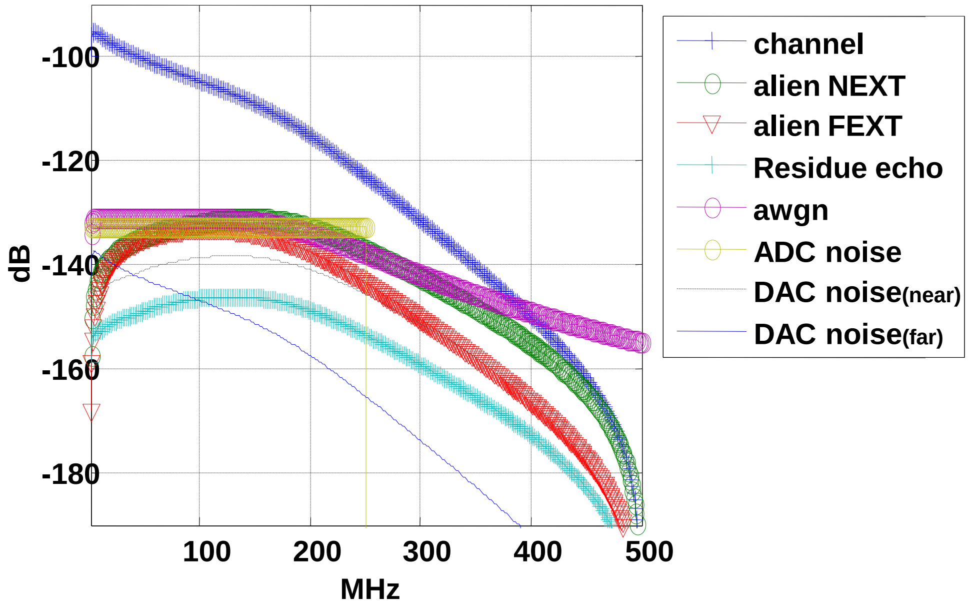
Cable model

- ❑ Automotive channel model is needed.
  - ➢ Cable & connector model
  - ➢ Alien noise model from other devices (LIN/CAN/MOST/FLEXRAY/LVDS…)
- ❑ Assumes 802.3an Ethernet cable model for current analysis.
- ❑ Simulation parameters
  - ➢ One twisted pair cable without NEXT and FEXT noise.
  - ➢ 50 meter long.
  - ➢ –140dBm/Hz AWGN.
  - ➢ The insertion loss, return lose, alien FEXT, and alien NEXT are the same as10GBASE-T(802.3an) environment.
  - ➢ Transmit amplitude is 0.4Volt peak-to-peak for reducing EMI effect.



Performance Analysis - Frequency domain Model

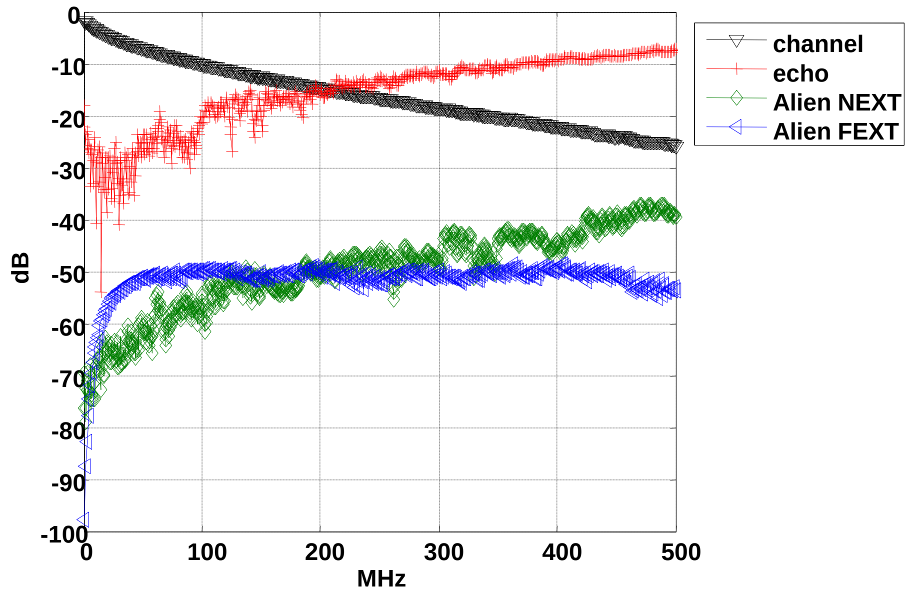
- With the following assumed AFE Spec and a perfect echo cancellation, the RX side Spectral can be shown in the right figure.
  - Sampling rate 500MHz
  - DAC 7bit ENOB
  - ADC 8bit EnoB
  - PGA gain 9.0dB
  - TX 1st order filter cut off 480MHz
  - RX 3rd order filter cut off 200MHz
  - DAC 0.4Vpp
  - ADC 1Vpp

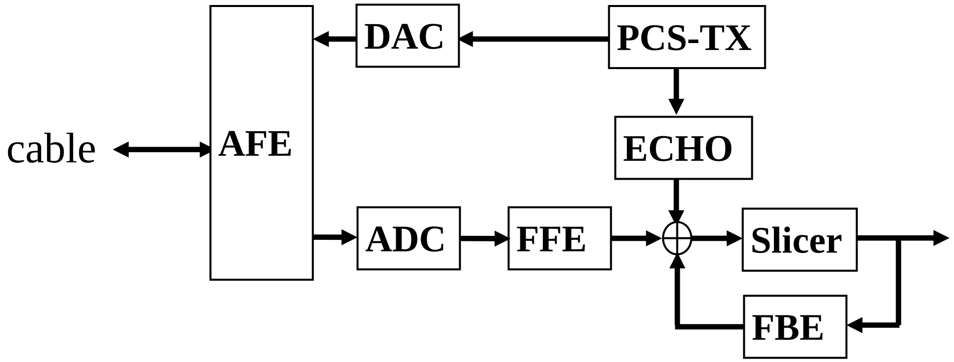


- We calculate the channel Capacity & Shannon limit SNR. According to the best ADC sampling phase (b.c.) and the worst ADC sampling phase (w.c.), we calculate
  - Salz SNR with ideal FFE and ideal FBE
  - Decision point SNR with ideal FFE and finite length FBE
  - Finite Length DFE SNR with finite length FFE and finite length FBE

Performance Analysis - Time domain Model

- Time domain floating point simulation with measured and scaled cable model (right figure).
- FFE/FBE equalization, and echo cancellation with LMS training. (below figure)





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Performance Analysis – Simulation Result

- Channel Capacity is less than 1Gbps with 6dB implementation loss when baud rate is less than 200MHz.
- Three baud rates (250,333,500 MHz) without channel coding were simulated.
- The 500MHz baud rate demonstrates a good result.
  - More SNR margin for Alien noise & channel coding.
  - Simple AFE Spec.
  - Simple modulation scheme.

Buad rate	250MHz	333.3MHz	500MHz	
Uncoded Modulation	PAM-16	PAM-8	PAM-4	Shannon Bound
Channel Capacity	1.48Gbps	1.82Gbps	2.43Gbps	Shannon Bound
Shannon limit SNR	24.1dB	18.0dB	11.8dB	Shannon Bound
Uncoded SNR at SER = 1E-12	36.1dB	30.1dB	23.9dB	
Salz SNR	36.9dB	34.3dB	30.3dB	Frequency Analysis
Decision point SNR(b.c.)	36.9dB	34.3dB	30.3dB	Frequency Analysis
Decision point SNR(w.c.)	34.5dB	32.2dB	28.3dB	Frequency Analysis
Finite length DFE SNR(b.c.)	35.4dB	33.6dB	29.6dB	Frequency Analysis
Finite length DFE SNR(w.c.)	32.9dB	31.3dB	27.5dB	Frequency Analysis
SNR margin **(w/o channel coding)**	**-0.7dB**	**3.5dB**	**5.7dB**	Frequency Analysis
Coded Modulation	PAM-20	PAM-10	PAM-5	Time Analysis
Time domain simulation SNR	33.9dB	33.3dB	28.8dB	Time Analysis
FFE taps	48 taps	48 taps	48 taps	System Parameter
FBE taps	32 taps	32 taps	32 taps	System Parameter
DAC linearity	9 bits	8 bits	7 bits	System Parameter
ADC linearity	10 bits	9 bits	8 bits	System Parameter
TX filter 1st order cut off freq	240MHz	300MHz	480MHz	System Parameter
RX filter 3rd order cut off freq	100MHz	125MHz	200MHz	System Parameter
PGA gain	7.9dB	8.5dB	9.0dB	System Parameter

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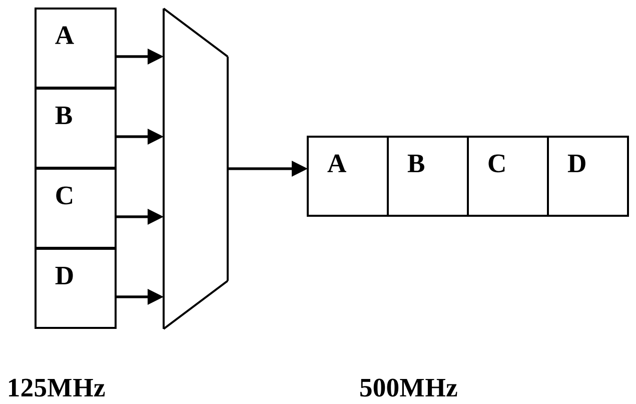
PCS, Channel Coding, and EEE

- Since the modulation scheme of 500MHz baud rate is PAM-5 which is the same as the Gigabit Ethernet (802.3ab), we can reuse the Physical coding sub-layer(PCS), Channel Coding, and Energy-Efficient Ethernet (EEE) with minimal modification.
  - 802.3ab PCS uses 4D-PAM5 symbols (125MHz baud rate). A 4-to-1 MUX can convert it to 500MHz 1-D symbol.
  - The PCS is mainly unchanged, and the channel coding can be reused smoothly.
  - EEE capability can be applied.
    - Wake up time becomes shorter due to the shorter cable and the faster symbol rate.



Auto-negotiation

- Traditional Ethernet use link pulse sequences to exchange PHY capability before the link is up.
- There is no need to be backward compatible with the traditional Auto-negotiation mechanism in the automotive environment .
- Only master/slave information is needed to be exchanged between link partners before the link is up.
- Additional PHY capability may be exchanged further.

Summary

- The study shows the One Twisted Pair Gigabit Ethernet solution with baud rate 500MHz is technically feasible.
- The PCS and Channel Coding of the Gigabit Ethernet (802.3ab) and the EEE (802.3az) capability can be adopted with only minor modifications .
- One pair auto-negotiation mechanism is needed.
- The model of connector, cable, and alien noise in automotive environment are needed for more accurate analysis.

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

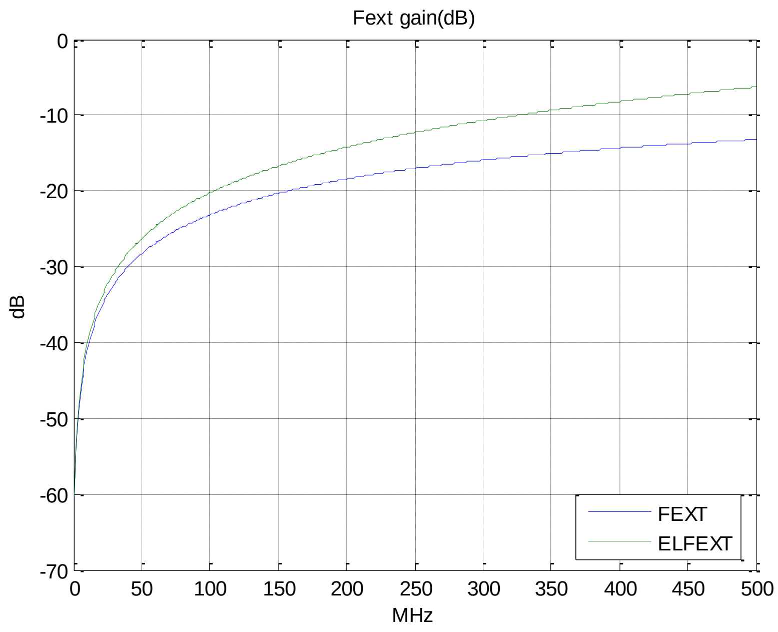
Thank you

Questions?

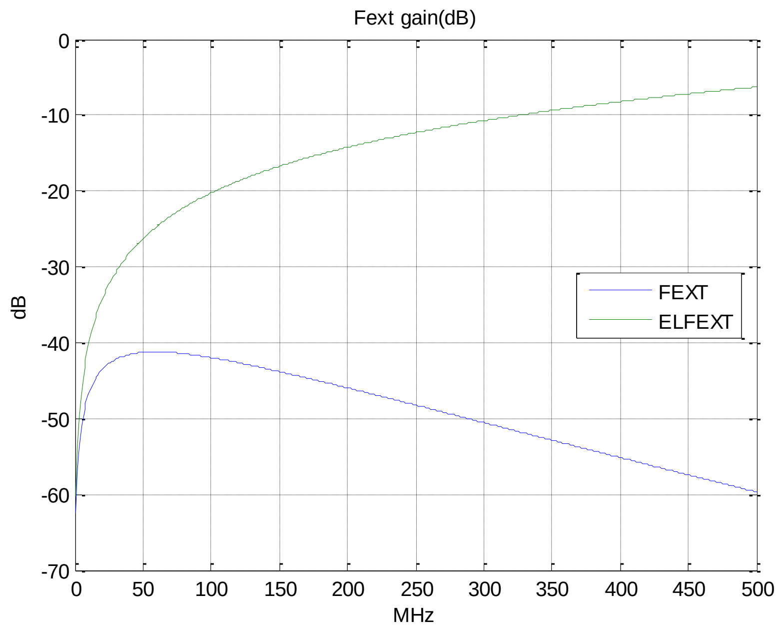
Backup

FEXT

- 10 meter



- 100 meter



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IEEE802.3an channel model

- ALL parameters are in Clause 55 of 802.3-2011
  - Insertion loss
    - Clause 55.7.2.1
    - Equations 55-11 & 55-27
  - Return loss
    - Clause 55.7.2.3
    - Equation 55-12
  - Alien NEXT
    - Clause 55.7.3.1
    - Equations 55-25 & 55-26
  - Alien FEXT
    - Clause 55.7.3.2
    - Equations 55-34 & 55-35

SNR References

- Salz SNR
  - J. Salz, “Optimum mean-square decision feedback equalization,” Bell Sysr. Tech. J.. vol. 52, no. 8, p. 1341, Oct. 1973.
- Decision point SNR
  - J. M. Cioffi, G. P. Dudevoir, M. V. Eyuboglu, and G. D. Fomey, Jr.,“MMSE decision-feedhack equalizers and coding-Part I: Equalization results,” IEEE Trans. Commun., vol. 43, no. 10, p. 2582-2594, Oct. 1995.
- Finite Length DFE SNR
  - N. AI-Dbahir and J. M. Cioffi, “MMSE decision-feedback equalizers and coding-Finite-length results,” IEEE Trans. Inform. Theory, vol. 41, no. 4, p. 961-975, May 1993.