PHY Feasibility Study for One or Two pair RTPGE

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IEEE Reduced Twisted Pair Gigabit Ethernet

Benson Huang, Joseph Chou

Realtek Semiconductor Corp.

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Supporters

- Richard Mei, Commscope
- George Zimmerman, CME Consulting/Commscope

The Purpose

- This presentation attempts to evaluate the technical feasibility for RTPGE using the measured cable model.
- The cable model is obtained from Commscope in the contribution of mei_01_0712.pdf. It includes one-pair and two-pair cables with 3 or 5 connectors in different cable lengths. The model is extracted with 4-port S-Parameters.
- Use the Salz SNR (refer to huang_01_0512.pdf) for performance evaluation
- This is a case study and does not provide any baseline proposal of the standard nor the limit line of the worst case channel.

Outline

- Performance Analysis method & Cable Model
- FEXT and NEXT in Two Twisted Pair Cable
- Effect of Baud Rate
- Performance Comparison
- Complexity Discussion
- Conclusion

Performance Analysis Method & Cable Model

- Use Salz SNR for analysis as explained in Huang_01_0512.pdf
- Simulation parameters
  - Transmission power = 3dBm
  - –140dBm/Hz AWGN
  - ADC/DAC of 8 bits ENOB
  - PGA gain setting with the condition of ADC clipping rate = 10^{-5}
  - TX 1st order filter cut off freq = baud rate & RX 3rd order filter cut off freq = 0.4*baud rate
  - Transformer pole at 1MHz
  - Perfect ECHO cancellation. Optional NEXT and FEXT cancellers as explained in the next page.
- Cable models

	Cable A	Cable B	Cable C	Cable D	Cable E	Cable F	Cable E'	Cable F'
Cable length	8m	8m	12m	12m	40m	40m	40m	40m
# of Twisted-pair	1	2	1	2	1	2	1	2
# of Connector	3	3	5	5	5	5	5	5
Alien NEXT/FEXT	YES	YES	NO	NO	YES	YES	**NO**	**NO**
NEXT/FEXT	NO	YES	NO	YES	NO	YES	NO	YES

FEXT and NEXT in Two Twisted Pair Cable

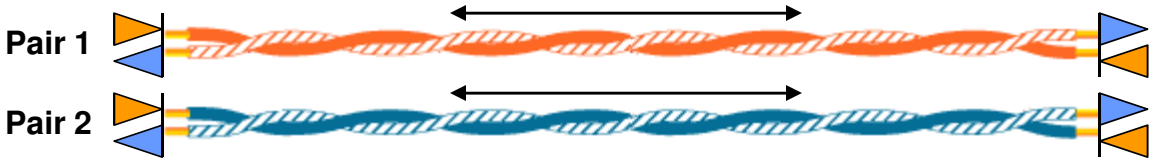
- 2 pair cable incurs NEXT and FEXT interference.
- The SNR difference of 40 meter cable with FEXT and w/o FEXT canceller is only 0.7dB.
  - PAM-4
  - baud rate = 250MHz

	Cable B	Cable F
Cable length	8m	40m
SNR w/i FEXT canceller	53.0dB	40.3dB
SNR w/o FEXT canceller	48.0dB	39.6dB
SNR difference	5.0dB	**0.7dB**

- Practically, SNR can be improved by less than 0.7 dB due to the implementation loss of FEXT canceller. Therefore, the FEXT canceller is not considered in this evaluation.
- On the other hand, the Alien Crosstalks dominate the overall noise. The NEXT canceller contributes less than 0.1dB in all cases. The NEXT canceller is also not considered here.

Effect of Baud Rates

- It is assumed that the signal in each twisted pair is conveyed bi-directionally



- The higher baud rate gives the higher SNR margin.

1 pair SNR margin	Cable A				Cable E			
Cable length	8m				40m			
Baud rate	1000MHz	500MHz	333.3MHz	250MHz	1000MHz	500MHz	333.3MHz	250MHz
Un-coded Modulation	PAM-2	PAM-4	PAM-8	PAM-16	PAM-2	PAM-4	PAM-8	PAM-16
SNR margin *	18.6dB	17.6dB	14.7dB	11.1dB	9.4dB	8.5dB	5.7dB	2.2dB

2 pair SNR margin (w/o FEXT/NEXT cancellation)	Cable B				Cable F			
Length	8m				40m			
Baud rate	500MHz	250MHz	166.6MHz	125MHz	500MHz	250MHz	166.6MHz	125MHz
Un-coded Modulation	PAM-2	PAM-4	PAM-8	PAM-16	PAM-2	PAM-4	PAM-8	PAM-16
SNR margin*	25.8dB	24.0dB	20.9dB	17.2dB	16.9dB	15.7dB	12.7dB	8.9dB

* SNR margin (**w/o channel coding**) = Salz SNR - Uncoded SNR at BER = 10^{-12}

- For ease of comparison, the same modulation coding scheme PAM-4 is picked, which yields different baud rates for I pair and 2 pair cables.

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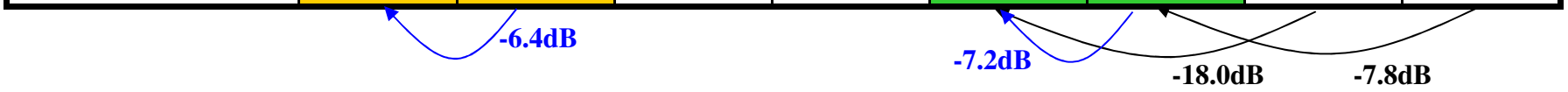
PAM-4 Performance Comparison

	Cable A	Cable B	Cable C	Cable D	Cable E	Cable F	Cable E'	Cable F'
Cable length	8m	8m	12m	12m	40m	40m	40m	40m
# of Twisted-pair	1	2	1	2	1	2	1	2
# of Connector	3	3	5	5	5	5	5	5
Alien EXT/FEXT	YES	YES	NO	NO	YES	YES	NO	NO
Baud rate	500MHz	250MHz	500MHz	250MHz	500MHz	250MHz	500MHz	250MHz
Salz SNR	41.5dB	47.9dB	55.6dB	44.3dB	32.4dB	39.6dB	50.4dB	47.4dB
SNR margin	**17.6dB**	**24.0dB**	**31.7dB**	**20.4dB**	**8.5dB**	**15.7dB**	**26.5dB**	**23.5dB**



- Common assumptions.
  - w/o NEXT/FEXT cancellation
  - PAM-4 modulation code (SNR = 23.9dB at BER = 10^{-12}); no channel coding
- 2 pair has better SNR margin than 1 pair by 6.4dB at 8 meter cable assembly and 7.2dB at 40 meter cable assembly.
- The 1 pair solution requires further study on channel coding to enhance the SNR margin which is severely affected by Alien noise.

Complexity Discussion

- Since the uncoded PAM-4 is used in both Gigabit Ethernet (802.3ab) and here 1 pair and 2 pair RTPGE, the SNR requirement is identical. The implementation complexity can be therefore easy to compare.
  - Minimum SNR = 23.9dB for AFE design target.
  - Assuming that the 1 pair and 2 pair RTPGE use the same scheme of PCS/EEE/channel encoding/decoding as in 802.3ab.
  - The complexity of equalization and interference cancellation can be reduced due to the shortening of cable length from 100 meter to 40 meter.
- An exemplary system spec. (All signals are bi-directional.)

	802.3ab (4 pairs)	2 pair RTPGE	1 pair RTPGE
ADC(Rx) ENOB	8 bit	8 bit	8 bit
DAC(Tx) ENOB	8 bit	8 bit	8 bit
System CLK	125MHz	250MHz	500MHz
max cable length	100m	40m	40m

Complexity Discussion (cont)

- The AFE complexity : 802.3ab > 2 pair RTPGE > 1 pair RTPGE
  - TSMC 40nm die size estimate (implementation dependent)

	802.3ab (125MB)		2 pair RTPGE (250MB)		1 pair RTPGE (500MB)	
	Quantity	Complexity	Quantity	Complexity	Quantity	Complexity
ADC	4	1*A	2	1.4*A	1	3.0*A
DAC	4	1*B	2	1.5*B	1	2*B
PLL/PGA/LPF/Hybrid	4	1*C	2	1.2*C	1	1.4*C
AFE Sub Total	4*A + 4*B + 4*C		2.8*A + 3*B + 2.4*C		3.0*A + 2*B + 1.4*C	

- The Computational complexity : 1 pair RTPGE >= 802.3ab > 2 pair RTPGE

	802.3ab (4 pairs)		2 pair RTPGE		1 pair RTPGE	
	Quantity	Complexity	Quantity	Complexity	Quantity	Complexity
FFE	4	8 taps*1	2	6 taps*2	1	13 taps*4
FBE	4	16 taps*1	2	13 taps*2	1	26 taps*4
NEXT	4	25 taps*1*3	2	0	1	0
ECHO	4	125 taps*1	2	100 taps*2	1	200 taps*4
PCS/channel decoding/interface	4	1*D	2	1*D	1	1*D
Digital Sub Total	896 taps +D		476 taps + D		956 taps + D	

- Overall Complexity: 802.3ab > 2 pair ≈ 1 pair

Conclusion

- Both 1 and 2 pair cables demonstrate the technical feasibility of RTPGE
- 2 pair exhibits better SNR margin than 1 pair RTPGE.
- If considering the cable cost or weight, the 1 pair RTPGE has advantage when its overall implementation complexity is close to that of 2 pair RTPGE
- The 1 pair 40 meter cable deserves the further study of the performance impact caused by the environment

Thank you

Questions?

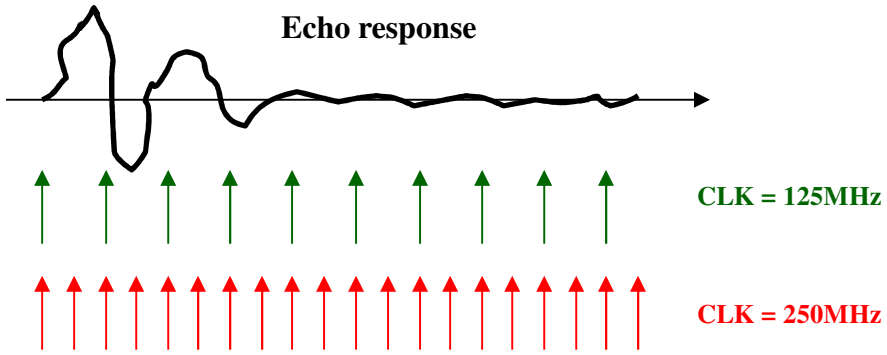
Backup

Minimum SNR

- Required minimum SNR in dB at BER = 10^-12
  - PAM-2 SNR = 17.0
  - PAM-4 SNR = 23.9
  - PAM-8 SNR = 30.1
  - PAM-16 SNR = 36.0

Computational complexity example

- Double the baud rate, the computational complexity becomes 4 times
  - Double the baud rate, the ADC output date becomes double
  - Double the baud rate, the processing speed (CLK) becomes double



- Take Echo Canceller as an example
  - Assuming that 100meter at 125MHz baud rate needs 125 taps
  - 40meter at 125MHz baud rate needs 125*40/100 = 50 taps
  - 40meter at 250MHz baud rate needs 50*2 = 100 taps.
    - Double the CLK rate, total computational complexity becomes 100 taps*2
  - 40meter at 500MHz baud rate needs 100*2 = 200 taps.
    - Quadruple the CLK rate, total computational complexity becomes 200 taps*4

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