
Investigation of PAPR Penalty on PAM4 Signaling

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Background

At San Antonio meeting in Nov. 2014, there were many discussion regarding PAPR penalty.

- Band limited PAM4 may induce intra-baud peaking
- PAPR penalty might be introduced at Tx

This presentation

Based on our investigation regarding relation between signal bandwidth and PAPR penalty of PAM4, we provide the following information;

- PAPR penalty vs. Tx signal bandwidth
- Consideration on Rx filtering penalty

CONCLUSIONS AND COMMENTS

- Peak TX waveform envelope for PAM-4 is identical to NRZ at the same Baud rate (so e.g., 100Gbps PAM-4 has the same envelope as 50Gbps NRZ)
 - For the same linear system response
- Systems with specified TX FFEs need to account for 'peaking' in their budgets
 - Nyquist shaping TXs, or traditional TX de-emphasis FFEs
 - Just as was included in the budget for TX De-emphasis with NRZ
 - This author's preference is for simple straight PAM transmissions with no TX FFE shaping
- All systems will strive for good transmission line behavior between electrical TX and the 'optical load'
 - Just as was done for NRZ. It pays to make your transmission lines 'decent' for your Baud rate.
 - Bad transmission lines create Insertion Loss Deviation (ILD), which makes equalization difficult, and which makes a 'peak problem' similar to those shown here
 - We have one presentation, where even with lab equipment the transmit waveform looks good.
- Any ultimate / residual transmission line 'problems' must be dealt with
 - For any modulation system, including NRZ
- So, does PAM-4 or NRZ Require an Intra-Baud Clipping Penalty?
 - Not generically for simple Baud rate straight PAM transmission. Only poor transmission lines would create a penalty

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2. Opinion on high PAPR issue

ROI* of higher PAPR in band-limited channel

*Return On Investment

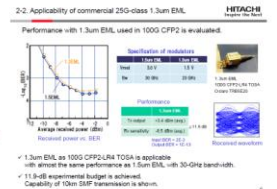
High PAPR is not just a waste of budget !

Investment :	- PAPR penalty
Return :	- Applicability of 28G-class devices and ADC/DAC ➡ Low cost, compatibility to 100GbE, etc - Better DSP and Rx sensitivity ➡ Increase of budget

Power budget of Nyquist-PAM4

In spite of ~1dB PAPR penalty, fairly large budget of 11.9 dB have been obtained experimentally with 28G-class devices.

- ✓ 2-km SMF PMD budget can be easily satisfied.
- ✓ 10-km SMF PMD budget is marginal, but may be satisfied by using APD or SOA.



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Simulation model & Parameter

- Band limitation at Tx is assumed to be adjusted by using roll-off factor.
 $\alpha \sim 0$: Band-limited signal, $\alpha \sim 1$: Broad band signal
- Other Tx filtering (DAC, Driver, Modulator) are included in the above.
- LPF represents a concatenation of all devices in Rx (PD-TIA, ADC).



Parameters	Values	Remarks
Modulation format	PAM4	56 Gbaud
Pattern length	32768	
Roll-off factor α	0.1 ~ 1.0	Bw : $28 \cdot (1 + \alpha)$ GHz
Clipping ratio	2.33σ	Assuming amplitude clipping or nonlinearity
LPF bandwidth	20, 25, 28 GHz @ 3dB down	Linear phase FIR filter

3. Simulation result - Transmitter side

- Band limitation in Tx causes PAPR penalty, which should be included in Tx budget because of OMA reduction.
- Relation between PAPR penalty and roll-off factor (signal bandwidth) is investigated.

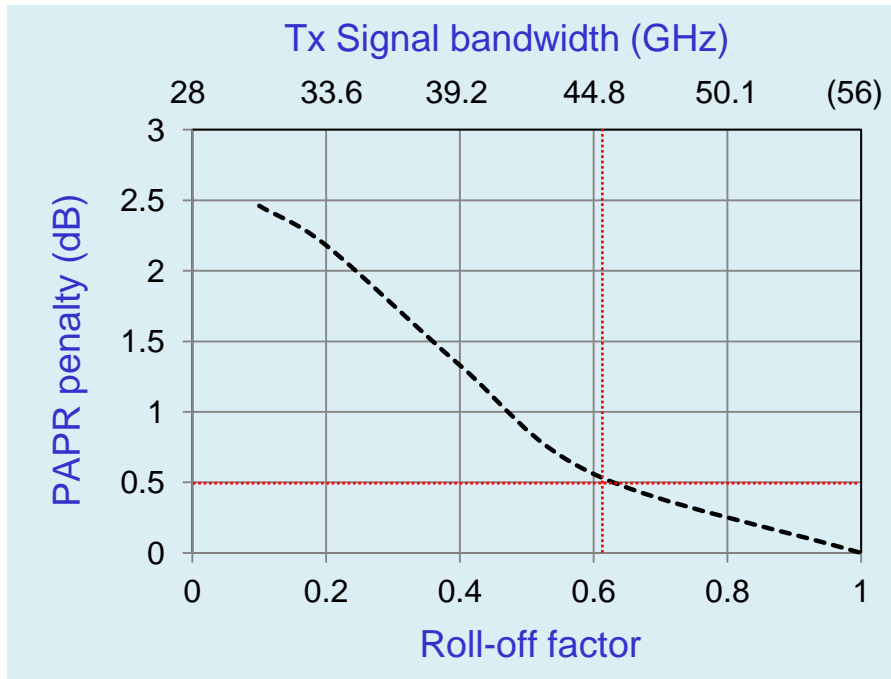


Fig.1 PAPR penalty vs. Roll-off factor
(Tx Signal bandwidth)

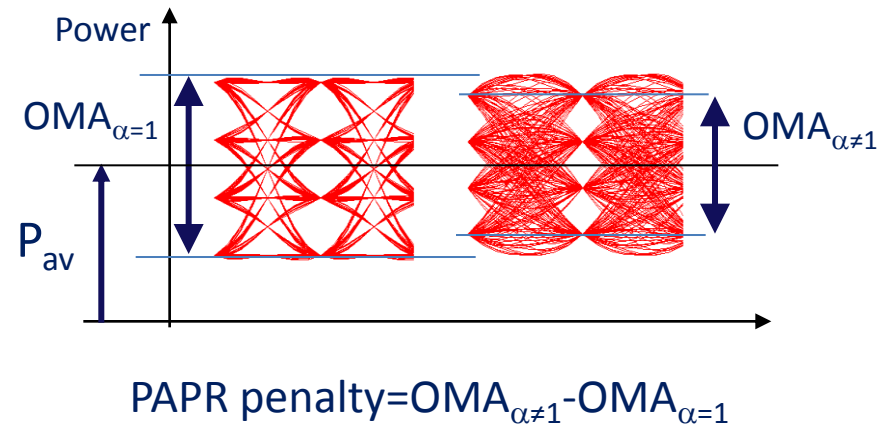


Fig. 2 Definition of PAPR penalty

✓ Fig.1 implies that moderate bandwidth limitation such as 45-GHz driver causes ~0.5-dB PAPR penalty.

3. Simulation result - Receiver side

- Impact of Tx-signal bandwidth on Rx filtering penalty is investigated.

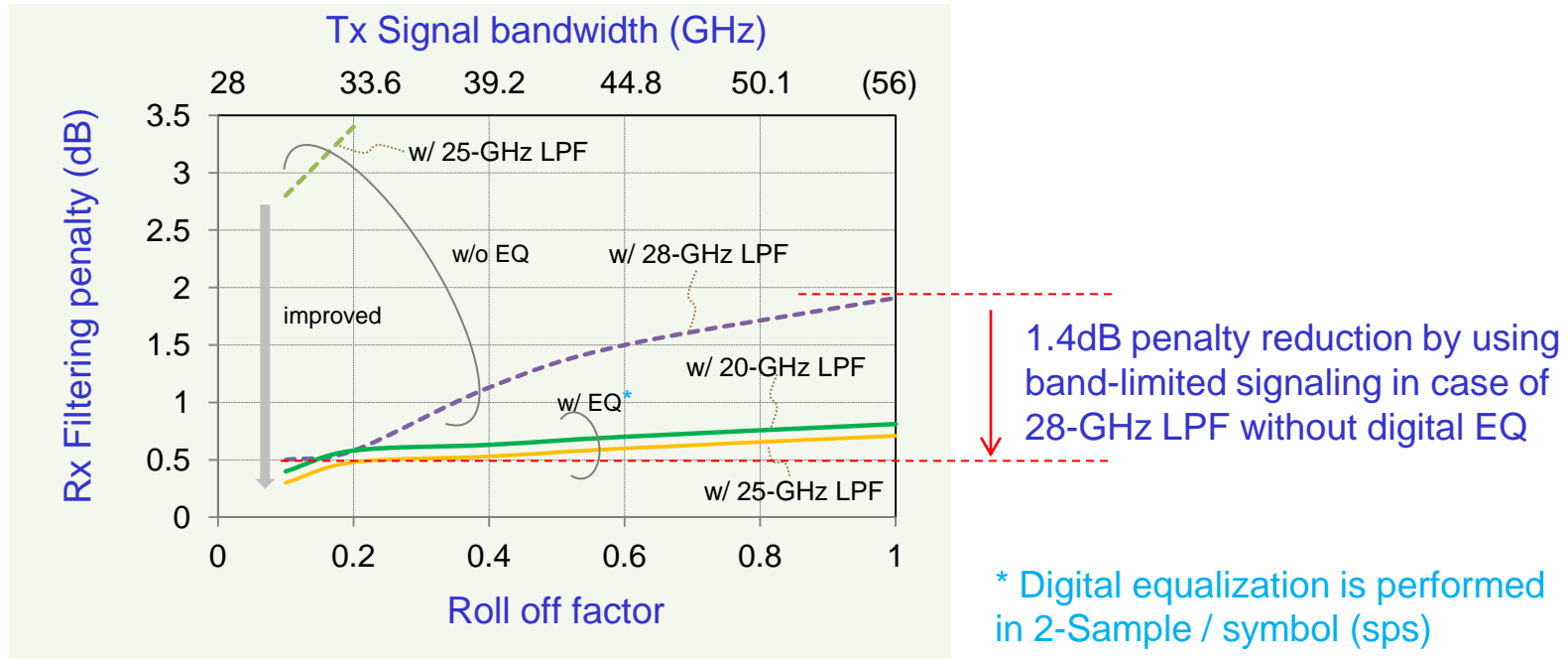


Fig.3 Rx filtering penalty vs. Tx signal bandwidth

- ✓ Band limited signals does not suffer Rx filtering than broad band signals. It is necessary to relax penalty accumulation in case of band limited signal. (See the next slide)
- ✓ Practically the channel bandwidth would be ~ 20 GHz due to narrow band components like ADCs. Therefore, digital equalization is required to reduce Inter-symbol interference.
- ✓ Significant mitigation of Rx filtering penalty is confirmed by using 2-sps digital equalization

In penalty accumulation, simultaneous consideration of both Tx-side PAPR penalty and Rx-side filtering penalty is needed.

To simplify penalty accumulation, “Net PAPR penalty” should be introduced at Tx-side, which includes both Tx-side and Rx-side filtering effect.

	$\alpha = 1.0$ (Base) w/ 28-GHz LPF	$\alpha = 0.1$ w/ 20-GHz LPF
Tx-side PAPR penalty (dB)	0	2.5
Rx-side filtering penalty (dB)	0	-1.5
Net PAPR penalty	-	1.0

✓Relation between PAPR penalty and Tx signal bandwidth of PAM4 is investigated. Any band limitation at Tx causes more or less PAPR penalty.

✓We propose “Net PAPR penalty” which includes both Tx-side and Rx-side filtering effect

Thank you