A New Approach to Measure Tx Signal Strength and Penalty

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Background

- In conventional communication theory, signal to noise ratio is based on signal (RF) energy per bit and noise power spectral density
  - Especially appropriate for LRM, where EDC accumulates signal energy dispersed across multiple time slots
- OMA is a point-property of selected bits in special square wave patterns – it does not consider bit energy dispersed among multiple time slots
  - There is no fixed relationship between bit energy and OMA unless the exact pulse shape is defined

Precompensation & OMA

- Precompensation has been suggested as a means of reducing ISI at the input of the receiver to improve "equalizability" of the received waveform
  - See aronson_1_0105.pdf
- Precompensated waveforms have greater RF energy (signal strength) even though OMA is same
  - Result is better transmit SNR
  - *Evidence that OMA is not the right metric*
- Since PIE-D is based on relative SNR (vs. ideal) with same OMA, penalty decrease is due in part to increased signal energy
  - Misappropriation of signal energy into penalty
  - How much easier is the waveform to equalize?
- This does not imply that pre-compensation has no merit – just that PIE-D (which TWDP approximates) overstates its benefit

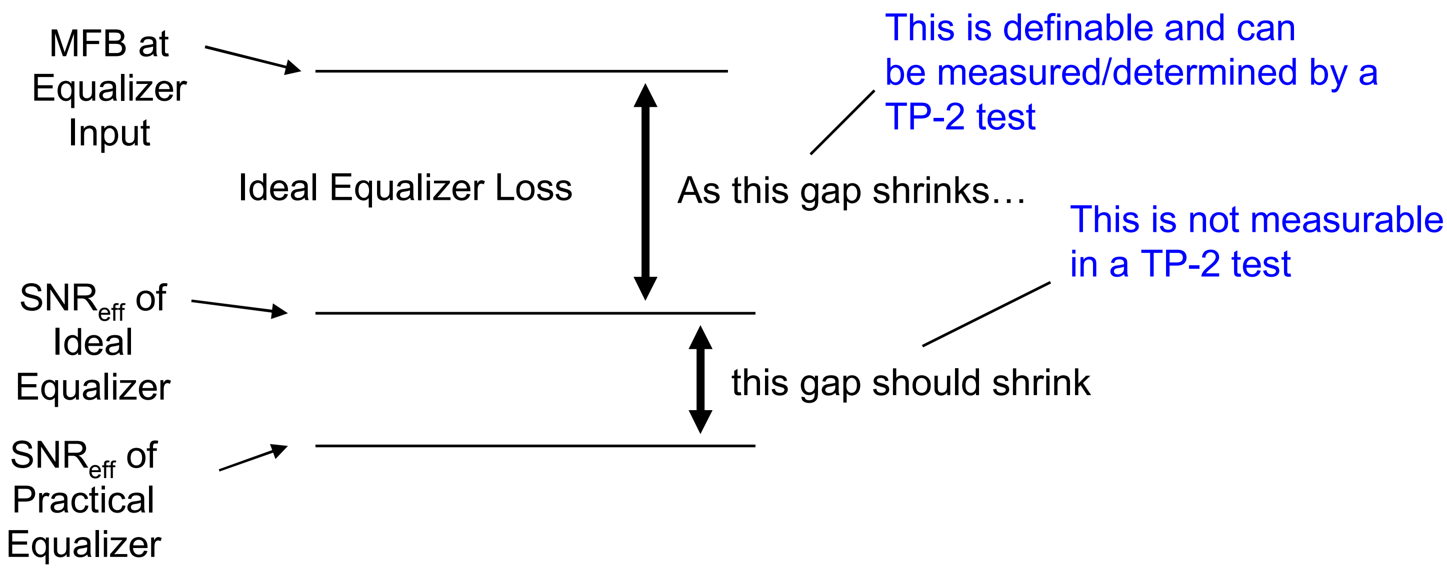
Additional problem

- TWDP penalty result is *directly* proportional to OMA measurement errors
  - OMA is difficult to define and measure accurately, especially for waveforms with overshoot, ringing, tilt, etc.
    - Okay for reference waveforms and for TP3 test, where waveshapes and relationships are known and controlled
  - Budget is very tight, little room for measurement errors

Introduction to new approach

- PIE-D compares:
  - the effective SNR at the DFE slicer to --
  - the Matched Filter Bound SNR (MFB) of a *square transmit* pulse,
  - assuming both signals are transmitted with minimum allowable OMA
    - OMA is defined as the difference in power levels between steady-state logical "0" and steady-state logical "1"
- Problem 1: MFB based on OMA may underestimate or overestimate the MFB of the transmitted pulse
- Problem 2: A measure of equalizability should compare:
  - the effective SNR at the DFE slicer to --
  - the MFB *at the input to the equalizer*
- Rationale: performance gap between an ideal equalizer and the MFB at its input should be positively correlated with performance gap between a practical equalizer and an ideal equalizer (see next slide)

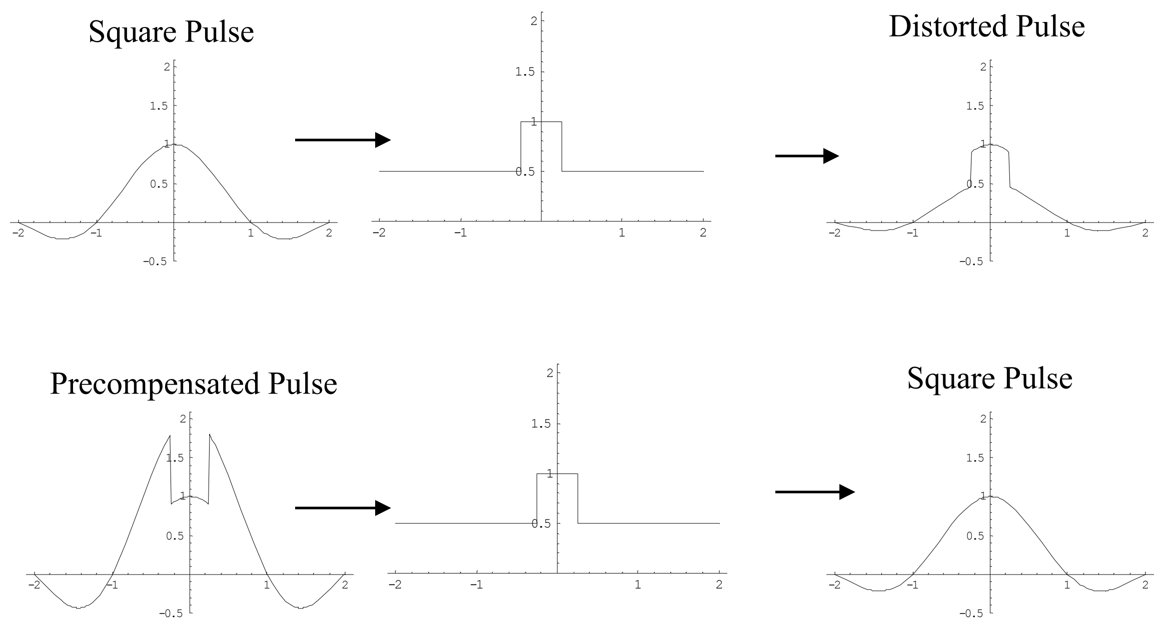
Distortion Metric



- Limiting distortion is necessary to bound implementation penalty of a compliant receiver
- May need to change to a finite length ideal equalizer to ensure this correlation
- Do *not* include loss of MFB due to fiber propagation in distortion metric
  - This would be inconsistent with precompensation, which preloads the high frequency bands with energy that will be sacrificed during fiber propagation to reduce distortion at the receiver (see next page)

Frequency Domain Example

Transmit Pulse Spectrum | ***Fiber Response*** | ***Pulse Spectrum at Receiver Input*** | ***Loss in MFB Between Tx & Rcv***

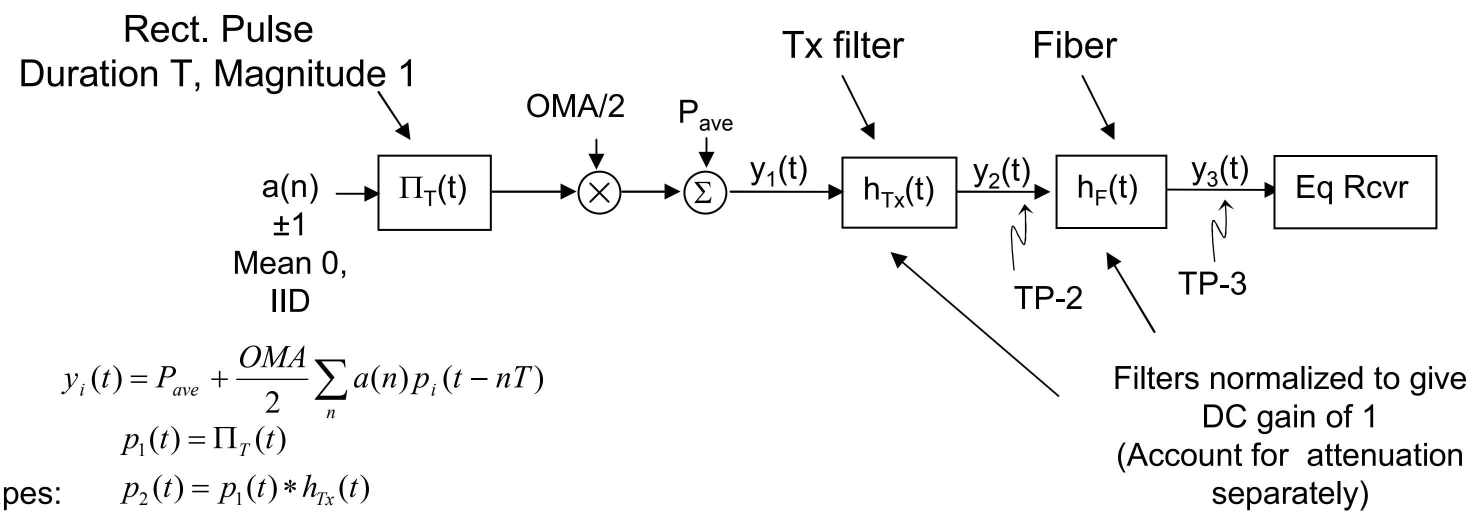


2.2 dB

4.1 dB

- Loss in MFB between transmitter and receiver should be excluded from distortion metric

Model



$$y_i(t) = P_{ave} + \frac{OMA}{2}\sum_n a(n)p_i(t-nT)$$

Pulse shapes:

$$p_1(t) = \Pi_T(t)$$
$$p_2(t) = p_1(t) * h_{Tx}(t)$$
$$p_3(t) = p_2(t) * h_F(t)$$

Note: $p_i(t)$ has the property $\sum_n p_i(t-nT) = 1$

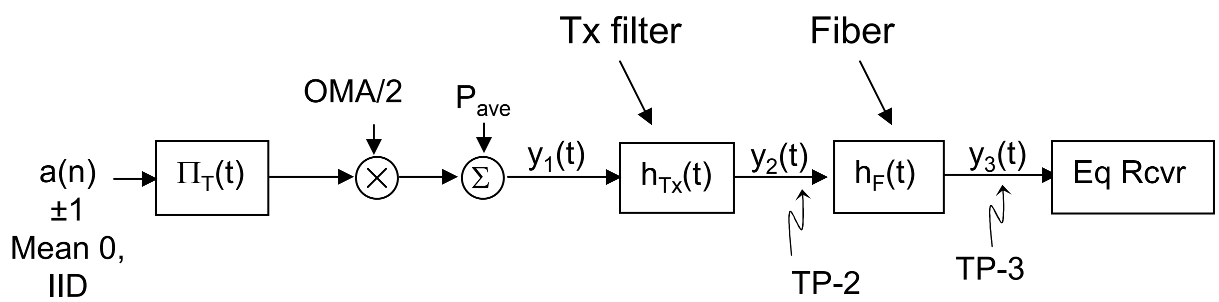
Pulse energy of y_i: $\varepsilon_i \equiv \int p_i(t)^2 dt$

Matched Filter Bound SNR of y_i: $MFB_i = \frac{OMA}{2}\sqrt{2\varepsilon_i / N_0}$

N_0 determined by link budget

- ε_i can be considered a shape factor that relates MFB to OMA
  - ε_i changes at different points in the channel
- Transmit filter can increase or decrease MFB: MFB2 ≤ MFB1 or MFB2 > MFB1 (latter results from precomp.)
- Fiber always decreases MFB: MFB3 ≤ MFB2 (equality when no DMD).

Definitions



Definitions: Transmit Filter Loss: TFL $\equiv$ MFB_1 - MFB_2 (in dB) (can be negative)

Unrecoverable Dispersion Penalty: UDP $\equiv$ MFB_2 - MFB_3 (in dB)

Effective SNR of ideal equalizer with a given BER: $BER = Q(SNR_{eff,ideal})$

For infinite length DFE $SNR_{eff,ideal} \approx \left(\sigma_n^2 + \sigma_{ISI}^2\right)^{-1/2}$ where signal is ±1

Ideal Equalizer Loss $\gamma \equiv MFB_3 - SNR_{eff,ideal}$ (in dB)

Optical Modulation Standard Deviation $OMSD_i \equiv \left\langle \left(y_i(t) - \left\langle y_i(t) \right\rangle\right)^2 \right\rangle^{1/2} \approx \dfrac{OMA}{2}\sqrt{\varepsilon_i / T}$

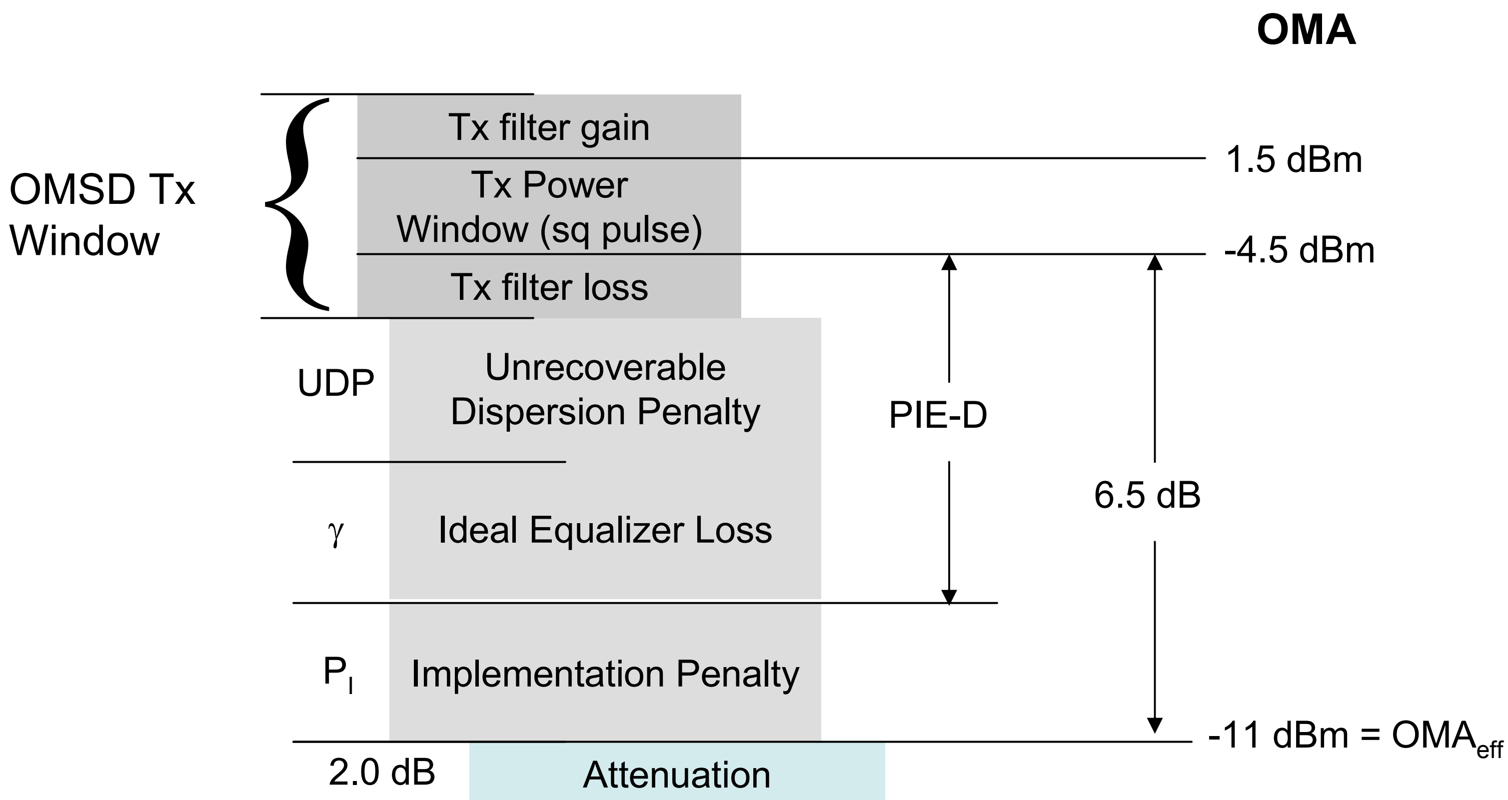
where <•> indicates time average.

For a square pulse, OMSD = OMA/2

OMSD is directly proportional to the MFB, independent of the shape of the pulse:

$$MFB_i = \frac{OMA}{2}\sqrt{2\varepsilon_i / N_0} = OMSD_i\sqrt{2T / N_0}$$

Link Budget



- Propose that TP-2 be specified by setting a minimum limit on $SNR_{eff,ideal}$ and a maximum limit on γ
  - The first ensures link closure, the second (indirectly) bounds implementation penalty
- $SNR_{eff,ideal}$ and γ can be calculated through simple modifications to TWDP code
  - $SNR_{eff,ideal}$ can be related back to OMSD and reported out as such