Electronic dispersion compensation for 10G EPON?

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Precedent in 802.3 and others

- Electronic dispersion compensation (EDC) is used in these projects and standards
  - Electrical
    - 10PASS-TS ADSL VDSL and so on
    - 10BASE-T, 100BASE-T?, 1000BASE-T, 10GBASE-T
    - 10GBASE-CX4
    - 10GBASE-KX4, 10GBASE-KR (P802.3ap)
    - Common Electrical I/O (CEI) from Optical Internetworking Forum (OIF)
  - Optical
    - 10GBASE-LRM (802.3aq)
    - OIF “Electronic Dispersion Compensation for 10 Gb/s, 1550 nm Optical Links”
- Note LRM is the first *optical* PMD in 802.3 to require EDC
- Other optical links e.g. high end SONET, may use equalisation even if standard does not require or expect it

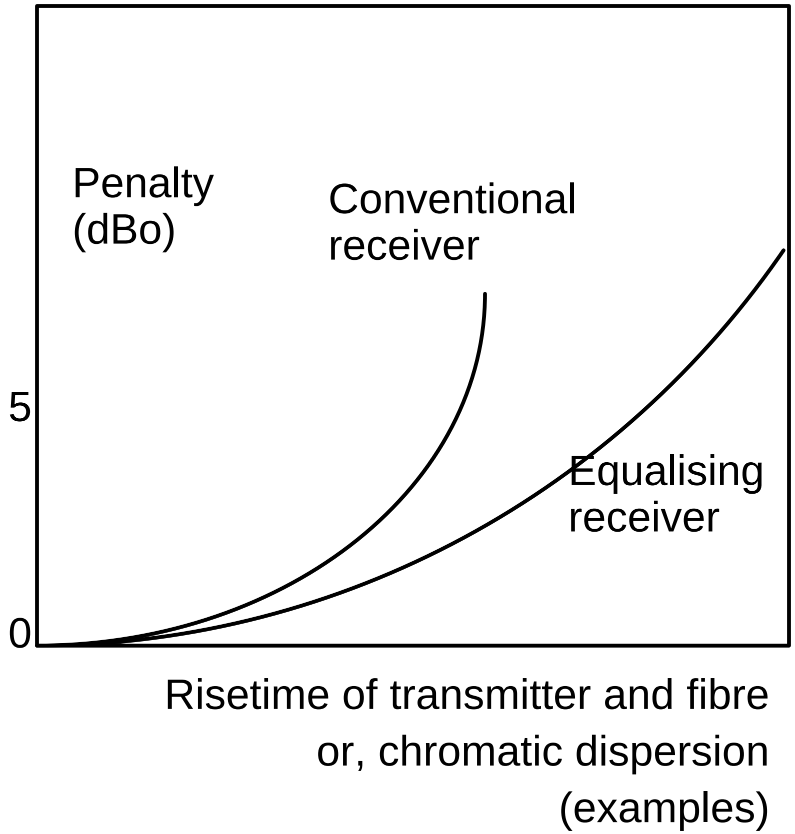
What does it compensate for?

- Filtering effects Yes
  - examples: coax and twisted-pair cable bandwidths, modal dispersion in multimode fibre
- Crosstalk Probably not relevant to 10G EPON
- Nonlinear distortions Maybe
  - example: chromatic dispersion (single mode lasers). Note: P802.3aq did NOT study this
- Noise No – if noise is the issue, consider FEC
  - examples; receiver noise, optical amplifier noise, mode partition noise

Transmit side or receive side?

- Transmit side equalisation (“pre-emphasis”) needs some knowledge of the impairment to follow
  - e.g. always on, factory set, training phase with feedback (handshaking) from peer receiver
- Receive side equalisation needs no handshaking and little prior knowledge but still needs to learn
  - Training phase then “show time”
    - e.g. DSL or 1000BASE-T
  - or, adaptive in service
    - e.g. 10GBASE-LRM

How much benefit?



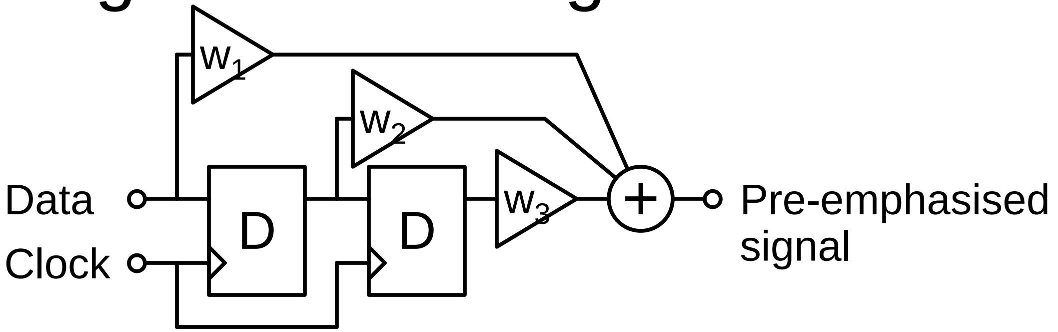
- For small equalisable ISI penalties, use of equalising receiver very roughly halves the penalty
- A good equaliser can in some circumstances open a completely closed eye
- Do not expect 10G equalisers to be as complex or effective as the much slower copper-cable equalisers
- Benefit of equaliser probably somewhat greater if APD or optical amplifier involved

More costs and benefits

- Silicon complexity and heat can be anywhere from mild to very severe
- As well as equaliser and signal-quality measuring circuits,often require linear/AGC receiver stages which take more power than traditional limiting receiver stages
- Need some way of measuring the “quality” of the equalised signal and tuning the equaliser
  - For receive side equalisation, this is an implementation choice and not defined in the standard
  - As an equaliser may have multi-dimensional optimisation, this control loop is much less agile than a (one-dimensional) clock recovery function
    - Interesting issue for a burst mode link
- Can correct for variations in receiver bandwidth and (somewhat) phase response allowing improved manufacturing uniformity or simplified setup

How it works   1/2

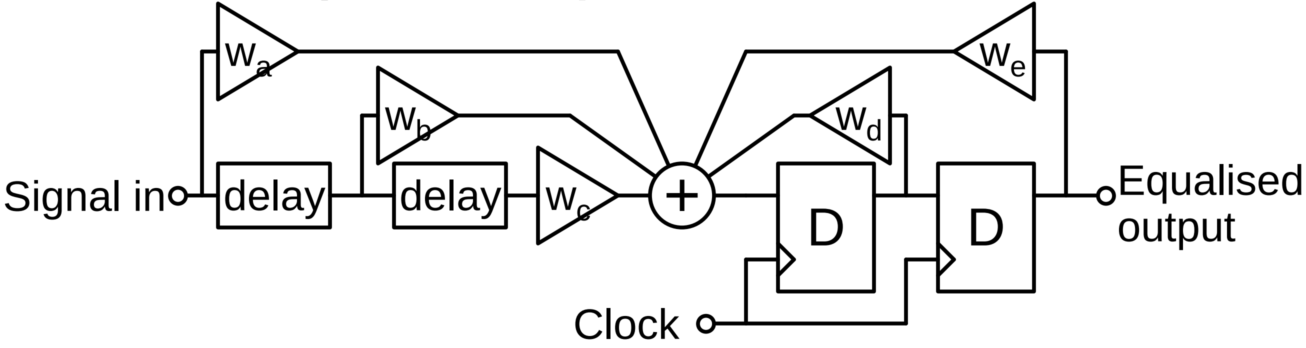
- In reality, many ways
- Some standards define “textbook” equalisers
- Real implementations of these standards may be not at all like the reference equalisers, which are defined to measure signals not as a recommended design (varies with the standard)
- Transmit side pre-emphasis may be described as a shift register with weighted and summed taps



  - ...or not described, just specified by a pulse mask

How it works 2/2

- Receive side equaliser may be described as a tapped delay line (“feed-forward equaliser”) followed by a tapped shift register (“decision feedback equaliser”)



  - e.g. 10GBASE-LRM reference equaliser
  - DSL may be completely different
- Clock recovery, signal-quality measurement and feedback to control equaliser settings are not shown: “secret sauce”

Terminology (from 802.3aq)

- PIE-D
  - SNR penalty (of a signal wave shape) as seen by an ideal equaliser of FFE/DFE type
  - In 802.3aq, considered as a measure of how correctable a particular multimode fibre’s frequency response is, by a FFE followed by a DFE, both with as many taps as necessary
  - Can be calculated by integrals
- Transmitter and waveform dispersion penalty (TWDP)
  - A measure of how correctable a particular transmitter is, if followed by 3 defined filters (representing different types of MMF frequency response)
  - Transmitter impairments could be linear or nonlinear
  - The (hypothetical, software) reference equaliser has a defined number of taps (14 FFE taps at T/2 spacing and 5 DFE taps at T spacing, where T = 1 / signalling rate
- Waveform “distortion” penalty (WDP)
  - Known as WDP in SFP+ committee
  - As TWDP but without the challenge filters
  - A measure of how recoverable a particular signal’s wave shape is – the signal might be at TP2 or TP3

How these metrics are determined

- TWDP (or WDP)
  - Transmitter (or other signal) is set to PRBS9
  - Signal at point of interest is received with the usual oscilloscope with fourth order Bessel-Thomson frequency response
  - Instead of showing an eye, scope is set in averaging mode and records the whole 511-bit waveform, sampled at 16 samples/UI if practicable. Noise is averaged out
  - TWDP or WDP algorithm calculates a close approximation to OMA, normalises the waveform's size, and applies a software equaliser at all possible phases. BER degradation from reference, converted to dBo, at best phase (for worst of 3 challenge filters if TWDP) is the result
- PIE-D
  - Algorithm calculates an integral of a folded frequency response adjusted for receiver noise (see references)
- Same scale of dB
  - All these metrics are defined as a SNR degradation at the decision point for a non-amplified reference receiver front end, in a scale of optical dB. The calculations are expressed as algorithms (rather complicated for a spreadsheet). An ideal NRZ optical signal with default Tx and Rx bandwidths has a PIE-D or WDP of 1.23 dBo *[check]* (effectively, an offset zero)
  - A metric of 4 dBo is challenging
  - Hence a very compressed scale: perfect to unreasonable in about 3 dBo

Equalisers for 10G EPON?

- Upstream (assumed DFB in 1310 nm band)
  - Chromatic dispersion not a problem
  - Difficulty of coping with burst mode
- Downstream (assumed single-longitudinal mode in 1550 nm band)
  - Chromatic dispersion significant for directly modulated DFB, perhaps not for electro-absorption modulator to 20 km
  - 802.3 has done no work in this area
  - (See next slide for OIF)
  - FEC may bring bigger benefits (expressed in dB of budget)
  - Can apply FEC and equalisation to same system (e.g. 10GBASE-KR, 10GBASE-T)

Equalisation of chromatic dispersion on SMF

- Key question for 10GEPON
- Very much depends on transmitter
- A great deal is possible
  - Usually proprietary
- Issue is, what can be done for low cost, heat and complexity?
- Note new OIF project using EDC on SMF
  - Target 2400 ps/nm or ~120 km – not 10GEPON reach scenario, may not be relevant transmitter type
- OIF work indicates that even short receiver equalisers can bring benefit
  - But, depends on transmitter

References

- IEEE Std 802.3aq-2006 (10GBASE-LRM)
- Sudeep Bhoja et al., “Channel Metrics for EDC-based 10GBASE-LRM”, http://ieee802.org/3/aq/public/jul04/bhoja_1_0704.pdf
- TWDP algorithm, see IEEE Std 802.3aq 68.6.6 or below
- Nick Weiner et al., “Towards transmitter compliance testing for ITU Recommendation G.959.1 Appendix VII – Applications using electronic dispersion compensation”, OIF2006.325
- Frank Chang “10G EDC For SMF”, http://ieee802.org/3/av/public/2006_09/3av_0609_chang_1.pdf
- Ali Ghiasi et al., “Experimental Results of EDC Based Receivers for 2400 ps/nm at 10.7 Gb/s for Emerging Telecom Standards”, http://www.asipinc.com/pdf/OFC06_EDC10c.pdf
- For more on TWDP and PIE-D, see http://ieee802.org/3/aq/public/tools/index.html