Edge-Equalized NRZ and Duobinary

IEEE 802.3ap Task Force

Ottawa

Sept 27-29, 2004

Brian Brunn, Xilinx

Intro

- It appears the equalization algorithm for EE-NRZ and Duobinary are the same. Both want to zero-force the composite pulse response to … 0 0 0 .5 .5 0 0 0 ...
- Duobinary is perceived as generally desiring a null at 5GHz. With duobinary we can "take advantage of the roll-off in the channel" but when we use symbol-spaced FIR equalization, it is hard to separate out the equalization from the duobinary function.
- The sampled sequence … 0 0 0 .5 .5 0 0 0 … has a null at 5GHz.
- This presents two questions:
  - How can a 10Gbps signal have a null at 5GHz and be NRZ detectable? What about the … 0101 … pattern?
  - Can a 10Gbps signal have a significant 5GHz component and still be DB detectable with no ISI at the bit center?
    - ISI is important not only at the bit center.

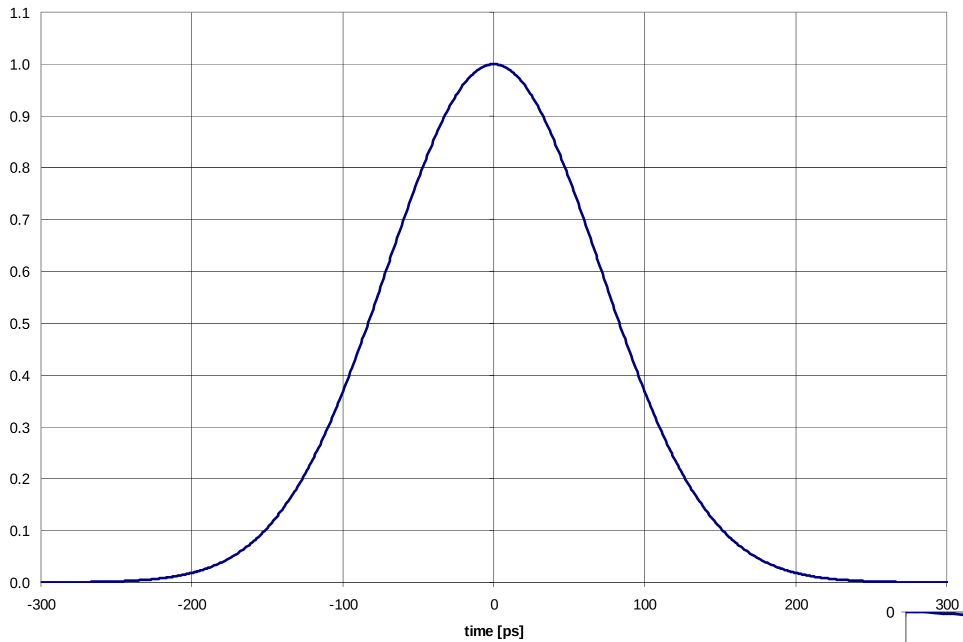
Hypothesis

- Perhaps there something else besides just zero forcing to … 0 0 0 .5 .5 0 0 0 …?
- If we restrict ourselves to symbol-spaced FIR filtering where UI = Tsample = 100ps then 5GHz = π in the z-domain.
  - Equalizer frequency response symmetric about 5GHz due to aliasing.
  - No fractional spaced taps.
- FIR filter design requires a priori selection of a symmetry "type".
  - Odd-symmetric FIR systems can not have a null at π (not good for low-pass)
  - Even-symmetric FIR systems always have a null at π (can't be high-pass).
- So this suggests odd-symmetric FIR filtering may be good for EE-NRZ and even-symmetric FIR filtering may be good for duobinary.
- Lets try the two different FIR "types" and perform ZFE to produce a 0 0 0 .5 .5 0 0 0 composite pulse response.

Analysis steps taken

- Start with a 10Gbps system that results in a pulse response that is a gaussian pulse with the 5GHz component @ -21.4dB
- Using odd-sense FIR symmetry for EE-NRZ equalization, generate MSE FIR tap coefficients to meet the … 0 0 .5 .5 0 0 … criteria on the composite pulse response.
- Repeat for even-sense FIR symmetry for duobinary equalization.
- Plot frequency and eye diagrams.

System Pulse Response

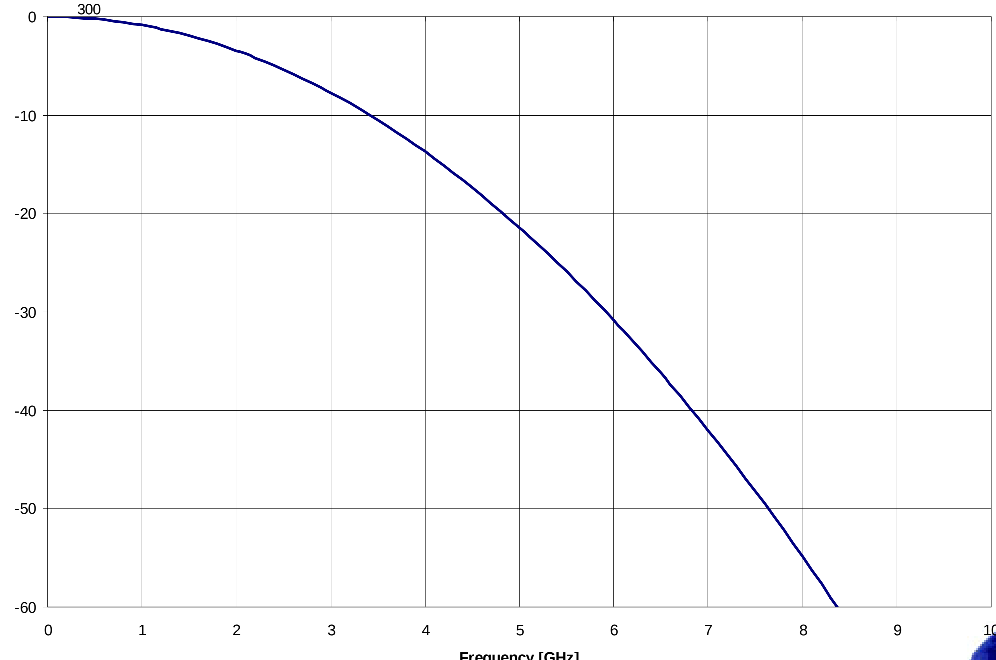


Time

$$y(t,\sigma) := e^{-\left(\frac{t}{\sigma}\right)^2} \qquad \sigma := 10^{-10}$$

$$Y(\omega,\sigma) := \left[\pi\cdot(|\sigma|)^2\right]^{\frac{1}{2}}\cdot\exp\left[\frac{-1}{4}\cdot\omega^2\cdot(|\sigma|)^2\right]$$

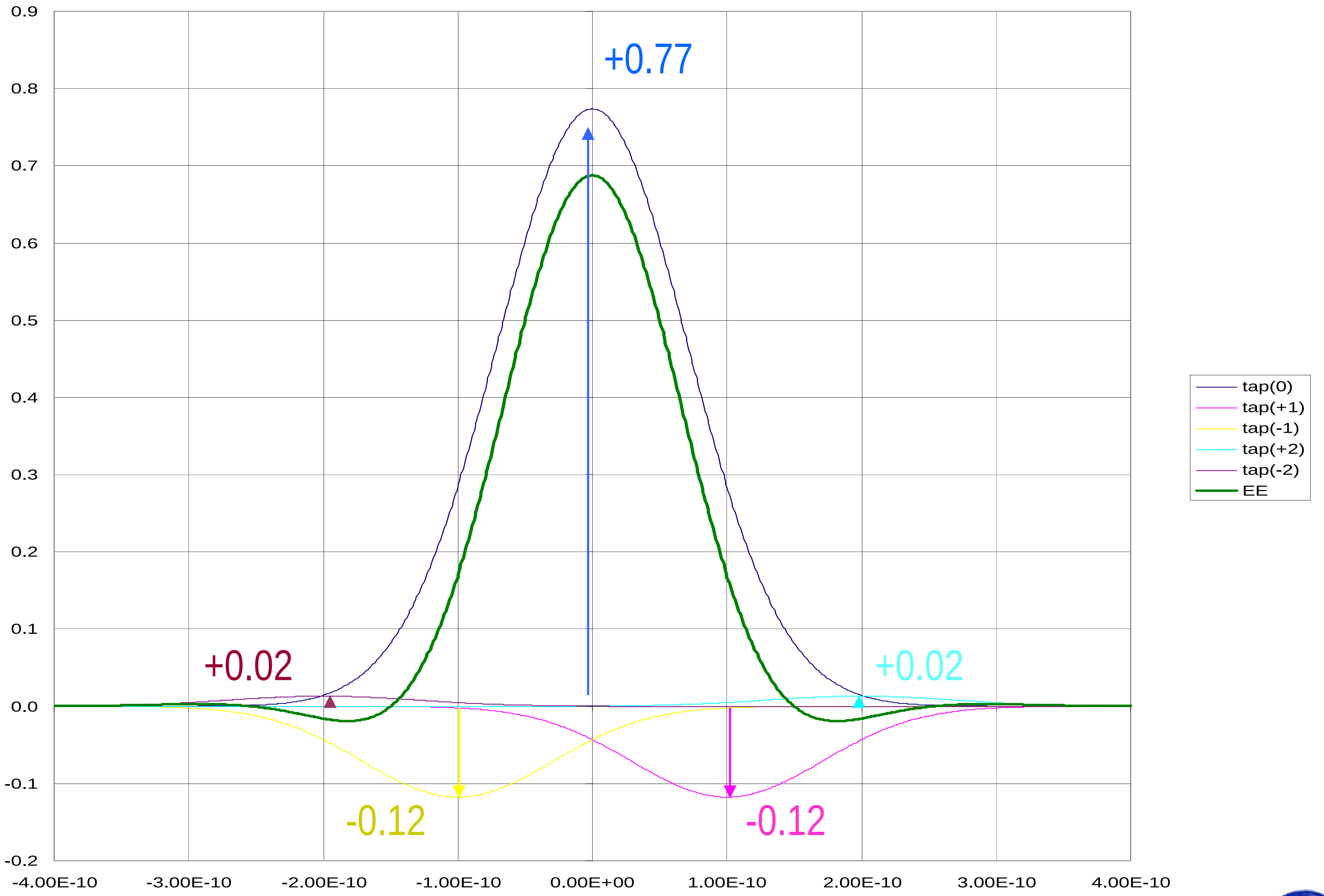
Frequency



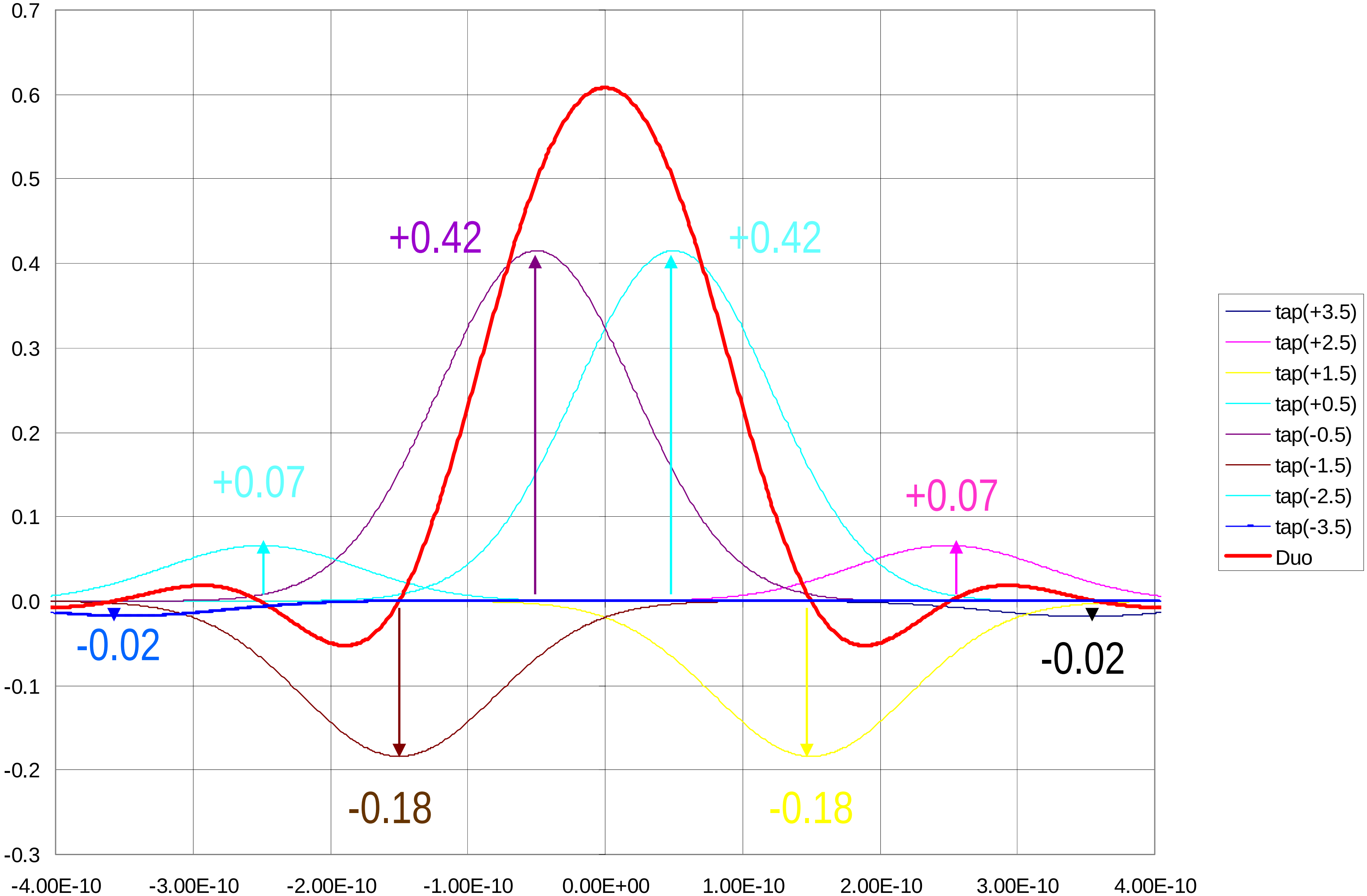
$$Y_{dB}(\omega,\sigma) := 20\cdot\log\left(\frac{Y(\omega,\sigma)}{Y(0,\sigma)}\right)$$

$$Y_{dB}\left(2\cdot\pi\cdot5\cdot10^9, 10^{-10}\right) = -21.432$$

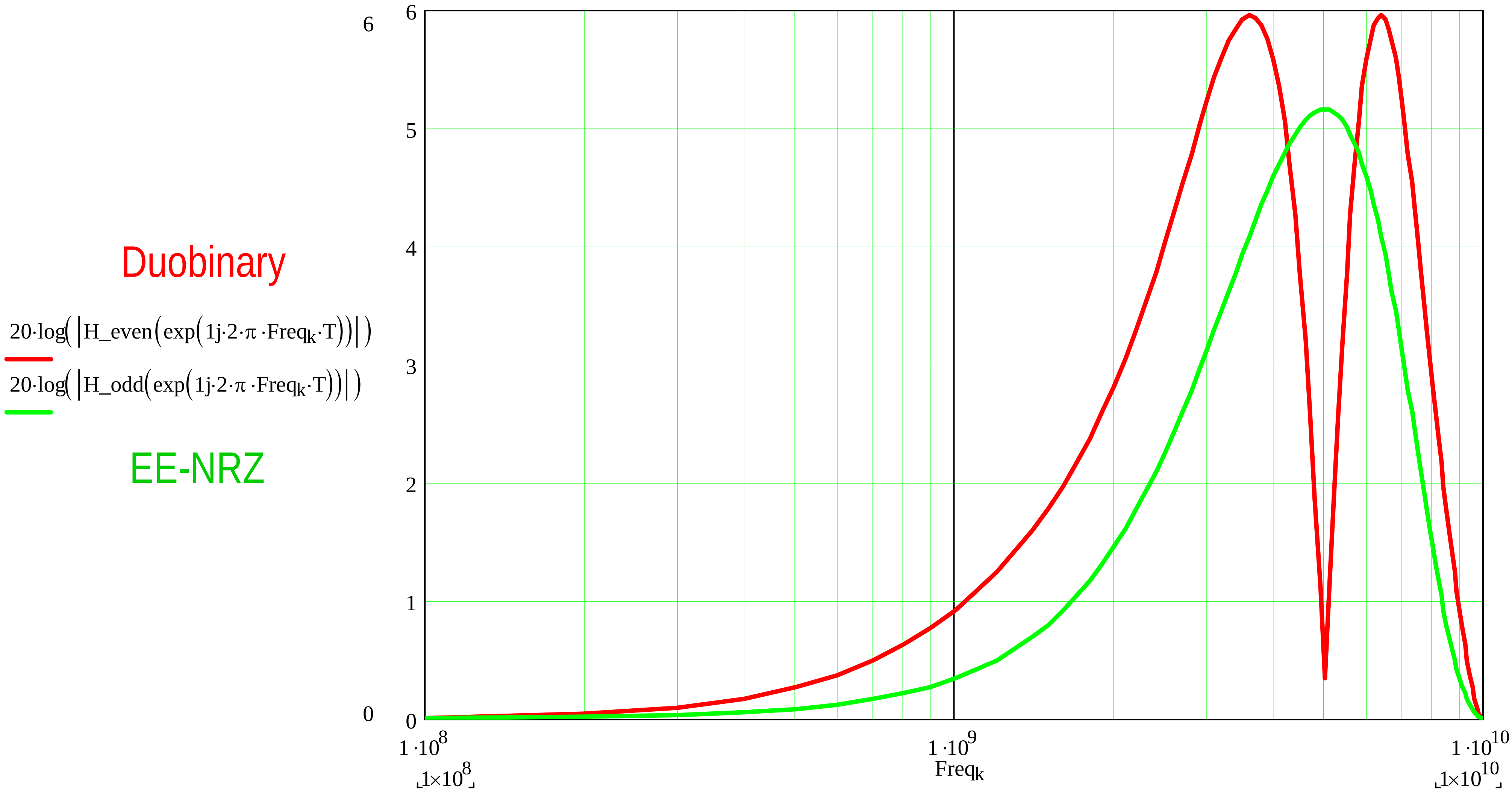
EE-NRZ composite pulse generation



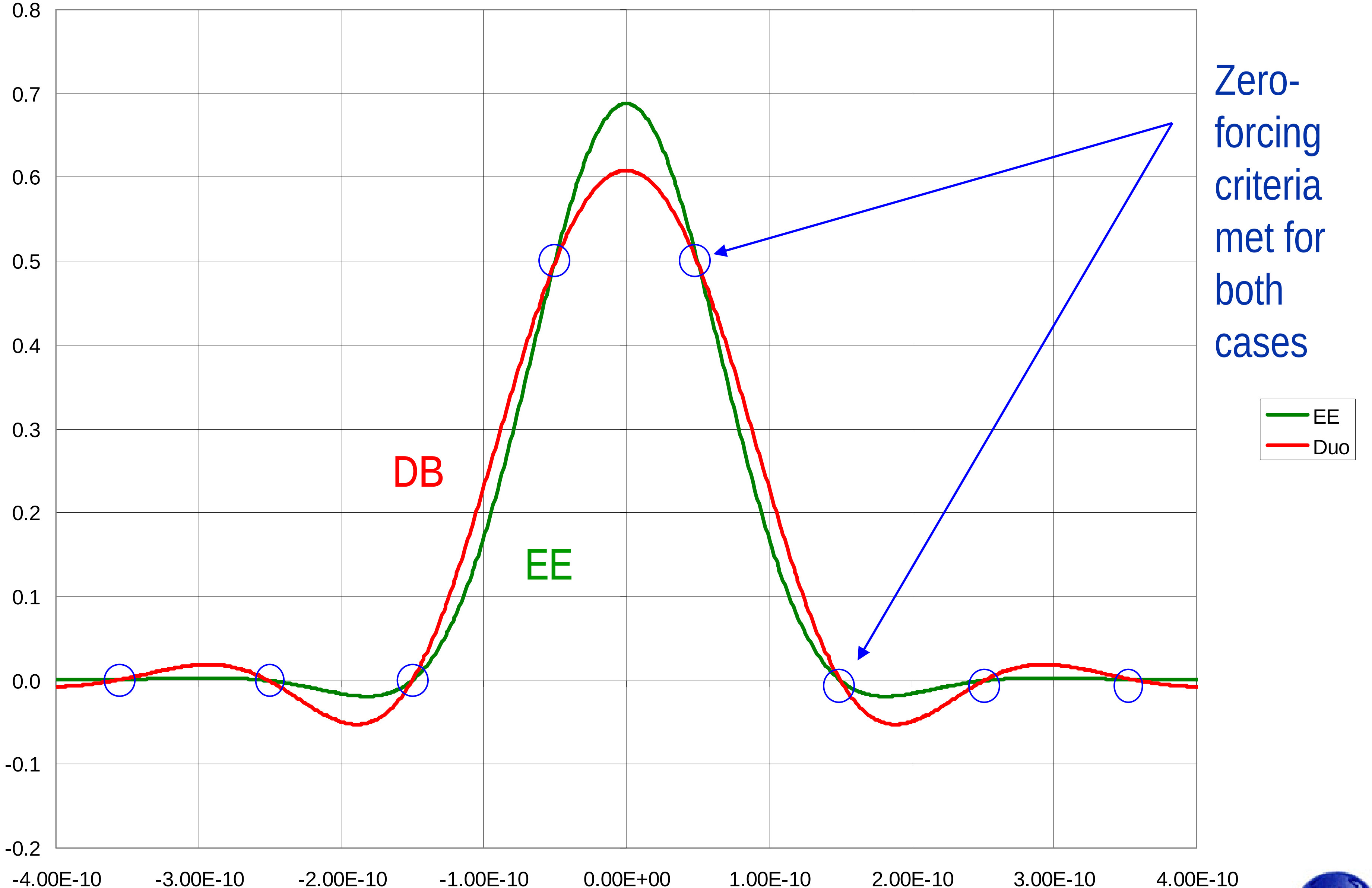
Duobinary composite pulse generation



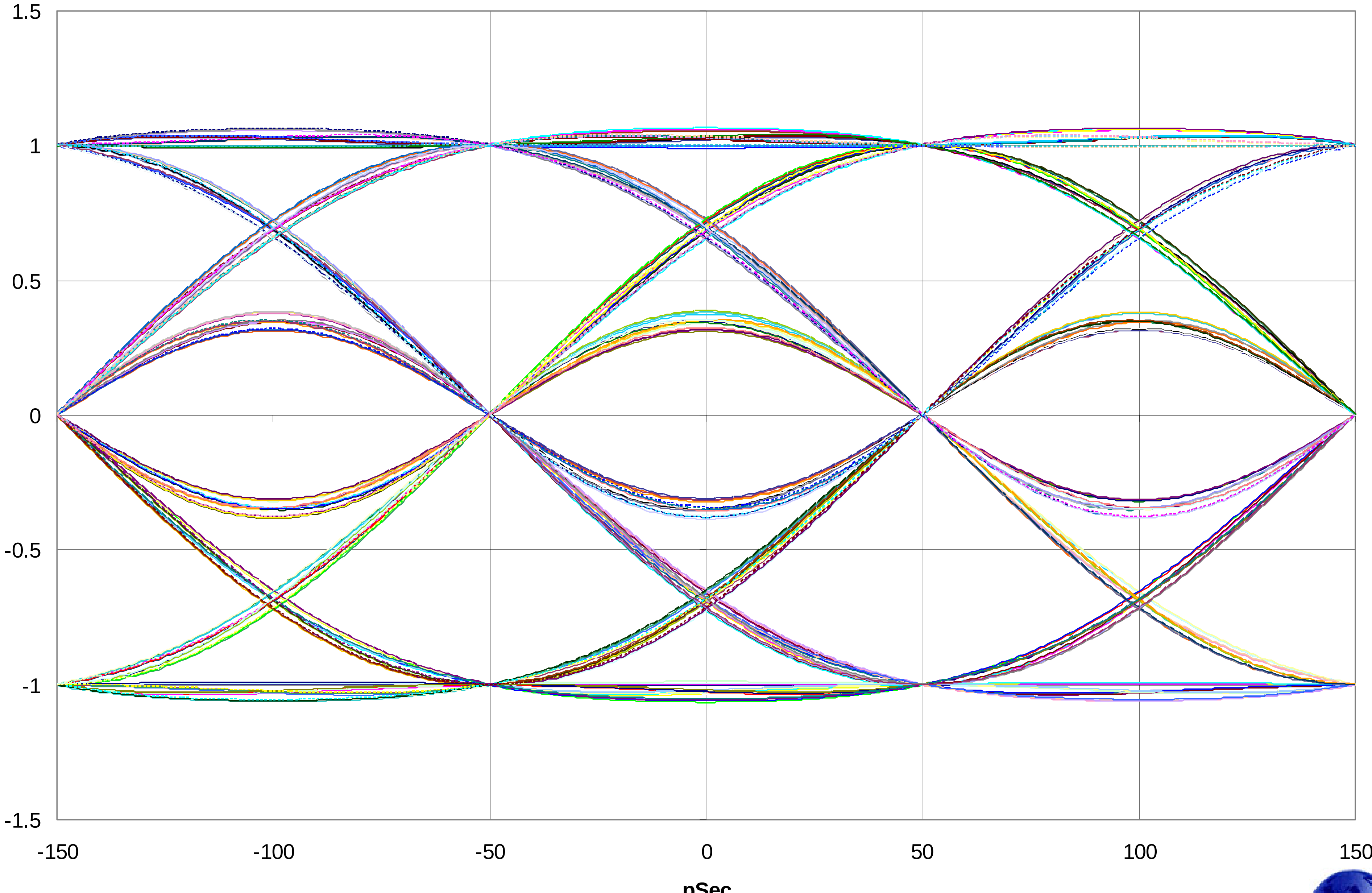
Equalizer Freq response overlay



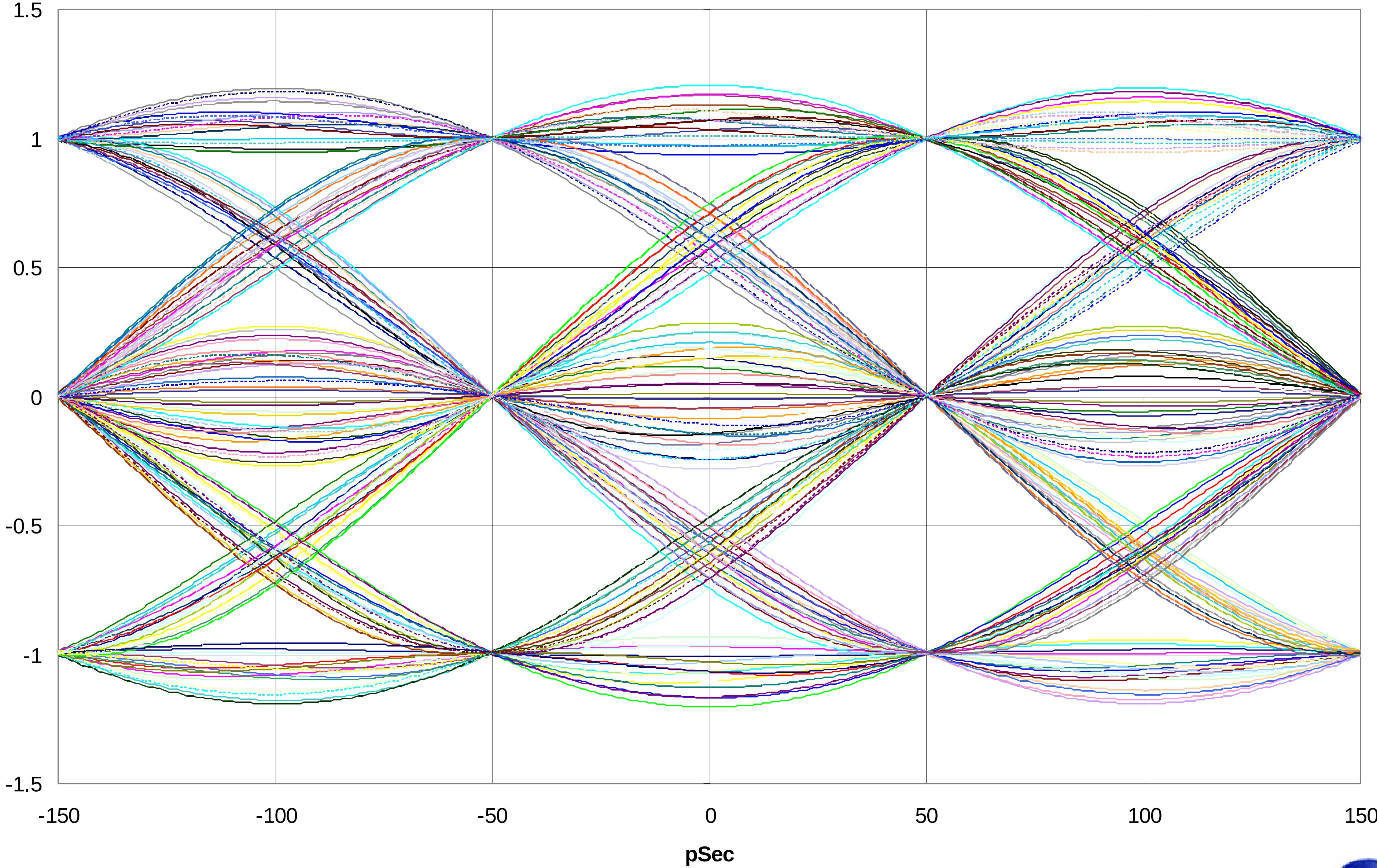
Composite pulse response overlay



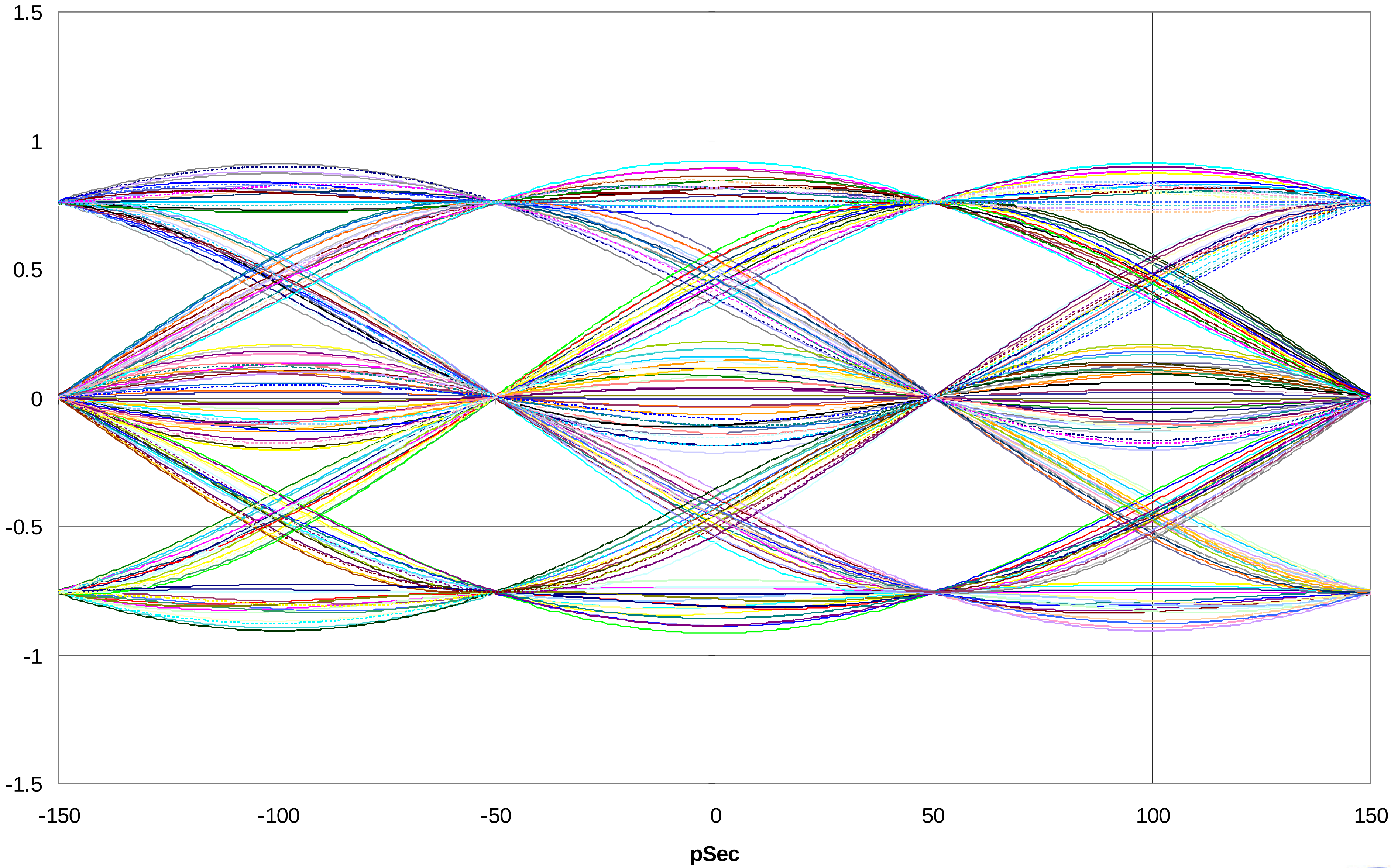
EE-NRZ eye diagram



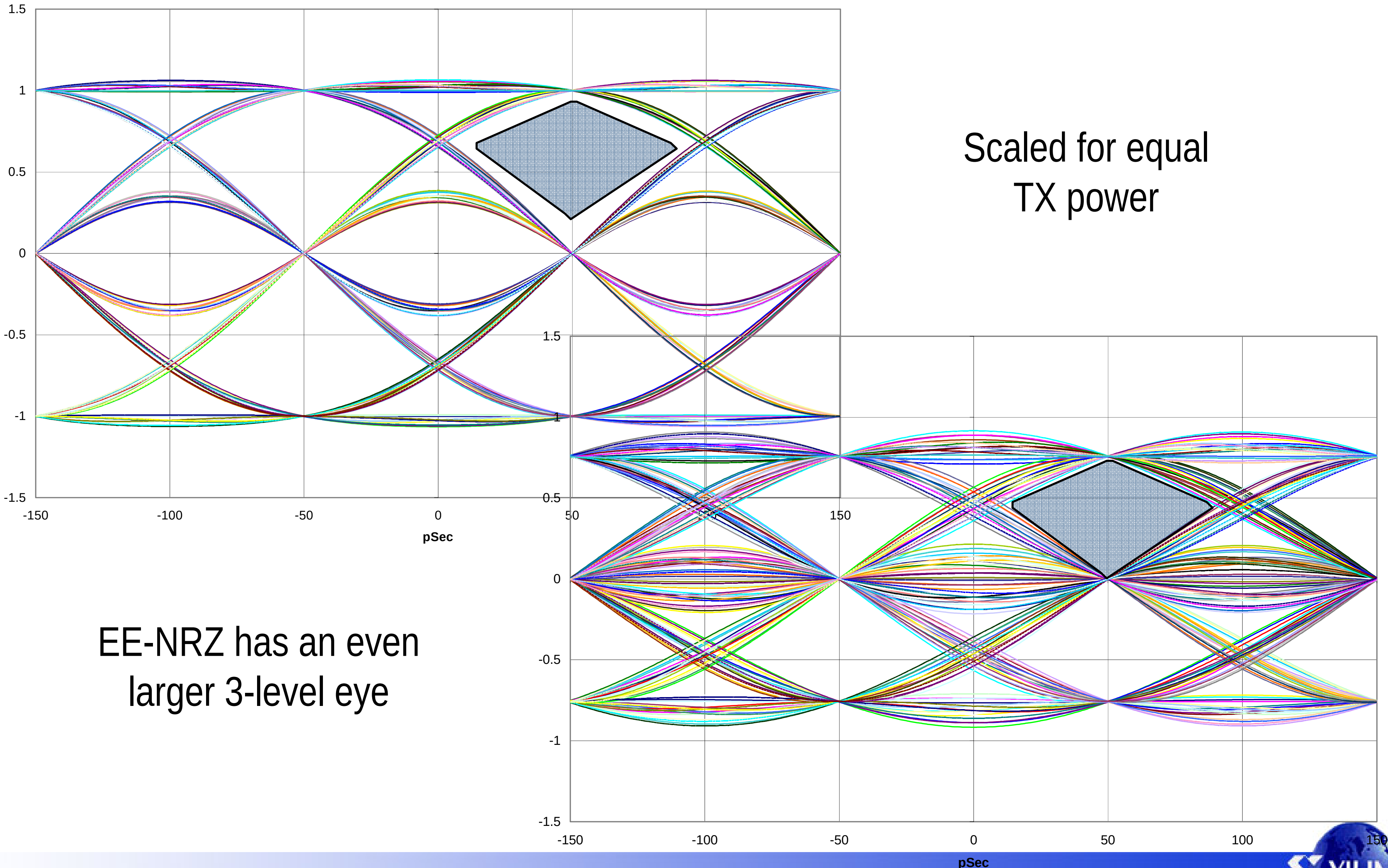
Duobinary eye diagram



Duobinary eye scaled for equal Tx power



EE-NRZ and Duobinary comparison



Scaled for equal TX power

EE-NRZ has an even larger 3-level eye

Conclusion

- Using a channel with a given pulse response, two ways to construct symbol-spaced FIR filtered signaling that results in a 3-level constellation were shown. Both satisfy the … 0 0 .5 .5 0 0 … minimum squared error criteria.
- Demonstrated two resulting and distinct composite pulse responses satisfying the same error criteria and offering insight into the apparent NRZ/null at 5GHz paradox.
- In one implementation (odd), the signal is both 2-level and 3-level detectable. This EE-NRZ.
- In the other implementation (even), the signal is only 3-level detectable. It has a null at 5GHz.
- When scaled for equal TX power, the 3-level eye opening is larger for the odd implementation.

- Optimal FIR equalized NRZ and duobinary receivers may want the exact same tap settings.