Dealing with De-emphasis in Jitter Testing

TECHNICAL BRIEF

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Summary

This paper addresses the use of the linear

Recently transmit de-emphasis has become a popular element in equalized serial data transmission systems. Most commonly, this is in the form (or an equivalent form) of a digital filter. The digital filter is most often a two tap filter with one cursor tap and one precursor tap. The digital filter can be represented as:

$$H(z) = C + P \cdot z^{-1}$$

where C is the weight of the cursor tap and P is the weight of the pre-cursor tap. Note that in this filter equation:

$$z = e^{j \cdot 2 \cdot \pi \cdot f \cdot UI}$$

and assumes that the sample rate of the filter is one sample per unit interval (UI).

The effect of this filter on the eye diagram as measured at the transmitter is shown in the Figure 1.

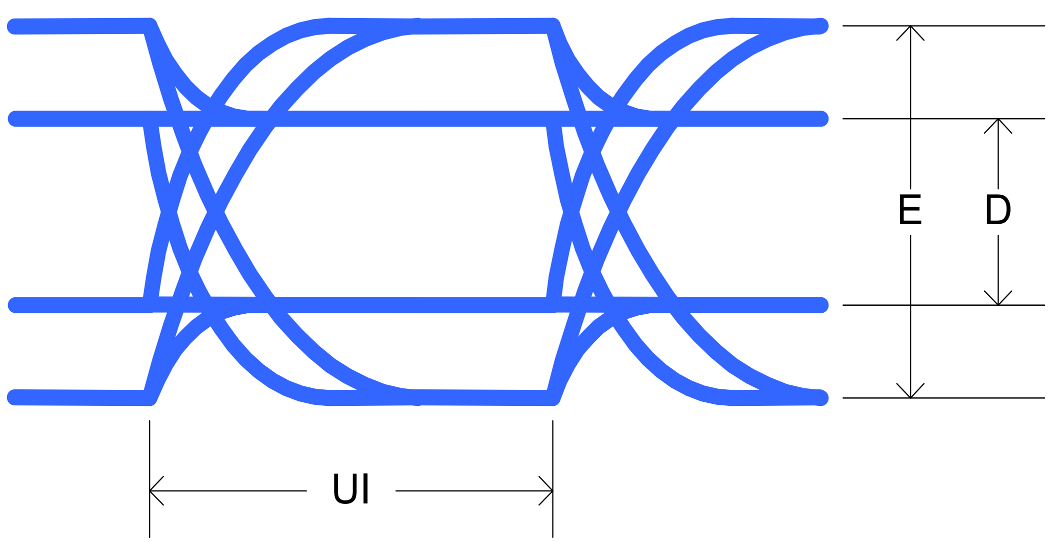

Figure 1 - Effect of De-emphasis on Transmitter Eye

In Figure 1, it can be seen that in the center of the bit, the intent is for the transmitter waveform to take on four discrete states, which form two eye heights designated as the de-emphasized height D and the emphasized height E.

The amount of de-emphasis is often expressed in decibels as:

$$dB = 20 \cdot \log\left(\frac{E}{D}\right)$$

The intent of this de-emphasis filter is to anticipate the loss in the transmission medium such that the signal arriving at the receiver is the de-emphasized height D. It turns out that for a given desired amount of de-emphasis, the filter coefficients C and P can be calculated as follows:

$$C + P = 10^{\frac{-dB}{20}}$$

$$C - P = 1$$

and therefore:

$$\begin{bmatrix} C \\ P \end{bmatrix} = \begin{bmatrix} 1 & 1 \\ 1 & -1 \end{bmatrix}^{-1} \cdot \begin{bmatrix} 10^{\frac{-dB}{20}} \\ 1 \end{bmatrix} = \begin{bmatrix} \frac{1}{2} \cdot 10^{\frac{-dB}{20}} + \frac{1}{2} \\ \frac{1}{2} \cdot 10^{\frac{-dB}{20}} - \frac{1}{2} \end{bmatrix}$$

A problem arises in the testing of transmitter jitter when this type of de-emphasis filter is applied. As can be seen, if the eye is measured at the transmitter, there is significant amounts of additional deterministic jitter in the form of inter-symbol interference (ISI). One expects this ISI because again, the channel is assumed to introduce an essentially equal and opposite amount of ISI such that the eye at the receiver has minimal amounts of ISI.

In testing jitter at the transmitter, it is advantageous to remove the added ISI effects due to de-emphasis when measurements are made.

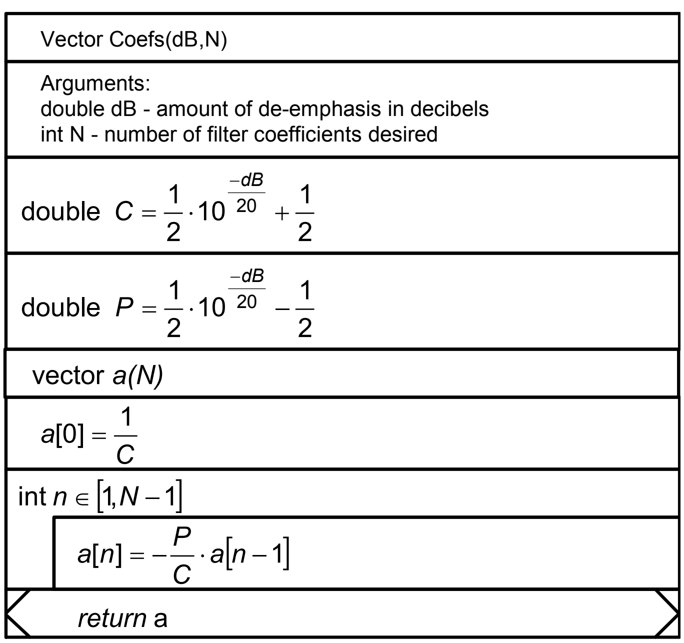

Figure 2 - NS diagram of inverse filter tap calculation algorithm

An obvious technique would be to create an inverse filter:

$$G(z) = \frac{1}{C + P \cdot z^{-1}}$$

such that:

$$H(z) \cdot G(z) = 1$$

Filter $G(z)$ presents some difficulties in the fact that it is infinite impulse-response (IIR).

This can be seen by calculating the difference equation:

$$G(z) = \frac{Y(z)}{X(z)} = \frac{1}{C + P \cdot z^{-1}}$$

$$X(z) = C \cdot Y(z) + P \cdot z^{-1} \cdot Y(z)$$

$$Y(z) = \frac{1}{C} \cdot X(z) - \frac{P}{C} \cdot z^{-1} \cdot Y(z)$$

Finally, taking the inverse z-transform:

$$y[k] = \frac{1}{C} \cdot x[k] - \frac{P}{C} \cdot y[k-1]$$

An easy way to implement the filter that undoes the de-emphasis effects is to expand the original filter in a series. This is most easily done by simply sampling the impulse response of the filter. This can be performed using the calculated difference and taking a desired number of terms such that the residual error due to truncation of the response (remember, the response is infinite) is negligible:

$y[0] = \frac{1}{C}$,

$y[1] = -\frac{P}{C} \cdot y[0]$,

$y[2] = -\frac{P}{C} \cdot y[1]$, etc.

Therefore, a concise algorithm for generating a filter that deals with a given amount of de-emphasis for transmitter testing can be given in Figure 2. The filter is implemented as:

$$y[k] = \sum_{n=0}^{N-1} a[n] \cdot x[k-n]$$

An example can be shown by using the built in linear equalizer in the LeCroy Serial Data Analyzer (SDA) software. More advanced types of equalizers require the Eye Doctor ™ option.

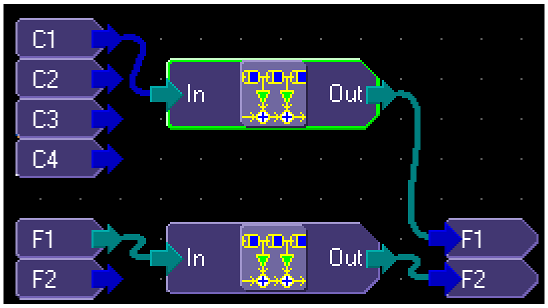

Figure 3 – Equalizers in LeCroy processing web

Figure 3 shows a configuration of two linear tapped-delay line equalizers in the LeCroy processing web.

In this example, a transmitter waveform is acquired on channel 1, and a tapped-delay line equalizer is utilized to simulate de-emphasis and is provided to math trace F1. F1 is then fed to another tapped-delay line equalizer that is utilized to remove the de-emphasis effects.

Figure 4 shows the jitter measurement of F1 where the de-emphasis has been applied. Here, one can see that significant amounts of deterministic jitter have been added due to the de-emphasis. Figure 5 shows the filter setup for the filter that simulates the de-emphasis. Note that 6 dB of de-emphasis has been used.

Figure 6 shows the result of F2 with another tapped delay line filter utilized to remove the de-emphasis. The algorithm provided in this document has been used to calculate the filter tap settings shown in Figure 7. Note that the measurement in Figure 6 shows almost no deterministic jitter and approximately the same amount of random jitter as in Figure 4.

As one final note: All discussion here was to undo the effect of the de-emphasis to generate the original, transition eye. Scaling all filter coefficients by $10^{-\frac{dB}{20}}$ generates the smaller, non-transition eye.

To summarize, an ideal equalizer component is useful for not only adding levels of receive or even transmit equalization, but are also useful for undoing equalization in the form of transmitter de-emphasis in order to perform proper jitter testing of transmitters that employ transmit equalization.

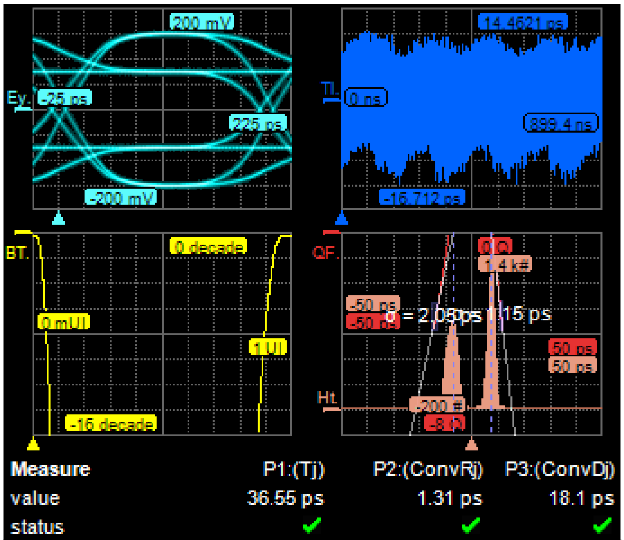

Figure 4 – De-emphasized Eye and Jitter Measurement

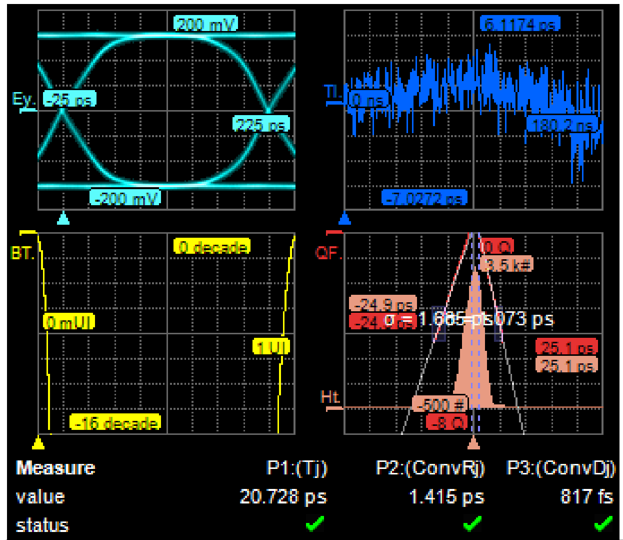

Figure 6 – Eye and Jitter Measurement with De-emphasis Removed

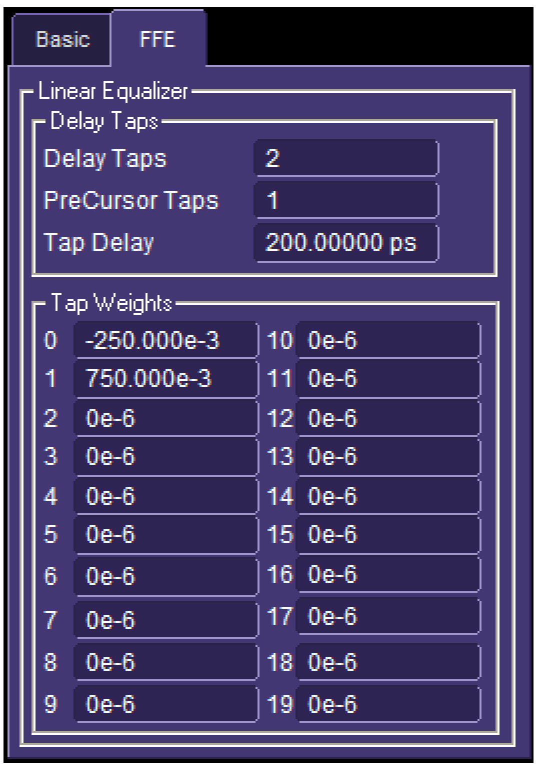

Figure 5 – De-emphasis Filter Settings

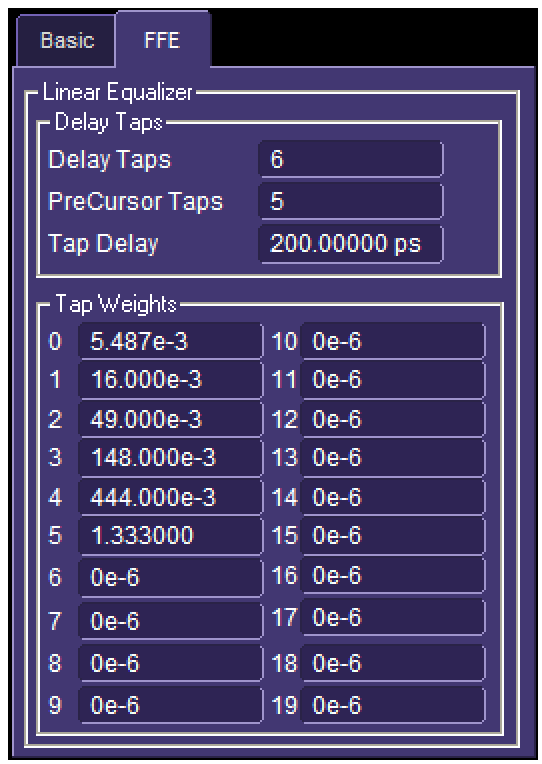

Figure 7 – Filter Settings for De-emphasis Removal