FIR Filter Optimization as Pre-emphasis of High-speed Backplane Data Transmission

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Abstract — FIR filter pre-emphasis has been used to counteract inter-symbol interference (ISI) in high-speed backplane data transmission. In this paper, backplane channel characteristics are first analyzed. It is found that channel group delay distortion is also a major ISI contributor in addition to amplitude attenuation. A MATLAB program is then described for optimization of FIR filter under LMS criterion. Both symbol-spaced FIR (SSF) and fractionally-spaced FIR (FSF) are comparatively studied at different data rates. The determination of tap number and preference of FSF to SSF are discussed.

Keywords: Pre-emphasis, ISI, FIR filter, backplane, LMS

I. INTRODUCTION

High-speed serial interface, which significantly reduces I/O pin count and increases maximum bandwidth per pin, is replacing conventional low-speed parallel bus for backplane communications. ISI is the major factor limiting the maximum distance and data rate of backplane data transmission. ISI is caused by channel impairments such as amplitude attenuation and group delay distortion. FIR filter pre-emphasis at transmit side is a widely used technique in industry to reduce ISI [1,2]. There are two types of FIR filter: symbol spaced and fractionally spaced. Optimization of FIR is needed in order to obtain the best performance at receive side.

A MATLAB program has been developed to study the FIR filter pre-emphasis. In this paper, channel characteristics are first analyzed in section 2. The MATLAB program is described in section 3. Simulation results are given and analyzed in section 4 and finally section 5 is the conclusion.

II. CHANNEL CHARACTERISTICS

Figure 1 shows the configuration of a backplane transceiver link with FIR pre-emphasis. The backplane channel typically consists of a transmit daughter card, a backplane, a receive daughter card and connectors. FIR filter pre-emphasis is used to counteract ISI caused by PCB traces, connectors, chip packages, etc.

Figure 1 shows the channel impulse response with and without group delay distortion. Without group delay distortion (amplitude attenuation alone), the impulse response is attenuated and symmetrically dispersed. However, the impulse response becomes asymmetrical due to group delay distortion. The resulting long tail of impulse response causes more severe post-cursor ISI, degrading the eye opening as shown in Figure 2 (c). Therefore, group delay distortion should be taken into account for channel modeling and FIR filter design.
III. MATLAB PROGRAM

The structure of FIR filter is shown in Figure 3. For symbol-spaced FIR (SSF), the delay D is equal to one symbol period T. The transfer function of SSF in z-domain is given by

\[ H(z) = \sum_{n=-\infty}^{\infty} h_n z^{-n} \]  

where \( h_n \) is the tap coefficient, \( z = \exp(j2\pi f/T) \), and the sampling frequency \( f_s = 1/T \). For a fractionally spaced FIR (FSF), the delay D is a fraction of T (e.g., D=1/2).

A MATLAB program is developed to optimize FIR filter pre-emphasis. It consists of two parts: FIR optimization and link simulation, as shown in Figure 4.

\[ C[n+1] = C[n] + \mu \cdot e \]  

where \( C \) is the tap coefficient, \( \mu \) is the step size, \( n \) is the distorted signal, and \( e \) is the error signal. The convergence of error drives the tap coefficients to their optimal values.

Once the optimal tap coefficients are obtained, FIR filter pre-emphasis is applied in link simulation. The data source, FIR filter and channel are first multiplied in frequency domain, and then converted to time domain using IFFT. Finally, the far-end eye diagram is plotted. The block called Parameters Input accepts user-defined parameters such as selection of symbol-spaced or fractionally-spaced FIR, tap number, file containing the measured S-parameters of channel, data rate and so on.
IV. CASE STUDIES AND ANALYSIS

The 34" FR4 backplane discussed above is used as transmission channel. SSF and FSF are optimized through the MATLAB program at data rates of 3.125Gbps, 6.25Gbps and 10Gbps. The tap number of SSF is varied to determine the optimum one. The performance of SSF and FSF is compared.

A. Symbol-spaced FIR Filter

The optimal tap coefficients of SSF are obtained at above data rates for the post-tap number varied from 1 to 10 (the total tap number is from 2 to 11). The far-end eye diagrams are drawn after applying the obtained SSF pre-emphasis to the link. The horizontal and vertical eye opening versus tap number is shown in Figure 5 (a) and (b), respectively.

![Figure 5](image)

(a)

![Figure 5](image)

(b)

Figure 5 Eye opening vs. tap number: (a) horizontal eye opening; (b) vertical eye opening with differential input voltage Vpp=500mV.

For both horizontal and vertical eye opening, there exists a tap number beyond which eye opening cannot be notably improved by simply increasing the number of taps. This tap number is optimal in terms of performance and complexity trade-off for FIR implementation. Figure 6 shows the pulse response of channel at different data rates.

![Figure 6](image)

Figure 6 Channel pulse responses at different data rates.

It is not surprising to find that the optimal tap number obtained through LMS optimization is close to the least number of symbol-spaced points (circle for 3.125Gbps, square for 6.25Gbps and star for 10Gbps) that cover the most part of the tail of the pulse response. For the 34" FR4 backplane used here, 4 post-taps is optimal for 3.125Gbps and 6.25Gbps, and 5 post-taps is optimal for 10Gbps. SSF pre-emphasis with the obtained optimal tap number is applied to the link at different data rates. Far-end eye diagrams with and without SSF pre-emphasis are compared in Figure 7. The effectiveness of SSF pre-emphasis can be clearly seen.

![Figure 7](image)

(a)

![Figure 7](image)

(b)

![Figure 7](image)

(c)

Figure 7 Comparison of eye diagrams without and with SSF pre-emphasis: (a) 3.125Gbps; (b) 6.25Gbps; (c) 10Gbps.
B. Fractionally-spaced FIR Filter

The performance of SSF is limited by aliasing, as a result of sampling at 1/T. It cannot compensate for channel impairments beyond the sampling frequency 1/T. FSF samples at a fraction of T and thus extends the compensation beyond 1/T. It is expected that FSF pre-emphasis can perform better than SSF. Three cases are studied in the following example: 3-tap T-spaced FIR, 3-tap T/2-spaced FIR and 5-tap T/2-spaced FIR. The performance comparison at different data rates is shown in Table 1.

<table>
<thead>
<tr>
<th>Horizontal (UI)</th>
<th>3-tap</th>
<th>3-tap</th>
<th>5-tap</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vertical (V)</td>
<td>SSF</td>
<td>FSF</td>
<td>FSF</td>
</tr>
<tr>
<td>3.125Gbps</td>
<td>0.93</td>
<td>0.93</td>
<td>0.96</td>
</tr>
<tr>
<td></td>
<td>/0.23</td>
<td>/0.20</td>
<td>/0.22</td>
</tr>
<tr>
<td>6.25Gbps</td>
<td>0.86</td>
<td>0.83</td>
<td>0.89</td>
</tr>
<tr>
<td></td>
<td>/0.11</td>
<td>/0.11</td>
<td>/0.12</td>
</tr>
<tr>
<td>10Gbps</td>
<td>0.66</td>
<td>0.62</td>
<td>0.68</td>
</tr>
<tr>
<td></td>
<td>/0.03</td>
<td>/0.03</td>
<td>/0.03</td>
</tr>
</tbody>
</table>

The eye opening of the 3-tap FSF is worse than that of the 3-tap SSF since the 3-tap FSF only covers half the time span of the 3-tap SSF. However, FSF always performs better than SSF if the same time span is covered. The 5-tap FSF shows larger horizontal eye opening than the 3-tap SSF for all three data rates. For the backplane channel studied here, the performance gain of T/2 FSF over SSF is not significant. Further improvement can be observed for FSF pre-emphasis by reducing the delay, D to a smaller fraction of T. The selection of FSF vs. SSF is channel dependent and involves a trade-off between performance and implementation complexity.

V. CONCLUSION

FIR filter pre-emphasis has been studied for backplane channel equalization using the developed MATLAB program. It is found that channel group delay distortion is a major ISI contributor that has to be taken into consideration for channel modeling and FIR design. SSF and FSF are comparatively studied at different data rates. It is verified that the optimal tap number obtained through LMS optimization is close to the least number of symbol-spaced points that cover the most part of the tail of the pulse response. As expected, FSF performs better than SSF if the same time span is covered. The MATLAB program can be used to optimize FIR pre-emphasis and provide design guidelines for given channels.

REFERENCES