Improved time domain simulation of optical multimode intrasystem interconnects

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Abstract

To increase the bandwidth of high-performance intrasystem interconnections optical multimode waveguides can be used. Since the design procedure of optical interconnections has to be widely compatible with conventional design processes, adequate simulation methods are required. This paper presents an improved time domain method for simulating the signal transmission along optical multimode interconnections. The improvements mainly result from the more efficient method for the piecewise approximation of the waveguides step responses by a few exponential functions. The adapted semi-analytical recursive convolution method decreases the computation times.

1 Introduction

As the throughput rates of future computer- and communication-systems approach several Tbit/s, the system interconnects are becoming a major bottleneck for overall performance. It is generally accepted that the use of light to transmit fast signals is currently the only realistic approach to solve such problems. Beside reasonable costs, the most important precondition for this new technology is its compatibility to existing design processes. This requires new simulation methods for an efficient design. To be compatible optical multimode technology will be used. Those waveguides support a high number of propagating modes and hence FEM/BPM methods aren't applicable for simulation of such interconnections. This paper deals with an improved semi-analytical approximation method for the step responses of an optical multimode waveguide. The work presented is the improvement of [2].

2 Basic approach and simulation strategy

In general the optical system consists of several receivers and one transmitter which are connected by a passive optical waveguide. A precise computation of the field distribution of higher order modes would be very expensive and therefore only ray tracing methods [1] are applicable. This allows it to represent the waveguide as a multiport. The transfer of a stimulating signal $x(t)$ along a path which is characterized by its pulse response $h(t)$ can be computed by the convolution of $x(t)$ and $h(t)$. The pulse response is derived from the step response, which has been calculated by an extended ray tracing algorithm. For the time domain convolution, very efficient semi-analytical recursive convolution algorithms can be applied if the pulse response is represented by exponential functions. Finally, the application of a recursive convolution of the optical stimulus signals enables a time efficient computation of the optical response signals.

3 Analytical approximation

The application of the ray tracing method results in a numerical representation of the step response $a(nT)$. The efficiency of the time domain simulation is determined significantly by the chosen approach for the approximation. The approximating function is ($\sigma(t)$: ideal step function):

$$\widetilde{a}(t) \approx \sum_{p=1}^{P} \widetilde{a}_p(t) \cdot \left[\sigma(t - t_{p,begin}) - \sigma(t - t_{p,end})\right] \ . \qquad (1)$$

Thus the pulse response which is the derivative of the step response will also be approximated piecewise by a sum of exponential functions. Due to the piecewise approximation of the step responses, it is possible to use simple exponential functions in each approximation interval.

$$\widetilde{a_p}(t) = \widetilde{a}_{p,0} + \widetilde{a}_{p,1} e^{\alpha_p (t - t_{p,begin})} . \tag{2}$$

Parametrization requires only the determination of the three parameters per interval. The solution of the nonlinear equation system can be calculated analytically.

3.1 Improved approximation algorithm

The improved approximation algorithm calculates an optimized approximation of the step response. The basic idea is, that for all arrangements of intervals for this step response the approximation will be calculated. To get the best accuracy the approximation with the minimal relative approximation error should be used but this is the approximation with the highest number of intervals ($P = 30$). To distinguish among approximations a cost function is defined:

$$C(Ar_P) = E_{R,min}(Ar_P) \cdot P. \tag{3}$$

In fact the run time of the algorithm (s. Tab. 1) is of quadratical order but it must be executed only *one* time.

```
for P = 2 to P_max do
 for all arrangements Ar_P_i do
  Calc. app. error E_R(Ar_P_i)
  if ( E_R(Ar_P_i) < E_R_min )
   E_R_min = E_R(Ar_P_i)
   Ar_P = Ar_P_i
 C(Ar_P) = E_R_min · P
 if ( C(Ar_P) < C_Min )
  C_Min = C(Ar_P)
  Min_Ar = Ar_P
return Min_Ar
```

Table 1. Algorithm outline.

4 Example and results

The very good agreement between the approximated and the original step response is shown in Fig. 2. The number of intervals was reduced from 10 to 3 with equal accuracy.

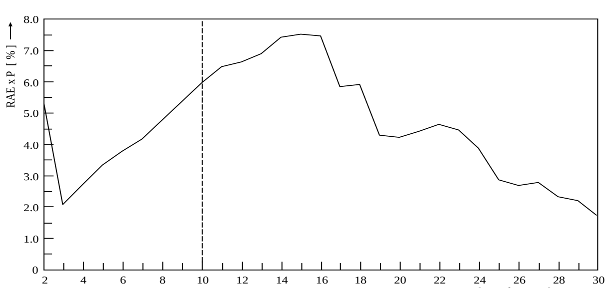

Figure 1. Cost function $C(Ar_P)$.

Every arrangement left of the dashed line in Fig. 1 is applicable because of the mixture between accuracy and a small number of intervals.

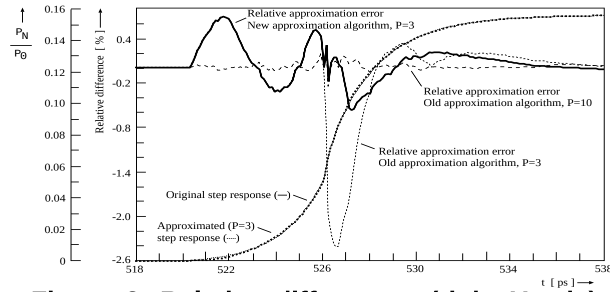

Figure 2. Relative differences (right Y-axis) and comparison of original and approximated step response (left Y-axis).

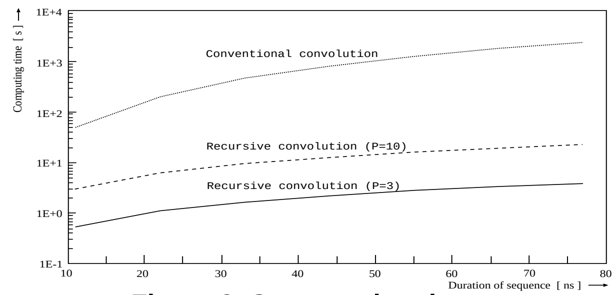

Figure 3. Computation times.

The computation time for the conventional convolution, the recursive convolution with $P = 10$ and $P = 3$ (new appproximation algorithm) is shown in Fig. 3. The speed factor is of nearly $15 \ldots 100$ of recursive convolution opposite to the conventional convolution. The recursive convolution with the new approximation algorithm has a speed factor to the old algorithm of nearly 5.

5 Conclusions

The improved approximation algorithm decreases the computation times significantly. The accuracy of the new approximation algorithm is nearly the same as with the conventional approximation algorithm. There is a significant improvement of computation times at the design process.

References

[1] T. Bierhoff, E. Griese, and G. Mrozynski. An efficient Monte Carlo technique for the characterization of highly multimode dielectric waveguides with rough surfaces. In *Proc. 30th European Microwave Conf., Vol. 1*, pages 379–382. Paris (France), Oct. 2000.

[2] E. Griese, J. Schrage, J. Gerling, and G. Mrozynski. Time domain simulation of optical multimode chip-to-chip interconnects. In *Proc. of SPIE's Int. Sym. on Optical Science and Technology, Vol. 4455, San Diego/CA (USA)*, 2001.