

Hybrid frequency/time domain field theory based CAD of microwave circuits

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Abstract

In this paper we report the first successful combination of a frequency domain CAD program, namely OSA90/hopeTM, with a time domain TLM electromagnetic field simulator running on various hardware platforms. The technique allows optimization of microwave structures using time domain field analysis without the need for equivalent circuits or lookup tables. A comparison of the execution speed of the TLM field simulator on a number of computers, from IBM PCs to workstations to massively parallel computers have been made. This provides a clear picture of the required CPU time for performing such simulations on various hardware platforms. A detailed account of the hybrid frequency/time domain procedures, advantages and disadvantages of combining the frequency and time domain methods as well as parallel programming techniques on the DECmvp 12000 with a view towards future hybrid domain CAD/CAM systems are given. The principal application is field-based hybrid domain modeling of complex microwave and millimeter wave structures.

Introduction

At present, field theory based microwave circuit CAD/CAM is performed in the frequency domain. This is more a matter of traditional practice and available computer power than a theoretical constraint. This paper reports the first successful combination of a frequency domain CAD program with a time domain TLM electromagnetic field simulator. Procedures, advantages and disadvantages of such a hybrid domain system are discussed.

The commercially available CAD program OSA90/hope has several DatapipeTM communication protocols, [1], which allow users to incorporate special elements into their circuit simulation using high-speed UNIX interprocess communication. This feature allows the OSA90/hope CAD program to run on its host machine, and to control external executable programs for the user defined elements running on the same or other machines. This is a very important feature for hybrid domain CAD systems, especially those depending on powerful field-based time domain simulators such as TLM and FD-TD. Furthermore, since the Datapipe protocol preserves the integrity of the field simulator, the user can visualize the fields while the structure is being optimized. We have successfully combined the OSA90/hope with a TLM electromagnetic field simulator [2], [3]. This allows analysis and optimization of complex microwave structures using field analysis directly without the need for equivalent circuits or lookup tables. Network piping was also used to combine a massively parallel version of the TLM electromagnetic field simulator, [4], with OSA90/hope, but there are a number of constraints at the present time to prevent this parallel engine to be used effectively with OSA90/hope. The constraints will be outlined in this paper as well.

Simulation Technique and Example

The simulation technique is depicted in Figure 1. The TLM

electromagnetic field simulator takes input parameters from the OSA90/hope program via an input pipe. The simulator then:

- Declares meshes of appropriate size.
- Sets up boundary conditions.
- Performs TLM simulation.
- Computes S parameters.
- Sends results back to the OSA90/hope program via an output pipe.

The above steps are applied repeatedly to optimize the geometry of a bandpass filter realized in WR28 rectangular waveguide, Figure 2. The mesh size of the filter structure is 128x20; it has six optimizable geometrical variables, and it takes about 30 seconds to perform a 4000-iteration analysis on a HP 9000 Series 700 Model 755 workstation. The optimized dimensions and responses are shown in Figure 2 and Figure 3, respectively. The corresponding OSA90/hope circuit file is shown at the end of this paper.

The TLM simulation module used with the OSA90/hope program can also run on IBM PCs, IBM RS 6000 stations, HP 9000 Series 700 stations, DEC RISC stations and DECmvp 12000. Figure 4 summarizes the performance of this module on these computers, and it can be used to estimate the CPU time requirement of similar modules on other machines.

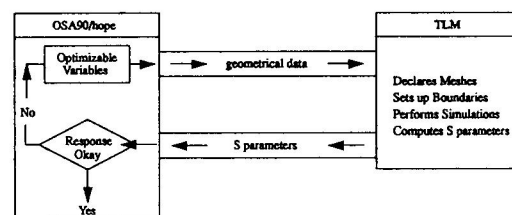


Figure 1 Simulation technique: OSA90/hope and TLM communicate through UNIX high speed Datapipe.

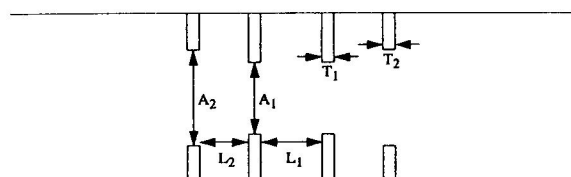


Figure 2 A bandpass filter in WR28 rectangular waveguide. The size of the structure is 128x20 Δ . The optimized dimensions are: $A_1 = 6 \Delta$, $A_2 = 11 \Delta$, $L_1 = 15 \Delta$, $L_2 = 13 \Delta$ and $T_1 = T_2 = 1 \Delta$, where $\Delta = 0.3556$ mm.

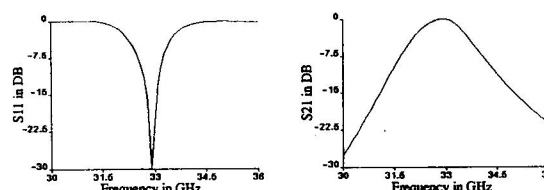


Figure 3 The frequency response of the bandpass filter shown in Figure 2.

Computers	CPU time in seconds
Toshiba PC, Model TS200/100	6500
IBM Model 90 XP486	1250
DEC RISC, Model 5100	352
IBM RS6000, Model 350	117
HP 9000, Series 7000, Model 755	88
DECmvp 12000	12

Figure 4 Execution time of the TLM field simulation module on various computers. The mesh size is 128x64 for 4000 iterations. This provides a clear picture of the required CPU time for performing TLM field simulations on various hardware platforms. A mesh size of 128x64 represents a full use of the DECmvp 12000 that we used which has 8K (8192) processors.

Advantages and Disadvantages

There are a number of advantages and disadvantages when combining frequency and time domain methods in CAD/CAM systems. The advantages are:

- In the time domain, a single analysis using an impulse excitation yields information at an arbitrary number of frequency points within the desired bandwidth.
- The computer expenditure for the time domain analysis depends mainly on the size of the computational domain and not on the complexity of the geometry or the number of variables describing it. The number of frequency points does not affect the simulation speed significantly because Fourier transform operations (DFT and FFT) are very fast.
- The bandwidth covered by the time domain analysis can be determined within reason by limiting the bandwidth of the excitation signal with a corresponding gain in computer time.

The disadvantages of these hybrid domain CAD/CAM systems are:

- Powerful computers, preferably computers with massively parallel processors, with fast execution speed and huge amounts of memory are needed to run the field-based simulator in order to have a reasonably fast turn-around time.
- Practitioners must grasp both the frequency and time domain concepts.
- There are no standards for pipe communication in CAD/CAM systems, which makes porting of the field simulators among them difficult.

DECmpp 12000 Constraints

The DECMpp 12000 is a very powerful machine for this type of applications. It can perform computations 30 times faster than its front-end, DEC RISC 5100. But there are also a number of constraints which make general use of the machine difficult. The constraints are as follows:

- The front-end station must be a DEC station. If the parent process cannot run on a DEC station then it must communicate with its child process via network pipes rather than the high speed UNIX pipes. Hence network piping becomes the bottle neck. The example in Figure 4 requires 12 and 30 seconds for simulation on the DECMpp 12000 and the network piping, respectively.
- The dimensions of the problem must fit the dimensions of the processor array of the DECMpp 12000 in order to realize the full computing power of the machine.
- Researchers must reformulate the CPU time intensive serial algorithm into a parallel one. Just recompiling the serial code with a parallel compiler usually does not gain any performance.

A Massively Parallel TLM Algorithm on the DECMpp 12000

In order to realize the full power of the DECMpp 12000, the TLM simulation module of the simulator in [2] was rewritten using the parallel languages of the DECMpp 12000. The theoretical and programming details of such a parallel implementation are described in [4]. The basic idea is that both the scattering and transfer of impulses are highly localized operations. The former is totally localized within each node and the latter is localized within the immediate surrounding region of a node, namely its four adjacent nodes. Therefore, scattering of impulses can be carried out in each node simultaneously, and transfer of impulses can be carried out in each region simultaneously as long as synchronization among adjacent nodes is preserved. In other words, these two operations can be carried out in parallel at each node and in the region of each node.

MPF and MPL are the two parallel languages available for programming the DECMpp 12000. Because the simulation module and OSA90/hope communicate with each other via pipe (or network pipe), the simulation module can be written in either language. Advantages and disadvantages of using MPF and MPL are discussed in [4].

Conclusion

A hybrid frequency/time domain CAD technique has been developed and implemented on various computers. The technique allows optimization of microwave structures using time domain field analysis without the need for equivalent circuits or lookup tables. A comparison of the execution speed of the TLM field simulator on a number of computers, from IBM PCs to workstations to massively parallel computers is given. This provides a clear picture of the required CPU time for performing such simulations on various hardware platforms. A detailed account of the procedures, advantages and disadvantages of combining the frequency and time domain methods as well as parallel programming techniques on the DECMpp 12000 with a view towards future hybrid domain CAD/CAM systems are given. The principal application is field-based hybrid domain modeling of complex microwave and millimeter wave structures.

References

- [1] OSA90/hope™ Version 2.0 User's Manual, Optimization Systems Associates Inc., P.O. Box 8083, Dundas, Ontario, Canada L9H 5E7, 1992.
- [2] W.J.R. Hoefer and P.P.M. So, The Electromagnetic Wave Simulator - A Dynamic Visual Electromagnetics Laboratory based on the Two-Dimensional TLM Method, John Wiley & Sons Ltd., 1991.
- [3] W.J.R. Hoefer, Time Domain Electromagnetic Simulation for Microwave CAD Applications, IEEE Trans. Microwave Theory and Technique, vol. MTT-40, no. 7, pp. 1517-1527, July 1992.
- [4] P.P.M. So, E. Channabasappa and W.J.R. Hoefer, Transmission Line Matrix Method on Massively Parallel Processor Computers, ACES Conference Proceedings, pp. 467-474, March 22-26, 1993.

OSA90/hope Circuit File

```
! Example 2d-wr28-filter.ckt
! optimization with external simulator via Datapipe
#define S11_FLAG 0
#define S21_FLAG 1
#define DEF_SPEC 0
#define ZERO_SPEC 0
#define ONE_SPEC 1
#define S11_SPEC 0
#define S21_SPEC 1
Expression
A = 20;
L = 128;
A1 = ? 4 6 16 ?;
A2 = ? 4 11 16 ?;
L1 = ? 13 15 17 ?;
L2 = ? 11 13 15 ?;
T1 = ? 1 1 4 ?;
T2 = ? 1 1 4 ?;
Datapipe: SIM FILE="WR28-Filter-osa"
N_INPUT=11 INPUT=(A,A1,A2,L,L1,L2,T1,T2,S11_FLAG,FREQ,DEF_SPEC)
N_OUTPUT=1 OUTPUT=(Mag_S11);
Datapipe: SIM FILE=SAME
N_INPUT=11 INPUT=(A,A1,A2,L,L1,L2,T1,T2,S21_FLAG,FREQ,DEF_SPEC)
N_OUTPUT=1 OUTPUT=(Mag_S21);
Datapipe: FUN FILE="WR28-Filter-osa"
N_INPUT=11 INPUT=(A,A1,A2,L,L1,L2,T1,T2,S11_FLAG,FREQ,ZERO_SPEC)
N_OUTPUT=1 NAME=S11_Pass_Band;
Datapipe: FUN FILE=SAME
N_INPUT=11 INPUT=(A,A1,A2,L,L1,L2,T1,T2,S11_FLAG,FREQ,ONE_SPEC)
N_OUTPUT=1 NAME=S11_Stop_Band;
Datapipe: FUN FILE=SAME
N_INPUT=11 INPUT=(A,A1,A2,L,L1,L2,T1,T2,S21_FLAG,FREQ,ONE_SPEC)
N_OUTPUT=1 NAME=S21_Pass_Band;
Datapipe: FUN FILE=SAME
N_INPUT=11 INPUT=(A,A1,A2,L,L1,L2,T1,T2,S21_FLAG,FREQ,ZERO_SPEC)
N_OUTPUT=1 NAME=S21_Stop_Band;
end
Sweep
FREQ: from 30.0GHZ to 36.0GHZ step 0.1GHZ Mag_S11, Mag_S21
end
Specification
Datapipe: FREQ: from 30.0GHZ to 32.0GHZ step 0.1GHZ S11_Stop_Band W=1;
Datapipe: FREQ: from 32.5GHZ to 33.5GHZ step 0.1GHZ S11_Pass_Band W=2;
Datapipe: FREQ: from 34.0GHZ to 36.0GHZ step 0.1GHZ S11_Stop_Band W=1;
Datapipe: FREQ: from 30.0GHZ to 32.0GHZ step 0.1GHZ S21_Stop_Band W=1;
Datapipe: FREQ: from 32.5GHZ to 33.5GHZ step 0.1GHZ S21_Pass_Band W=2;
Datapipe: FREQ: from 34.0GHZ to 36.0GHZ step 0.1GHZ S21_Stop_Band W=1;
end
Control
Optimizer=Random;
end
```