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NETWORK SUPERCOMPUTER IMPLEMENTATION IN MASSIVE CAD FOR VLSI COMPUTATIONS

Summary. The paper presents integrated network system containing the workstation and a supercomputer, fulfilling the tasks for graphic presentation of the massive numerical computations results, performed for CAD of multiconductor transmission lines design for VLSI structures. Time-consuming computations of energy characterization of the scaled multiconductor transmission lines has been shortened and the optimization of high speed CMOS buses was possible by parallel realization of numerical procedures. The computation process is controlled from the workstation working under Win98/2000 operating system, and numerical computations are performed by the SUN ENTERPRISE 6500 working on the UNIX platform.

ZŁOŻONE OBLICZENIA NUMERYCZNE W CAD DLA STRUKTUR VLSI W SIECIOWEJ IMPLEMENTACJI SUPERKOMPUTERA

Streszczenie. W pracy przedstawiono zintegrowany system sieciowy umożliwiający graficzną prezentację na stacji roboczej wyników złożonych obliczeń numerycznych realizowanych na superkomputerze dla celów komputerowego wspomaganie projektowania wieloliniowych transmisyjnych w strukturach VLSI. Czasochłonne obliczenia numeryczne związane z energetyczną charakterystyką wieloliniowych transmisyjnych na bazie skalowania geometrii struktur, poprzez zrównoleżenie procedur obliczeniowych znacznie skrócono, co pozwala w konsekwencji na optymalizację parametrów magistrali szybkich układów CMOS. Proces obliczeniowy jest sterowany ze stacji roboczej pracującej pod systemem Win98/2000, natomiast procedury numeryczne realizuje na platformie UNIX'owej superkomputer SUN ENTERPRISE 6500.

1. Introduction

Scaling of structures is conformed to high-speed VLSI/ULSI integrated circuit design [5, 12, 29]. In case when the geometrical dimensions decrease, multiconductor interconnections between parts of a system become strongly coupled multiconductor transmission lines (MTL), which have to be recharged with small geometry devices [18, 17]. The computer algorithms used for MTL characterization for design purposes are complex and time-consuming so the effective use of CAD tools needs a proper configuration of computing resources. In the paper, the workstation/supercomputer (parallel computer) system [19] called KSCAD fulfilling the above requirements is described. The numerical example are also included.

2. Outline of the Integrated Network System KSCAD

The integrated network system KSCAD performs two basic computer-aided design tasks in the two-computer system: the Graphic User Interface (GUI) is realized in the PC workstation, and the numerical computing needed in a CAD application are performed in the multiprocessor based parallel computer. Time-consuming computations of energy characterization of the scaled multiconductor transmission lines has been effectively shortened and the optimization of high speed CMOS buses was possible by parallel realization of the numerical procedures. The computation process is controlled from the workstation working under Win98/2000 operating system, and a numerical computations are performed by the Sun Enterprise 6500 server (12 high performance, 64-bit SPARC™ [Scalable Processor ARChitecture] V9 RISC microprocessors with full throughput equal to 6 GFLOPS) working under the Solaris™ 7 Operating Environment [21].

The KSCAD system integrates six main software modules distributed between a supercomputer (modules AlfaU, SerwerU, MM2, and Scaling2 characterized later) and a workstation working as a computation control unit (modules: Wykres3d and Spline of the KSCAD system).

3. Tasks Performed in the System

In the KSCAD system, existing programs MM2 (computing the capacitance coefficients matrix of the MTL basing on geometrical and electrical data from the layout of a structure) and scaling2 (program for computing a quasi-static energy gathered in electrostatic and mag-

netic fields of MTL) are adopted in Solaris environment, broken into the separate processes, executed in parallel, and finally, integrated results are sent to the workstation for presentation in graphical or numerical form. These tasks are performed by communication protocols and the AlfaU module residing on a Sun computer.

The modules of a system perform the tasks of data preparation, inter-module communication, network communication, numerical computing for CAD with inter-processes communication control, graphics, and storing final and inter-mediate results on systems' disks.

3.1. Software Tools

Completion of the system required adoption of existing stand alone CAD programs and writing a few new modules for system integration. Depending on proper platform [13, 20], it was necessary to use different compilers, scripts, protocols etc. In a system we have six main modules:

Wykres3d - Control program in the KSCAD system maintaining the main menu in the workstation, organizing operation on the input and output data in the computing process, and responsible for communication between operating systems in the two-computer CAD system. Wykres3d module resides on PC workstation – compiled in Visual C++ environment.

AlfaU - Program working on a Unix platform. AlfaU organizes computing process by division the data set into subsets, and ordering to the subsets separate processes. This function is fulfilled in the MPI (Message-Passing Interface) environment [8, 22]. AlfaU module resides on Sun supercomputer – compiled with `mpicc`.

Compilation: `/usr/local/mpl/bin/mpicc -o <name of the executable program> <name of the source program>`.

Execution: `/usr/local/mpl/bin/mpirun -np <number of processes> <name of the executable program>`.

SerwerU - Program for listening the demands of client in a client-server communication model. In the SerwerU program are used the system function of the sockets interface [7]. Before starting any input/output operation, the system function `socket()` have to be used. System function `bind()` determined the name for non-name socket. After call a function `socket()`, client process adds a socket descriptor calling the system function `connect()` to set a connection with server. Function `listen()` declares readiness for connection receiving, next connection server can complete the system function `accept()`, to fulfill a request of the waiting client process. SerwerU module resides on Sun supercomputer – compiled with CC compiler.

MM2 - Batch program for computing the capacitance coefficient matrix for multi-conductor transmission line basing on geometrical and electrical data of the structure [11].

MM2 module resides on Sun supercomputer – compiled with CC compiler. This is done while working under control of AlfaU.

Scaling2 - Batch program [29] for computing the energies for multiconductor transmission line basing on geometrical and electrical data of the structure. Scaling2 can use scaling factors in three dimensions: width of conductors (α_1 scale factor – see Appendix Eq. (7), in logarithmic scale denoted as α_1), high of conductors (α_2 scale factor – in logarithmic scale α_2), and distance between conductors (α_3 - α_3). Scaling2 computes the following partial results (for convenient processing in next applications basing on KSCAD system):

- electrostatic energy of the capacitance part of the “slice”,
- static magnetic field energy stored in the inductance part of the “slice”,
- energy dissipated on conductors' resistance,
- conservative energy (for capacitance and inductance of the “slice”),
- total energy.

Scaling2 module resides on Sun supercomputer – compiled with f77 compiler. Working under control of AlfaU module.

Spline - Program for interpolation using spline technique [23]. Spline module resides on PC workstation – compiled in Visual C++ environment.

3.2. Client-Server Communication Model

In the computer network applications, the standard model of data exchange is a client-server communication model. Server is a process waiting for requirement to connect from process called client to fulfill the determined tasks.

In KSCAD system the selected communication protocol is TCP/IP. Firstly, layer TCP (Transmission Control Protocol) is responsible for correct delivery of data between client and server. In a case when data is lost, TCP initializes the retransmission until the data is completely and correctly received. This improve reliability of CAD system (in a case of time-consuming computation lost of data is expensive). Secondly, login to the supercomputer can be performed from arbitrary computer working in the Internet. In KSCAD system, the client workstation and computational server working in the network, communicate with each other using the package of subroutines that provide access to TCP/IP i.e. sockets interface [7].

It was practical to implement character protocol for data exchange between network client and network server for interpretation of client requests and to inform client for which request the answer is valid. The features of a character protocol are following:

- begin 'p' - start of data sending and start of computing (Fig. 2)
- status 's' - status of computing presenting error type or computations progress
- end 'k' - end of data transfer

- purge 'n' - time-break of computations
- error 'b' - error during session
- resume 'w' - transfer of results (Fig. 2)
- results 'z', 'j', 'd', 't', 'c' - transfer of computed energies (sec. 3.1): electrostatic, magnetic, dissipated, conservative, and a total respectively.

3.3. Parallel Computations

To speed up time consuming computations, in the system KSCAD, a supercomputer with 12 processors was used. The computations in multiprocessor's system are comparable to computations performed with parallel computations on multicomputer's system. In both cases the programs have to communicate with each other, and one process (or respectively program) have to supervise all operations. The difference is only in the type of communication. In multicomputer system, messages are sent through the computer network. In a case of multiprocessor system, the queues of messages resulting from processes' activity are created and supervisor process gather the waiting results together. The operating system of multiprocessor computer have to fulfill these requirements. The Solaris 7 Operating Environment is very well adapted to the tasks of this kind.

For the parallel computations, the numerical task of CAD for VLSI MTL energy characterization performed in the KSCAD system, have to be moved from sequential to the parallel (Appendix) execution. In our case, the massive computation for vector scaling of MTL are based on a declared grid which determine a set of scale vectors (see Appendix, Eqs. (7 and (8)). Division of this set of scale vectors into 11 similar subsets is assumed, and indicate last processor (twelve) as a master gathering results. Each parallel process is ordered to the physical processor and the processes are mutually independent. Also, all variables in the processes are unique in each module. Data are gathered on a disk, and can be simultaneously read by processes. The parallel process of computing in the KSCAD system is coded using MPI Environment by a program module AlfaU. Message-Passing Interface is a specification for a library of routines to be called from ANSI C and Fortran 77 programs.

Sending and receiving of messages between the parallel processes is basic operation in MPI environment for fulfilling the communication tasks. The basic point-to-point communication operations are *send* and *receive* implemented by the MPI functions `MPI_Send()` and `MPI_Recv()`, with proper (slightly different for the languages Fortran 77 and ANSI C, but functionally analogous) sets of arguments. In the system KSCAD, the C code of the modul AlfaU is divided into three parts, a common part for master and slave processes preparing data gotten from GUI (PC workstation), a second part for 11 slave processes sending the results (`MPI_Send()` function) for energies computing (the main part of time-consuming com-

putation), and third part for master gathering results from 11 slave processes (MPI_Recv() function).

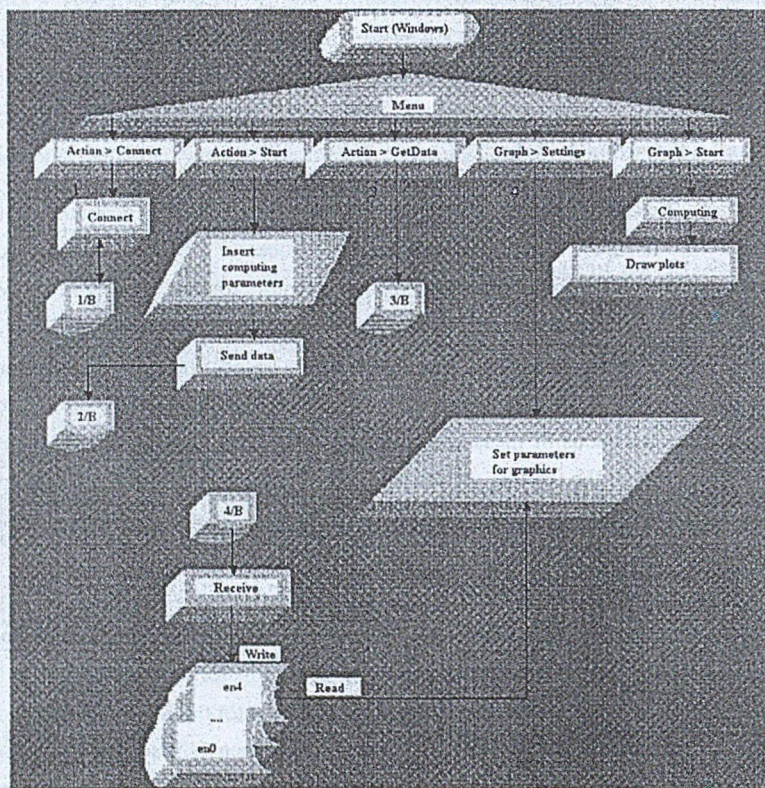


Fig. 1. Flow graph of the system: Part A - Data flow for Win98/2000 workstation
Rys. 1. Schemat blokowy przepływu danych dla stacji Win98/2000

The second and third part are surrounded with MPI environment activation functions `MPI_Init()` and `MPI_Finalize()`, the functions `MPI_Comm_rank()` and `MPI_Comm_size()` are used for processes initialization and find out the number of processes. The internal inter-process' communication in AlfaU module is based on `MPI_DOUBLE` C datatype and `MPI_COMM_WORLD` predefined communicator [8, 19].

3.4. GUI of the KSCAD System

Graphic User Interface in the KSCAD system is running on PC workstation as a control program `Wykres3d`. Control program maintains the main menu in the workstation, organizes operations on the input data and output data from the computing process. The output data

have two form: the results 2D tables (scale factors α_2 and α_3) with α_1 as a parameter, and a visualized plots.

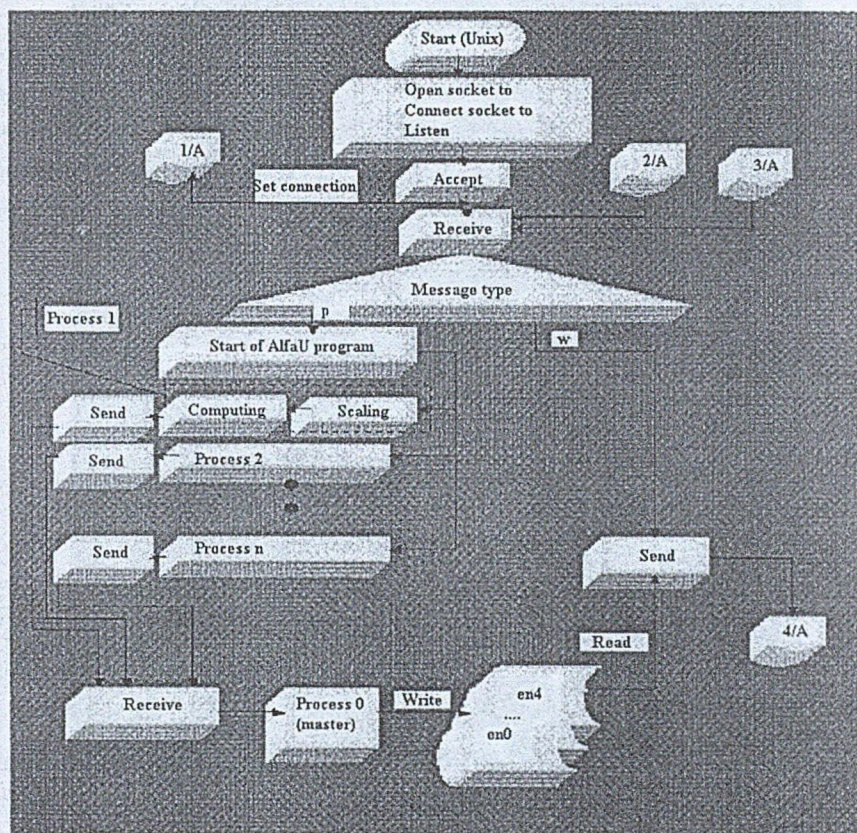


Fig. 2. Flow graph of the system: Part B - Data flow for Sun Enterprise 6500

Rys. 2. Schemat blokowy przepływu danych dla superkomputera Sun Enterprise 6500

The quasi-3d plots are performed basing on 2D tables and the spline interpolation [6, 16]:

α_1 – consecutive plots (width of conductors),

α_2 – x axis (high of conductors),

α_3 – y axis (distance between conductors), and energies – z axis (Figs. 5 to 8).

4. Flow Algorithm of the System

The KSCAD system integrates six program modules: three existing were adopted and modified for requirements of the system [29, 11, 23], and three were work out as new [19].

Flow algorithm of the system is presented in Figs. 1 to 3.

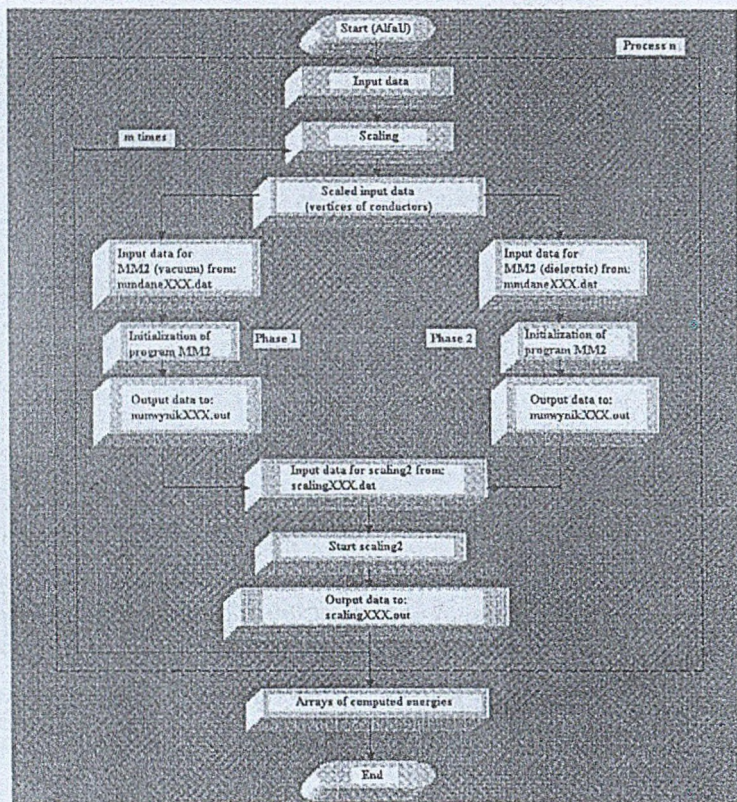


Fig. 3. Data flow performed by n^{th} process

Rys. 3. Schemat blokowy przepływu danych w n -tym procesie

Data flow for Win98/2000 workstation (part A) is presented in Fig. 1. The connections between parts A and B describe the pairs of contacts e.g. 1/B-1/A. The part B of the system characterizing data flow for Sun Enterprise 6500 is presented in Fig. 2. After start of AlfaU program, eleven processes in parallel, solving the CAD tasks, and twelfth process gathers the results on a disk, and put them to the PC workstation for presentation. The user can get result which are basic for design, but it is also possible to access the intermediate results of computation. This is necessary for checking the correctness of actual algorithms as well as in future development of the system. In Fig. 3, more detailed the data flow in one of eleven processes is presented. Phase 1 and phase 2 represent solving the equations (1) and (4), as an input to the second part of computing in a n^{th} process branch.

5. Numerical Example

We will present the results of energy calculations for a multiconductor transmission line with a cross-section presented in Fig. 4 in a certain chip structure [28, 25]. The length of 8 conductors in perpendicular direction (z -axis direction) to cross-section is $l=1$ [cm], and resistance per square is $R_S=0.125$ [Ω/\square]. The cross-section view of the MTL is presented in Fig. 4 (case b [11] in Fig. 9), with conductors embedded in air over a silicon substrate (for silicon $\epsilon_2=K_S \epsilon_0$ with dielectric constant $K_S=11.7$ and permittivity of vacuum $\epsilon_0=8.854 \cdot 10^{-12}$ [F/m]). The structure is supplied with two voltage vectors V_1 and V_2 in the following forms:

$$V_1 [5, 5, 5, 5, 4, 4, 4, 4] \text{ [V]},$$

$$V_2 [1, 1, 1, 1, 0.5, 0.5, 0.5, 0.5] \text{ [V]}.$$

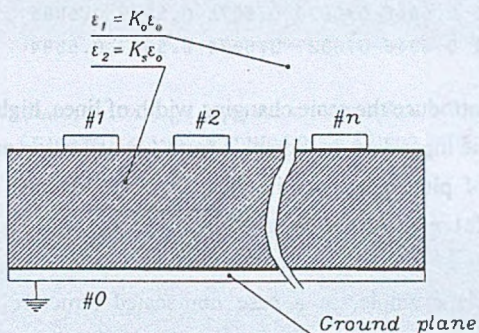


Fig. 4. The cross-section of the MTL for Numerical Example ($n=8$)

Rys. 4. Przekrój linii MTL dla Przykładu Numerycznego ($n=8$)

In a Settings Window of the KSCAD [19] system, we declare set of data for computing, that to get the graphic results with the grid (in logarithmic scale with base 2) equal to 1.

Input data (without these inserted from Settings Window) are represented in the following deck:

```

0 10 5 10 5 11 0 11 //coordinates of vertices of the MTL,
10 10 15 10 15 11 10 11
20 10 25 10 25 11 20 11
30 10 35 10 35 11 30 11
40 10 45 10 45 11 40 11
50 10 55 10 55 11 50 11
60 10 65 10 65 11 60 11
70 10 75 10 75 11 70 11

3 1 11.7 10 //parameter for mm program, dielectric
//constants for air and silicon, the distance

```

```

5 5 5 5 4 4 4 4 //between the ground plane and a dielectric
1 1 1 1 0.5 0.5 0.5 0.5 //interface,
250 //conductor's resistance,
1.0E-10 //time.

```

For these data, without scaling (width of conductors) i.e. $\alpha_1=0$ ($\alpha_1=\log_2 \alpha_1$ and $\alpha_1=1$), the energy matrix has a form:

```

1.3934 0.9948 0.7860 0.6818 0.6315 0.6083 0.5999 0.5997
1.4044 1.0000 0.7888 0.6832 0.6321 0.6079 0.5974 0.5943
1.4118 1.0031 0.7906 0.6843 0.6328 0.6082 0.5966 0.5917
1.4158 1.0046 0.7914 0.6848 0.6332 0.6081 0.5961 0.5903
1.4179 1.0051 0.7916 0.6850 0.6332 0.6080 0.5956 0.5895
1.4170 1.0039 0.7907 0.6843 0.6325 0.6073 0.5948 0.5886
1.4178 1.0045 0.7912 0.6846 0.6328 0.6075 0.5949 0.5885
1.4185 1.0046 0.7911 0.6846 0.6327 0.6074 0.5947 0.5884

```

In a case, when we introduce the scale changing width of lines, high and distance between lines in comparison to the input data, in a graphic form (visualization program in the KSCAD system) we get a set of plots presented in Figs. 5 to 8. We have accordingly plots for relatively energy: for $\alpha_1 = 1$ (Fig. 5), for $\alpha_1 = 2$ (Fig. 6), $\alpha_1 = 3$ (Fig. 7), and $\alpha_1 = 4$ (Fig. 8).

Additionally, for this example, in a case non-scaled structure of MTL, we present computed Maxwell's and inductance matrices.

Maxwell matrix with dielectric [pF/cm]:

```

1.59917      -0.345783      -0.211890E-01      -0.424700E-02      -0.198100E-02
-0.125900E-02  -0.888000E-03      -0.791000E-03
-0.345783      1.68663      -0.340605      -0.201920E-01      -0.379600E-02
-0.169900E-02  -0.107200E-02      -0.888000E-03
-0.211890E-01  -0.340605      1.68695      -0.340535      -0.201600E-01
-0.377800E-02  -0.169900E-02      -0.125900E-02
-0.424700E-02  -0.201920E-01      -0.340535      1.68697      -0.340529
-0.201600E-01  -0.379600E-02      -0.198100E-02
-0.198100E-02  -0.379600E-02      -0.201600E-01      -0.340529      1.68697
-0.340535      -0.201920E-01      -0.424700E-02
-0.125900E-02  -0.169900E-02      -0.377800E-02      -0.201600E-01      -0.340535
1.68695      -0.340605      -0.211900E-01
-0.888000E-03  -0.107200E-02      -0.169900E-02      -0.379600E-02      -0.201920E-01
-0.340605      1.68663      -0.345785
-0.791000E-03  -0.888000E-03      -0.125900E-02      -0.198100E-02      -0.424700E-02
-0.211900E-01  -0.345785      1.59914

```

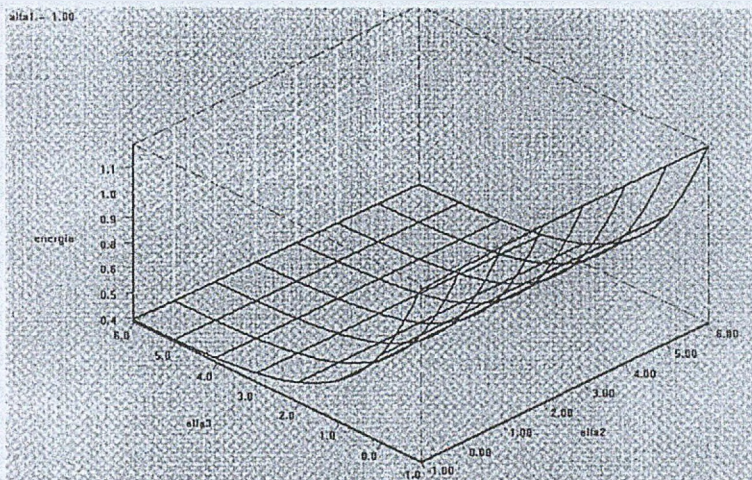


Fig. 5. Relative energy for 8 conductors MTL ($\alpha_1=1$)
 Rys. 5. Energia względna dla wielolini 8-przewodowej ($\alpha_1=1$)

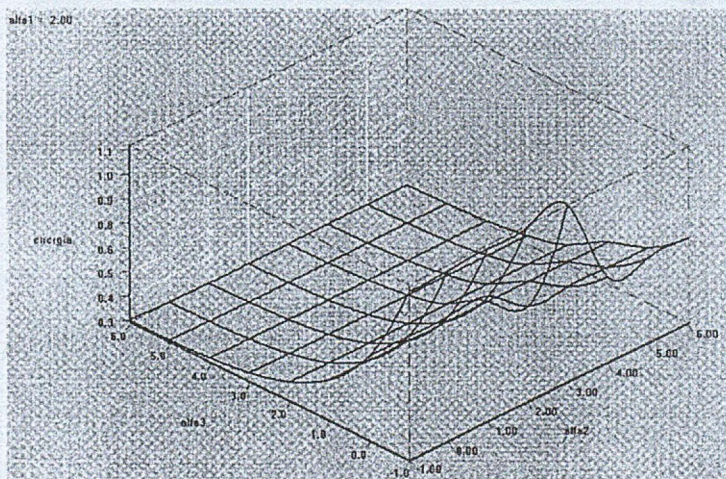
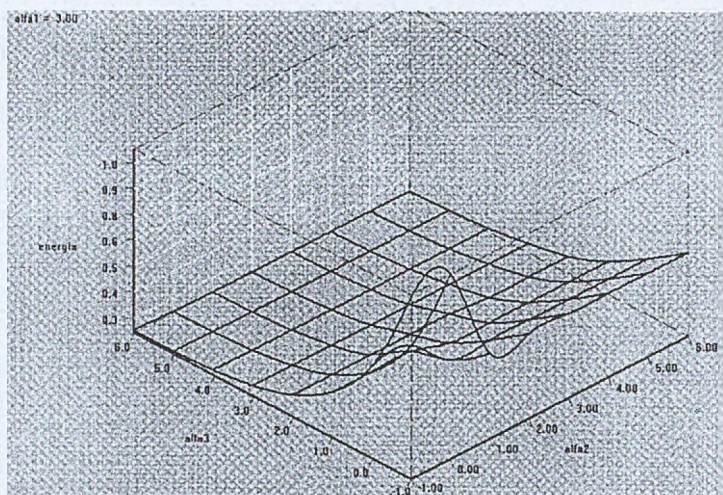
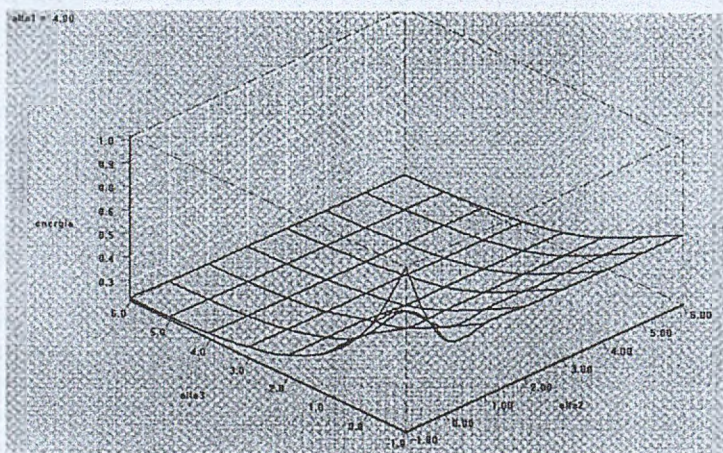


Fig. 6. Relative energy for 8 conductors MTL ($\alpha_1=2$)
 Rys. 6. Energia względna dla wielolini 8-przewodowej ($\alpha_1=2$)

Fig. 7. Relative energy for 8 conductors MTL ($\alpha_1=3$)Rys. 7. Energia względna dla wielolini 8-przewodowej ($\alpha_1=3$)Fig. 8. Relative energy for 8 conductors MTL ($\alpha_1=4$)Rys. 8. Energia względna dla wielolini 8-przewodowej ($\alpha_1=4$)

and Maxwell matrix in vacuum [pF/cm]:

0.257418	-0.868770E-01	-0.103930E-01	-0.410700E-02	-0.232400E-02
-0.153100E-02	-0.112100E-02	-0.113000E-02		
-0.868770E-01	0.290094	-0.832760E-01	-0.902000E-02	-0.334700E-02
-0.183900E-02	-0.121000E-02	-0.112100E-02		
-0.103930E-01	-0.832760E-01	0.290522	-0.831120E-01	-0.893400E-02
-0.330200E-02	-0.183900E-02	-0.153100E-02		
-0.410700E-02	-0.902000E-02	-0.831120E-01	0.290581	-0.830880E-01

-0.893400E-02	-0.334700E-02	-0.232400E-02		
-0.232400E-02	-0.334700E-02	-0.893400E-02	-0.830880E-01	0.290581
-0.831120E-01	-0.902000E-02	-0.410600E-02		
-0.153100E-02	-0.183900E-02	-0.330200E-02	-0.893400E-02	-0.831120E-01
0.290522	-0.832760E-01	-0.103930E-01		
-0.112100E-02	-0.121000E-02	-0.183900E-02	-0.334700E-02	-0.902000E-02
-0.832760E-01	0.290094	-0.868760E-01		
-0.113000E-02	-0.112100E-02	-0.153100E-02	-0.232400E-02	-0.410600E-02
-0.103930E-01	-0.868760E-01	0.257424		

and finally, inductance matrix computed from Maxwell matrix in vacuum [nH/cm]:

4.95186	1.73454	0.811310	0.439065	0.264806
0.173684	0.121745	0.904018E-01		
1.73454	4.87755	1.70670	0.798814	0.432781
0.261461	0.172054	0.121740		
0.811310	1.70670	4.86691	1.70190	0.796475
0.431743	0.261458	0.173676		
0.439065	0.798814	1.70190	4.86482	1.70105
0.796473	0.432775	0.264789		
0.264806	0.432781	0.796475	1.70105	4.86481
1.70189	0.798799	0.439027		
0.173684	0.261461	0.431743	0.796473	1.70189
4.86690	1.70668	0.811271		
0.121745	0.172054	0.261458	0.432775	0.798799
1.70668	4.87752	1.73446		
0.904018E-01	0.121740	0.173676	0.264789	0.439027
0.811271	1.73446	4.95170		

6. Conclusions

Presented KSCAD system is framework for computer-aided design fully using network computer system's features, where depending on task division between resources of a system, it is possible to build friendly user interfaces, and independently improve system performance. In implemented system, through modules integration and parallel operation, the time of the system interaction was considerably shortened, and it is possible in this kind of design task, to convert the functions of the system into optimization tasks. Integrity of the system is satisfied through the compatibility of the data structures, control of the system from main graphic application, and automatic transfer of data between PC workstation and the supercomputer through the network. The user can get results which are basic for design, but it also is possible to access to intermediate results of computation. This is necessary for check-

ing the correctness of actual algorithms as well as in future development of the system's capabilities.

7. APPENDIX – Numerical Task of CAD for VLSI Performed in the KSCAD System

The system KSCAD [19] is used in the numerical computations of scaled (in geometrical sense) multiconductor transmission lines (MTL) for its energetical characterization – i.e. computing the energy gathered in the MTL in a quasi-static state. This can be used for proper design of MTL in a VLSI/ULSI structures working with high-speed switching.

7.1. Multiconductor Transmission Line Models

Models of the MTL and simulation tools using those models [1, 2, 4, 14] are usually determined for particular simulation task in connection with special boundary conditions and geometrical data extracted from layout [3, 10, 18, 24]. For our goal, i.e. quasi-static energetical characterization of MTL representing interconnections in VLSI/ULSI structures when the scaling (width and high of planar conductors, and distance between them) takes place, we will use a model based on a layout description and cross-sectional characterization described in [2, 24]. We will build the model basing on a capacitance/inductance cross-sectional slice parameters as a per-unit-length (PUL) capacitance and a PUL inductance for non-homogeneous dielectric medium, with the conductors resistance (PUL) network in a serial connection. It is possible to extend the model introducing nonhomogeneity, nonisotropy, skin-effect, dielectric dispersion and absorption effects using direct physical models for those phenomena [27, 9, 26]. We will consider a geometrical configuration for cross-sections of MTL, shown in Fig. 9 (a through c).

In all cases the conductors are ideal (a capacitance network). The conductors' resistances excluding ground, are assumed to be connected in serial in z direction (perpendicular to the x - y plane) with conductors' capacitances and inductances network.

In case a) (Fig. 1), the space is divided into two halfspaces; the first with dielectric permittivity ϵ_1 , and the second with ϵ_2 .

The plane of the dielectric interface is for $y=h$ with infinite dimension. The finite dimensional ideal ground conductor has potential equal to zero.

In case b), the dielectric interface plane and ground plane are of infinite extent and they are parallel to each other. The dielectric interface is at height h above the ground plane being an ideal conductor. The n conductors are over the ground plane.

In case c), the ground conductor (an ideal conductor) is formed by a pair of parallel ground planes with one layer of dielectric of permittivity ϵ and of thickness h .

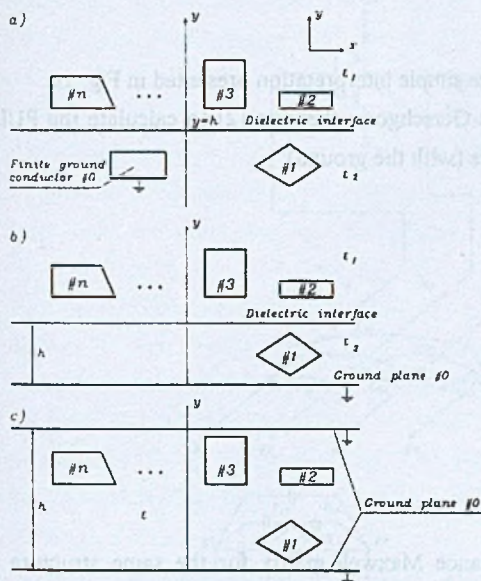


Fig. 9. Cross-section for the MTL cases

Rys. 9. Przekroje rozpatrywanych przypadków MTL

We have numbered conductors from #1 to # n . The ground conductor is numbered a #0.

In order to determine the PUL capacitance coefficients matrix i.e. the Maxwell matrix C for multilayer nonhomogeneous dielectric and n conductors (and the ground) imbedded, we have a basic equation for the matrix $C=[C_{ij}]$ definition:

$$\begin{bmatrix} Q_{1,1} \\ Q_{1,2} \\ \dots \\ Q_{1,n} \end{bmatrix} = \begin{bmatrix} C_{11} & C_{12} & \dots & C_{1n} \\ C_{21} & C_{22} & \dots & C_{2n} \\ \dots & \dots & \dots & \dots \\ C_{n1} & C_{n2} & \dots & C_{nn} \end{bmatrix} \begin{bmatrix} V_{1,1} \\ V_{1,2} \\ \dots \\ V_{1,n} \end{bmatrix}, \quad (1)$$

where:

$Q_1^T = [Q_{1,1}, Q_{1,2}, \dots, Q_{1,n}]$ – is a PUL charges vector of a n -conductor MTL,

$V_1^T = [V_{1,1}, V_{1,2}, \dots, V_{1,n}]$ – is a corresponding voltages vector.

Properties of the matrix C are discussed in [10, 24]. We will use the approach [10] generalized in [24] to find C_{ij} . Using the calculated PUL capacitance coefficients C_{ij} , we can do its object illustration using the "two-terminal" capacitance matrix T can be found [15], with following elements:

$$T_{ij} = -C_{ij} \quad \text{for } i \neq j,$$

$$T_{ij} = \sum_{j=1}^n C_{ij}.$$
(2)

These "two-terminal" capacitances have simple interpretation presented in Fig. 10.

We can apply the Levy-Hadamard-Gerschgorin theorem [2] to calculate the PUL inductance matrix L for a set of n -conductors (with the ground):

$$L = \begin{bmatrix} L_{11} & L_{12} & \dots & L_{1n} \\ L_{21} & L_{22} & \dots & L_{2n} \\ \dots & \dots & \dots & \dots \\ L_{n1} & L_{n2} & \dots & L_{nn} \end{bmatrix}$$
(3)

from equation:

$$L = \frac{1}{v_0^2} C_0^{-1},$$
(4)

where:

v_0 – velocity of light,

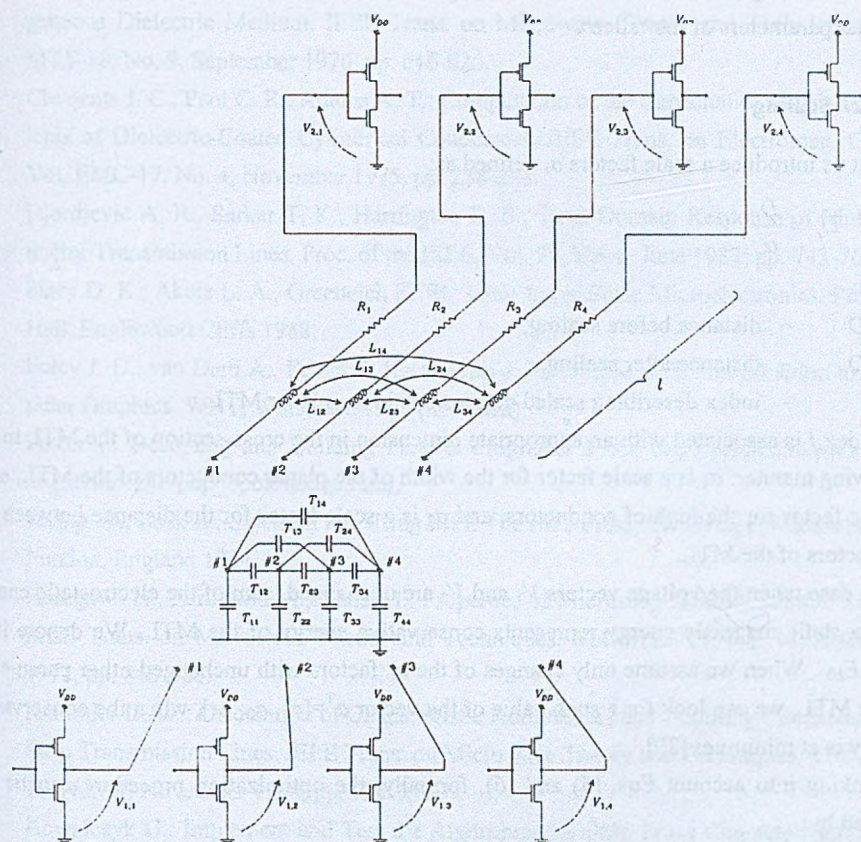
C_0^{-1} – the inverted PUL capacitance Maxwell matrix for the same structure with surrounding dielectric all removed.

We assume, that there is no resistance between conductors (i.e. there are no leakage currents), therefore the per-unit-length conductors' resistance matrix R can be simply calculated from the resistance per square, and width of the conductors.

In order to discuss the energy properties of the "slice" of MTL with cross-section described above, we assume that the three-part "slice" is a serial "circuit" with PUL capacitances, PUL inductances and PUL resistances of the conductors connected serially in z axis direction (perpendicular to the x - y plane). We assume also, that the thickness of the "slice" is l (in z axis direction).

Using the diagram presented in Fig. 10 for orientation, let us discuss the energy gathered in the "slice", in a quasi-static state (the voltage vectors V_1 and V_2 "holding up" the "slice" are constant) but in dependency on geometrical dimensions of the cross-section of the MTL.

The first side of the MTL "slice" is connected to the voltage vector V_1 , which coordinates are numbered as conductors, and reference is shunted to the ground plane (Fig. 9). We will consider the case with the ground as an ideal conductor. The second side of MTL "slice" is connected to the vector V_2 in the same manner. We have the capacitance network connected to the vector V_1 , the resistance network supplied by V_1 - V_2 voltage vector and the inductance network supplied with the current vector $\Gamma^{-1}R^{-1}(V_1-V_2)$, where R is the per-unit-length resistance matrix for the conductors and l is the thickness of the "slice".



Rys. 10. Part of CMOS circuit, including the driving inverters, the "slice" MTL line, and the load inverters

Fig. 10. Wielolinia CMOS zawierająca inwerty sterujące, "plasterek linii" MTL oraz inwerty obciążenia

The electrostatic energy of the capacitance part of the "slice" can be expressed as follows:

$$E_c = \frac{1}{2} V_1^T C V_1, \quad (5)$$

where:

V_1^T – transposition of the vector V_1 , with Maxwell matrix C defined by (1).

The static magnetic field energy stored in the inductances part of the "slice" is:

$$E_L = \frac{1}{2l} (V_1 - V_2)^T R^{-1} L R^{-1} (V_1 - V_2), \quad (6)$$

since matrix R representing PUL resistances network is symmetric. Inductance matrix L was determined from equation (4). From equations (5) and (6) results, that for constant vectors V_1 ,

V_2 , and unchanged resistance matrix R , energies E_C and E_L depend only on geometrical and material parameters of the "slice".

7.2. Scaling

Let us introduce a scale factors α_i , defined as:

$$D_i = \frac{D_i}{\alpha_i}, \quad (7)$$

where:

- D – distance before scaling,
- D_i – distance after scaling,
- i – index describing scaled dimensions in the planar MTL.

Index i is associated with an appropriate dimension in the cross-section of the MTL in the following manner: α_1 is a scale factor for the width of the planar conductors of the MTL, α_2 is a scale factor for the high of conductors, and α_3 is a scale factor for the distance between the conductors of the MTL.

In case when the voltage vectors V_1 and V_2 are unchanged, sum of the electrostatic energy and a static magnetic energy represents conservative energy of the MTL. We denote it as $E_{C0} + E_{L0}$. When we assume only changes of the α_i factors with unchanged other parameters of the MTL, we can look for a such value of the vector $\alpha^T = [\alpha_1, \alpha_2, \alpha_3]$, when the conservative energy is at minimum [29].

Taking into account Eqs. (5) and (6), formally, the optimization procedure can be expressed by:

$$E_{rel} = \min_{\alpha^T = [\alpha_1, \alpha_2, \alpha_3]} \left\{ \frac{E_C + E_L}{E_{C0} + E_{L0}} \right\}, \quad (8)$$

where:

- α_1 – is in the range $[\alpha_{1min}, \alpha_{1max}]$,
- $\alpha_2 \in [\alpha_{2min}, \alpha_{2max}]$,
- $\alpha_3 \in [\alpha_{3min}, \alpha_{3max}]$,
- E_{rel} – relative conservative energy.

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Streszczenie

Zrealizowany system KSCAD jest systemem komputerowego wspomagania projektowania w pełni wykorzystującym cechy systemów sieciowych, w których poprzez podział zadań realizowanych na bazie komputerów pracujących w sieci można tworzyć jednocześnie przyjazne interfejsy, a jednocześnie podnieść bardzo znacznie wydajność obliczeniową systemu.

W zaprojektowanym i wykonanym systemie poprzez integrację modułów i równoległe obliczeń uzyskano znaczne skrócenie interakcji systemu, co pozwoliło na rozszerzenie zakresu zadań projektowych realizowanych przez system o zadania optymalizacyjne.

Integralność systemu KSCAD osiągnięto poprzez zapewnienie kompatybilności formatów danych wejściowych i wyjściowych poszczególnych modułów programowych systemu, sterowanie zadaniami systemu z poziomu rozwijanego menu głównej aplikacji graficznej oraz automatycznego transferu danych pomiędzy systemami operacyjnymi komputerów pracujących jako stacja graficzna i serwer obliczeniowy.

System generuje wyniki zarówno w formie tablic, jak i graficznej. Ponadto przechowuje wyniki pośrednie obliczeń, pozwalające na weryfikację, modyfikację kodów źródłowych modułów oraz ich rozbudowę rozszerzającą funkcje systemu.