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# Parallel Algorithm for the Quasi-TEM Analysis of Microstrip Multiconductor Line

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## Introduction

The generalized structure of the microstrip multiconductor line (MMCL) is shown in Fig. 1 (a). The MMCL consists of a dielectric substrate with a conducting layer (ground plane) on the one side and microstrip conductors on the other side. The number of microstrip conductors, their width and space between them may be specified independently. Due to their planar design these lines are broadly used in many electronics areas, e.g. as transmission lines for data paths in computer systems and integrated circuits [1], directional couplers [2], etc. MMCL are also successfully used as physical models designing microwave devices such as retard systems [3–5] (Fig. 1 (b)), antennas [6], etc.

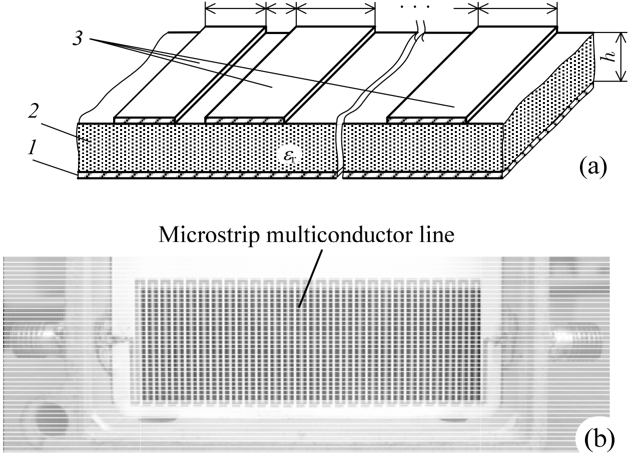

**Fig. 1.** Generalized structure of the microstrip multiconductor line (a): *1* – ground plane; *2* – dielectric substrate; *3* – microstrip conductors; example of microstrip multiconductor line using as a physical model of the meander delay line (b)

It is known, that, generally, in an MMCL consisting of $N$ conductors (plus ground plane), $N$ normal waves (or normal modes) can propagate [7]. Phase and group velocities of different types of normal waves differ from each other in the MMCL, as a result the interference of the propagated normal waves occurs in the MMCL and transmitted signals suffer from distortions. Therefore it is desirable to use only normal waves for information transmission [8].

Modelling various microwave devices by the multiconductor line approach it is enough to confine to two main normal waves only [9]. These are c-normal wave, which excites when phase difference between signals sending to the adjacent conductors of the MMCL is 0, and π-normal wave, when phase difference between mentioned signals is π radians [9]. Main characteristics of the MMCL are the effective dielectric permittivity and the characteristic impedances of conductors may be find using various quasi-TEM techniques, numerical methods such as the finite difference method (FDM), the finite elements method [3], the method of moments (MoM) [10, 11] are more universal and accurate though. It should be noted that when objects under analysis become more sophisticated (in case of the MMCL it means increasing number of microstrip conductors, or when the profile of the microstrip conductors become more elaborate, or increasing demand for the model accuracy) realization of numerical methods demands huge computer resources: CPU time and memory size [12]. To overcome this problem the analysis task may be distributed among computers – the parallel analysis system should be created.

The parallel algorithm for the analysis of the MMCL is proposed in this article.

This paper is organized as follows. Section II describes the proposed parallel algorithm. Verification of the parallel algorithm, investigation of its effectiveness, and calculation results of five-conductor MMCL, operating in normal mode regime, are presented in Sections III. Finally the brief conclusions are formulated in Section IV.

## Parallel Algorithm

In general any calculation process may be organized in parallel manner – calculation operations distributed among computers. However, creating a parallel computing system the shortening of calculation time and the increment of inter-computer communication should be taken into account together [13].

Main characteristics of the MMCL: the effective dielectric permittivity and the characteristic impedance of conductors are found knowing capacitances per unit length of these conductors:

$$\varepsilon_{\mathrm{r\,eff}} = C_i \Big/ C_i^{(\mathrm{a})}, \tag{1}$$

$$Z_i = 1 \Big/ \left( \mathrm{c}_0 \sqrt{C_i C_i^{(\mathrm{a})}} \right), \tag{2}$$

where $\mathrm{c}_0$ is the velocity of light in free space; $C_i$ is the capacitance per unit length of the *i*-th conductor of MMCL; $C_i^{(\mathrm{a})}$ is the capacitance per unit length of the same conductor when the substrate in the line is changed by air ($\varepsilon_\mathrm{r} = 1$). Calculations according to (1) and (2) are executed two times examining propagation of c- and π-normal waves in the MMCL. So, to evaluate mentioned characterristics of the MMCL for c- and π-normal waves, these four operations should be done: 1) to calculate capacitance per unit length of the conductors of the MMCL for c-mode; 2) to calculate capacitance per unit length of the conductors of the MMCL for π-mode; 3) to calculate capacitance per unit length of the conductors of the MMCL for c-mode changing the dielectric substrate by air; 4) to calculate capacitance per unit length of the conductors of the MMCL for π -mode changing the dielectric substrate by air.

The good decision of the problem of machine time is the distribution of calculation of the conductors' capacitances per unit length for c- and π-mode among computers (nodes) of the parallel system. In this case, every node will have initial parameters of the MMCL for which the conductors' capacitance per unit length will be calculated. Here we present the software algorithm (Fig. 2) for the calculation of the characteristic impedance and the effective dielectric permittivity of the MMCL. This algorithm uses "master-slave" parallel programming paradigm [14]. The algorithm consists of 7 steps:

1. Design parameters of MMCL are entered: the relative permittivity $\varepsilon_\mathrm{r}$ and the height $h$ of the dielectric substrate; width of microstrip conductors $W_i$ and the space between them $S_i$ ; dimensions of the analysis area $x$ and $y$.
2. Initial parameters of the analysis are found: bound values of the interface between the dielectric substrate and air, conductors' positions in the analysis area.
3. Sending design parameters of the MMCL and calculated initial parameters of the analysis to the four nodes.
4. Each node calculates conductors' capacitance per unit length for specific mode and environment. Nodes 2 and 3 calculate capacitance per unit length of MMCL for c- and π-mode correspondently, and nodes 1 and 4 calculate the same capacitances for the same modes, but the substrate in the MMCL is changed by air.
5. Calculated values of conductors' capacitance per unit length are sent back to the master.
6. The master sorts received data and calculate characterristic impedance for each conductor of the MMCL.
7. The calculated characteristic impedance and other parameters of the MMCL are stored.

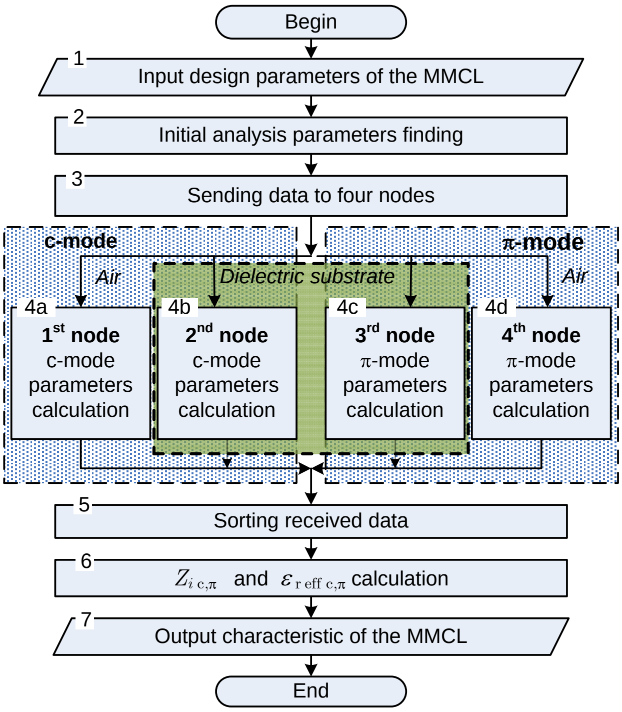

**Fig. 2.** Flowchart of the parallel algorithm of the quasi-static analysis of the MMCL

## Investigation of the Parallel Algorithm

The proposed parallel algorithm (Fig. 2) has been realized on the MPICH2 cluster [14] which has been implemented on PC computers (CPU – Pentium™ 4, 2.8 GHz; RAM – 512 MB; OS – Fedora 6; the network – Ethernet 100 Mb/s). The number of computers (nodes) was varied from 1 up to 5 with the purpose of defining the growth of cluster throughput. The results of the growth of cluster throughput are shown in Table 1.

**Table 1.** The source code of the parallel algorithm is adapted to 5 nodes. The number of the processes is constant and equal to 5

| | Number of nodes | | | | |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 |
| Execution time, s | 136 | 80 | 78 | 39 | 38 |
| Efficiency, % | – | 70.0 | 74,4 | 248,7 | 257,9 |

As an analysis method in the proposed parallel algorithm any numerical quasi-static approach may be used. We have implemented the algorithm using FDM. For calculation procedure speed up the potential distribution of the MMCL was calculated using the band-matrix technique and sparse-matrices approach [15].

Effectiveness of the parallel algorithm was calculated by this equation:

$$effectiveness, \% = 100\% \left[ t^{(1)} - t\left(N\right) \right] \Big/ t\left(N\right), \tag{3}$$

where $t^{(1)}$ is the execution time of the MMCL analysis algorithm using the one node only; $t\left(N\right)$ is the execution time of the MMCL analysis algorithm using $N$ nodes. For the investigation of the effectiveness of the parallel algorithm the analysis area of $5\times10^4$ elements was used. It is seen in Table 1 that when the number of nodes in the cluster is even (e.g. $n$) the algorithm effectiveness is slightly lower than cluster has $n+1$ nodes. In the last case processes are distributed to the master node also. The greatest increase of the effectiveness in our tests, using the cluster of 5 nodes, has reached 3.6 times.

Our proposed algorithm has been verified by comparison of calculated parameters that were obtained by MoM and spectral domain method [16]. Results of calculations of parameters of the investigated MMCL are submitted in Table 2. It is obvious, that values in Table 2 agree within 3 % in the most cases, and it is possible to tell about good reliability of the received results and the proposed algorithm.

**Table 2.** Comparison parameters for four coupled microstrip lines* obtained using the proposed technique (parallel algorithm with the FDM), the MoM, and the spectral domain method [16]

| Conductor number | c-mode | | | π-mode | | |
|---|---|---|---|---|---|---|
| | Parallel algorithm | [16] | MoM | Parallel algorithm | [16] | MoM |
| Relative Effective Dielectric Permittivity | | | | | | |
| #1–#4 | 7.315 | 7.55 | 7.54 | 5.419 | 5.45 | 5.42 |
| Characteristic Impedance, Ω | | | | | | |
| #1, #4 | 65.25 | 66 | 66 | 24.35 | 24 | 24 |
| #2, #3 | 119.5 | 123 | 121 | 41.67 | 42 | 41 |

* $W_1 = W_4 = 0.6$ mm, $W_2 = W_3 = 0.3$ mm, $S_1 = S_3 = 0.3$ mm, $S_2 = 0.2$ mm, $h = 0.635$ mm, $\varepsilon_r = 9.8$.

Further, using the proposed algorithm we investigated the effective dielectric permittivity and characteristic impedance of the five-conductor MMCL, operating in c- and π-mode regimes. The calculation results of normal modes parameters versus the normalized microstrip width $W/h$ and the space $S/h$ are shown correspondently in Fig. 3 and Fig. 4.

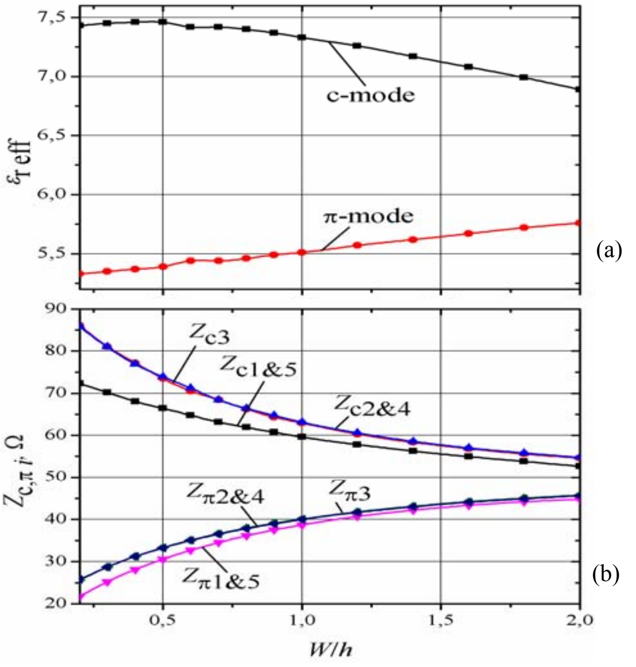

**Fig. 3.** Effective dielectric permittivity (a); characteristic impedance (b) of five-conductor symmetrically coupled MMCL versus the normalized microstrip width; $W/h = 1$; $\varepsilon_r = 9.6$

It is seen in Fig. 3 and Fig. 4 that incrementing width of microstrip conductors supporting constant space between them or, on the contrary, incrementing space between conductors not changing their width, the behavior of the submitted dependences of the MMCL corresponds to the behaviors of dependences of the microstrip coupled lines [11]. It should be noted also, that characteristic impedances of the internal conductors (#2, #3 and #4) of the MMCL practically coincide. The difference of characteristic impedance of these conductors in all range of the explored $W/h$ and $S/h$ does not exceed 0.3 % that testifies to a sufficient regularity of an internal structure even such MMCL, which consists only from 5 microstrip conductors.

## Conclusions

The parallel algorithm for the quasi-static analysis of the multiconductor microstrip lines (MMCL) is presented. As the method of the analysis any numerical quasi-static approach may be used in the proposed algorithm. Authors have implemented an algorithm in the five computer cluster using the finite difference method. For calculation speed up the potential distribution was calculated using the band matrix technique and sparse matrix approach. The proposed parallel algorithm was tested in four- and five-conductors MMCL. Authors' obtained results that differ from those of other investigators and the results obtained by other means no more than 3 %. It was found that the proposed parallel algorithm allows speed up of calculations up to 3.6 times.

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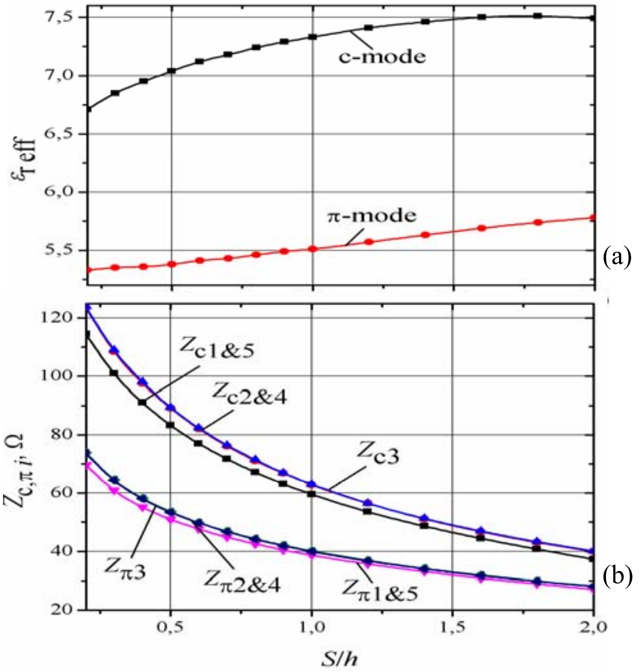

**Fig. 4**. Effective dielectric permittivity (a); characteristic impedance (b) of five-conductor symmetrically coupled MMCL versus the normalized space; $S/h = 1$; $\varepsilon_r = 9.6$

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**R. Pomarnacki, A. Krukonis, V. Urbanavičius. Parallel Algorithm for the Quasi-TEM Analysis of Microstrip Multiconductor Line // Electronics and Electrical Engineering. – Kaunas: Technologija, 2010. – No. 5(101). – P. 83–86.**

Presented parallel algorithm for the quasi-static microstrip multiconductor lines (MMCL) analysis, with optional conductor number, width and spaces between conductors. To apply MMCL as a physical model for various microstrip devises design, for example, meander microstrip delay lines, it is sufficient to study only quasi-static parameters of the MMCL inducing c- or p-normal waves. As analysis method in the proposed parallel algorithm any numerical quasi-static approach may be used. Authors have implemented an algorithm in five computer cluster using the finite difference method. For calculation procedure speed up the potential distribution of the MMCL was calculated using band matrix technique and sparse matrix approach. The proposed parallel algorithm was tested in four- and five-conductors MMCL. Authors obtained results that differ from those of other investigators and the results obtained by other means no more than 3 %. It was found that the proposed parallel algorithm allows speed up of calculations up to 3.6 times. Ill. 4, bibl. 16, tabl. 2 (in English; abstracts in English, Russian and Lithuanian).

**Р. Помарнацки, А. Круконис, В. Урбанавичюс. Параллельный алгоритм для квазистатического анализа микрополосковых многопроводный линий // Электроника и электротехника. – Каунас: Технология, 2010. – № 5(101). – С. 83–86.**

Представлен параллельный алгоритм для квазистатического анализа микрополосковых многопроводных линий (МПМЛ) с произвольным числом проводников, их шириной и расстоянием между ними. При использовании МПМЛ в качестве физической модели различных микрополосковых устройств, например, меандровых микрополосковых линий задержки, необходимы лишь параметры МПМЛ в квазистатическом приближении при возбуждении в МПМЛ чётной и нечётной нормальных волн. В качестве метода анализа в предложенном алгоритме может использоваться любой квазистатический метод. Авторами алгоритм был реализован с использованием метода конечных разностей в кластере из пяти компьютеров. Для ускорения процесса анализа распределение потенциала в поперечном сечении МПМЛ находилось способом связанных разряженных матриц. В качестве примера исследованы четырех- и пятипроводная МПМЛ. Результаты, полученные авторами отличаются от опубликованных и полученных другими способами не более чем на 3 %. Установлено, что предложенный параллельный алгоритм позволяет сократить процесс анализа до 3,6 раз. Ил. 4, библ. 16, табл. 2 (на английском языке; рефераты на английском, русском и литовском яз.).

**R. Pomarnacki, A. Krukonis, V. Urbanavičius. Lygiagretusis algoritmas mikrojuostelinėms daugialaidėms linijoms tirti esant kvazistatiniam artiniui // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2010. – Nr. 5(101). – P. 83–86.**

Pateiktas lygiagretusis algoritmas kvazistatinei mikrojuostelinių daugialaidžių linijų (MJDL) analizei atlikti esant laisvai pasirenkamam laidininkų skaičiui, pločiams ir tarpams tarp jų. Taikant MJDL kaip fizikinį modelį įvairiems mikrojuosteliniams įtaisams, pvz., meandrinėms mikrojuostelinėms vėlinimo linijoms, tirti, pakanka nustatyti tik kvazistatinius MODL parametrus žadinant joje lyginę arba nelyginę normaliąsias bangas. Kaip analizės metodas siūlomame lygiagrečiajame algoritme taikytinas bet kuris skaitinis kvazistatinis metodas. Autoriai įgyvendino algoritmą taikydami baigtinių skirtumų metodą penkių kompiuterių telkinyje. Skaičiavimo procedūroms paspartinti potencialų pasiskirstymo MJDL skerspjūvyje buvo ieškomas taikant susietųjų retųjų matricų skaičiavimo būdą. Siūlomas lygiagretusis algoritmas buvo išbandytas tiriant keturių ir penkių laidininkų MJDL. Autorių gauti rezultatai skiriasi nuo kitų tyrėjų ir kitais būdais gautų rezultatų ne daugiau kaip 3 %. Nustatyta, kad siūlomas lygiagretusis algoritmas leidžia paspartinti skaičiavimus iki 3,6 karto. Il. 4, bibl. 16, lent. 2 (anglų kalba; santraukos anglų, rusų ir lietuvių k.).

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