Parallel Algorithms for the Synthesis of the Multi-Tapped Meander Delay Lines

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***Abstract*—An algorithm, based on the successive approximation technique for the parallel synthesis of the multi-tapped meander microstrip delay line (MTMDL), is presented. Multiconductor line model and finite difference method are used for analysis of the MTMDL. Parallel computations in the proposed algorithm are organized according to both – data parallelism and task parallelism concepts. Efficiency of two parallel synthesis algorithms one proposed, and another based on Monte Carlo method, is compared. It is shown that while number of computational nodes is small by comparison (e.g. not larger than 3) then efficiency of the proposed algorithm about 5 times exceeds Monte Carlo method based algorithm efficiency. It is revealed that efficiency of both algorithms becomes similar when computational nodes number increases several times.**

***Index Terms*—Circuit topology, delay lines, integrated circuit synthesis, microwave devices, parallel algorithms.**

I. INTRODUCTION

Usage of the numerical methods provide us with flexible design techniques of the microwave devices and also significantly increase analysis possibilities of such devices.

Most difficult challenge for usage of numerical methods is much longer time of the analysis of the microwave devices than using analytical methods. This challenge becomes especially evident in the synthesis process during which analysis procedure must be repeated many times.

Several approaches to speed up both an analysis and a synthesis processes may be named, for instance, optimization functions, artificial neural networks (ANN) techniques or parallel computing systems [1], [2]. The last two approaches are most popular at this time, because they allow us to use intelligent systems and newest possibilities of modern computer hardware.

Briefly reviewing the newest articles referred to the using of the ANN techniques in microwave modeling, optimization and design [3]–[6] it may be concluded that usage of the ANN techniques significantly decrease time of analysis of microwave devices, while computation accuracy remain the same such as using analytical methods. The main drawback of intelligent systems is guarantee of analysis accuracy only for particular ranges of constructional parameters of analyzed device. This is conditioned by joint use of analytical methods and the ANN. It should be noted that it took a lot of time to train the ANN and only after this training it is possible to get analysis results instantly. Another disadvantage of intelligent system is that if a design of analyzed devices is changed, e.g. new element is installed then the ANN must be reconfigured and trained again.

Another way to decrease time of the analysis and the synthesis processes is use of parallel computational techniques and special hardware [7]–[9]. To analyze a microwave device a mathematical model based on a particular numerical method should be created. Despite the fact that calculation time in this case may be longer than using the ANN techniques, numerical methods allow us to vary design of analyzed devices more flexible. How quickly computation will be done depends on the implemented algorithm and on the used hardware. To speed up an analysis of a microwave device, computation procedures may be organized in parallel manner using data parallelism or task parallelism paradigm.

A parallel algorithm for synthesis of the multi-tapped microstrip meander delay line (MTMDL), based on the successive approximation technique (SAT) and implemented using both data parallelism and task parallelism paradigms, is proposed in this paper.

General structure of the MTMDL is shown it Fig. 1. It consists of a meander shape signal conductor situated on the dielectric substrate which opposite side is covered by conducting layer (it serves as a reference conductor). An electric signal in such line is slowed down due to construct of the medium where electromagnetic wave propagates more slowly than in vacuum and desirable delay is insured by stretching the signal paths along meander (zigzag) banded conductor.

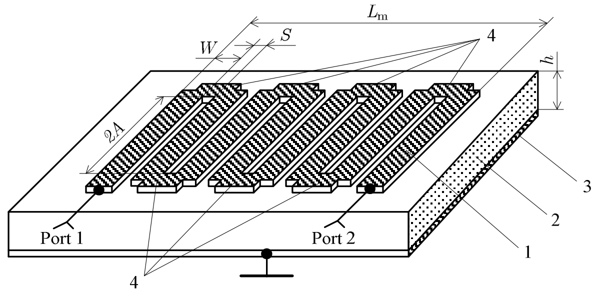

Fig. 1. General structure of the multi-tapped meander microstrip delay line: 1 – strips of the meander conductor; 2 – dielectric substrate; 3 – reference conductor; 4 – intermediate taps.

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At this time most microwave devices are investigated using general purpose commercial software tools. It should be noted that commercial software do not use the ANN techniques or it is not mentioned in user manuals, this curiosity may be explained by before-mentioned disadvantages of the ANN techniques. However more developers are using commercial software tools having parallel computation capabilities [10]. So it is very actually to create mathematical models of the microwave devices which allow us to use parallel computing systems.

Multiconductor line model and finite difference method are used for the analysis of the MTMDL in the proposed algorithm. Parallel computations in this algorithm are organized according to both – data parallelism and task parallelism paradigms. Efficiency of the proposed algorithm, and parallel algorithm based on Monte Carlo method [7], are compared.

II. Implementation of the Parallel Successive Approximation Algorithm

The sequence of procedures of the analysis of the mathematical model of the designed microwave device and optimization of its construction parameters is repeated iteratively during device synthesis process. Mathematical background of such process in our case is the analysis of the MTMDL based on quasi-TEM model of the multiconductor microstrip line [8]. Furthermore, the synthesis process of the MTMDL must be attached with corresponding boundary conditions and dispersion equation, which are related to the analyzed frequency and phases differences between voltages of the neighboring meander strips.

Most important electric characteristics of the MTMDL are: characteristic impedance Z_0, delay time t_d and bandwidth ΔF, so proposed synthesis algorithm of the MTMDL composes iteratively repeated search of this electric characteristics.

Proposed parallel synthesis algorithm of the MTMDL, based on the SAT, differs from the algorithm based on Monte Carlo method [7] by the approach of search of construction parameters of the MTMDL.

The main ideas of the SAT are illustrated in Fig. 2. It is seen here that allowable range of the construction parameter values $\left[X_{\min}, X_{\max}\right]$ is equally divided into P values between p cluster nodes, where P is the number of cluster processes (Fig. 2(a)).

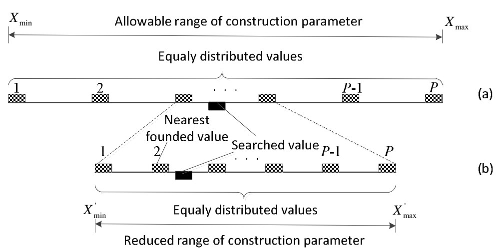

Fig. 2. Construction parameter values distribution among cluster nodes (*a*) and values range reducing (*b*).

After these values were distributed, the parallel process of the analysis of the MTMDL is started. During this parallel analysis values of one of the needed electric characteristic are calculated in parallel and the nearest value to given nominal one is selected.

Next the algorithm, using founded nearest searched construction parameter value, which corresponds to the nearest searched value of analyzed electric characteristic, creates a new values range $\left[X'_{\min}, X'_{\max}\right]$. This new values range is also divided into P equal parts and corresponding construction parameter values are distributed between cluster nodes. This process will end only when will be true the condition

$$\min \delta\left(e_i\right) \leq \delta_e, \tag{1}$$

where

$$\delta\left(e_i\right) = \frac{e_i - e_{\mathrm{nom}}}{e_{\mathrm{nom}}}, \tag{2}$$

where δ_e is given calculation accuracy of the e electric characteristic, $\delta\left(e_i\right)$ is the relative difference of the electric characteristic value e_i calculated on the *i*-th computer node and given nominal value of this characteristic e_{nom}.

The data flow diagram of the MTMDL parallel synthesis algorithm, based on the SAT, is shown in Fig. 3. The algorithm consists of 13 steps. This algorithm differs from the algorithm based on Monte Carlo technique [7] by steps 2, 5, 6 and 9.

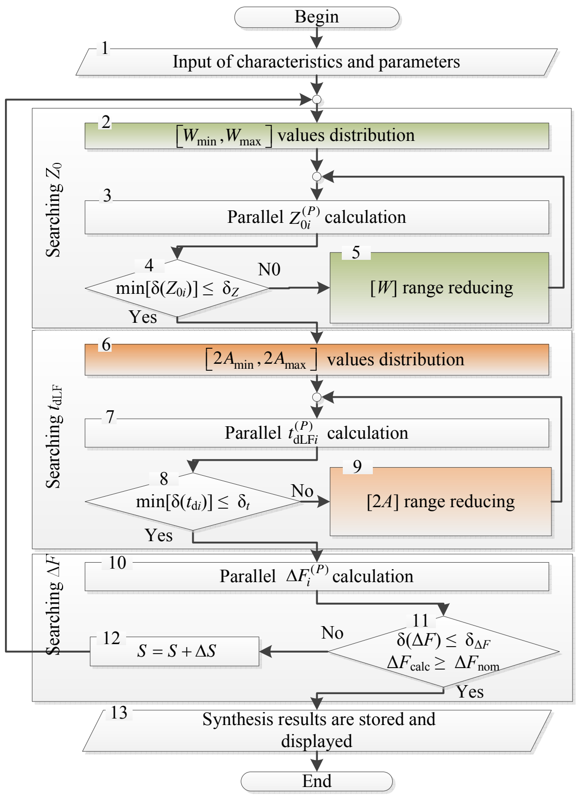

Fig. 3. Data flow diagram of the parallel synthesis algorithm of the multi-tapped microstrip meander delay line, based on the successive approximation technique.

Let us briefly discuss the proposed algorithm.

1. Nominal values of the required electric characteristics, their tolerances, ranges of values of changeable construction parameters and values of constant construction parameters of the MTMDL, and boundary values of the analysis are entered. Required electric

characteristics of the MTMDL are: characteristic impedance Z_0 and its tolerance δ_Z, nominal delay time at low frequency t_{dLF} and its tolerance δ_t, nominal bandwidth ΔF and its tolerance $\delta_{\Delta F}$. Changeable construction parameters of the MTMDL are: minimum and maximum values of the meander microstrip width $W_{\min}$ and $W_{\max}$, minimum and maximum values of the space between meander microstrips $S_{\min}$ and $S_{\max}$, minimum and maximum values of the meander altitude $2A_{\min}$ and $2A_{\max}$. Constant construction and analysis parameters of the MTMDL are: relative permittivity ε_{r} and thickness h of the dielectric substrate.

2. Initial range of values of the microstrip width $\left[W_{\min}, W_{\max}\right]$ is divided into P equal subranges which maximum boundary values $W_i^{(P)}$ are chosen for the analysis of the characteristic impedance $Z_i^{(P)}$. The number of the calculated values is equal to the number of processes P, which is defined at the algorithm start-up.
3. Values of characteristic impedance $Z_i^{(P)}$ are calculated in parallel in all computer nodes according to the microstrip width $W_i^{(P)}$ values obtained at step 2.
4. If one of the P calculated characteristic impedance values $Z_i^{(P)}$ satisfies the condition

$$\min \frac{\left|Z_i^{(P)} - Z_0\right|}{Z_0} \le \delta_Z , \tag{3}$$

then algorithm goes to the step 6, if not – algorithm goes to the step 5.

5. Initial range of the microstrip width values $\left[W_{\min}, W_{\max}\right]$ is reduced to the smaller one $\left[W_{\min}^{'}, W_{\max}^{'}\right]$ using the founded value $W_i^{(P)}$ which corresponds to the smallest relative difference $\left(Z_i^{(P)} - Z_0\right)/Z_0$. Here $W_{\min}^{'} = W_i^{(P)}$, if the nearest calculated value $Z_i^{(P)}$ is larger than given nominal value of characteristic impedance i.e. $Z_{0i}^{(P)} > Z_0$, and $W_{\max}^{'} = W_i^{(P)}$, if $Z_{0i}^{(P)} < Z_0$.
6. Initial range of the meander altitude values $\left[2A_{\min}, 2A_{\max}\right]$ is divided into P equal subranges, where $2A_i^{(P)}$ are maximum boundary values of these subranges.
7. A delay time at low frequency of the MTMDL is calculated according to the following equation [7]

$$t_{\mathrm{dLF}i}^{(P)} = \frac{L_{\mathrm{m}} k_{\mathrm{dLF}i}}{\mathrm{c}_0} , \tag{4}$$

where $k_{\mathrm{dFL}i}$ is a delay factor of the MTMDL at low frequency, calculated according to [8], c_0 is velocity of light in vacuum, L_{m} is the meander length (Fig. 1)

$$L_{\mathrm{m}} = N \cdot (W + S) - S , \tag{5}$$

where N is the number of meander strips.

8. If one of the calculated values of the delay time $t_{\mathrm{dLF}i}^{(P)}$ meets the condition

$$\min \frac{\left|t_{\mathrm{dLF}}^{(P)} - t_{\mathrm{dLF}}\right|}{t_{\mathrm{dLF}}} \le \delta_t , \tag{6}$$

then calculations continue at the step 10, if not – algorithm goes to the step 9.

9. Initial range of the meander strips altitude values $\left[2A_{\min}, 2A_{\max}\right]$ is reduced to the smaller one $\left[2A_{\min}^{'}, 2A_{\max}^{'}\right]$ using the founded value $2A_i^{(P)}$ which corresponds to the smallest relative difference $\left(t_{\mathrm{dLF}i}^{(P)} - t_{\mathrm{dLF}}\right)/t_{\mathrm{dLF}}$. Here $2A_{\min}^{'} = 2A_i^{(P)}$, if the nearest calculated value $t_{\mathrm{dLF}i}^{(P)}$ is larger than given nominal value of delay time i.e. $t_{\mathrm{dLF}i}^{(P)} > t_{\mathrm{dLF}}$, and $2A_{\max}^{'} = 2A_i^{(P)}$, if $t_{\mathrm{dLF}i}^{(P)} < t_{\mathrm{dLF}}$.
10. Parallel calculation of the bandwidth $\Delta F_i^{(P)}$ [7].
11. If one of two conditions are satisfied

$$\min \frac{\left|\Delta F_i^{(P)} - \Delta F\right|}{\Delta F} <= \delta_{\Delta F} \tag{7}$$

or

$$\Delta F_i^{(P)} \ge \Delta F , \tag{8}$$

then algorithm continues at the step 13, if not – at the step 12.

12. Space between microstrips is increased and algorithm goes to the step 2.
13. The calculated and nominal values of electric characteristics and synthesized construction parameters of the MTMDL are displayed and stored.

III. PERFORMANCE COMPARISON OF THE PARALLEL SYNTHESIS ALGORITHMS

To compare the performance of the proposed parallel MTMDL synthesis algorithm, based on the SAT, and parallel algorithm, based on Monte Carlo method [7], the experimental cluster was equipped with the same 14 computer nodes (CPU – Pentium™ 4, 2.8 GHz; RAM – 512 MB; OS – Fedora 6; the network – Ethernet 1 Gb/s) and for all experiments the same number of processes corresponding to the maximum number of nodes $p = 14$ was chosen.

Diagrams, illustrated performance of the MTMDL parallel synthesis algorithms, are presented in Fig. 4.

It is seen in Fig. 4 that execution time of the MTMDL parallel synthesis algorithm, based on the SAT, is about 5 times smaller comparing with the Monte Carlo method based algorithm which is random in nature, under all equal conditions. Therefore execution of the MTMDL synthesis algorithm, based on Monte Carlo method, was repeated 30 times for each implemented number of the cluster nodes and then obtained values of execution time were averaged.

Curves 1 and 2 on Fig. 4(a) demonstrate that increasing the number of the cluster nodes, algorithm execution time decreasing in inverse ratio. It is a common feature of all the parallel algorithms. Shorter execution time of the algorithm, based on the successive approach technique, may be explained by significant reduction of searching construction parameter range during each iteration. It should be noted that when the number of nodes becomes large enough (in our case the largest number of nodes was 14), the probability to find the optimal design parameter values, using Monte Carlo method based synthesis algorithm, executing a small number of iterations, becomes very high and similar to the probability given by the algorithm, based on the SAT.

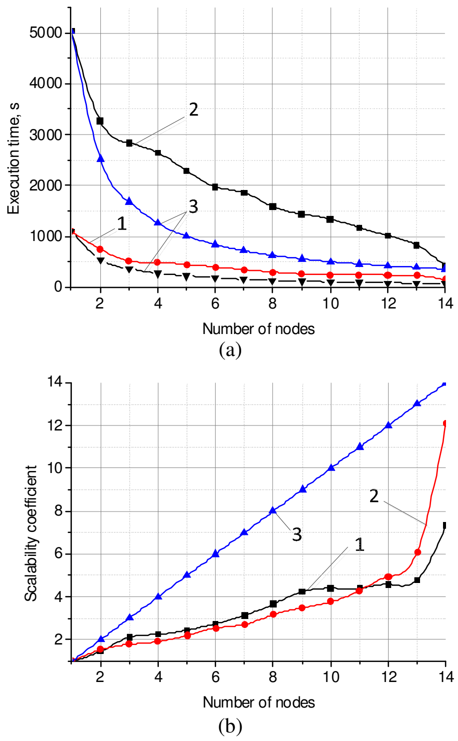

Fig. 4. Dependences of the MTMDL parallel synthesis algorithms execution time (a) and scalability (b) versus number of cluster nodes. Here curves 1 correspond to the proposed algorithm; curves 2 correspond to the parallel algorithm, based on Monte Carlo method, and curves 3 correspond to the ideal parallel algorithm, where for the execution time dependencies symbol ▼ means ideal case for proposed algorithm, and sign ▲ notes ideal case for the algorithm, based on Monte Carlo method.

Dependences of algorithms scalability on the number of cluster nodes are shown in Fig. 4(b). The scalability allows us to evaluate the amount of algorithm operations those can be executed in parallel [11] It is seen here that when the number of cluster nodes is less than 12, then scalability of the both algorithms differ from each other not more than 18 %. At maximum number of nodes (14 nodes) scalability of the algorithm, based on Monte Carlo method increase much high, because having plenty of nodes this algorithm could find needed construction parameters more quickly than algorithm, based on the SAT. In our case both algorithms have demonstrated high level of the scalability: 54 % algorithm, based on the SAT, and even 87 % algorithm, based on Monte Carlo method. So both algorithms may be effectively implemented in parallel computing systems.

IV. CONCLUSIONS

1. Parallel algorithm for the synthesis of the multi-tapped meander microstrip delay lines (MTMDL), based on the successive approximation technique is proposed.
2. Parallel computations in the proposed algorithm are organized according to both – data parallelism and task parallelism concepts.
3. Efficiency of two parallel synthesis algorithms one proposed, and another based on Monte Carlo method, was compared.
4. It is determined that while number of computational nodes is small by comparison (e.g. not larger than 3) then efficiency of the proposed algorithm about 5 times exceeds Monte Carlo method based algorithm efficiency. It is revealed that efficiency of both algorithms becomes similar when computational nodes number increases several times.

It is revealed that more than half of the proposed algorithm operations may be executed in parallel so this algorithm may effectively implemented in parallel computing systems.

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