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Simulation of the Meander Delay Line using the Hybrid Method

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I. Introduction

The dielectric substrate is the basis of the meander microstrip delay line (MMDL), as however in all other microstrip devices. One side of this substrate is covered by a solid layer of a conductor that carries out the function of the electric shield. The signal conductor, having the form of a meander (Fig. 1), is formed on the other side.

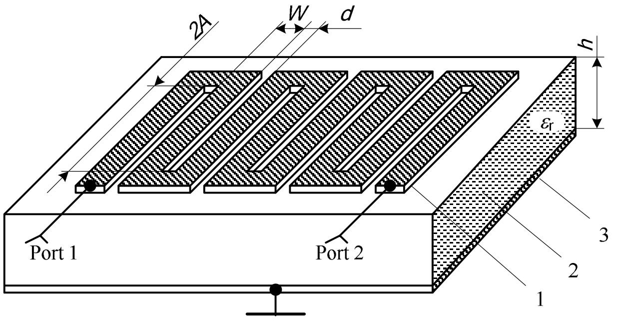


Fig. 1. The design of the a microstrip delay line: 1 – meander shape conductor; 2 – dielectric substrate; 3 – solid shield

At present, the delay lines, designed using active components, are popular [1]. Despite of that, MMDLs have many advantages like linearity of characteristics and stability of parameters. For these reasons, MMDLs are also widely used in electronic devices and equipment for signal synchronization [2] and for analogue and digital filtering [3], [4]. Besides that, MMDLs are frequently applied as specific meander structures, for example, as small-sized antennas [5], resonators [6] and other devices [7], [8].

The methods used for analysis of MMDLs can be conditionally united in two groups: analytical and numerical. Analytical methods are based on the strict solution of the Maxwell's equations and application of the specific boundary conditions. The group of the analytical methods frequently includes as well the approached methods of analysis for which rather sophisticated equations are deduced describing behavior of specific MMDL in set conditions of operation. Using analytical methods, MMDLs are investigated in [9] and [10].

Nowadays there is tendency to use numerical methods (e.g., the method of moments [11], and the method of finite differences in time domain [12], [13]) for simulation and analysis of MMDLs. Numerical methods allow to obtain accurate characteristics of sophisticated electrodynamic systems and microwave devices. However, the duration of calculations can reach tens of hours even if modern workstations are used [14].

Besides analytical and numerical methods, the hybrid methods (joining numerical and analytical methods) are used in practice in order to accelerate calculations of characteristics and preserve the accuracy of calculations [15]–[17].

We propose the new hybrid method for simulation and analysis of MMDLs and other periodical electrodynamic structures.

This paper is organized as follows. Section II describes the model of a MMDL and the proposed hybrid method. The investigated MMDL and the results of its simulation and experimental investigation are presented in Sections III and IV. Finally the conclusions are formulated in Section V.

II. The model of the MMDL and the hybrid method

The developed hybrid method is based on three ideas: (1) application of the microstrip multi-conductor line (MMCL) for modeling of the MMDL, (2) the method of moments for calculations parameters of MMCL, and (3) the method of scattering matrixes (**S** matrixes) for analysis of MMDL in frequency domain.

The structure of the MMCL used for modeling of the MMDL is presented Fig. 2.

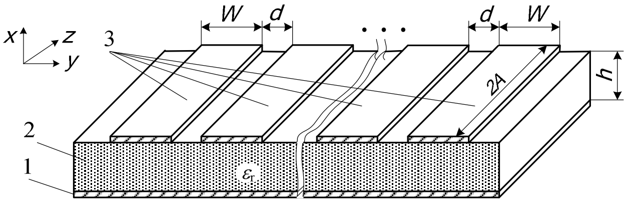


Fig. 2. The cross-section of the microstrip multi-conductor line: 1 – solid shield; 2 – dielectric substrate; 3 – conductors

Traditionally MMCLs, that are infinite in y and z directions, are used in the models of meander structures [15], [18]. The distinctive feature of our MMCL is the finite number n of its conductors corresponding to number of the strips of the MMDL. This makes the multi-conductor line non-periodic and allows taking into account an inequality of electric characteristics of its conductors, which can be more than 40 % [19].

The basic characteristics of a MMCL are characteristic impedances ($Z_i^{(\mathrm{e})}$ and $Z_i^{(\mathrm{o})}$) for even and odd modes and relative effective dielectric permittivities ($e_{\mathrm{ref}i}^{(\mathrm{e})}$ and $e_{\mathrm{ref}i}^{(\mathrm{o})}$). In order to increase accuracy of calculations of the mentioned characteristics, we used the method of moments [18] that does not demand many computer resources.

Having calculated characteristics of the MMCL for each conductor, we (1) use the boundary conditions at the ends of the section of the MMCL, (2) calculate simple **S** scattering matrix for each MMCL strip, (3) apply topology of MMDL and calculate global **S** scattering matrix for investigated MMDL like in [20].

III. The investigated microstrip meander delay line

The layout of the experimental MMDL is presented in Fig. 3. It contains a meander section consisting of 55 meander paces. The meander conductor is formed on the dielectric substrate with thickness $h = 0.5$ mm and dielectric permittivity $\varepsilon_{\mathrm{r}} = 9.85$.

Our attention was concentrated on the phase delay time versus frequency in order to reduce phase-frequency distortions, inserted by the MMDL. Unfortunately, the accuracy of measured characteristics is limited. Besides that, results of experimental investigation of the designed MMDL depend on its manufacturing accuracy that is difficult to control. For these reasons, simulation of the MMDL was used and the hybrid method was developed.

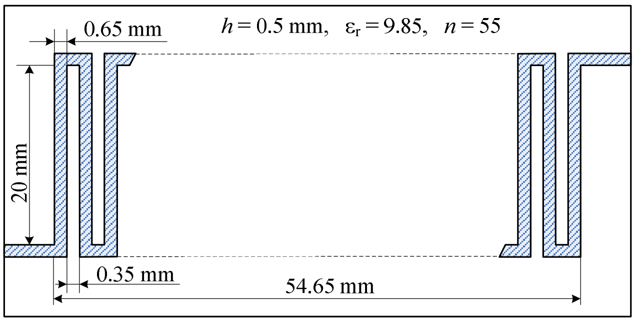


Fig. 3. The topology view of the MMDL layout

IV. Results of simulation and measurements

Initially we used the conform transformation method [9] for calculation of characteristic impedances and effective dielectric permittivities of the multi-conductor line that was followed by the scattering matrixes method. The calculated characteristic of the MMCL is presented by curve (a) in Fig. 4.

The characteristic, calculated using the developed hybrid method based on the moment method for calculation of parameters of the MMCL, and **S** matrixes, is shown by curve (b).

The experimental characteristic is shown by curve (c).

At simulation of the MMDL, we modeled the conditions similar to the conditions used at measurements based on the method of π points [21]. According to this method, after calculation of the **ABCD** matrix of the delay line, the line was short-circuited (its load impedance equal zero) and turned into mathematical model of the measurement circuit to the alternative voltage source.

Parameters of the MMCL along the y axis are homogeneous according to presumptions of conform transformation method. Thus, the effects at the ends of the MMDL, caused by the changed structure (scattering) of the electromagnetic field are not taken into account. As a result, according to characteristic (a), the phase delay time without fluctuations slowly increases with frequency.

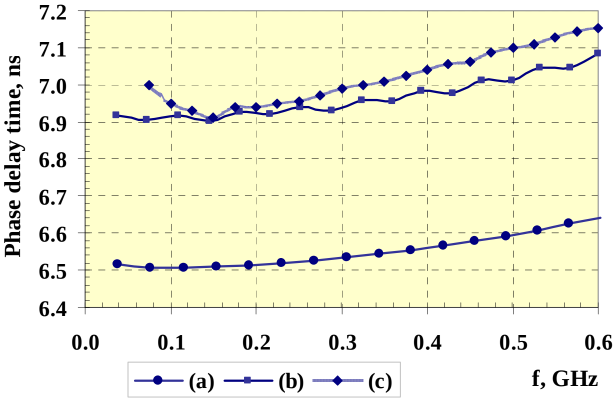


Fig. 4. The phase delay time of the MMDL versus frequency: (a) – calculated using the conform transformation method and **S** matrix, (b) – at application of the developed hybrid method, (c) – according to experimental measurements

The method of moments estimates the inhomogeneous behaviour of the electromagnetic field along the y axis of the MMCL (Fig. 5.). As a result, we got the phase delay time increasing with frequency and see fluctuations of the curve in the calculated frequency range. We guess that the

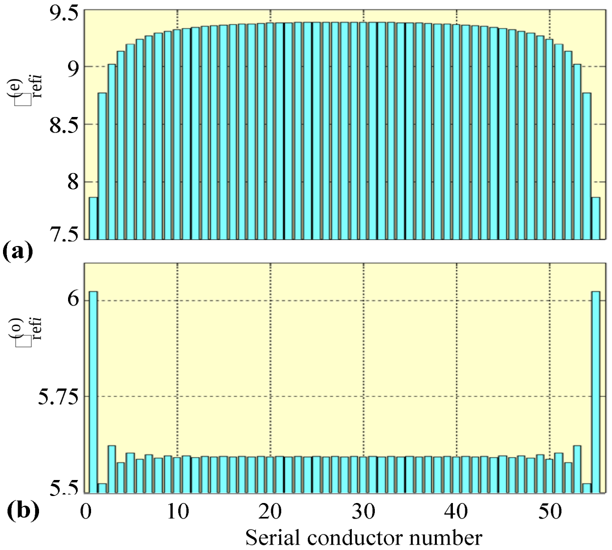


Fig. 5. Relative effective permittivity of 55-conductors' microstrip multi-conductor line for even mode (a) and odd mode (b), when $W = 0.65$ mm, $d = 0.35$ mm, $h = 0.65$ mm, and $\varepsilon_{\mathrm{r}} = 9.85$

reason of both effects is related to evaluation of the end effects of the MMCL with finite length.

It is possible to evaluate the end effects in MMCL model more simply by addition of distributed or lumped capacitances at the first and last conductors of MMCL structure. It allows us to take into account the changed intensity of the electrical field at both ends of the MMCL.

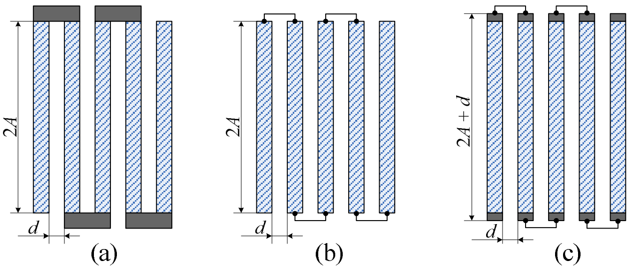
The method of moments and the proposed hybrid method evaluate end effects more precisely. The electromagnetic field in the MMCL with the finite length is not periodic. Fig. 5 illustrates the changes of the effective dielectric permittivities across the MMCL.

Thus, the increasing of the phase delay time, gotten by the suggested method, may be explained taking into account the more exact evaluation of effective dielectric permittivity that directly influences the speed of propagation of electromagnetic waves in the MMDL.

The fluctuation of the curve in Fig. 4, (b) can be explained taking into account the end effects in the MMCL and multiple reflections of the waves inside of the MMDL. Experimental results confirm this presumption.

The dispersion of the phase delay time is close for all three curves (Fig. 4).

Curves represented in Fig. 4 are obtained using the model of the MMDL layout shown in Fig. 6 (b). According to it, electromagnetic waves travel along the meander strips except their ends (dark segments in Fig. 6 (a)). As a result of this presumption, the calculated phase delay time is less than experimentally measured. In the advanced MMDL topology model, each meander strip was prolonged by the distance *d* between the neighbor meander strips.



(a) (b) (c)

Fig. 6. The MMDL topology (a), the simplified MMDL topology model (b), and the advanced topology model (c)

Prolongation of the strips by 1.75 % causes increase of the values of calculated delay time approximately by 1.75 % (Fig. 7). According to Fig. 7, the results obtained using the developed hybrid method coincide with the experimental results better than the results obtained using the infinitively long model of the MMCL and conform transformation method.

V. Conclusion

We propose the hybrid method for simulation and analysis of the microstrip meander delay line (MMDL). The method is based on three analysis methods: (1) the method of microstrip multi-conductor line (MMCL) for meander structure modeling, (2) the method of moments for MMCL parameters calculation, and (3) the method of scattering matrixes for simulation of the MMDL.

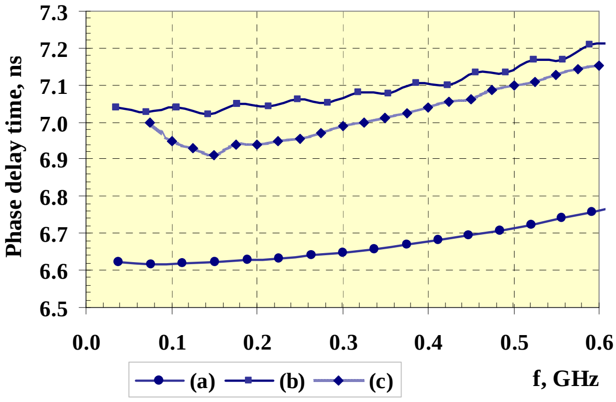


Fig. 7. Characteristics of the MMDL obtained using the advanced MMDL topology model (when meander strips are prolonged by the conductors step *d*: (a) – according to calculations based on conformal transformation; (b) – according to the developed hybrid model; (c) – experimental curve

The developed hybrid method allows taking into account scattering of the electromagnetic field at the edges of the MMDL of finite length. The results of analysis, obtained using the developed method, are closer to the experimental results with respect to the results, obtained when infinitively long the MMCL and the conform transformation method are used. The hybrid method needs less computer resources (RAM and CPU speed) with respect to the finite element and other numerical methods.

More precise evaluation of the proposed hybrid method for simulation and analysis of MMDLs and other slow-wave electrodynamic devices is possible using other numerical methods, commercial software packages and experimental measurement results of different MMDL layouts. The work continues, and the results will be published in the next papers.

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The hybrid method of analysis of the microstrip meander delay line (MMDL), which takes into account non-periodicity of electrical parameters along the meander structure, is proposed. Three known methods of analysis are used for creation of the hybrid method: the method of multi-conductor lines, the method of moments and the scattering matrixes approach. The MMDL model in the proposed method is created using a multi-conductor line of the corresponding design, electric parameters of the multi-conductor line are calculated using the method of moments, and conductors of the multi-conductor line are connected to form the meander structure, which in turn is analyzed by scattering matrixes. The created method takes into account non-periodicity of electric parameters of strips of the meander and allows finding characteristics of MMDL precisely enough. The accuracy of the proposed hybrid method was verified. Calculated basic dynamic characteristics of the MMDL in frequency domain showed good coincidence with the experimentally measured results. Ill. 7, bibl. 21 (in English; summaries in English, Russian and Lithuanian).

В. Урбанавичюс, А. Гурскас, Р. Мартавичюс. Моделирование меандровой микрополосковой линии задержки гибридным методом // Электроника и электротехника. – Каунас: Технология, 2009. – № 2(90). – С. 3–6.

Представлена гибридная математическая модель меандровой микрополосковой линии задержки (ММЛЗ), учитывающая непериодичность электрических параметров штырей в продольном направлении меандровой струкруры. Для построения математической модели ММЛЗ использованы три метода анализа: метод многопроводных линий, метод моментов и теория матриц рассеяния. ММЛЗ в представленной модели создается с помощью многопроводной линии соответствующей конструкции. Электрические параметры многопроводной линии рассчитываются с использованием метода моментов, а проводники многопроводной линии соединяются в меандровую структуру, которая анализируется затем матрицами рассеяния. Созданная модель учитывает непериодичность электрических параметров штырей меандра и позволяет достаточно точно определять характеристики ММЛЗ. Точность созданной интегральной модели проверялась авторами с помощью написанного ими программного обеспечения. Были рассчитаны основные электродинамические характеристики ММЛЗ в частотной области. Проведённые расчёты показали хорошое совпадение полученных результатов с экспериментально измеренными. Ил. 7, библ. 21 (на английском языке; рефераты на английском, русском и литовском яз.).

V. Urbanavičius, A. Gurskas, R. Martavičius. Mikrojuostelinės meandrinės vėlinimo linijos modeliavimas hibridiniu metodu // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2009. – Nr. 2(90). – P. 3–6.

Pateiktas mikrojostelinės meandrinės vėlinimo linijos (MMVL) hibridinis modelis, įvertinantis meandro strypų elektrinių parametrų nevienalytiškumą išilgai meandro struktūros. Matematiniam modeliui sudaryti pritaikyti trys analizės metodai: daugialaidžių linijų metodas, momentų metodas ir sklaidos matricų teorija. MMVL pateiktame modelyje sukuriama iš atitinkamos konstrukcijos daugialaidės linijos, kurios elektriniai parametrai apskaičiuojami taikant momentų metodą, daugialaidės linijos laidininkai jungiami į meandro formos struktūrą, o ši analizuojama taikant sklaidos matricas. Sukurtas matematinis modelis įvertina meandro strypų elektrinių parametrų neperiodiškumą ir leidžia pakankamai tiksliai nustatyti MMVL charakteristikas. Siūlomo modelio tikslumas patikrintas naudojant autorių sukurtą programinę įrangą. Atlikti skaičiavimai parodė, kad gauti rezultatai gerai sutampa su išmatuotais eksperimentiškai. Il. 7, bibl. 21 (anglų kalba; santraukos anglų, rusų ir lietuvių k.).