Journal of Physics: Conference Series

PAPER • OPEN ACCESS

Adaptive segmentation of multiconductor transmission lines in quasi-static analysis by the method of moments

To cite this article: A Maksimov and S Kuksenko 2021 *J. Phys.: Conf. Ser.* **1862** 012020

Adaptive segmentation of multiconductor transmission lines in quasi-static analysis by the method of moments

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Abstract. The paper proposes a new algorithm for constructing an adaptive mesh for quasi-static analysis of multiconductor transmission lines by the method of moments. Its versatility in analyzing transmission lines with complex geometry is shown in comparison with well-known algorithms. The algorithm showed high accuracy of calculations, memory savings are at least 1.6 times, and calculation time savings are at least 1.7 times compared to a tight uniform mesh.

1. Introduction

Transmission lines (TL) are widely used in designing microwave devices and their elements [1]. However, since these devices are getting increasingly complicated, the number of conductors is constantly growing, and so the developers often resort to using multiconductor transmission lines (MCTL). If the length of the propagating electromagnetic wave is many times greater than the transverse dimensions of an MCTL, a quasi-static approach is applied [2]. Then the problem is reduced to the need to calculate the matrices of per-unit-length parameters of the MCTL: **L**, **C**, **R** and **G** [3]. In this case, the calculation of matrix **C** is the main procedure, and the other matrices are derived procedures [4, 5].

When analyzing MCTLs with complex geometry, analytical methods are not applicable and it is necessary to use numerical methods, one of which is the method of moments (MoM) [6]. When using MoM, it is not necessary to artificially set boundary conditions that emulate remote boundaries, which reduces the cost of calculations.

It is known that for the numerical analysis of any physical problem, it is necessary to construct its mathematical model which takes into account the features of a real object (process or phenomenon) essential for this problem. When constructing a mathematical model, the most interrelated and computationally expensive stages are the construction of a mesh, the calculation entries of a system of linear algebraic equations (SLAE) and its solution [7]. Therefore, it is obvious that in order to reduce the total computational costs, it is advisable to develop and use effective methods for constructing a mesh, forming and solving SLAE.

The purpose of this work is to develop an algorithm for constructing an adaptive mesh for quasi-static analysis of an MCTL by the MoM.

2. Approach description

It is known [1] that frequent uniform segmentation of a structure with a segment length of one-third of the conductor thickness is optimal and gives fairly accurate results. It is also known that the charge in the conductors is unevenly distributed. Since the charge carriers of the same sign tend to move away from each other, and there is no balancing charge outside the conductor, the entire charge is pushed to the edges. This effect is much more noticeable in the corners, because there is no balancing charge in two dimensions simultaneously, just as there is no in one, like it happens far from the corners along the edges. This is clearly shown by the example of the charge distribution on a metal plate, Figure 1 [8]. Consequently, the charge density in the corners of the conductors is maximal. Since the conductors that are used to create MCTLs have a width that is many times greater than their thickness, it is further assumed that the charge is evenly distributed at their vertical boundaries (perpendicular to the x-axis), and concentrated at the edges at their horizontal boundaries (perpendicular to the y-axis).

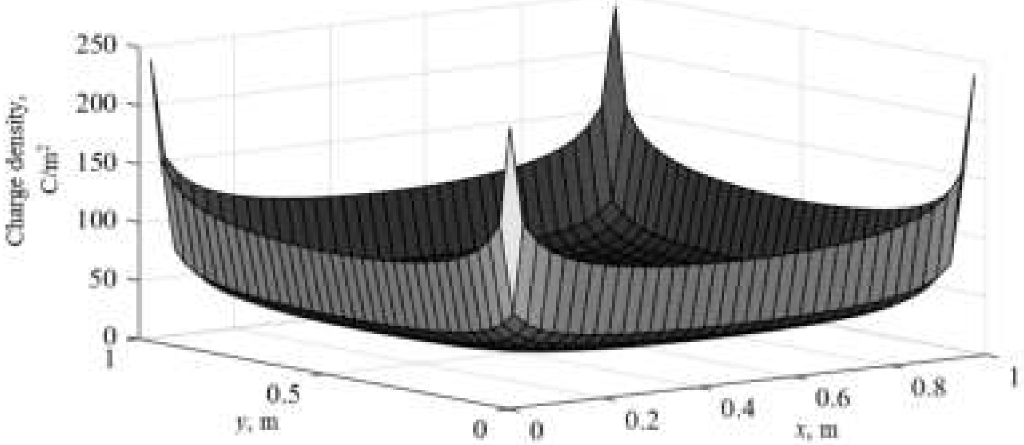


Figure 1. Charge distribution on a metal plate [8].

On the basis of the above, we propose an algorithm for constructing an adaptive mesh for quasi-static analysis of an MCTL by the MoM. The following is a description of this algorithm. Its features are the initial mesh with non-uniform segmentation and the method of its subsequent increase.

First, the structure boundaries that are perpendicular to the x-axis are divided into 3 segments (to obtain a segment length equal to one-third of the conductor thickness). Then the boundaries perpendicular to the y-axis are segmented. They are divided into 3 parts, and the length of the extreme parts is set equal to the thickness of the conductor. After that, the extreme parts are divided into 3 segments each, the central part is taken as 1 segment. Next, the segments with the longest length are iteratively halved.

The iterative process continues until the condition $|C_i - C_{i-1}|/|C_{i-1}| < tol$ is met, where C is the controlled value and tol is the required tolerance of calculations. Figure 2 schematically shows the initial segmentation and the segmentation obtained after the first and second iterations according to the described algorithm, using the example of a microstrip TL.

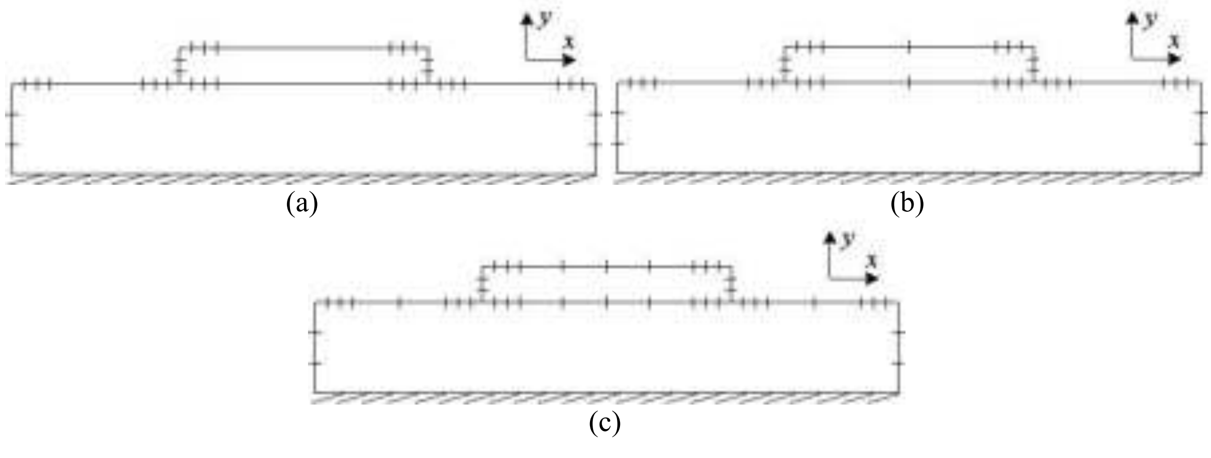


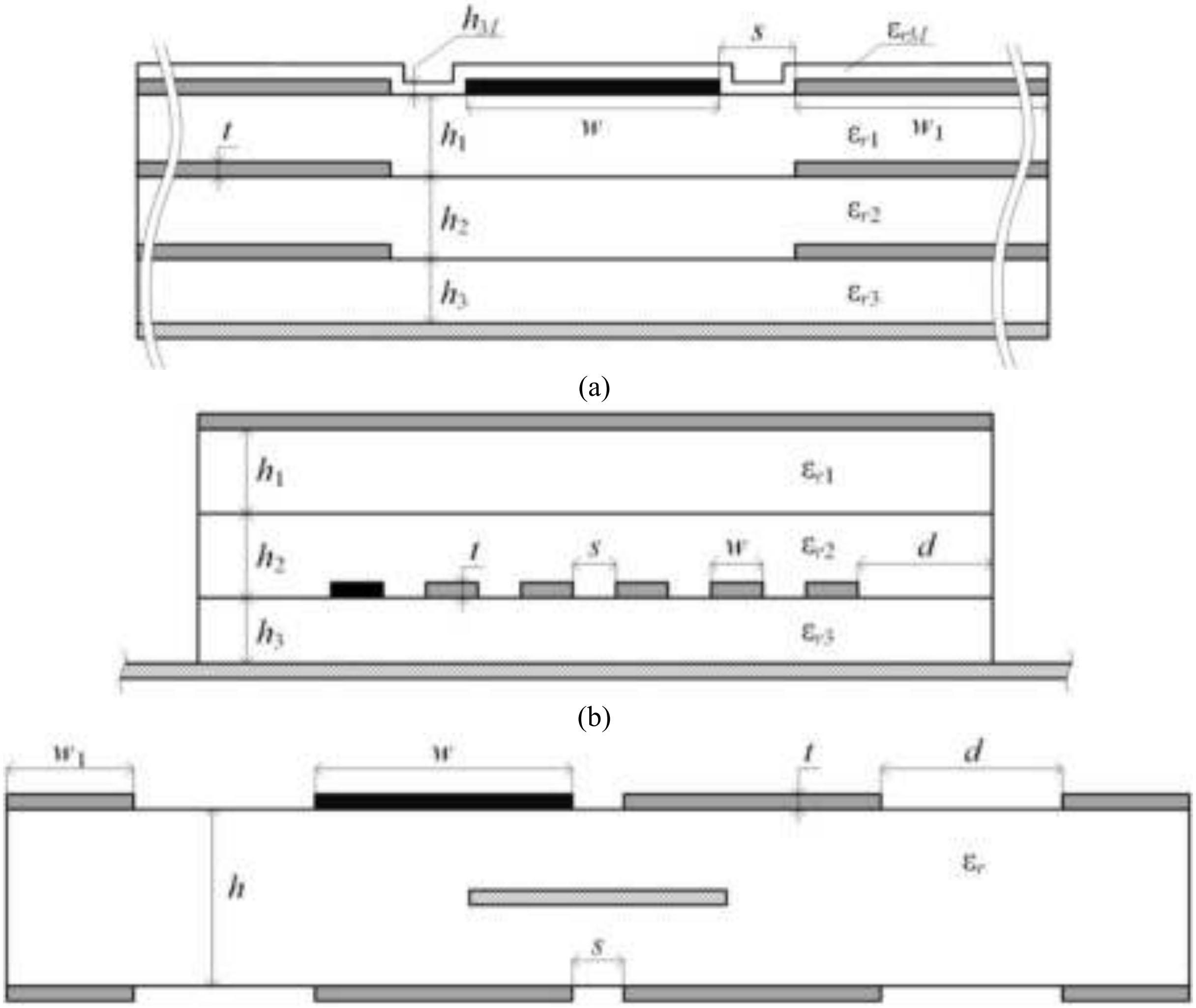
Figure 2. Structure segmentation: initial (a); after the first (b) and second (c) iterations.

3. Numerical results

To test the proposed mesh construction algorithm, a computational experiment was performed to find matrix **C**. The calculations were performed for three MCTLs, Figure 3. Dielectrics are white, conductors are black and gray. The parameters of MCTL 1 are the following: the conductors thickness t=0.035 mm; the width of the central conductor w=0.89 mm; the width of other conductors w_1=3w; the distance between adjacent conductors s=0.5 mm; the dielectrics thicknesses h_1=h_3=0.144 mm, h_2=0.22 mm; the solder mask thickness h_M=0.03 mm; the relative permittivity values ε_{r1}=ε_{r3}=4.5, ε_{r2}=5.4, ε_{rM}=3.5. The parameters of MCTL 2 are the following: t=0.005 mm; w=0.05 mm; s=0.05 mm; d=0.15 mm; h_1=h_2=h_3=0.05 mm; ε_{r1}=ε_{r3}=3.8, ε_{r2}=2. The parameters of MCTL 3 are the following: t=0.018 mm; w=1.6 mm; w_1=1 mm; s=0.51 mm; d=3 mm; h=1 mm; ε_r=4.5. The diagonal entries of matrices **C** are used as the controlled value C. In the Figure 3, this corresponds to the black conductors. The *tol* value is set to 10^{-2}, which corresponds to a difference of less than 1% between the values of C in neighboring iterations [9].

The calculations were performed using the Octave software package and a PC with the following specifications: CPU – AMD Ryzen 3 3200G; clock speed – 3.6 GHz; RAM – 16 GB; number of cores – 4.

The SLAE is solved by the Gauss method, and the time complexity when calculation entries of a SLAE is $O(n^2)$, and when solving it – $O(n^3)$.



(c)

Figure 3. Cross-sections of the MCTL under investigation: 1 (a), 2 (b) and 3 (c).

First, we compared the accuracy of the controlled value obtained using the developed algorithm (Algorithm I) – C_{I} and for a tight uniform mesh with a segment length equal to $t/3$ – C_R, as well as the required computational costs: the calculation time (T_{I} и T_R) and the amount of machine memory (V_{I} и V_R). The difference in the controlled values was estimated using formula $\Delta C=|C_{\mathrm{I}} - C_R|/|C_R|$ in percentages. Next, we compared the efficiency of Algorithm I with the well-known algorithm (Algorithm II) which is based on iterative separation of 25% of the segments with the highest charge density values [10]. The time complexity of the algorithms is the same, but by reducing the number of segments N, and, consequently, reducing the number of entries of a SLAE matrix, the time for its calculation and solution is reduced. The results are summarized in Tables 1 and 2.

Table 1. Results of Algorithm I.

MCTL	ΔC (%)	V_R/V_{I}	T_R/T_{I}	N_R/N_{I}
1	0.42	1.8	2.0	1.4
2	0.61	40.6	31.0	6.4
3	0.26	1.6	1.7	1.3

Table 2. Results of Algorithms I and II.

MCTL	Algorithm	ΔC (%)	$V_{\mathrm{I}}/V_{\mathrm{II}}$	$T_{\mathrm{I}}/T_{\mathrm{II}}$
1	I	0.42	0.8	0.4
	II	0.89		
2	I	0.61	2.6	1.3
	II	0.84		
3	I	0.26	0.9	0.6
	II	14.80		

As can be seen from Table 1, the accuracy of calculations for all MCTLs obtained by using Algorithm I is high, memory savings are at least 1.6 times, and calculation time savings are at least 1.7 times. In addition, MCTL 2 is characterized by significant savings in machine resources; therefore, for such MCTLs, Algorithm I is the most efficient. However, as can be seen from Table 2, for this MCTL, Algorithm II provides even greater savings in computing resources. At the same time, Algorithm I is more efficient for the other MCTLs. In addition, its use allows obtaining more accurate results relative to Algorithm II. Finally, for MCTL 3, Algorithm II is poorly applicable since it is characterized by low accuracy of results. Therefore, the developed algorithm was found to be more versatile.

4. Conclusion

In this paper, we propose a new algorithm for constructing an adaptive mesh for quasi-static analysis of MCTLs by the MoM. The comparison of the proposed algorithm with the known ones has shown its high efficiency and versatility in the analysis of MCTLs with complex geometry. In the future, it is advisable to study its use in multivariate analysis and optimization of MCTLs, as well as in combination with other ways for reducing the computational costs necessary for forming and solving SLAEs.

Acknowledgements

This work was financially supported by the Ministry of Education and Science of Russia under project FEWM-2020-0039.

References

[1] Gazizov T R, Sagiyeva I Ye and Kuksenko S P 2019 Solving the complexity problem in the electronics production process by reducing the sensitivity of transmission line characteristics to their parameter variations *Complexity* **2019** 6301326
[2] Jackson J D 1962 *Classical electrodynamics* (New York-London-Sydney: John Wiley and Sons, Inc.)
[3] Paul C R 2008 *Analysis of multiconductor transmission lines* (Hoboken, New Jersey: John Wiley

and Sons, Inc.)
[4] Harrington R F and Wei C 1984 Losses on multiconductor transmission lines in multilayred dielectric media *IEEE Transactions on microwave theory and techniques* **MTT–32** pp 705–10
[5] Matthaei G L and Chinn G C 1992 Approximate calculation of the high-frequency resistance matrix for multiple coupled lines *IEEE Microwave Symposium Digest* pp 1353–4
[6] Harrington R F 1968 *Field computation by moment methods* (USA, NY: Macmillan) p 240
[7] Rylander T, Ingelström P and Bondeson A 2013 *Computational electromagnetics* (New York: Springer)
[8] Dworsky L N 2014 *Introduction to numerical electrostatics using MATLAB* (Hoboken, New Jersey: John Wiley and Sons, Inc.)
[9] Swanson D G and Hofer W J 2003 *Microwave circuit modeling using electromagnetic field simulation* (Norwood: Artech House Publishers)
[10] Makarov S N, Noetscher G M and Nazarian A 2015 *Low-frequency electromagnetic modeling for electrical and biological systems using MATLAB* (Hoboken, New Jersey: John Wiley and Sons, Inc.)