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Simulation and Properties of the Wide-Band Hybrid Slow-Wave System

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Introduction

Helical structures and meander systems are applied as the wide-band slow-wave structures for retardation of electromagnetic waves in traveling-wave tubes, traveling-wave cathode-ray tubes, delay lines and other electronic devices. Methods, models and properties of various types of helical and meander systems are described in [1–4] and other monographs and papers.

Modern technologies can be used for manufacturing of planar meander electrodes. Unfortunately, relatively low characteristic impedance and dispersion of phase velocity of electromagnetic wave are characteristic features of the meander systems. In order to increase characteristic impedance, meander electrodes with bended peripheral parts are developed for cathode-ray traveling-wave tubes [2].

A new type of the meander traveling-wave deflecting system (Fig. 1) with high characteristic impedance is proposed in [2, 5]. According to [2], the bended parts of the meander electrodes are formed and have the shape of the turns connecting the central parts of conductors of the meander electrodes. As a result, the system contains the peripheral elements similar to the helical turns and the central part with conductors like in a meander system. Thus, the proposed system can be specified as a hybrid Helical-Meander-Helical (HMH) system consisting of two helical elements and the central meander part.

Experimental investigation confirmed high characteristic impedance of the hybrid system [2]. At the same time, the lack of information about properties of the hybrid system inhibits its application in electronic devices.

In this paper, we propose models and present results of simulation of the hybrid HMH system.

Simulation using the method of multiconductor lines

In order to reveal general properties of the hybrid HMH system (Fig. 1), we can use the multiconductor line method [2, 6–8].

At opposite potentials of deflecting electrodes, analysis of the symmetrical HMH system can be simplified. Distribution of electromagnetic field does not change at inserting of electrical wall in the symmetry plane. Thus, we can consider an asymmetrical system consisting of one slow-wave electrode and a shield instead of symmetrical

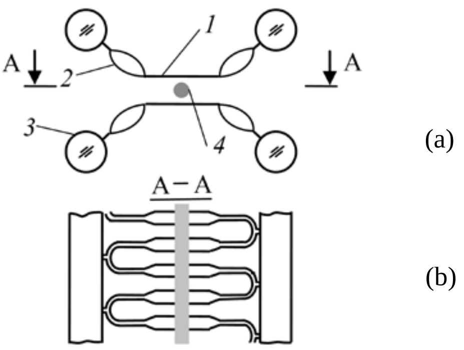

Fig. 1. (a) The cross-section and (b) the top view of the hybrid HMH line (*1* – central part; *2* – formed peripheral parts; *3* – dielectric holder; *4* – electron beam

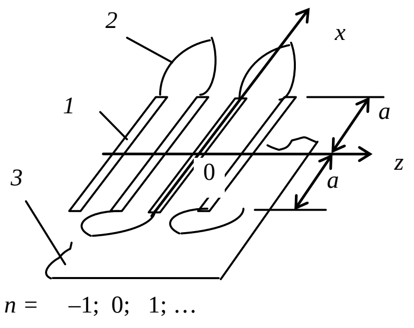

Fig. 2. The model of the asymmetrical hybrid HMH system: *1* – central conductor of the multiconductor line; *2* – turn of conductor in the peripheral part; *3* – shield

system.

The model of the asymmetrical HMH system is presented in Fig. 2. It consists of the parallel conductors modeling the central meander-like part of the system and inductive elements modeling turns connecting conductors of the central part in the way similar to that in meander systems.

Assuming that conductors of the system are in the vacuumed space, using the quasi-TEM wave approximation and taking into account that the multiconductor line modeling meander must contain two conductors in a period, we can write the following expressions [2] for voltages and currents of the conductors in the multiconductor line:

$$\begin{aligned}\underline{U}_n(x) = \left(\underline{A}_1 \sin kx + \underline{A}_2 \cos kx\right)\mathrm{e}^{-\mathrm{j}n\theta} + \\ +\left(\underline{A}_3 \sin kx + \underline{A}_4 \cos kx\right)\mathrm{e}^{-\mathrm{j}n(\theta+\pi)},\end{aligned} \quad (1)$$

$$\begin{aligned}\underline{I}_n(x) = \mathrm{j}Y(\theta)\left(\underline{A}_1 \cos kx - \underline{A}_2 \sin kx\right)\mathrm{e}^{-\mathrm{j}n\theta} + \\ +\mathrm{j}Y(\theta+\pi)\left(\underline{A}_3 \cos kx - \underline{A}_4 \sin kx\right)\mathrm{e}^{-\mathrm{j}n(\theta+\pi)},\end{aligned} \quad (2)$$

where $\underline{A}_i$ are coefficients, n is the number of the conductor of the line, $k = \omega / \mathrm{c}_0$ is the wave number, c_0 is the light velocity in the free space, ω is the angular frequency, θ is the phase angle between the voltages on the adjacent conductors of the multiconductor line, $Y(\theta)$ and $Y(\theta+\pi)$ are characteristic admittances of the line [9].

In the case of the slow-wave propagating in z direction, voltages and currents in the model must satisfy boundary conditions:

$$\underline{U}_1(0) = \underline{U}_0(0)\mathrm{e}^{-\mathrm{j}\theta}, \quad (3)$$

$$\underline{I}_1(0) = -\underline{I}_0(0)\mathrm{e}^{-\mathrm{j}\theta}. \quad (4)$$

$$\underline{U}_0(a) = \underline{U}_1(a) + \mathrm{j}\omega L_\mathrm{H}\underline{I}_0(a), \quad (5)$$

$$\underline{I}_0(a) = -\underline{I}_1(a), \quad (6)$$

where L_H is the inductance of the helical turn.

Substituting (1) and (2) into (3)–(6), we obtain a set of algebraic equations. Considering the set at zero determinant, we can find values of the retardation factor k_R and frequency f [2]:

$$k_\mathrm{R} = \mathrm{c}_0 / v_\mathrm{ph} = \theta / kL, \quad (7)$$

$$f = k\mathrm{c}_0 / 2\pi, \quad (8)$$

where, v_ph is the phase velocity of the traveling wave and L is the step of the conductors of the multiconductor line.

After that we can find the input impedance of the system. It is dependent on the coordinate x. At $x = 0$, according to (1) and (2)

$$Z_\mathrm{IN}(0) = \frac{\underline{U}_0(0)}{\underline{I}_0(0)} = \frac{1}{\mathrm{j}Y(\theta)} \cdot \frac{(1-\mathrm{e}^{-\mathrm{j}\theta})\cos ka}{(1-\mathrm{e}^{-\mathrm{j}\theta})\sin ka}. \quad (9)$$

Characteristics of the hybrid HMH structure (retardation factor and input impedance versus frequency), calculated using the multiconductor line method are presented in Fig. 3. According to them, using meander electrodes with formed lateral parts, we can considerably increase retardation factor and input impedance of the slow-wave system. Variations of retardation factor and input impedance of the HMH system are relatively small in the wide frequency range.

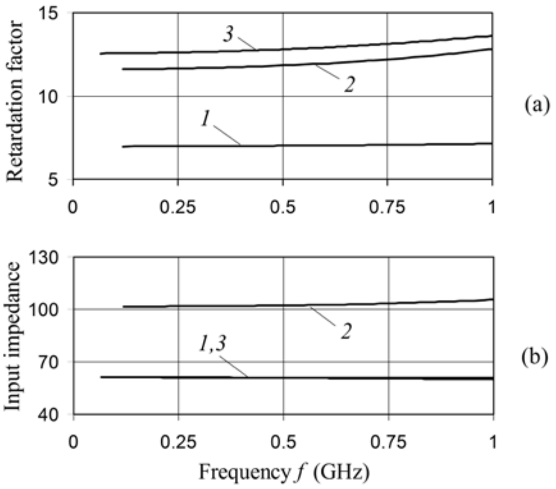

Fig. 3. (a) Retardation factor and (b) input impedance of the hybrid HMH system versus frequency at L = 2 mm, thickness of conductors 0.2 mm, gaps between them in the central part 0.5 mm, shield distances 0.5 and 10 mm, characteristic impedances $Z(0)$ = 87.7 Ω, $Z(\pi)$ = 42.6 Ω:
1 – a = 10 mm, L_H = 0 nH; *2* – a = 10 mm, L_ind = 5 nH;
3 – a = 18 mm, L_H = 0 nH

It is also important that characteristic impedances of ordinary helical and meander systems reduce with frequency [1, 2]. The input impedance of the HMH system (Fig. 3(b), curve *2*) slowly increases with frequency. This property of the system can be used in traveling-wave deflection systems for compensation of amplitude-frequency distortions caused by other factors [2].

Simulation using the *CST MWS* software package

Simulation using multiconductor line method confirmed the idea that characteristic impedance of the HMH system can be higher than that of the meander system. On the other hand, using the multiconductor line method, we considered peripheral parts of the HMH system as lamped inductances. Besides that, we did not take into account coupling of the peripheral parts.

In order to verify the results obtained using the multiconductor line method, we used the *CST Microwave Studio* (CST MWS) software system [10].

Presenting the results of simulation, we will compare characteristics of HMH structures with characteristics of the non-symmetrical flat meander system presented in Fig. 4. Main dimensions of the meander system: width of the meander electrode $2a$ = 15 mm, step of conductors L = 2 mm, gaps among the conductors l = 0.5 mm, thickness of conductors t = 0.2 mm, the gap between the meander electrode and the shield w_2 = 0.5 mm, the length of the system L_s = 29.5 mm.

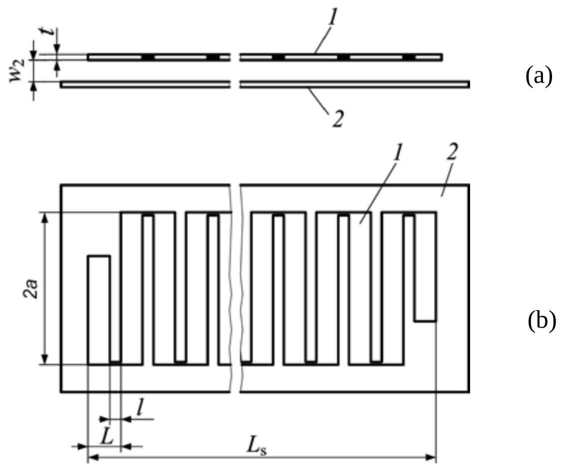

Fig. 4. Non-symmetrical flat meander system: *1* – meander electrode; *2* – shield

Using CST MWS graphical editor, we composed the model of the signal path, containing the system (Fig. 4), its input and output ports, a signal source and a load and used methodology of simulation of slow-wave systems described in [11, 12]. According to Fig. 4, the conductors of the meander electrode are short circuited like in the model of the meander system based on multiconductor line.

The structural retardation of the meander system is given by $k_{\mathrm{Rs}} = L/2a$ [2]. At indicated dimensions, $k_{\mathrm{Rs}} = 7.5$. Calculated value of input impedance of the system $Z_{\mathrm{IN}} = 65\ \Omega$. Curve *1* in Fig. 5(a) characterizes dispersion properties of the system. Its retardation factor is less than structural retardation and increases with frequency. The results of simulation using *CST Microwave Studio* practically coincide with results presented in Fig. 3(a).

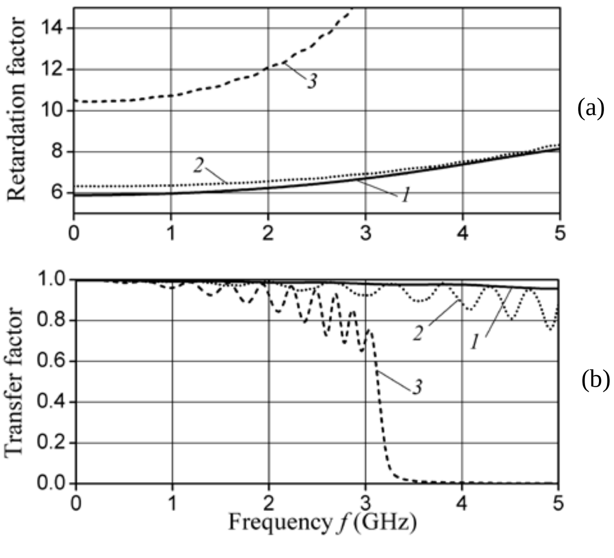

Fig. 5. (a) Retardation factor of meander and HMH systems and (b) transfer characteristics of the signal paths: *1* – flat meander system (Fig. 4); *2* – hybrid meander system (Fig. 6); *3* – hybrid meander system (Fig. 7)

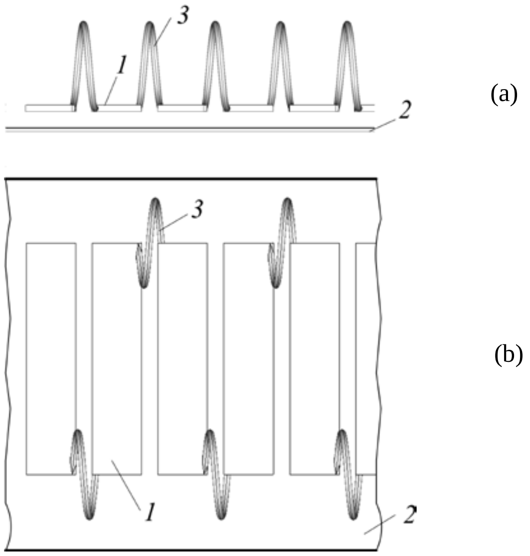

Fig. 6. The hybrid meander system: *1* – meander electrode; *2* – shield; *3* – turn connecting conductors

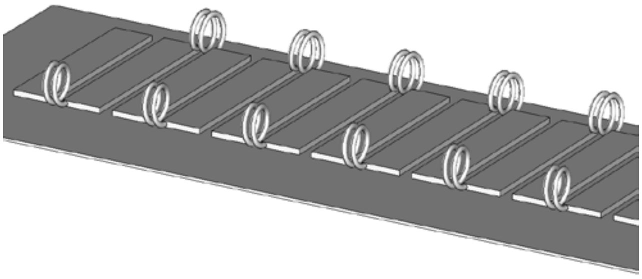

Fig. 7. The model of the system with coils connecting conductors to form the hybrid HMH system

The transfer characteristic of the matched signal path containing the meander system is presented by curve *1* in Fig. 5(b).

The model of the HMH system is presented in Fig. 6. The longitudinal section dimensions of the central part of the system are same as dimensions of the meander system. The length of conductors is reduced to 7 mm in order to obtain the same retardation factor as in the ordinary meander system (Fig. 4). The short-circuiters of conductors used in the model of the meander electrode are replaced by turns. Diameter of the turns is 2.5 mm. Diameter of the conductors of the turns is the same as the thickness of the meander electrode (0.2 mm.).

According to calculations, at indicated dimensions of the HMH system, its input impedance is 110 Ω. Other frequency characteristics of the system are presented by curves *2* in Fig. 5. Thus, using formed meander electrodes, we can considerably increase the characteristic and input impedances of the system at the same retardation and ensure wide pass-band (more than 5 GHz).

We can further increase characteristic impedance using coils (Fig. 7) instead of single turns. According to calculations, at application of coils consisting of two identical turns (like in Fig. 6), characteristic impedance becomes 185 Ω (2.8 higher than that of the ordinary meander system). Unfortunately, application of coils is followed by increase of retardation factor, considerable increase of dispersion (curve *3* in Fig. 5(a)) and decrease of the width of the pass-band of the signal path (curve *3* in Fig. 5(b)).

Conclusions

Properties of the slow-wave system containing formed meander electrodes are investigated using multiconductor line method and the *CST Microwave Studio* software system.

The system containing formed meander electrodes has features of meander and helical systems and can be considered as the hybrid Helical-Meander-Helical (HMH) system.

Using formed meander electrodes we can considerably increase characteristic impedance and ensure the wide-pass-band of the slow-wave system.

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The meander slow-wave system with bended and formed lateral parts of meander electrodes is considered. The system has features of meander and helical systems and can be considered as the hybrid helical-meander-helical (HMH) system. The multiconductor line method and the *CST Microwave Studio* software system are used for simulation of the HMH system. Expressions for retardation factor and input impedance of the systems are derived using the multiconductor line method. The *CST Microwave Studio* software is used for calculation of characteristic impedance, retardation factor versus frequency and transfer function of the signal path containing meander and HMH systems. According to results of simulation, using formed meander electrodes, we can considerably increase characteristic impedance and ensure the wide-pass-band of the signal path. Ill. 7, bibl. 12 (in English; abstracts in English, Russian and Lithuanian).

В. Дашкевичюс, Ю. Скудутис, А. Каткевичюс, С. Штарас. Моделирование и свойства широкополосной гибридной замедляющей системы // Электроника и электротехника. – Каунас: Технология, 2010. – № 8(104). – С. 43–46.

Рассматриваются свойства меандровой системы, содержащей меандровые электроды с отогнутыми и формированными периферийными участками. Система имеет характерные меандровым и спиральным системам признаки и может рассматриваться как гибридная спиральная-меандровая-спиральная (СМС) система. Для анализа системы и выявления ее свойств применен метод многопроводных линий и пакет программ *CST Microwave Studio.* Метод многопроводных линий применен для вывода выражений дисперсионного уравнения и входного сопротивления. Пакет программ *CST Microwave Studio* использован для расчета волнового сопротивления, частотной зависимости коэффициента замедления и амплитудно-частотной характеристики сигнального тракта, содержащего простую меандровую систему и систему с формированными меандровыми электродами. Показано, что применяя отогнутые меандровые электроды можно обеспечить повышенное волновое сопротивление СМС системы и широкую полосу пропускания. Ил. 7, библ. 12 (на английском языке; рефераты на английском, русском и литовском яз.).

V. Daškevičius, J. Skudutis, A. Katkevičius, S. Štaras. Plačiajuostės hibridinės lėtinimo sistemos modeliavimas ir savybės // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2010. – Nr. 8(104). – P. 43–46.

Nagrinėjama lėtinimo sistema, kurioje panaudoti meandriniai elektrodai su nukreiptomis ir suformuotomis periferinėmis dalimis. Sistema turi meandrinėms ir spiralinėms sistemoms būdingų bruožų ir gali būti laikoma spiraline-meandrine-spiraline (SMS) sistema. Sistemai modeliuoti ir jos charakteristikoms apskaičiuoti naudotas daugialaidžių linijų metodas ir kompanijos *CST* programų paketas *Microwave Studio*. Taikant daugialaidžių linijų metodą išvesta sistemos dispersinė lygtis ir įėjimo varžos išraiška. Paketas *Microwave Studio* panaudotas sistemos banginei varžai, lėtinimo koeficiento dažninei charakteristikai ir signalinio trakto, kuriame panaudota meandrinė sistema ir SMS sistema, amplitudės dažninėms charakteristikoms apskaičiuoti. Parodyta, kad, naudojant SMS sistemas su nukreiptais ir suformuotais meandriniais elektrodais, galima gauti didelę sistemos banginę varžą ir plačią praleidžiamųjų dažnių juostą. Il. 7, bibl. 12 (anglų kalba; santraukos anglų, rusų ir lietuvių k.).