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Simulation and Properties of the H-profile Meander System

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Introduction

Meander-type structures are applied for retardation of electromagnetic waves in traveling-wave tubes, traveling-wave cathode-ray tubes, delay lines and other electronic devices [1–3]. Models of meander-type and helical slow-wave structures are proposed and their properties are described in [1–4] and other monographs and papers.

The pass-band of meander systems depends on dispersion of retardation factor and change of characteristic impedance with frequency [1, 2]. In order to widen the pass-band and reduce the linear distortions of signals, we must reduce the electromagnetic coupling between the parts of the meander conductor at the sides of the meander electrode where the phase angle of voltage between the neighbor conductors is maximal.

The coupling can be reduced by bending the neighbor parts of the meander electrode in the opposite directions at the sides of the electrode. The cross-section of the modified meander structure is presented in Fig. 1(a). Fig. 1(b) illustrates the simplified configuration of the H-profile meander electrode.

In this paper we will use the multi-conductor line method and the *CST Microwave Studio* (*CST MWS*) software package for simulation of the H-profile meander system in order to reveal its properties.

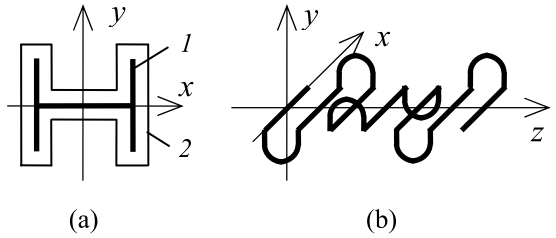


Fig. 1. The view of the H-profile meander system (a) (*1* – meander electrode; *2* – shield), and the simplified view of the meander electrode (b)

Simulation using multi-conductor line method

To verify the idea that reducing the coupling of the lateral parts of the meander electrode can help to improve characteristics of the meander system, we used the model presented in Fig. 2. It consists of the segments of the multi-conductor lines. The lateral segments are different with respect to the central part.

Using the quasi-TEM wave approximation and taking into account the normal modes, we have the following expressions [1, 2] for voltages and currents of the conductors in the multi-conductor line:

$$\underline{U}_{in}(x) = \left(\underline{A}_{i1}\sin kx + \underline{A}_{i2}\cos kx\right)e^{-jn\theta} + \left(\underline{A}_{i3}\sin kx + \underline{A}_{i4}\cos kx\right)e^{-jn(\theta+\pi)}; \quad (1)$$

$$\underline{I}_{in}(x) = jY_i(\theta)\left(\underline{A}_{i1}\cos kx - \underline{A}_{i2}\sin kx\right)e^{-jn\theta} + jY_i(\theta+\pi)\left(\underline{A}_{i3}\cos kx - \underline{A}_{i4}\sin kx\right)e^{-jn(\theta+\pi)}; \quad (2)$$

where A_i are coefficients, i is the number or the segment of the multi-conductor line, n is the number of the conductor of the line, $k = \omega / c$ is the wave number, ω is the angular frequency, c is the light velocity, θ is the phase angle between the voltages on the adjacent conductors of the multi-conductor line, $Y_i(\theta)$ and $Y_i(\theta+\pi)$ are characteristic admittances of the line.

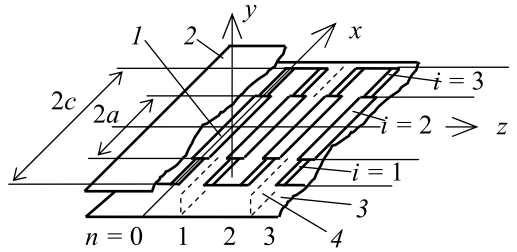


Fig. 2. The model of the meander system: *1* – conductor of the multi-conductor line; *2*, *3* – shields; *4* – shielding wall

The voltages and currents must satisfy the boundary conditions at $x = -a$ and $x = a$:

$$\underline{U}_{1n}(-a) = \underline{U}_{2n}(-a) \; ; \tag{3}$$

$$\underline{I}_{1n}(-a) = \underline{I}_{2n}(-a) \; ; \tag{4}$$

$$\underline{U}_{2n}(a) = \underline{U}_{3n}(a) \; ; \tag{5}$$

$$\underline{I}_{2n}(a) = \underline{I}_{3n}(a) \; . \tag{6}$$

The system of the multi-conductor lines models the meander line if the following boundary conditions are satisfied:

$$\underline{U}_{10}(-c) = \underline{U}_{1(-1)}(-c) \; ; \tag{7}$$

$$\underline{I}_{10}(-c) = -\underline{I}_{1(-1)}(-c) \; ; \tag{8}$$

$$\underline{U}_{30}(c) = \underline{U}_{31}(c) \; ; \tag{9}$$

$$\underline{I}_{30}(c) = -\underline{I}_{31}(c) \; ; \tag{10}$$

Substituting (1) and (2) into (3)–(10), we arrive at a set of algebraic equations. Considering the set at zero determinant [3], we can find values of the retardation factor K_{r} and frequency f , i.e.,

$$K_r = \mathrm{c} / v_f = \theta / kL \; , \tag{11}$$

$$f = k\mathrm{c} / 2\pi \; , \tag{12}$$

where v_f is the phase velocity of the traveling wave and L is the step of the conductors of the multi-conductor line.

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

$$Z_{\mathrm{IN}}(0) = \frac{\underline{U}_{20}(0)}{\underline{I}_{20}(0)} = \frac{\underline{A}_{22} - \underline{A}_{24}}{j[Y_2(\theta)\underline{A}_{21} - Y_2(\theta + \pi)\underline{A}_{23}]} \; . \tag{13}$$

The numerical finite difference method [5] was used for calculation of characteristic admittances and corresponding to them characteristic impedances $Z_i(0) = 1/Y_i(0)$, $Z_i(\pi) = 1/Y_i(\pi)$. In order to take into account that coupling of lateral parts of the meander electrode in the H-profile meander system is reduced, during calculations of characteristic admittances of multi-conductor lines we admitted that the shielding walls (Fig. 2) are far from the conductors of the line.

Characteristics of the meander structure, calculated using the model, presented in Fig. 2, are shown in Fig. 3. According to them, reducing the coupling of conductors at the lateral parts of the meander electrode by widening the lateral parts of the electrode and narrowing down its central part and using the modified H-profile meander system allow us to reduce dispersion of retardation and change of input impedance. So, there are possibilities to improve properties of the meander system using H-type profile.

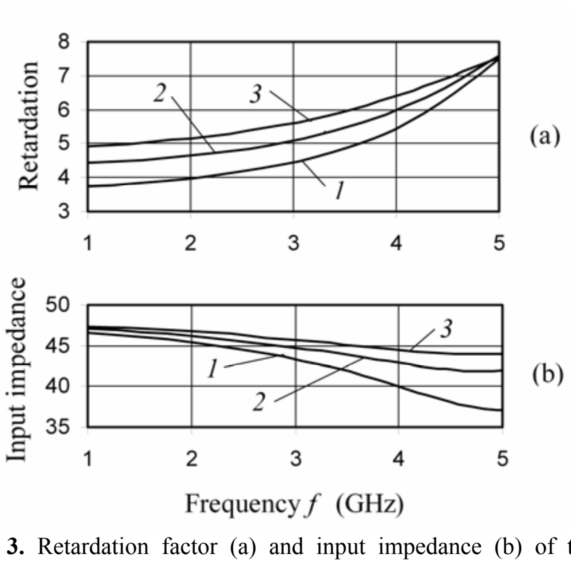


Fig. 3. Retardation factor (a) and input impedance (b) of the meander system versus frequency at $2c/L = 7.5$, $Z_2(0) = 57\ \Omega$, $Z_2(\pi) = 36.5\ \Omega$, $Z_1(0) = Z_3(0) = 52\ \Omega$, $Z_1(\pi) = Z_3(\pi) = 36.5\ \Omega$, and different widths $(c - a)$ of the lateral parts of the meander electrode: *1* – $(c - a) = 0$; *2* – $(c - a) = a = 0.5c$; *3* – $(c - a) = 0.85c$

Simulation using the *CST MWS* software package

The used model, based on multi-conductor lines, does not take into account that bending of the lateral parts of the meander electrode in the H-profile meander system causes the change of the period of the meander electrode. The system becomes an inhomogeneous structure and its period becomes twice longer. In order to verify the discovered properties of the system and reveal effects caused by inhomogeneities and change of the period, we used the software package *CST MWS* [6].

The model of the flat and H-profile meander systems, made using the *CST MWS* graphical editor, is presented in Fig. 4. Applying the program package graphical editor, the system construction scheme is drawn and the ports of the signal source and load are indicated. The calculation methodology of characteristics of slow-wave systems using the *CST MWS* package are described in [7].

The frequency characteristics of the flat and H-profile meander systems (retardation and transfer factors versus frequency) are presented in Fig. 5(a, b). According to Fig. 5(a), using bended lateral parts of the meander electrode, we can really reduce the dispersion of retardation and phase distortions in the meander system.

Analyzing the H-profile meander delay system properties in a wider frequency range, we can see that the

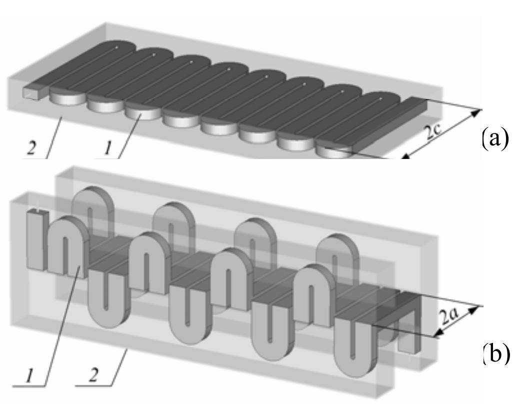
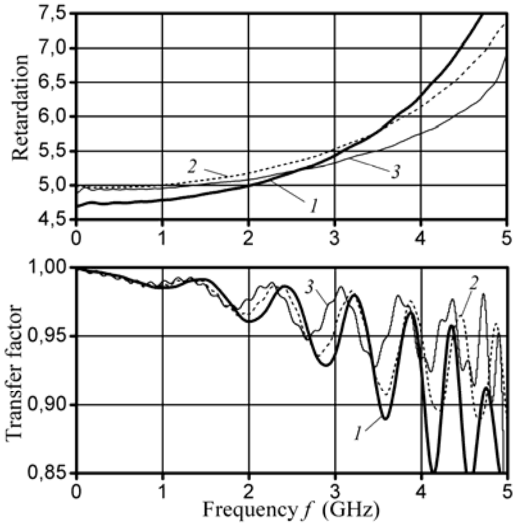


Fig. 4. The flat (a) and H-profile (b) meander systems: *1* – meander electrode; *2* – shield



(a)

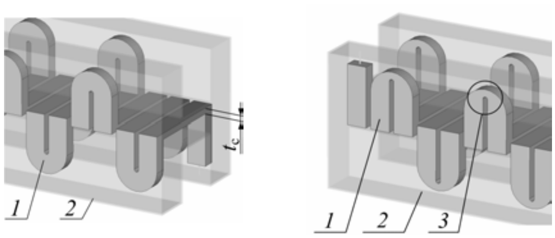
Fig. 5. Retardation factor (a) and transfer factor (b) versus frequency: *1* – flat meander system (Z_0 = 46 Ω); *2* – H-profile meander system at $a = 0.5c$ (Z_0 = 47 Ω); *3* – H-profile meander system at $a = 0.25c$ (Z_0 = 47 Ω)

stop-band appears at frequency above 5 GHz. It is known [1, 2] that the stop-band usually exists at the phase angle $\theta \cong \pi$ in the meander systems. For the investigated systems it would be about 10 GHz. Since the period of the H-profile meander line is twice greater, the stop-band appears at $\theta \cong \pi/2$ and approximately twice lower frequency, i.e., near frequency $f \cong 5$ GHz.

Because of dispersion, the upper limit of the pass-band of a meander system usually is less than frequency, corresponding to $\theta \cong \pi/2$. Taking this into account, here we will not consider the questions, related to the stop-band in more detail.

The transfer (amplitude-frequency) characteristics of the meander systems are presented in Fig. 5(b). Oscillations (ripples) of the characteristics are caused by reflections from the terminals of the systems. They increase with frequency because characteristic impedances of the systems reduce with frequency (Fig. 3(b) and influence of reactances at the terminals increases. The period of the ripples (in the frequency domain) is related to the delay time ($\Delta f \cong 1/2t_d$, where Δf is the period of the ripples and t_d is the delay time).

Besides that, it is important to notice that inhomogeneities of the transfer characteristics depend on the type of the meander electrode. Narrowing the central



(a) (b)

Fig. 6. Thinned (a) and narrowed (b) meander conductor of the H-profile system: *1* – meander electrode; *2* – shield, *3* – lateral (loop) part of the meander electrode

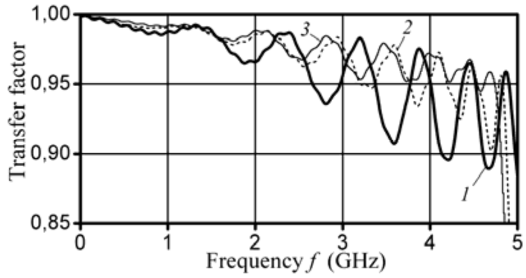


Fig. 7. The transfer characteristic of the H-profile meander system at $a = 0.5c$: *1* –constant cross-section of conductor; *2* – narrowed conductor at the lateral sides of the meander electrode; *3* –thinned conductor in the central part and narrowed at the sides of the electrode

part of the electrode and widening the bended lateral parts we can reduce amplitudes of the ripples.

According to the results, obtained using the multi-conductor line method and the *CST MWS* software package, the H-profile meander system has advantages with respect to the simple flat meander system. Furthermore the further improvements of the H-profile system are possible.

The H-profile meander system is the inhomogeneous structure. The characteristic impedance changes along the conductor of the meander electrode. In order to reduce the ripples of the transfer characteristic we must reduce the periodic change of the characteristic impedance [8].

The characteristic impedance $Z_2(\pi) = 1/Y_2(\pi)$, corresponding to the central part of the system, is less than $Z_1(\pi) = 1/Y_1(\pi)$ and $Z_3(\pi) = 1/Y_3(\pi)$. In order to reduce the periodic change of the characteristic impedance, we must reduce the difference between $Z_2(\pi)$ and $Z_1(\pi) = Z_3(\pi)$.

Besides that, periodic inhomogeneities of the characteristic impedance of a meander system at the constant cross section of the conductor appear at the lateral sides of the meander electrode (at the ends of the meander loops) as a result of dissipation of the electrical field.

We can reduce the change of the characteristic impedance $Z_i(\pi)$ reducing the thickness of the conductor in the central part of the system (Fig. 6(a)). The periodic reactances at the loops can be reduced by narrowing of the conductor (Fig. 6(b)). The transfer characteristics, presented in Fig. 7, illustrate that the mentioned means are effective. The ripples of the curve *3* are sufficiently less with respect to curve *1*.

The presented results confirm that using the H-profile we can improve characteristics of the meander line in comparatively simple ways.

Conclusions

The multi-conductor line method and the *CST Microwave Studio* software package are used for analysis of the modified (H-profile) meander slow-wave system.

Characteristics of the H-profile meander system are better with respect to the simple flat meander structure.

Means for further improvement, of H-profile meander system, based on reduction of periodic inhomogeneities along the meander conductor, are proposed.

The H-profile meander system is the inhomogeneous structure. The characteristic impedance changes along the conductor of the meander electrode. In order to reduce the ripples of the transfer characteristic we must reduce the periodic change of the characteristic impedance.

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The modified (H-profile) meander slow-wave structure is considered. The multi-conductor line method and the CST Microwave Studio software package are used for analysis of the system. Using the H-type profile (bending the lateral parts of the meander electrode in the opposite directions) we can reduce the electromagnetic coupling between the parts of the meander conductor at the sides of the meander electrode and, as a result, reduce dispersion of retardation factor and ripples of the transfer characteristic of the system. Means for further improvement of H-profile meander system are proposed. The H-profile meander system is the inhomogeneous structure. The characteristic impedance changes along the conductor of the meander electrode. In order to reduce the ripples of the transfer characteristic we must reduce the periodic change of the characteristic impedance.Ill. 7, bibl. 8 (in English, summaries in English, Russian and Lithuanian).

В. Дашкевичюс, Ю. Скудутис, С. Штарас. Моделирование и свойства меандровой системы с Н профилем // Электроника и электротехника. – Каунас: Технология, 2007. – № 3(75). – С. 65–68.

Рассматривается модифицированная меандровая замедляющая система, имеющая Н профиль. Анализ свойств системы проводится методом многопроводных линий, а также с применением программного пакета *CST Microwave Studio.* Показано, что Н профиль (отгиб крайних петлевидных участков меандрового электрода в противоположные стороны) позволяет уменьшить электромагнитную связь между соседними проводниками электрода и, вследствие этого, уменьшить дисперсию замедления и неравномерность амплитудно-частотной характеристики системы. Показана возможность дальнейшего улучшения характеристик системы. Меандровая замедляющая система, имеющая Н профиль, является неоднородной электродинамической системой. Имеется возможность улучшить ее свойства путем уменьшения периодического изменения волнового сопротивления вдоль проводника меандра и периодических реактивностей, проявляющихся на боковых участках меандрового электрода. Ил. 7, библ. 8 (на английском языке; рефераты на английском, русском и литовском яз.).

V. Daškevičius, J. Skudutis, S. Štaras. H profilio meandrinės sistemos modeliavimas ir savybės // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2007. – Nr. 3(75). – P. 65–68.

Nagrinėjama modifikuota (H profilio) plačiajuostė meandrinė lėtinimo sistema. Sistemos analizei taikomas daugialaidžių linijų metodas ir programų paketas *CST Microwave Studio*. Parodyta, kad H profilis, gaunamas nukreipus meandrinio elektrodo kraštines kilpų pavidalo dalis priešingomis kryptimis, leidžia sumažinti lėtinimo dispersiją ir sistemos dažninės amplitudės charakteristikos netolygumus (virpesius). Atskleistos H pavidalo meandrinės sistemos tolesnio tobulinimo galimybės. H profilio meandrinė sistema yra nevienalytė elektrodinaminė sistema. Jos savybes galima pagerinti mažinant banginės varžos periodinius netolygumus išilgai meandrinio laidininko ir šalinant periodinius reaktyvumus, atsirandančius dėl elektromagnetinio lauko sklaidos meandrinio elektrodo kraštinėse kilpų pavidalo dalyse. Il. 7, bibl. 8 (anglų kalba; santraukos anglų, rusų ir lietuvių k.).

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