

## Simulation of the Inhomogeneous Meander Line

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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, 2]. Models of meander-type lines are proposed and their properties are described in [2, 3] and other monographs and papers. On the other hand, idealized models of the systems are usually used. The real meander systems are inhomogeneous structures. Inhomogeneities appear due to dielectric holders, bending of the conductor of the meander electrode, errors of manufacturing of the system, and for other reasons.

Periodic inhomogeneities of the wide-band helical and meander systems cause non-uniformities of their frequency characteristics [3, 4].

The inhomogeneities of the meander systems can be symmetrical or asymmetrical with respect to the longitudinal axis of the meander system. Only symmetrical inhomogeneities are usually taken into account in the models of the meander systems. The influence of asymmetrical inhomogeneities on properties of the meander systems is not investigated.

The new opportunities of simulation of the super-wide-band electrodynamic systems appear due to application of numerical methods and developed software packages for investigation of electromagnetic fields and design of microwave circuits and devices [5, 6].

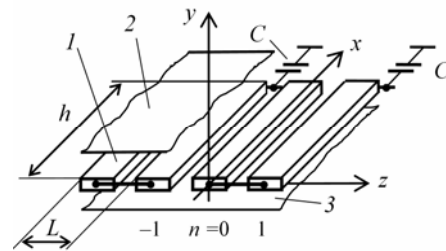
In this paper, we analyze the influence of the asymmetrical inhomogeneities, inhomogeneities that appear at the sides of the meander electrode due to bending of the conductor, and inhomogeneities at the ends of the electrode on characteristics of the meander line using the multi-conductor line method [1–3] and the CST software package *Microwave Studio* [6].

### Simulation of the asymmetrical inhomogeneities

Symmetric inhomogeneities of the meander system cause non-uniformity of frequency characteristics. The

stop-band appears when the phase angle between the voltages on the adjacent conductors approaches to  $\pi$ .

In order to reveal the influence of asymmetrical inhomogeneities, we can use the multi-conductor line method. The model of the meander-type line is presented in Fig. 1. The periodical asymmetrical inhomogeneities are modeled by capacitances, connected to one side of the meander electrode.



**Fig. 1.** The model of the meander line containing capacitive asymmetrical inhomogeneities: 1 – conductor of the multi-conductor line; 2, 3 – shields

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

$$\underline{U}_n(x) = (\underline{A}_1 \sin kx + \underline{A}_2 \cos kx)e^{-jn\theta} + (\underline{A}_3 \sin kx + \underline{A}_4 \cos kx)e^{-jn(\theta+\pi)}; \quad (1)$$

$$\underline{I}_n(x) = jY(\theta) (\underline{A}_1 \cos kx - \underline{A}_2 \sin kx)e^{-jn\theta} + jY(\theta + \pi) (\underline{A}_3 \cos kx - \underline{A}_4 \sin kx)e^{-jn(\theta+\pi)}; \quad (2)$$

where  $A$  are coefficients,  $n$  is the number of the conductor of the multi-conductor line,  $k = \omega/c$  is the wave number,  $\omega$  is the angular frequency,  $c$  is the light velocity,  $\theta$  is the phase angle between the voltages on the adjacent conductors of the multi-conductor line,  $Y(\theta)$  and

$Y(\theta + \pi)$  are characteristic admittances of the multi-conductor line.

The segment of the multi-conductor line models the meander line (Fig. 1) if the following boundary conditions are satisfied:

$$\underline{U}_0(0) = \underline{U}_1(0); \quad (3)$$

$$\underline{I}_0(0) = -\underline{I}_1(0); \quad (4)$$

$$\underline{U}_0(h) = \underline{U}_1(h); \quad (5)$$

$$\underline{I}_{-1}(h) = -\underline{I}_1(0) + j\omega C U_0(h). \quad (6)$$

Substituting (1) and (2) into (3)–(6), we arrive at a set of algebraic equations. Considering the set at zero determinant, we can find values of the retardation coefficient  $K_r$  and frequency  $f$ , i.e.,

$$K_r = c/v_f = \theta/kL, \quad (7)$$

$$f = kc/2\pi, \quad (8)$$

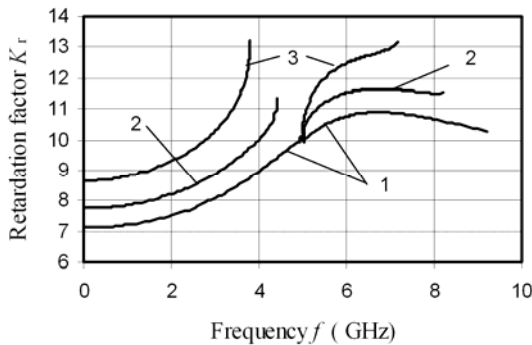
where  $v_f$  is the phase velocity of the traveling wave and  $L$  is the step of the conductors of the multi-conductor line.

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)

$$Z_{IN}(0) = \frac{\underline{U}_0(0)}{\underline{I}_0(0)} = \frac{\underline{A}_2 + \underline{A}_4}{j[Y(\theta)\underline{A}_1 - Y(\theta + \pi)\underline{A}_3]}. \quad (9)$$

The dispersion characteristics of the meander line, calculated using the multi-conductor line method, are presented in Fig. 2. The numerical finite difference method [7] was used for calculation of characteristic admittances and corresponding to them characteristic impedances  $Z(0) = 1/Y(0)$ ,  $Z(\pi) = 1/Y(\pi)$ . At known characteristic admittances  $Y(0)$  and  $Y(\pi)$ , the characteristic admittance at any phase angle  $\theta$  is given by [2]

$$Y(\theta) = Y(0) + [Y(\pi) - Y(0)]\sin^2(\theta/2). \quad (10)$$

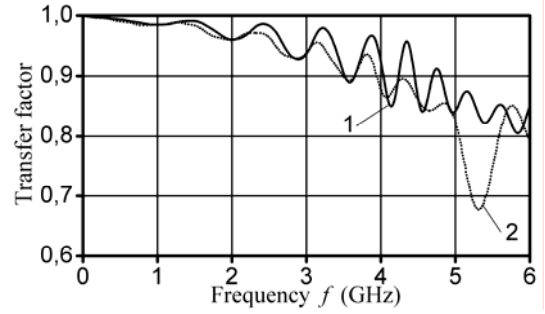


**Fig. 2.** Retardation factor versus frequency at  $Z(0) = 100 \Omega$ ,  $Z(\pi) = 50 \Omega$ : 1 –  $C = 0$ ; 2 –  $C = 0.1$  pF, 3 –  $C = 0.5$  pF

According to Fig. 2, at  $C = 0$ , the graph  $K_r(f)$  is continuous in the phase angle range from 0 to  $\pi$ . At  $C \neq 0$ , the stop-band exists at  $\theta \cong \pi/2$ . The width of the stop-band increases if the values of the periodic

capacitances  $C$  increase.

In order to verify the idea about the appearance of the stop-band of the meander line, containing asymmetrical inhomogeneities, at  $\theta \cong \pi/2$ , the CST software package *Microwave Studio* was used. The meander electrode, placed in the shield having rectangular cross section, was considered. When the gap between the meander electrode and the shield at one side of the meander electrode was reduced with respect to the gap at the other side, the non-uniformity of the transfer characteristic of the meander line appeared at frequencies, corresponding to  $\theta \cong \pi/2$  (Fig. 3).



**Fig. 3.** The transfer characteristic of the meander line, (1) containing meander electrode symmetrical with respect to the shield with rectangular cross section, and (2) meander electrode, shifted in the plane of the electrode with respect to the shield

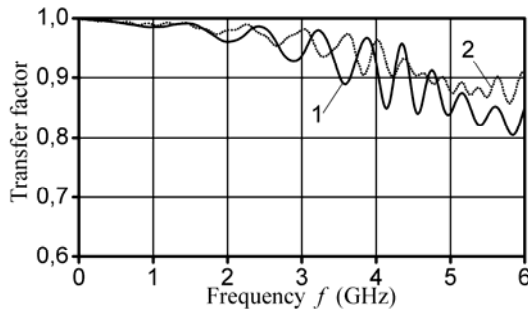
According to [8], the stop-band of the meander system, containing symmetrical inhomogeneities, exists at  $\theta \cong \pi$ . Then the period of inhomogeneities equals the half of the meander period (the length  $h$  of the segment of the multi-conductor line in Fig. 1). We can explain the appearance of the stop-band at  $\theta \cong \pi/2$  in the case of the meander system, containing asymmetrical inhomogeneities, taking into account that the period of the system becomes equal  $2h$ . Because the period of inhomogeneities becomes twice longer, the stop-band appears at twice lower frequencies. In the same way we can explain appearance of the stop-band at  $\theta \cong \pi/2$  in the meander systems with different dimensions of the neighbor conductors.

### Simulation of inhomogeneities at the sides of the meander electrode

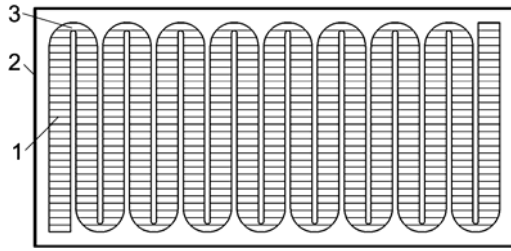
Periodic inhomogeneities at the sides of the meander electrode exist due to change of the direction of the conductor and the spread of the electric field. In order to decrease the inhomogeneities caused by the spread of the field, the width of the conductor must be reduced. This idea was verified using the CST *Microwave Studio* software.

The transfer characteristic of the meander system, containing the meander electrode with the constant width of the conductor is presented by curve 1 in Fig. 4. Curve 2 corresponds to the system with the reduced width of the conductor at the sides of the meander electrode (Fig. 5).

According to Fig. 4, the amplitude response of the meander line can be really improved using the modified meander electrode (Fig. 5).



**Fig. 4.** The transfer characteristics of the meander line: 1 – with the constant width of the meander conductor; 2 – with the reduced width of the conductor at the sides of the electrode



**Fig. 5.** The view of the meander line: 1 – meander electrode; 2 – shield; 3 – the part of the meander conductor with the reduced width

### Simulation of terminals

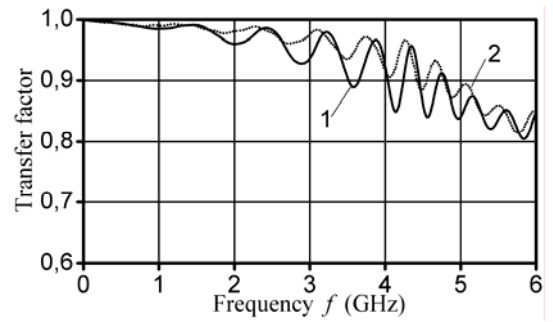
Infinitely long systems were modeled using the multi-conductor line method in [1–3, 8]. The real systems have a limited length, and the conditions of the last rods of meanders at the ends of the lines are different with respect to the other rods. Due to this, inhomogeneities of the signal path at the ends of the systems appear. These inhomogeneities can be considered as the inhomogeneities of the terminals.

To reduce the inhomogeneities of the terminals, sometimes the width of the terminal rods is reduced.

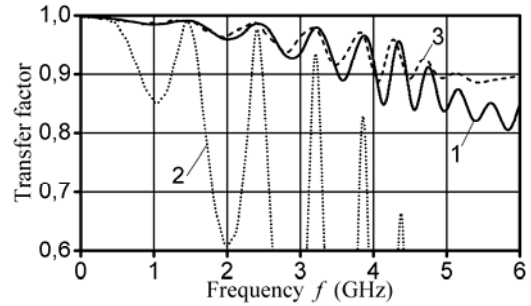
According to simulation, realized using the *CST Microwave Studio*, the transfer characteristic of the meander line is dependent on the cross section dimensions of the terminal rods, their length, and other dimensions of the meander line.

The transfer characteristics of the meander line at different widths of the terminal rods are presented in Fig. 6. According to them, it is necessary to widen terminal rods in order to improve the amplitude-frequency characteristic of the meander line.

The transfer characteristics of the meander line at different lengths of the meander electrode are presented in Fig. 7. According to Fig. 7, the frequency of the best matching of the signal path, containing the meander line, is dependent on the length of the terminal rods. At the length  $h$ , the best matching is realized at the phase angle  $\theta \cong \pi/2$  and frequency  $f \cong 1/(4t_d)$ , where  $t_d$  is the delay time of electromagnetic wave along the terminal rod. Increasing the rods we can shift down the frequency of the best matching.



**Fig. 6.** The transfer characteristics of the meander line at (1) not changed, and (2) at widened terminal rods



**Fig. 7.** The transfer characteristics of the meander line at the different lengths  $b$  of the terminal rods: 1 –  $b = h$ ; 2 –  $b = 0.7 h$ ; 3 –  $b = 1.25 h$

We can explain the latter statements taking into account that the terminal rods act as the quarter-wave-length transformers [9]. Because the characteristic impedance of the meander line decreases from  $Z(0)$  to  $Z(\pi)$  with the phase angle  $\theta$  increasing from 0 to  $\pi/2$ , the characteristic impedance of the terminal rods  $Z_c$  must be less than  $Z(0) = Z_{cn}$ , where  $Z_{cn}$  is the nominal characteristic impedance of the signal path. For this reason the better matching can be achieved at widened terminal rods.

Finally, it is important to note that using the quarter-wave-length transformers we can improve matching of the meander system with the signal path and improve the transfer properties of the meander systems, but this way does not help to improve properties of the traveling-wave deflection systems and other devices, where the best transfer of signals to the input of the meander system is necessary [9].

### Conclusions

The asymmetrical inhomogeneities of the meander electrode cause non-uniformity of the frequency characteristics of the meander line at the phase angle  $\theta \cong \pi/2$ , and frequency  $f \cong 1/(4t_d)$ , where  $t_d$  is the delay time along a rod of the meander electrode.

The frequency characteristics of the meander lines can be improved and the distortions of signals can be reduced using modified meander electrodes (Fig. 5).

The terminal rods of the meander electrode act as the quarter-wave-length transformers. Changing their length

we can change the frequency, at that the signal path is best matched.

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**V. Daškevičius, J. Skudutis, S. Štaras. Simulation of the Inhomogeneous Meander Line // Electronics and Electrical Engineering. – Kaunas: Technologija, 2007. No. 2(74). – P. 37–40.**

The influence of asymmetrical and other inhomogeneities on properties of the meander line is considered. The multi-conductor line method and the CST software package *Microwave Studio*, based on the numerical method, are used for simulation of the system. Applying the multi-conductor line method it is shown that due to even slight asymmetry of the meander electrode with respect to the shield of the delay system (in the transverse direction) the stop-band appears if the quarter of the wave length approaches to the length of the meander rod. The width of the stop-band increases if the asymmetry increases. The results, obtained using the *Microwave Studio* software package, confirmed the conclusions made using multi-conductor line method. The possibilities of improving the meander line characteristics (reducing non-uniformities of the amplitude-frequency characteristic and widening the frequency pass-band) by narrowing the meander conductors in the loop region are revealed. It is shown that the length of terminals (terminal meander electrode rods) has large influence on the meander delay system characteristics. In the high frequency range, terminal rods of the meander electrode act as the quarter-wave-length transformers. By proper selection of the length of the meander electrode terminal rods, the pass-band of the delay system can be expanded. Il. 7, bibl. 9 (in English, summaries in English, Russian and Lithuanian).

**V. Дашкевичюс, Ю. Скудутис, С. Штарас. Моделирование неоднородной меандровой линии // Электроника и электротехника. – Каунас: Технология, 2007. – № 2(74). – С. 37–40.**

Рассматривается влияние неоднородностей на характеристики меандровой линии. Анализ проводится методом многопроводных линий и численным методом, с применением пакета программ *CST Microwave Studio*. Расчеты, проведенные методом многопроводных линий, показали, что даже небольшая ассиметричность меандра относительно экрана, в плоскости меандрового электрода, придает системе свойства заграждающего фильтра в области, когда четверть длины волны приближается к длине стержня меандрового электрода. Это подтвердили и результаты, полученные с применением пакета программ *CST Microwave Studio*. Выявлена возможность улучшения частотных характеристик системы – уменьшения неравномерности амплитудно-частотной характеристики и расширения полосы пропускания путем сужения проводника меандра в области петель. Показано, что значительное влияние на характеристики меандровой замедляющей системы оказывают выводы (длина крайних проводников меандра). В области высоких частот крайние проводники меандра действуют как четверть-волновые трансформаторы. Правильно подобрав их длину, можно расширить полосу пропускания меандровой системы. Ил. 7, библи. 9 (на английском языке; рефераты на английском, русском и литовском яз.).

**V. Daškevičius, J. Skudutis, S. Štaras. Nevienalytės meandrinės linijos modeliavimas // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2007, Nr. 2(74). – P. 37–40.**

Nagrinėjama asimetrinių ir kitų netolygumų įtaka meandrinės linijos savybėms. Analizei taikomas daugialaidžių linijų metodas ir skaitmeniniu metodu pagrįstas firmos *CST* programų paketas *Microwave Studio*. Taikant daugialaidžių linijų metodą parodyta, kad net dėl nedidelio lėtinimo sistemos meandrinio elektrodo asimetriškumo ekrano atžvilgiu (elektrodo plokštumoje) atsiranda užtvartinė juosta, kai bangos ilgio ketvirtis tampa artimas meandro strypo ilgiui. Užtvartinės juostos plotis didėja didėjant asimetriškumui. Tą patvirtino ir programų paketu *Microwave Studio* gauti rezultatai. Atskleistos galimybės pagerinti meandrinės linijos charakteristikas (sumažinti dažninės amplitudės charakteristikos netolygumus ir išplėsti praleidžiamų dažnių juostą) siaurinant meandro laidininkus kilpų srityje. Parodyta, kad didelę įtaką meandrinės lėtinimo sistemos charakteristikoms turi išvadų (kraštinių meandro laidininko dalių) ilgis. Aukštųjų dažnių srityje kraštiniai meandro strypai veikia kaip ketvirčio bangos ilgio transformatoriai. Tinkamai parinkus kraštinių meandro strypų ilgį, galima išplėsti lėtinimo sistemos praleidžiamų dažnių juostą. Il. 7, bibl. 9 (anglų kalba; santraukos anglų, rusų ir lietuvių k.).