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Excitation of Circularly Polarized Electromagnetic Waves Based on Striped Transmission Lines

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Abstract: **The article investigates the scheme of excitation of an electromagnetic field with circular polarization due to crossed strip transmission lines. Two variants are compared: coplanar and microstrip transmission lines that excite circular polarization of the magnetic field in the space above the intersection of strip structures. The degree of ellipticity of the field at the intersection of strip structures can be changed by changing the phase mismatch between exciting oscillation sources. Modeling of these devices in the computer-aided design system made it possible to quantify the amplitudes of the components of the electromagnetic field, from which the ellipticity coefficient was calculated at different values of frequency and phase. The obtained results allow us to determine the conditions necessary for the realization of circular polarization of the magnetic field. The studied structures are planned to be used in an integral design to excite circular polarization oscillations in magnetic micro- and nanostructures.**

Keywords: **circular polarization, strip transmission line, ellipticity coefficient, magnetism, ferromagnetic resonance**

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Contents

1. INTRODUCTION

Excitation of electromagnetic (EM) waves with controlled magnetic field polarization is a crucial task in the area of magnetism. Changing the polarization of EM waves gives a wider possibility to excite own frequencies of different resonators. Excitation of linearly polarized radiation is a standard problem of practical electrodynamics. On the other hand, the excitation of EM waves with circular or, more widely, elliptical polarization presents significant difficulties. The elementary way to excite circularly polarized EM waves is to use cavity waveguides and resonators [1-8]. At the same time there is a necessary to implement circular or elliptical polarized EM waves in integral design using strip transmission lines in the microwave frequency range.

In this work we consider the scheme of EM waves excitation with circular polarization due to the crossed stripline transmission lines [9]. We are interested in the realization of circular polarization of the magnetic component of EM waves, which is explained by the need to excite different modes of oscillations of magnetic materials: ferro-, ferri- and antiferromagnets in the microwave range, up to the subterahertz frequency range (at frequencies up to 100 GHz). Comparison of two variants was carried out: coplanar and microstrip transmission lines, which excite circular polarization of the magnetic field in the space above the intersection of the strip structures. Ellipticity degree of the field at the intersection of strip structures can be changed by changing the phase mismatch between the excitation sources of oscillations. Modeling of these devices in the system of computer-aided design allowed to quantify the amplitudes of electromagnetic field components, according to which the ellipticity coefficient at different values of frequency and phase was calculated. These results make it possible to determine the conditions necessary for realization of circular polarization of the magnetic field. The investigated structures are planned to be used in integral design for excitation of circular polarization oscillations in magnetic micro- and nanostructures.

2. MODELING AND CALCULATION OF A CROSSED COPLANAR TRANSMISSION LINE

To excite EM waves with circularly polarized magnetic field, it is possible to use two grounded coplanar transmission lines and place them perpendicular to each other so that at the crossroads the addition of electromagnetic oscillations takes place (see **Fig. 1**). The result of adding the two waves will be a wave with polarization depending on the spatial and temporal configurations of the folding waves. In order to achieve circular polarization of the magnetic field it is necessary to adhere to the condition of spatial and temporal quadrature in the excitation of EM waves with two crossed transmission line [7,8]. The result of modeling of this transmis-sion line is the dependence of changes in parameters, characterizing EM waves polarization at the intersection of transmission lines on changes of frequency and phase. Fig. 1 shows transmission line, which has four

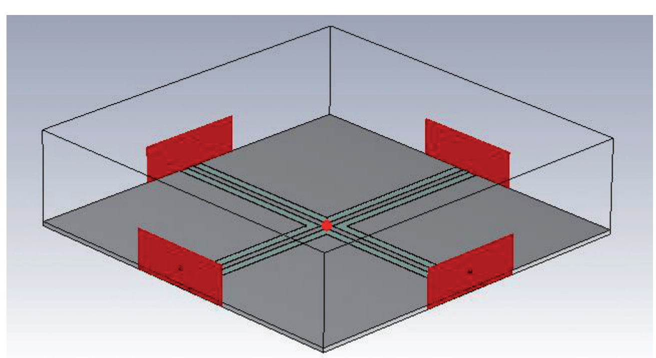

Fig. 1. *Model of the crossed coplanar transmission line.*

ports. At that, two adjacent inputs excite oscillations in the transmission line. Signals excited from these ports will be different by the value of the initial phase specified in the simulation.

The ferrite material can be placed at the point of maximum of circular polarization of the magnetic field. For this purpose, it is necessary to investigate the electric and magnetic components of the fields at the intersection of the two coplanar transmission lines, because it is at the intersection that the vectors will be added and the circular polarization will appear. Investigated magnetic material has a height of 3 mm, therefore field measurement is carried out in three points, on the surface of the transmission line H = 0 mm and on the heights H = 1.5 mm and H = 3 mm.

For a quantitative assessment of the magnetic field polarization parameter ellipticity coefficient will be used, which is calculated by the following expression [6]:

$$k = \frac{|H_r| - |H_l|}{|H_r| + |H_l|}, \quad (1)$$

where the quadrature components of the fields

$$H_r = \frac{1}{\sqrt{2}}(H_x + jH_y),$$

$$H_l = \frac{1}{\sqrt{2}}(H_x - jH_y),$$

where $H_{x,y}$ – are the magnetic field components.

The ellipticity coefficient can take values from –1 to 1, where k = 0 – linear polarization, and k = 1 (k = –1) – right (left) circular polarization. Below are numerically obtained data of magnetic field vector components, and calculated values of ellipticity coefficients.

Table1

Numerical data of magnetic field components at 20 GHz with phase difference of 90 degrees.

H, A/m / H, mm	ReH_x	ImH_x	ReH_y	ImH_y	k
0	17.5	27	-25.5	18	-0.95
1.5	1.1	1.9	-1.9	1.2	-0.96
3	0.14	0.45	-0.42	0.17	-0.91

The results obtained from **Table 1** show that in each of the three calculated points elliptic polarization is realized with ellipticity coefficient k = –0.94 (average value), which is close to circular polarization value. The total magnetic field vector will be maximum at the surface of the coplanar transmission line and will decrease with distance, so the minimum field value will be at the height of 3 mm.

For the analysis of the magnetic field amplitude, determine its dependence on the height above the coplanar transmission line structure.

We show in **Fig. 2** that the maximum value of the field is limited by the value of H = 40 A/m. The field of EM waves spreading perpendicular to the transmission line decreases. EM wave field tends to zero when spreading along the transmission line. At a height

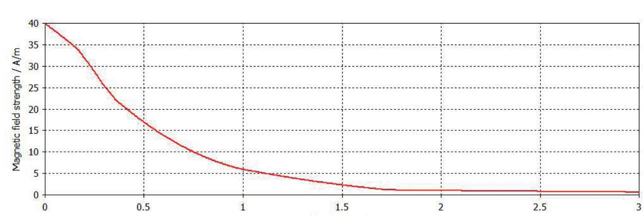

Fig. 2. *The H-field amplitude dependence on the distance at 20 GHz, for the model of crossed coplanar transmission line.*

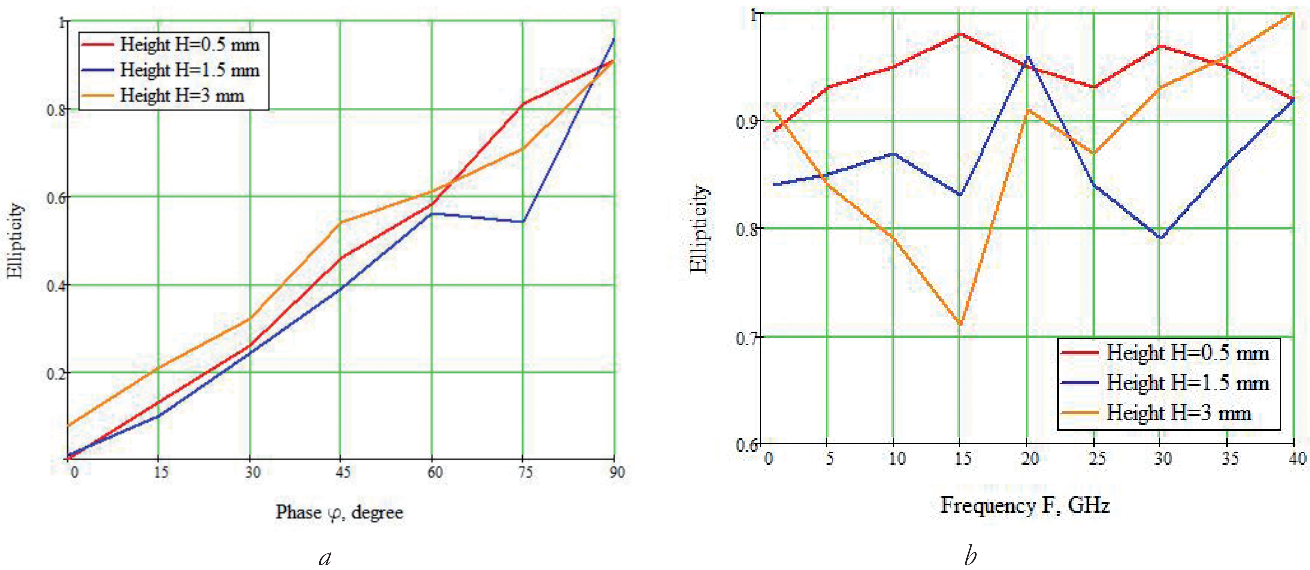

Fig. 3. *Ellipticity coefficient (K) dependence on the phase difference (a) of the excited electromagnetic waves and on the frequency (b) at different heights in the structure of crossed transmission lines*

of 3 mm, the field has a value of H = 1A/m. **Fig. 3***a* plots the dependence of the ellipticity coefficient on the phase difference of the excited EM waves. It can be seen that with approaching the phase difference of excited oscillations in 90 degrees, the ellipticity coefficient approaches 1 at different heights above the structure. In Fig. 3*b* plots the dependence of the ellipticity coefficient on frequency (from 0 to 40 GHz). It can be seen that for different values of the height above the structure, there is an optimal value, which corresponds to the maximum ellipticity coefficient. At the same time, the ellipticity coefficient decreases with increasing distance above the structure.

3. MODELING AND CALCULATION OF A CROSSED COPLANAR TRANSMISSION LINE WITH GROUNDING

As a second example of crossed stripline transmission lines to excite EM waves with circular polarization, consider a broadband transmission line consisting of two coplanar transmission lines crossed at right angles, with a short-circuit at the end. Similar in purpose design can be implemented without resorting to two different sources of EM waves with a phase difference of 90 degrees, but then it is necessary to observe the difference in distances to the crossing, so that the electromagnetic wave, reaching the center, had a phase delay relative to the second in 90 degrees. To idealize and model the short-circuit transmission line, a model was used in which the phase difference is set in the power sources.

In [7] the dimensions of a similar device are presented, but this design is difficult to imple-ment in practice, since high-tech production is required. Specifically, the width of the metal conductor of 10 (μm) and a gap of about 5 (μm) is difficult to implement, in view of the lower accuracy of the laser, as a consequence already at the stage of production model, will not meet the stated characteristics. Therefore, a transmission line model with excellent geometry was taken as a basis. Also, this type of transmission line is easy to implement in practice, as it has the

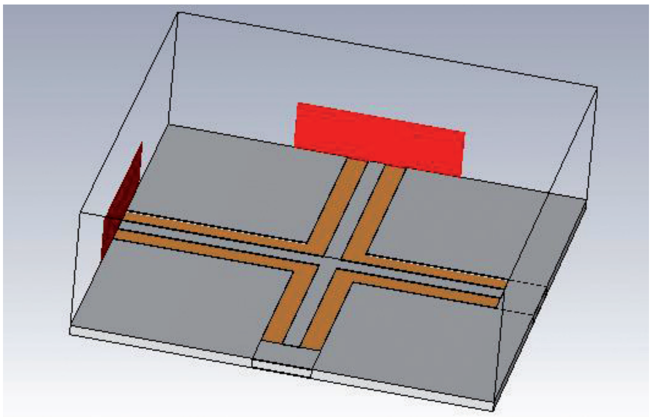

Fig. 4. *Model of the crossed coplanar short-circuit transmission lines.*

dimen-sions often used in the microwave range. In this regard, the real device will have close characteristics compared to the device calculated in the CAD systems. In **Fig. 4** the construction of the coupled transmission lines from the CAD tool is shown in Fig. 4.

Fig. 5 shows the dependence of the magnetic field amplitude on the height above the coplanar transmission line structure, and **Table 2** shows the calculated values of the magnetic field component amplitudes at three points.

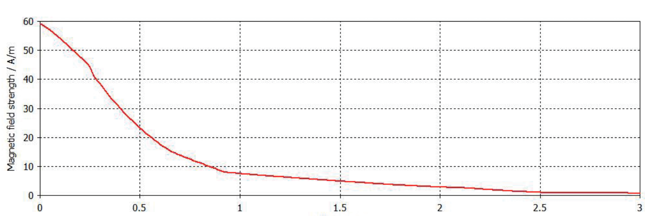

Fig. 5. *H-field amplitude dependence on distance at 20 GHz for the model crossed coplanar short-circuit transmission lines.*

Table 2

Numerical data of magnetic field components at 20 GHz

H, A/m / H, mm	ReH_x	ImH_x	ReH_y	ImH_y	k
0	-13.7	-55.2	40	11.2	-0.53
1.5	-1.31	-4.03	3.05	0.96	-0.48
3	0.15	-0.6	0.38	0.3	-0.61

Comparing the plots of magnetic field spread in the two coplanar transmission lines, namely Fig. 2 and Fig. 5, it follows that the crossed coplanar transmission line with short-circuit has a higher value of excitation of circular polarization of the magnetic field. The field values at the surface of the transmission line are 1.5 times greater than those of the model without short-circuiting in Fig. 2. The amplitude of the field decreases according to the same law, hence, at a distance of 3 mm the amplitude value is higher, and as a consequence, greater excitation of the magnetic material.

According to the calculated amplitudes of the magnetic field components, the ellipticity coefficient equal to one was not obtained, on average it is –0.54. This indicates that the transmission line values are not optimized. Despite this, according to the dependences of the field amplitude on the length of Fig. 2, 5 it can be seen that for a short-circuited transmission line we can obtain ellipticity characteristics better than in a transmission line with 4 ports, and therefore there is more effective excitation.

4. MODELING AND CALCULATION OF MEANDER TYPE TRANSMISSION LINE

Below are the results of simulation of another type of transmission line, which excites circular polarization of the magnetic field. The structure is a microstrip transmission line, in which the strips are arranged in the form of a meander, where the addition of two waves also occurs, result-ing in the realization of circular polarization [11]. In contrast to the previous types, this transmis-sion line has

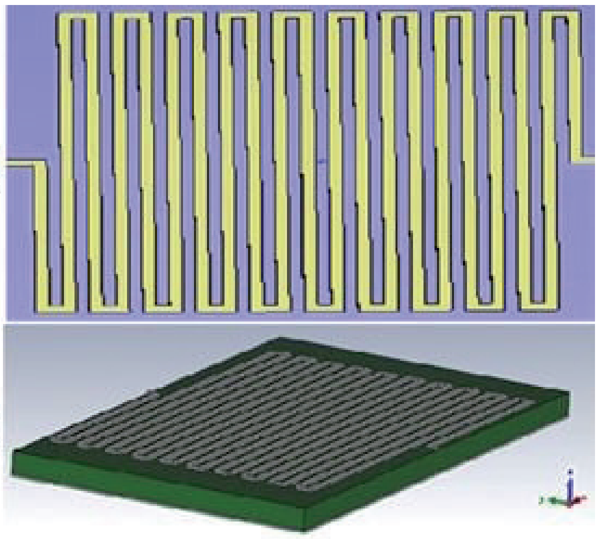

Fig. 6. *Model of microstrip transmission line of meander type: a) top view, b) side view.*

a significant disadvantage, which is that it operates only at a certain frequency, that is, it is narrowband, whereas the transmission lines discussed above are broadband [4]. The advantage of this transmission line in comparison with those considered above is the ability to im-plement circular polarization of the EM wave in the plane perpendicular to the plane of the structure, whereas the transmission lines considered in the previous section, implement circular polar-ization of the field in the plane of the sample. The geometry of the structure is presented in **Fig.** 6. The determination of the amplitude of the magnetic field vectors in three points and the calcu-lation of the ellipticity coefficient is performed according to formula (1) and is presented in **Table 3**.

Table 3

Numerical data of magnetic field components at 20 GHz.

H, A/m / H, mm	ReH_x	ImH_x	ReH_y	ImH_y	k
0	18	6	-8	-15	0.4
1.5	-2.5	-1.4	1.1	3.4	0.38
3	-0.07	-0.12	-0.19	-0.06	0.35

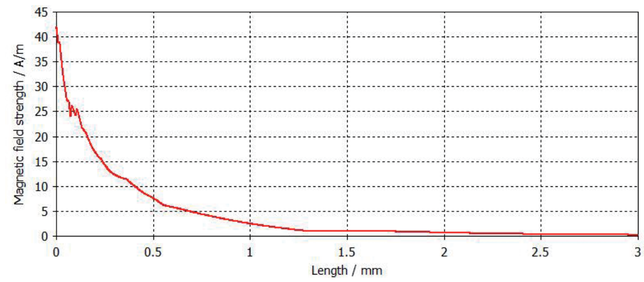

Fig. 7. *H-field amplitude dependence on length at 20 GHz, for a meander-type microstrip transmission line model.*

According to the calculation results, it can be seen that the transmission line has an elliptical polarization of the magnetic field. **Fig. 7** shows the dependence of the amplitude of the H-field vector on the height above the transmission line structure by analogy with Figs. 2, 5.

This transmission line has a high amplitude on the surface of the strip, but since circular polarization is formed only between the lines, this polarization only in some points will be circular, which significantly limits the use of this structure to excite EM waves in magnetic materials. There also remains the problem of the complexity of implementation in practice, since to obtain high characteristics of the amplitude of the magnetic field it is required to reduce the size of both the board and the width of the strip, at a size of 0.01 mm will be a large error in manufacturing, and as a consequence, the deterioration of the characteristics of obtaining circular polarization.

5. DISCUSSION OF RESULTS

Analyzing **Table 4**, it can be concluded that the crossed coplanar transmission line is the best option for the excitation of magnetic materials in a wide range of frequencies. Although this device does not have the maximum amplitude of the

Table 4

Comparison of transmission line characteristics.

Parameter	Ellipticity coefficient (k)	Frequency Range (GGz)	Amplitude of the magnetic field H on the surface of the line (A/m)	Feasibility
Crossed coplanar transmission line	-1	1-40	40	good
Crossed coplanar short-circuit transmission line	-0.54	1-40	59	good
Meander type transmission line	-0.38	20	42	bad

magnetic field on the surface of the strip, but provided that the EM wave with circular polarization more effectively excites the magnetic material, we can neglect the amplitude in favor of the ellipticity factor, since this type of transmission line excites the polarized magnetic field with the ellipticity factor $|k| \approx 1$.

6. CONCLUSION

The CAD modeling performed in this work made it possible to evaluate numerically the possibility of designing strip structures that excite EM waves with circular polarization. It was realized that effective excitation of magnetic materials requires circular polarization of the magnetic field in the location space of this material. For this reason, transmission lines with different structures were investigated. Based on the results of numerical simulations, it can be concluded that the best option for excitation of ferrite materials, in the location space of a given material, in an integral configuration would be a crossed coplanar transmission line with loaded outputs. In this configuration, circular polarization of the EM waves magnetic component is realized, with the ellipticity coefficient practically equal to 1. It can be noted that this type of transmission line is easy to implement in practice, which is its great advantage. Currently, the construction of integrated microwave circuits is trying to minimize the size of the main components. Analyzing the frequency and phase dependence for different transmission lines, it can be concluded that there is a possibility to control the ellipticity coefficient, changing the phase difference of oscillation sources. Note that the values of ellipticity coefficients at different ratios between the phases of excited oscillations will be constant and do not change from the frequency in a given transmission line structure.

REFERENCES

1. Kolomeitsev VA, Kovryakov PV, Semenov AE, Drogaitseva OV. Excitation of electro-magnetic field in a rectangular resonator partially filled with dielectric material. *Vestnik SGTU,* 2014, 1(77):47-54 (in Russ.).
2. Nelson CE. Circularly Polarized Microwave Cavity Filters. *IRE Transactions on Micro-wave Theory and Techniques*, 1957, 5(2):136-147.
3. Dionne GF, Oates DE, Temme DH, Weiss JA. Superconductivity for Improved Micro-wave Ferrite Devices. *The Lincoln Laboratory Journal*, 1996, 9(1):19-32.
4. Mohebbi HR, Majedi AH. CAD model for circuit parameters of superconducting-based hybrid planar transmission lines. *Supeconductor Science and Technology*, 2009, 22(1):12.
5. Sazonov DM. *Antenny i ustroystva SVCH* [Antennas and microwave devices].

Moscow, Vysshaya shkola Publ., 1988, 432 p. (in Russ.).

6. Kogan BL. *Polyarizatsionnye kharakteristiki antenn* [Polarization characteristics of antennas]. Moscow, MEI Publ., 2013, 42 p. (in Russ.).
7. Kan I, Soeno Y, Roppongi T, Nozaki Y. Circularly polarized magnetic field generated by two microfabricated crossed coplanar waveguides. *Applied Physics Letters*, 2017, 110(20).
8. Broeder FJ, Janssen E, Hoving W, Zeper WB. Perpendicular magnetic anisotropy and co-ercivity of Co/Ni multilayers. *IEEE Transactions on Magnetics,* 1992, 28(5):2760-2765.
9. Dionne GF, Oates DE, Temme DH. YBCO/ferrite low-loss microwave phase shifter. *IEEE Transactions on Applied Superconductivity*, 1995, 5(2):2083-2086.
10. Lax B, Button KJ. Microwave ferrites and ferrimagnetics. *Solid State Electronics,* 1963, 6(4):392-393.
11. Lax B. Frequency and Loss Characteristics of Microwave Ferrite Devices. *Proceedings of the IRE*, 1956, 44(10):1368-1386.