ГОДИШНИК НА СОФИЙСКИЯ УНИВЕРСИТЕТ „СВ. КЛИМЕНТ ОХРИДСКИ“
ФИЗИЧЕСКИ ФАКУЛТЕТ
Том 111

ANNUAL OF SOFIA UNIVERSITY “ST. KLIMENT OHRIDSKI”
FACULTY OF PHYSICS
Volume 111

NUMERICAL INVESTIGATION OF COUPLED FERRITE-DIELECTRIC IMAGE GUIDE STRUCTURE FOR Ka-BAND

ILIYANA ARESTOVA

Department of Radiophysics and Electronics

Илияна Арестова. ЧИСЛЕНО ИЗСЛЕДВАНЕ НА СВЪРЗАНА ФЕРИТО-ДИЕЛЕКТРИЧНА ОГЛЕДАЛНА СТРУКТУРА ЗА Ka-ОБХВАТА

Свързани феритен и диелектричен вълноводи са изследвани числено по метода на крайните елементи (МКЕ) в честотния диапазон 26–40 GHz. Моделирана е свързана ферито-диелектрична огледална структура със същата геометрия, както в предходно експериментално изследване при нехомогенно намагнитване. Феритният елемент в настоящото числено изследване е намагнитен хомогенно перпендикулярно на огледалната равнина и на посоката на разпространение. Това хомогенно намагнитване представлява първо приближение на реалното нехомогенно намагнитване. Получената честотна зависимост на загубите в права и обратна посока на разпространение в структура с дължина на свързване *l,* равна на 17.6 mm, показва силно изразена невзаимност в широк честотен диапазон: от 36.2 до 38 GHz. С цел да се установи зависимостта на невзаимното поведение от дължината на свързване, *l* беше променяно от 12.5 до 19.5 mm. Резултатите показват, че при по-големи дължини на свързване се постига по-добра невзаимност, което означава по-голяма абсолютна стойност на изолацията и по-широка работна честотна лента.

Iliyana Arestova. NUMERICAL INVESTIGATION OF COUPLED FERRITE-DIELECTRIC IMAGE GUIDE STRUCTURE FOR Ka-BAND

Coupled ferrite and dielectric image guides have been investigated numerically by finite element method (FEM) in the frequency range 26–40 GHz. We have modelled the coupled ferrite-dielectric

For contact: Iliyana Arestova, Department of Radiophysics and Electronics, Faculty of Physics, Sofia University „St. Kliment Ohridski”, 5 James Bourchier Blvd., Sofia 1164, Phone: 359 2 8161 724, E-mail: ilar@phys.uni-sofia.bg

image guide (CFDIG) structure with the same geometry as in our recent experimental investigation of nonreciprocal inhomogeneously magnetized CFDIG structure. The ferrite element in this numerical investigation has been homogeneously magnetized perpendicularly to the ground plane and the direction of propagation. The ferrite element in this numerical investigation has been homogeneously magnetized perpendicularly to the ground plane and the direction of propagation. This homogeneous magnetization represents first approximation of the real inhomogeneous magnetization. The frequency dependences of losses in forward and backward direction of propagation for CFDIG structure with coupling length l equal to 17.6 mm have shown strong nonreciprocity of the structure in a wide frequency band from 36.2 to 38 GHz.

In order to investigate the dependence of nonreciprocity on the coupling length, l has been successively varied from 12.5 to 19.5 mm. Results have revealed that at longer coupling lengths better nonreciprocal behaviour can be achieved, which means greater absolute value of isolation and wider frequency band of operation.

Keywords: nonreciprocal devices, image guide, finite element method, millimeter waves, coupled image guide structures.

PACS number: 84.40.Az

1. INTRODUCTION

Nonreciprocal devices have been traditionally invented on the basis of magnetized ferrite elements. The ferrite materials unfortunately decrease their gyrotropy as the frequency is increased. That is the reason the conventional ferrite devices developed for centimetre-wave range cannot be used with the same success in millimetre-wave range. Alternative approaches are sought to invent nonreciprocal devices for millimetre-wave range that require only weak gyrotropy [1, 2]. One of these alternative approaches is the achievement of nonreciprocal behaviour of CFDIG structures [3–6].

Very good nonreciprocal parameters have been reported in [4, 5] for a CFDIG structure with inhomogeneously magnetized ferrite element (bar). The ferrite element has been magnetized by using a disk-shaped permanent magnet, whose diameter is comparable with the length of the ferrite bar. The experimental investigation of such type CFDIG structure has been completed recently with the help of electric probes [6]. The distributions of all three electric field components in forward and backward direction of propagation have been measured. These distributions have revealed a nonreciprocal coupling between dielectric and ferrite image guides. In forward direction of propagation the period of power transfer L equals to a half coupling length l/2, while in backward direction it is two times greater and equals to the coupling length l. Insertion losses equal to –2.5 dB and an isolation equal to –16 dB have been registered at a frequency of 34 GHz. Isolation better than –10 dB has been measured in the frequency range (33.6–34.5) GHz.

The measurement of the permanent inhomogeneous magnetic field [6] has shown that the transverse component, which is perpendicular to the ground plane, predominates over the longitudinal one in almost the whole coupled region. That is the reason to replace as first approximation in our numerical investigation the inhomogeneous magnetic field with a homogeneous one. Here we have modelled the homogeneously magnetized CFDIG structure with the same geometrical parameters as in the experimental investigation [6]. After that, we have investigated numerically by FEM the behaviour of this structure in Ka-band (26–40 GHz). Strong nonreciprocity at about 37 GHz has been registered.

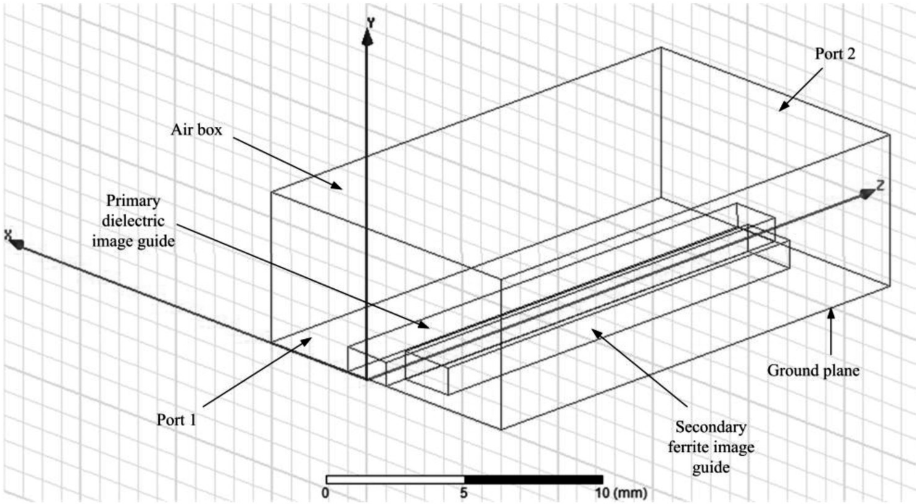

Fig. 1. The model of the coupled ferrite-dielectric image guide structure

2. MODEL

The geometry of the model of the CFDIG structure is shown in Fig. 1. The model volume coincides with the volume of the so-called air box (radiation box) with dimensions 12×6×20 mm^3. The primary dielectric image guide (IG) represents a parallelepiped (bar) with dimensions 2×0.97×20 mm^3. It is made by alumina with a relative permittivity $\varepsilon_r = 9.6$ and a dielectric loss tangent $tg\delta_\varepsilon = 10^{-4}$. The dimensions of the primary IG ensure single mode operation in Ka-band with the mode E^y_{11} according to the Marcatili's mode classification [7, 8]. The secondary ferrite IG represents a bar with dimensions 2.2×1.1×17.6 mm^3 and is made by nickel ferrite (1СЧ4, Russia). The ferrite has a relative permittivity $\varepsilon_r = 11.1$, a dielectric loss tangent $tg\delta_\varepsilon = 10^{-2}$ and a saturation magnetization $4\pi M_s = 4.63$ kG. The coupling length l coincides with length of the ferrite bar and is equal to 17.6 mm. The ferrite bar has been modelled as homogeneously magnetized along Oy axis with a field strength $H = 80$ kA/m.

The upper wall of the air box in the xz plane and both side walls in the yz planes have been defined as radiating surfaces. They have been chosen to be far enough from the corresponding walls of the primary and secondary IGs. The bottom wall of the air box represents an image plane and it has been defined as a perfect conductor. Both side walls of the air box in the *xy* planes have been defined as ports.

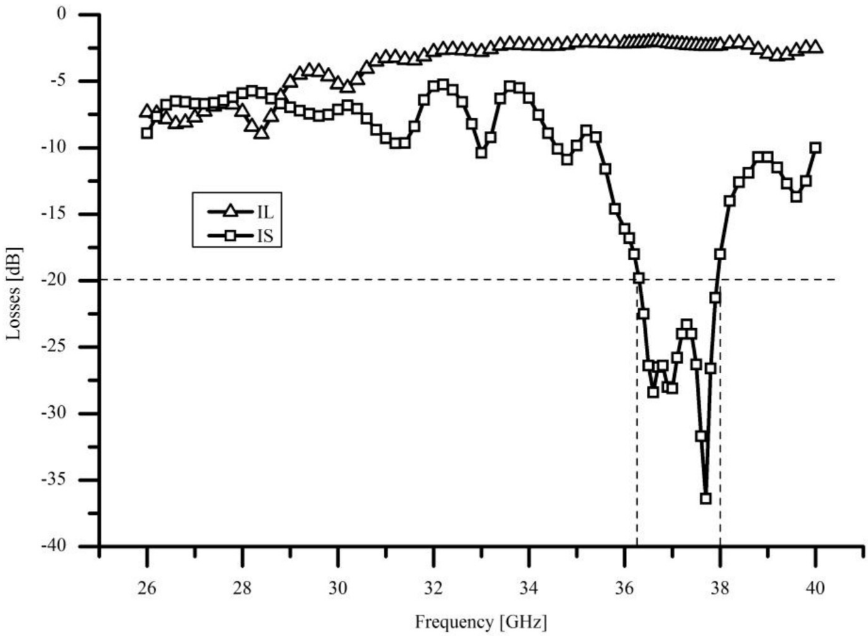

Fig. 2. Frequency dependences of losses for CFDIG structure with l = 17.6 mm

3. RESULTS

The frequency dependences of losses in forward and backward direction of propagation for CFDIG structure with coupling length l equal to 17.6 mm are shown in Fig. 2. The losses in forward direction known as insertion losses *IL* coincide with the scattering matrix element S_{21}, and those in backward direction named isolation *IS* – with the scattering matrix element S_{12}. The curves in Fig. 2 have shown well-expressed nonreciprocal behaviour of the CFDIG structure. The insertion losses vary from –9 dB at 28.4 GHz to –2 dB at 36.7 GHz. They are approximately constant in a wide frequency range from 33 to 38.6 GHz. The isolation has its absolute minimum at 37.7 GHz and is equal to –36.7 dB. Isolation greater than –20 dB has been registered in frequency range from 36.2 to 38 GHz. The nonreciprocal behaviour with insertion losses about –2 dB and isolation better than –20 dB in bandwidth *BW* equal to 1.8 GHz represents very good wideband performance for isolators at millimetre waves.

Table 1

l [mm]	f_{min} [GHz]	IL [dB]	IS [dB]
12.5	33.1	–3.39	–12.7
13	33.1	–2.53	–9.52
13.5	34.5	–3.36	–11.9
14	33.6	–2.26	–11.9
14.5	34.9	–2.05	–13.7
15	34.8	–2.17	–19.9
15.5	36	–2.12	–19.4
16	35.9	–2.09	–39
16.5	36.8	–2.22	–21.4
17	36.6	–2.1	–38.7
17.6	37.7	–2.35	–36.4
18	37.5	–2.24	–22.9
18.5	38	–2.09	–47.2
19	39.1	–2.35	–28.7
19.5	38.5	–2.29	–31.5

In order to investigate the dependence of nonreciprocity on the coupling length we have successively modelled CFDIG structures with coupling length from 12.5 mm to 19.5 mm. Results from these numerical investigations are presented in Tabl. 1. The frequency f_{min} represents frequency; at which isolation IS has its absolute minimum. The values of insertion losses IL and isolation IS shown in Tabl. 1 corresponds to frequency f_{min}. It is evident from Tabl. 1 that in general f_{min} increases and IS decreases with increasing the coupling length l. The insertion losses IL keep almost constant value in the range (–2) – (–3) dB. These results imply that the longer CFDIG structures possess better nonreciprocity. Additional investigation has also shown that the longer CFDIG structures have wider bandwidth BW, defined as frequency band in which the absolute value of isolation is greater than 20 dB.

We have applied some efforts to find a homogeneously magnetized CFDIG structure, which has parameters close in value to those in the experimental investigation [6]. The numerical investigation has shown that the CFDIG structure with coupling length l equal to 14 mm possesses the closest parameters. The frequency dependences of losses in forward and backward direction of propagation for this CFDIG structure are shown in Fig. 3. It is evident that it has worse nonreciprocal behaviour in comparison to structure with coupling length 17.6 mm (Fig. 2). The absolute value of isolation does not reach the standard value of 20 dB. Frequency band in which the absolute value of isolation is greater than 10 dB is from 33.3 to 34 GHz.

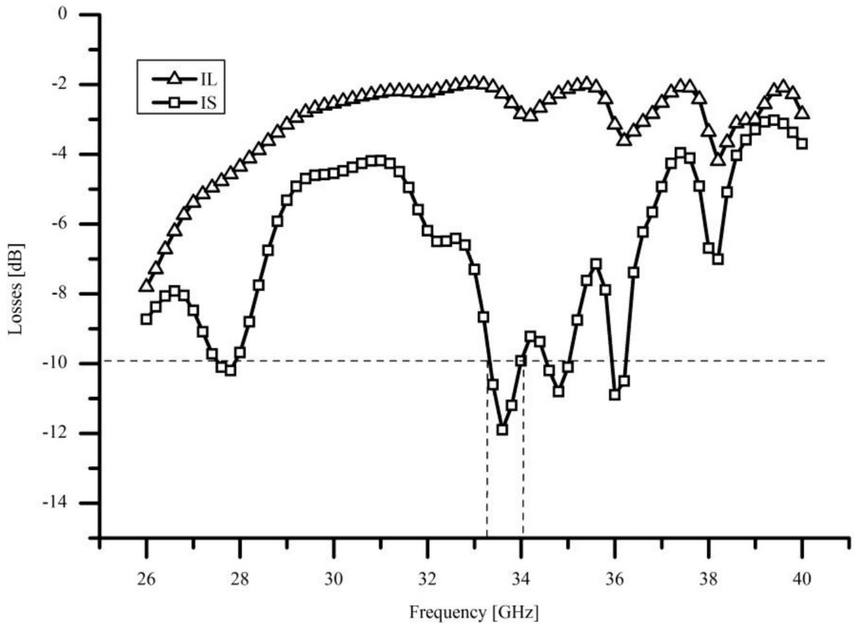

Fig. 3. Frequency dependences of losses for CFDIG structure with l = 14 mm

4. DISCUSSION

Geometrically identical CFDIG structure with coupling length 17.6 mm has been investigated experimentally in [6]. Insertion losses equal to –2.5 dB and an isolation equal to –16 dB have been measured at a frequency of 34 GHz. Isolation better than –10 dB has been registered in the frequency range (33.6–34.5) GHz. The corresponding insertion losses were about –3 dB. The magnetization of this structure was inhomogeneous due to the used disk-shaped permanent magnet, whose diameter is comparable with the length of the ferrite bar. The model for numerical investigation of the CFDIG structure does not permit the definition of inhomogeneously magnetized ferrite element, but only of homogeneous one. The comparison of the measured and calculated parameters has shown that the inhomogeneously magnetized CFDIG structure has worse nonreciprocity than the homogeneous one with the same coupling length. At the same time, the calculated frequency f_{min} is greater than the measured frequency of minimal isolation. As the f_{min} increases with the coupling length we can conclude that inhomogeneous magnetization makes the effective coupling length shorter. The explicit role of the existing longitudinal components of the inhomogeneous permanent magnetic field could not be understood in the frames of the model with homogeneous magnetization.

5. CONCLUSIONS

Coupled ferrite-dielectric image guide structure has been investigated numerically by finite element method. Frequency dependences of forward and backward losses in Ka-band have been derived for coupled ferrite-dielectric structures with different coupling lengths. Strong nonreciprocal behaviour of the coupled ferrite-dielectric structures in a wide frequency range has been registered. We can conclude that nonreciprocity depends on the coupling length and improves as it increases. The numerical results for the coupled ferrite-dielectric structure with coupling length equal to 17.6 mm have been compared with data obtained experimentally earlier. The comparison has shown that the inhomogeneously magnetized structure with coupling length 17.6 mm has lower operating frequency, which corresponds to homogeneously magnetized ferrite-dielectric structure with coupling length equal to 14 mm. The future work will aim to properly model the coupled ferrite-dielectric structure with inhomogeneous magnetization that could reveal the role of the axial components of the permanent magnetic field.

REFERENCES

[1] Akyol, Ahmet Soydan, Lionel Edward Davis. *IEEE Trans. Microwave Theory Tech*., 2003, **51**, 1476.

[2] Akyol, Ahmet Soydan, Lionel Edward Davis. In: *IEEE International Microwave Symposium*, 2001, 1179.

[3] Kwan, P., C. Vittoria. *IEEE Trans. Microwave Theory Tech*., 1993, **41**, 652.

[4] Belyakov, S. V., S. S. Gigoyan, B. A. Murmuzhev. *Elektonnaya tehnika*, 1989, **419**, 42 (In Russian).

[5] Arestova, I. I., S. A. Ivanov. In: *XII ICMF (International Conference on Microwave Ferrites*) *Proceedings*, 1994, 188.

[6] Arestova, Iliyana, Rositza Tomova, *Radioengineering*, 2018, in processing.

[7] Marcatili, E. A. J. *Bell System Technical Journal*, 1969, **48**, 2071.

Arestova, Iliyana, Rositza Tomova, Gergina Angelova. *Annuaire de l'Universite de Sofia "St. Kliment Ohridski", Faculte de Physique*, 2010, **103**, 5.