MICROSTRIP FERRITE DECOUPLING DEVICES WITH IMPROVED CHARACTERISTICS FOR MM-WAVE RANGE MICROWAVE EQUIPMENT

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Abstract. The report discusses the design and technological features that arise before developer, when creating microstrip ferrite devices for microwave equipment millimeter wavelength range. The results of the development of microstrip ferrite circulators and isolators of millimeter wavelength range, which have improved characteristics in comparison with domestic and foreign analogues, are presented.

Keywords: mm-wavelength range, Ka-frequency range, microstrip ferrite isolator, microstrip ferrite circulator, electrodynamic modeling, nickel-zinc spinel.

Introduction

One of the most important tasks of modern microwave electronics is the development of radio electronic equipment (REE) operating in the millimeter wavelength range. Mastering millimeter wavelength range allows us to solve important issues in the field of navigation, communications, medicine and the country's defense. The transition to the millimeter wavelength range will make it possible to reduce the overall dimensions of modern radio equipment, increase the resolution of radio navigation systems and increase the data transmission density, which is especially important for 5th generation communications (5G). An important place in all radio systems is occupied by ferrite decoupling devices, which ensure uniformity of microwave power level of the generators, stability of amplifying circuits for variable loads, and allow power of microwave signal to be distributed in circuits of radar stations. Despite the fact that there are microstrip ferrite decoupling devices of mm-wavelength range on the world market, their electrical and size characteristics do not meet modern requirements of developers of promising electronic equipment. To create a new generation of electronic equipment, a microstrip ferrite decoupling devices (MFDD) with an increased operating frequency band, with low direct losses and with reduced size characteristics is required. As part of research and development work carried out at the Research and production corporation «Istok», it was required to develop an MFDD with improved characteristics. Requirements for developed devices are shown in Table 1.

Table 1 - Requirements for developed devices

Device type	Operating frequency range Δf, GHz	VSWR	Insertion losses, α_{ins} dB	Inverse losses/isolation, α_{inv}/α_{is}, dB	Input continuous power P_{in}, W
Ka-range circulator	36,5…38,5	< 1,4	< 0,8	> 20	0,1
Ka-range isolator	33…37	< 1,4	< 1	> 20	2
V-range isolator	45,8…48,9	< 1,4	< 0,9	> 18	0,1

Selection of ferrite material

The key element of any ferrite decoupling device is ferrite material, due to which it is possible to achieve nonreciprocal properties in device in a given frequency range. Existing ferrite materials introduce their own features in the development of millimeter wave range ferrite devices, defining the maximum achievable characteristics in them.

On basis of the studies carried out in [1, 2, 5], a ferrite material was chosen as a substrate for devices, developed at Research and production corporation «Istok» named after Shokin - nickel-zinc spinel (NZS). This material has a high value of saturation magnetization ($Ms \approx 380$ kA / m), which will provide a wide range of operating frequencies for developed devices. Low level of summary loss tangent of the NZS, in turn, will ensure low insertion losses of microwave signal passing through developed devices.

With the help of measuring techniques and stands developed at NPP "Istok" [3], the electromagnetic parameters of workpieces from NCV were measured for the subsequent calculation of the design of the developed mm-range devices (Table 2).

Table 2 - Electromagnetic characteristics of NCV blanks

Parameter name	Designation	Specification value	Measured value
Dielectric constant	ε	12,3÷13,7	13,0 ± 4 %
Summary loss tangent	tg(δ)Σ	$1,6 \cdot 10^{-3}$	$1,1 \cdot 10^{-3} \pm 3,7 \cdot 10^{-4}$
Magnetic saturation, kA/m	Ms	378±27	380 ± 4 %

Electrodynamic modeling of construction of MFDD mm-range

On basis of precisely measured electromagnetic characteristics of nickel-zinc spinel, an analytical calculation of topology of developed devices was carried out using formulas from the book written by M.V. Vambersky "Design of microwave ferrite decoupling devices" [4], then it was required to create electrodynamic models of devices for analysis of their S-parameters and subsequent optimization of their design.

When constructing electrodynamic models of microstrip ferrite decoupling devices by finite element method, the following boundary conditions are used:

1. Topology drawing and reverse side of ferrite board are considered ideal conductors (with exception of tantalum load at isolators), which excludes radiation losses to free space from the calculation.

2. External magnetic field is assumed to be uniform and is applied only to the area under the instrument circulation disk.

3. Devices are excited by lumped ports with a resistance of Z_0 = 50 Ohm.

4. Ferrite board is specified in the form of two materials - magnetized ferrite (circulation area) and non-magnetized ferrite (the rest of the board). In magnetized ferrite, the value of saturation magnetization of material is seted, while in non-magnetized ferrite it is not.

According to proposed by A.S. Semenov design algorithm [5], were created and optimized electrodynamic models of mm-wave range microstrip ferrite decoupling devices. Optimization of device models was carried out by varying radius of circulation disk, width of leading microstrip lines, and load resistance of ferrite isolators. The optimized models of MFDD mm-wavelength range and their S-parameters are shown in Figures 1 ÷ 3.

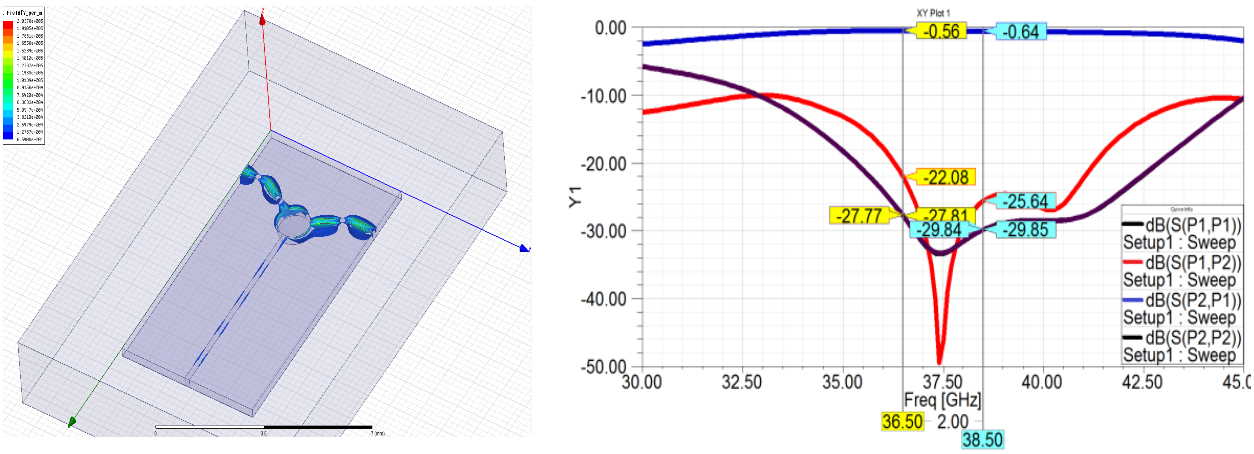

Fig. 1 - Electric field distribution and S-parameters of Ka-frequency range Y-circulator model

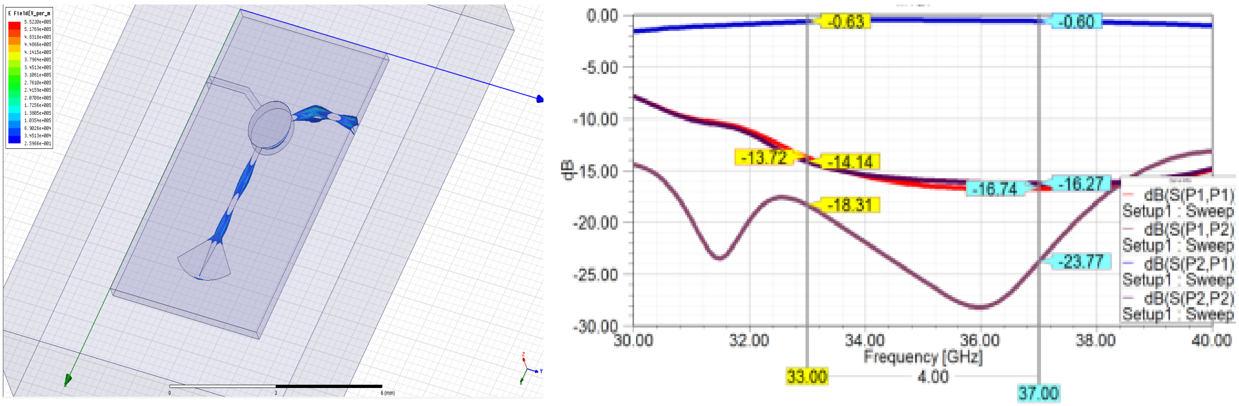

Fig. 2 - Electric field distribution and S-parameters of the Ka-frequency range isolator model

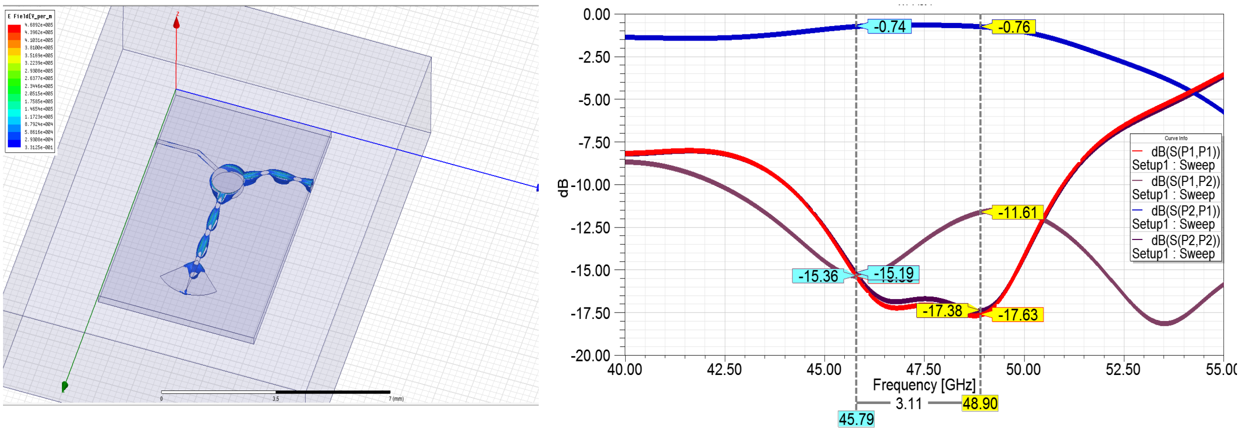

Fig. 3 - Electric field distribution and S-parameters of the V-frequency range isolator model

Thus, with help of electrodynamic modeling and subsequent optimization, it was possible to develop constructions of microstrip ferrite decoupling devices of millimeter range that meet specified requirements.

Manufacturing MFRP mm-range and measuring their electrical parameters

Performed calculations and simulations showed that construction of developed isolators and Y-circulator should consist of an NZS board, 0.25 mm and 0.2 mm thick for Ka- and V-frequency range devices, respectively, and a magnetic system that provides required external field bias (not less than 0.53 T).

Therefore, to obtain required magnitude of magnetic bias field of devices, a base made of a soft magnetic material - technical iron GOST 19904-90 was added to their construction (Fig. 4).

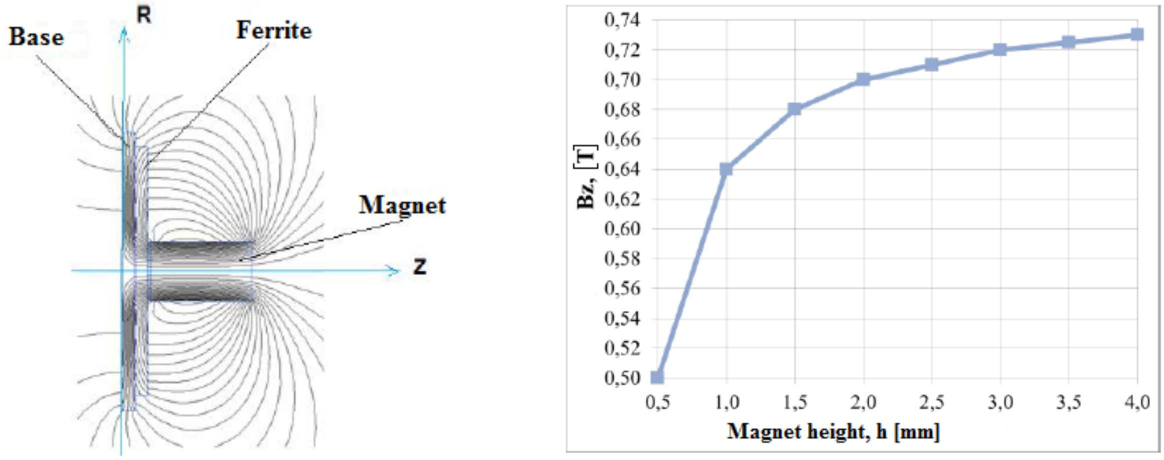

Fig. 4 - Distribution of lines of force in a Ka-range Y-circulator with a magnetic system consisting of a magnet and a base made of soft magnetic material and the dependence of the bias field on the height of a magnet with a diameter of 1.2 mm

According to the technology developed in Research and production corporation «Istok», microstrip ferrite decoupling devices of mm-wavelength range were manufactured and their electrical parameters were measured.

Figures 5-7 show the prototypes and electrical parameters of the Y-circulator and millimeter-wave isolators.

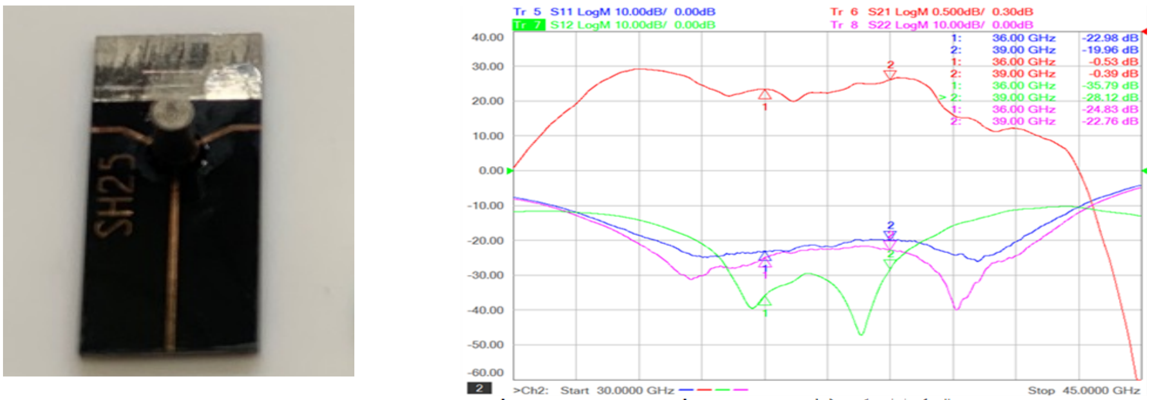

Fig. 5 - Prototype of Ka-range Y-circulator and its electrical parameters

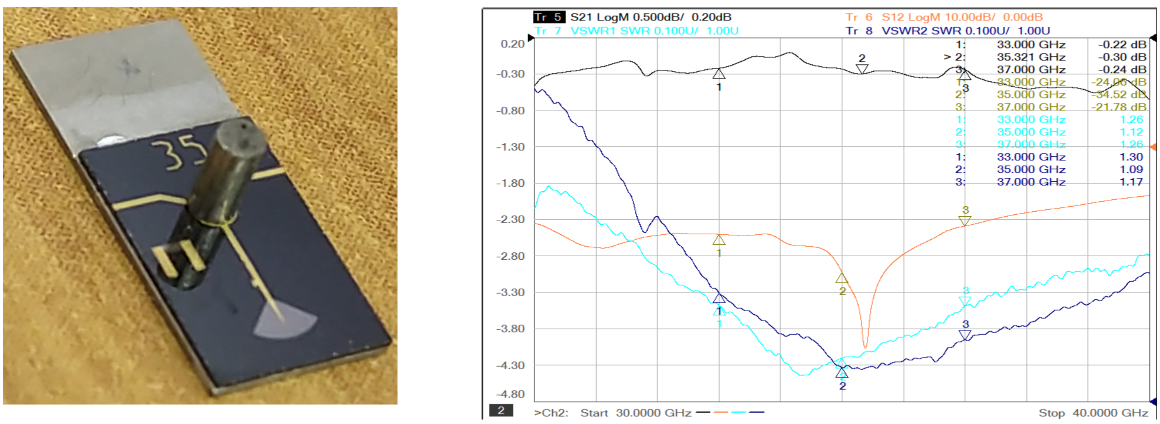

Fig. 6 - Prototype of a Ka-range ferrite isolator and its electrical parameters

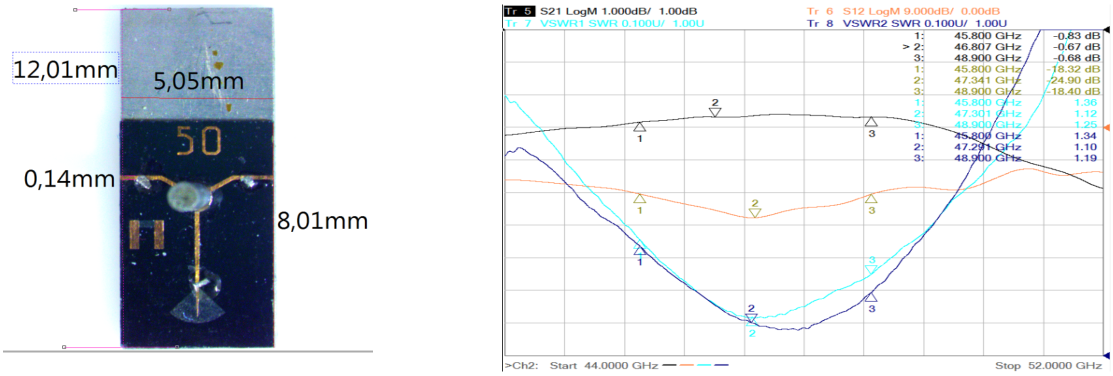

Fig. 7 - Prototype of a V-range ferrite isolator and its electrical parameters

As can be seen from figures 5-7, developed mm-wave range ferrite devices have electrical parameters close to those obtained in the course of modeling, which made it possible to significantly reduce the time to refine their design.

Conclusion

In the course of the work carried out, an isolator and a Y-circulator of Ka-frequency range, as well as an isolator of V-frequency range, were developed and manufactured. The electrical parameters of developed MFDD are shown in Table 3.

Table 3 - Electrical parameters of MFDD of millimeter wavelength range

Parameter name	Designation	Ka-range Y-circulator	Ka-range isolator	V-range isolator
Operating frequency range, GHz	Δf	36…39	33…37	45,8…48,9
Insertion losses, dB	α_{ins}	< 0,7	< 0,8	< 0,9
Inverse losses/isolation, dB	α_{inv}/α_{is}	> 22	> 20	> 18
VSWR	VSWR	< 1,3	< 1,4	< 1,4
Input continuous power, W	P_{in}	0,1	2	0,1

Comparison of developed isolators and Y-circulator with their domestic and world counterparts showed that they surpass them in terms of complex of electrical parameters.

Developed devices have an extended operating frequency band and reduced insertion losses, which makes it possible to effectively use them in development of 5th generation communication systems (5G) and other promising civil and military microwave technology.

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