Miniaturization of microstrip directional coupler by means of artificial transmission lines

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***Abstract*—this paper presents a brief analysis of the existing methods of reducing microstrip device dimensions. This paper also presents a miniaturization method based on using artificial transmission lines, which possess characteristics similar to those of quarter-wave transmission lines. Based on this method, a compact directional coupler, which divides the power in a 1:2 ratio, was designed and manufactured. FR-4 with dielectric permeability of ε = 4.4 and thickness of h = 1 mm serves as substrate material. Using the R&S vector network analyzer, the experimental characteristics were ob-tained, which coincided with simulation results with minor error. The proposed miniaturization method allowed reducing the bridge coupler dimensions by 70% compared to the standard design.**

I. Introduction

The 20th century saw the invention of microstrip transmission lines. Using lines of this type made it possible to create such de-vices as directional couplers and flat antennas, capable of operating in high frequency ranges. Directional coupler is a device for branching part of electromagnetic energy from the main transmission channel into auxiliary channel. Such devices have found broad application in microwave power dividing devices , antenna array power systems and other devices. Today there is a great variety of directional coupler designs existing. However the most popular is a design implemented on four quarter-wave microstrip transmission lines. When designing new microstrip structures, attempts are usually taken to make them technologically feasible and compact. Much attention is paid to the latter factor nowadays, especially if a device operates at low frequencies. The literature describes various miniaturization methods. Usually they boil down to substituting the microstrip line with an electrodynamic structure of a specially designed shape. For example, in [1] it is proposed to reduce the size by using a quasi-lumped elements, periodic capacitive loads are used in [2], asymmetrical T-shaped structures in [3], low-pass filter in [4–5]. It is worth noting that not all of the proposed methods allow achieving characteristics of the compact bridge coupler comparable to those of a conventional bridge coupler. There is a correlation between the dimensions of a device and its characteristics: the smaller the dimensions, the lower are its characteristics, thus it is necessary to find a compromise between these factors. This paper proposes a peculiar method, based on substitution of the transmission line segment with an artificial transmission line having similar characteristics to those of the replaced segment.

II. Design

This paper aims at reducing the dimensions of the conven-tionalmicrostrip directional coupler structure, dividing power with 1 to 2 ratio. The entire miniaturization process consists in synthesis of artificial transmission lines (ATLs), which will be installed instead of quarter-wave segments. The proposed ATLs have the same phase progression of 90 degrees at the operating frequency as the quarter-wave segment.

This paper studies the compact directional microstrip coupler, operating at the frequency of 1900 MHz. Glass-fiber plastic was used as substrate material in the designed structure, with dielec-tric permeability ε = 4.4, dielectric loss tangent tgδ = 0.02 and thickness of h = 1 mm.

Initially the standard-sized directional coupler was designed prior to miniaturization. This structure consists in two microstrip transmission line segments, connected to each other by quarter-wave stubs. The wave resistance values of quarter-wave seg-ments are selected depending on required power division at the output ports of the coupler [13].The entire simulation process was performed in AWR DE 12 software. The dependencies between S-parameters and phase shift between the output ports standard directional coupler layout versus frequency are shown in fig. 1.The dimensions of the standard structure are 22.6 mm x 27.2 mm = 615 mm^2. The obtained characteristics are summarized in table 1.

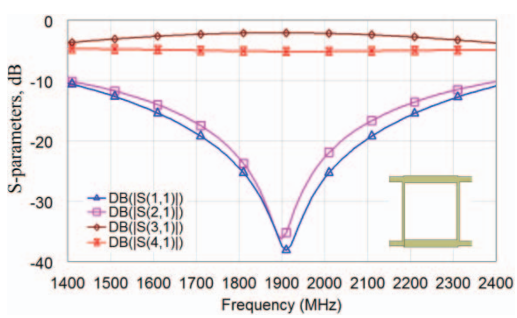

Fig.2 The simulated S-parameters of the compact coupler

Once the conventional structure was designed, we proceeded with miniaturization. This process started with designing the artificial transmission lines. Using such lines allows reducing the longitudinal dimensions of the device, while introduction of open-circuit stubs into the free space inside the bridge coupler allows to additionally increase the miniaturization efficiency. In order to increase the miniaturization efficiency, the length of each stub is selected individually. This allows positioning all the elements in the most compact manner. The obtained compact bridge coupler layout consists of two similar pairs of transmission lines (fig. 2). The dimensions of the miniature structure are 13.4 mm x 13.6 mm = 182.2 mm2.Fig. 3show characteristics of a compact directional coupler with a central frequency of 1.9 GHz. The obtained characteristics are summarized in table 1.

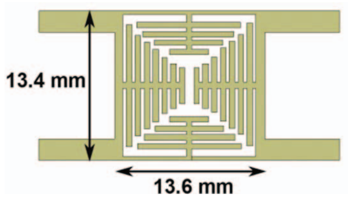

Fig.2 The standart directional coupler layout

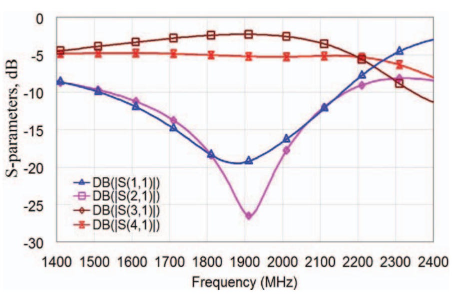

Fig.3 The simulated S-parameters of the compact coupler

A prototype was manufactured using standard PCB manufacturing method, according to the layout, obtained as a result of simulation (fig. 4). The experimental characteristics obtained using the vector network analyzer are shown in fig. 5.

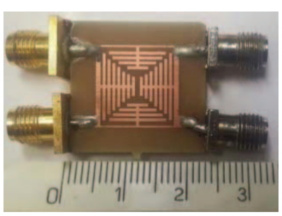

Fig.4 The compact directional coupler layout

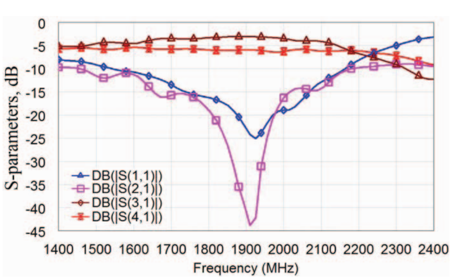

Fig.5 The measured characteristics of the compact coupler

The advantage of the miniaturized layout is that such implementation allows to achieve a significant surface area reduction of the substrate. The surface area of the compact bridge coupler was reduced by 70% compared to the conventional design. The measured characteristics are summarized in table 1.

TABLE I. COMPARE DESIGN

Design	Area, mm2	Isolation bandwidth –20 dB, MHz	Transmission coefficient	
			S31	S41
Conventional	269	615	-2.05	-5.1
Compact measured	157	182	-2.3	-5.2
Compact simulated	166	182	-3	-6

III. CONCLUSION

This paper describes the process of reducing the dimensions of a directional coupler. This procedure consists in using artificial transmission lines, which are installed instead of quarter-wave transmission line segments. According to simulation results a prototype of microstrip directional coupler with a central frequency of 1.9 GHz was manufactured. The surface area of the prototype is 70% less compared to that of conventional design structure. The working frequency band, determined by decoupling level of -20 dB, is reduced by approximately 38%. Also, the propagation ratio loss was increased. The difference between simulation results and experimental results can be caused by both manufacturing tolerances and difference between substrate parameters used in simulation and prototype production.

ACKNOWLEDGEMENT

The research was executed by the grant of the Ministry of education and science of the Russian Federation (project № 8.2538.2017/4.6).

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