Overview: Spoof Surface Plasmon Polariton Transmission Line and Splitters

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***Abstract*—Spoof Surface Plasmon Polariton (SSPP) transmission line is a novel type of surface wave structure in microwave and terahertz frequency range. For limited electromagnetic field between corrugated metal and dielectric, SSPP transmission lines and components have the advantages of wideband adjustment, miniaturization and high integration. In this paper, the influence of several geometric parameters on the dispersion curves of the oral-ring SSPP unit is analyzed. And then, the attenuation constant of the oval-ring transmission line is calculated. Finally, the SSPP splitters with oval-ring unit cell are reviewed.**

Keywords—Spoof Surface Plasmon Polariton (SSPP), transmission line

I. INTRODUCTION

Surface plasmon is a vital optical phenomenon. When the light in the free space illuminates the metal surface, oscillations between the free electrons in the metal and the incident wave are observed [1]. The electromagnetic field is confined to the surface between the free space and metal. And the electromagnetic field is exponentially attenuated in the vertical direction to the interface. However, when the metal exhibits a perfect electrical conductor (PEC) at microwave and terahertz frequencies, the Surface Plasmon phenomenon disappears. In order to realize the electromagnetic wave of Surface Plasmon mode in the low frequency band, a metal structure of periodic grooves is proposed [2]. On the surface of the artificially modified metal and dielectric, the electromagnetic fields mode is similar to the Surface Plasmon mode in optics, which is known as Spoof Surface Plasmon (SSP). SSP has the characteristic of capturing electromagnetic fields in the sub-wavelength range, which provides a way to design miniaturized circuits such as detectors [3], enhanced absorption [4] enhanced coupler [5], surface-enhanced spectroscopy [6] and so on.

SSP can be divided into two types. One is localized Spoof Surface Plasmon [7]. And the other is Spoof Surface Plasmon Polariton (SSPP) for the ability to propagate at the interface between metal and dielectric [8]. For this performance, SSPP transmission lines can be fabricated.

With the development of communication technologies, miniaturization, high integration, and ultra-wideband requirements of radio frequency (RF) devices have been proposed. SSPP transmission lines and components have recently been extensively studied due to their unique advantages. The SSPP transmission line has an ultra-wideband. And the cutoff frequency is freely controlled by the corrugation geometric parameters [9]. In addition, the SSPP electromagnetic field is tightly concentrated in the corrugation. Therefore, SSPP components can be fabricated in sub-wavelength ranges to achieve miniaturization of electronic components and circuits [10]. At the same time, the crosstalk between SSPP transmission lines is smaller than that of conventional transmission lines [11]. Moreover, single-layer SSPP transmission lines and components can be bent without significant electrical characteristic changes [12].

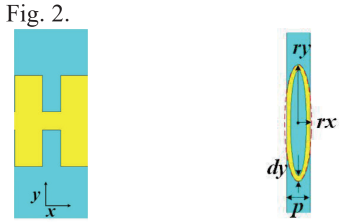
The SSPP transmission lines composed of differently shaped units and related RF microwave components are designed such as SSPP antennas [13], [14], SSPP filters [15], [16], SSPP amplifiers [17], [18], etc. However, the electromagnetic wave of the SSPP mode is very different from the electromagnetic waves propagated on conventional microwave waveguides, such as microstrips and coplanar waveguides (CPW). It is desirable to design the conversion structures to enable interconnection between SSPP waveguides and conventional microwave waveguides [19]-[20]. In addition, electrically adjustable SSPP components have been designed to meet the needs of communication systems [21].

This article focuses on our work on SSPP transmission lines and power dividers. First of all, the performance of the SSPP oval-ring unit cell is further analyzed. And then, the SSPP transmission line with oval-ring cells are introduced. Finally, two kinds of SSPP splitters with oval-ring cells are overviewed.

II. SSPP UNIT CELLS

The structure supporting SSPP wave propagation consists of metal cells with small holes. As is shown in Fig. 1, SSPP units with different shapes are designed for use in various situations. The metal structure of the rectangular grooves in Fig. 1(a) is a typical SSPP unit with extensive research [22]. Our work is based on oval-ring SSPP units in Fig.1 (b).

The oval-ring SSPP unit is composed of metallic copper on a dielectric plate with a dielectric constant of 2.55. And the dielectric loss angle of the substrate is 0.0029. Moreover, the dispersion curves are calculated by CST Microwave Eigenmode, which is explained in [23]. The effect of the oval-ring SSPP parameters on the dispersion curve is displayed in Fig. 2.



(a) (b)

Fig. 1 The geometrical shapes of the SSPP unit cells. (a) SSPP unit with rectangle groove. (b) oval-ring SSPP unit. rx = 1.2, ry = 5.2, p = 2.1, dy =0.4 (all in mm).

In Fig. 2, the dispersion curves of oval-ring SSPP cells gradually move away from the dispersion curves of the light as the frequency increases. The wave vectors of oval-ring SSPP cells are much larger than that of the light and the cutoff frequency occurs when $k_x p/\pi$ is equal to 1. In design, the parameter *ry* mainly controls the cutoff frequency, while *rx* and *dy* have less effect on the cutoff frequency. Therefore, the passband can be tunable by virtue of *ry* in the adjustable range.

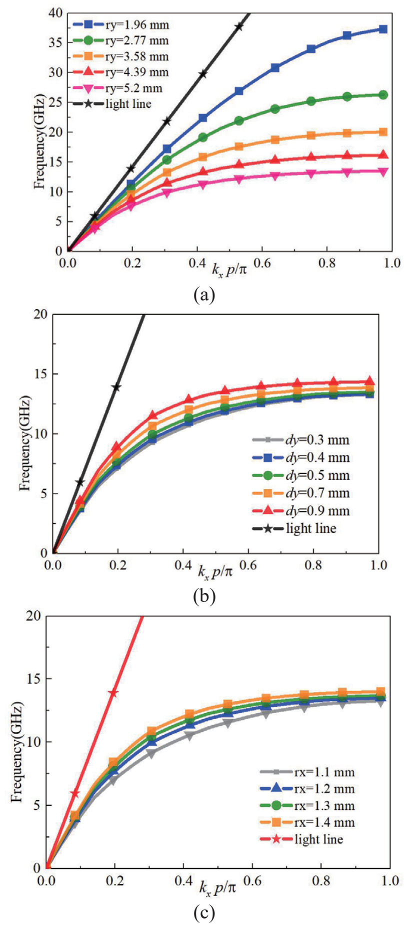


Fig. 2 Dispersion graphs of the proposed oval-ring SSPP units. (a) Influence of the length of the long axis on the dispersion curves. (b) The effect of the line width on the dispersion curve. (c) The effect of ellipse short axis radius on dispersion curve.

III. SSPP Transmission Line

Transmission line is an important interconnect device. SSPP transmission line is the basis for SSPP components and circuits. However, transition section is necessary to complete impedance matching and electromagnetic field matching. The classic conversion structure is a flaring disappearing ground and gradient grooves structure between SSPP waveguides and CPWs [24]. At the same cutoff frequency, the oval-ring SSPP transmission line is smaller than the rectangular one. In designed oval-ring SSPP waveguide and conversion sections are displayed in Fig.3 (a). In Fig. 3 (b), the simulated and measured results verified the effective conversion of the proposed transitional structure.

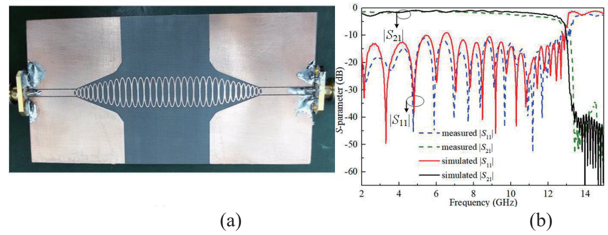


Fig. 3 (a) The oval-ring SSPP waveguide and conversion structures. (b) The simulated and measured *S*-parameters.

Fig. 4 shows the electromagnetic field distributions of oval-ring SSPP waveguides. Fig. 4 (a) show the amplitude of the electric field distributed on the *x*-*y* plane. The electric field is mainly concentrated in the oval-ring center. In addition, Fig. 4 (b) show the amplitude of the magnetic field. The magnetic field is mainly distributed on the long axis side of the oval-ring units, and the magnetic field distribution on the centerline of the SSPP waveguide is the weakest.

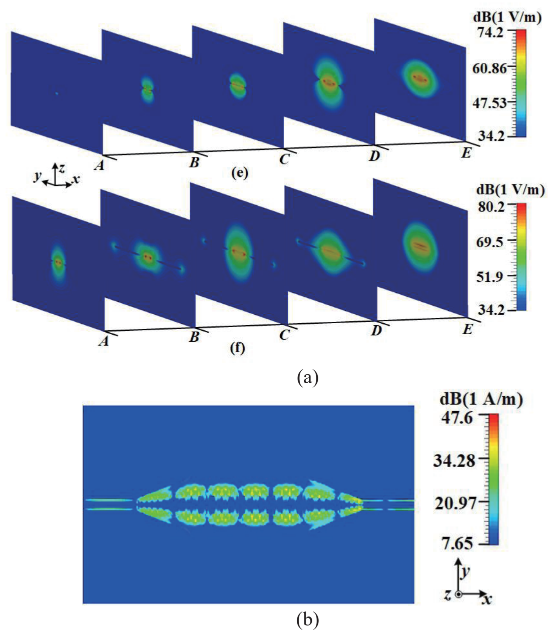


Fig. 4 The electromagnetic field distribution of the proposed oval-ring SSPP unit. (a) Electric field distribution. (b) Amplitude distribution of magnetic field at 8 GHz.

IV. SSPP Splitter

The splitter/combiner is an important component in multi-channel SSPP circuits and systems. The SSPP splitters/combiners can be connected to SSPP components and circuits such as array antennas and phase shifts due to the ability to synthesize and separate signals.

Many SSPP splitters with different unit cells have been designed to successfully split the electromagnetic waves of the SSPP mode into two equal paths [23]. Moreover, an unequal power divider was proposed in [25]. However, there are few studies on the isolation characteristics of SSPP splitters [26], [27].

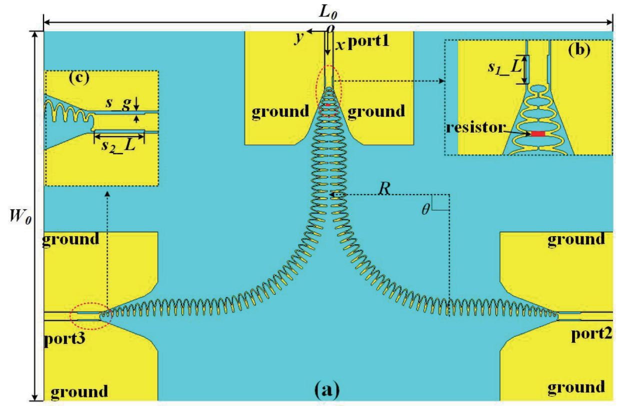


Fig.5 The geometrical structure of the designed SSPP power divider with isolation resistor in fourth oval ring.

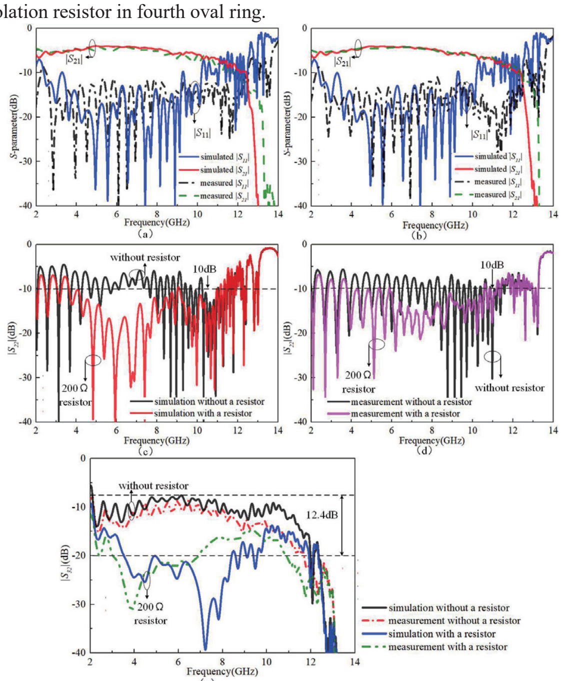


Fig. 6 *S*-parameters of the proposed oval-ring SSPP power divider with and without 200 Ω resistance.

Fig. 5 depicts that the designed oval-ring SSPP power divider [26], based on the classical Wilkinson power divider model. But, the SSPP transmission line is a non-uniform transmission line composed of periodic cells, and the placement of the isolation resistor is limited. In order to place the isolation resistor at a quarter wavelength of the SSPP transmission lines, this designed power divider separates the SSPP waveguides at the conversion structure which connected to port 1. Because the gradient-sized elliptical ring provides more length options.

In Fig.6, simulation and measurement results indict that the SSPP power divider enables equal power distribution of the two output ports, and the isolation resistor improves $|S_{22}|$ and $|S_{33}|$ bellow -10 dB and the $|S_{32}|$ bellow -20dB in frequency band.

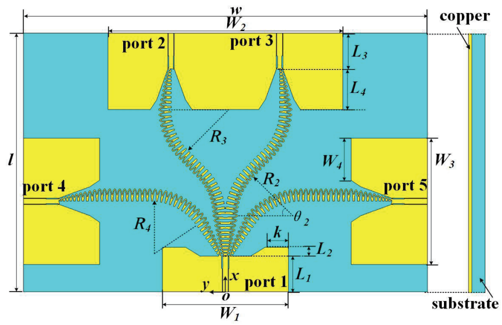


Fig. 7 Structure of four-way SSPP splitter.

In order to further increase the signal paths, multiple-way SSPP splitters are proposed in [28], [29]. In our previous work [28], a radial four-way SSPP splitter is designed in Figure 7. Based on the design of two-way SSPP splitter, two new SSPP transmission lines are connected to the two ground lines of the CPW. As shown in Fig. 8, the simulation and measurement results indicate that the four-way SSPP splitter realizes the function of equally dividing the signal into four channels.

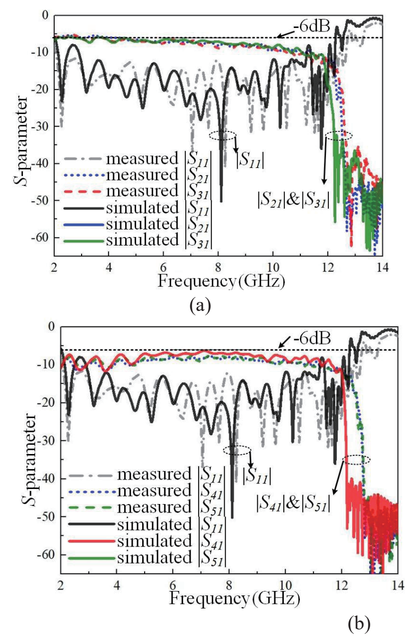


Fig. 8 Measured and simulated *S*-parameters of the four-way SSPP splitter.

V. Conclusion

In this paper, oval-ring SSPP transmission line and splitters have been reviewed. The SSPP splitter requires further analysis by impedance analysis. In addition, the isolation resistor design of the multi-channel power divider also needs to be researched. Multi-channel SSPP splitters/combiners will play an important role in the development of SSPP circuits and systems.

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