A New Design for Spoof Surface Plasmon Polaritons Using Periodic Holes Etched on the Stripline

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***Abstract*—In this paper, a symmetrical ultrathin spoof surface plasmon polaritons (SSPPs) is realized based on the traditional coplanar waveguide (CPW), which can achieve multi-band high-efficiency transmission by employing the periodic holes etched on the middle stripline. Physical mechanism of the proposed SSPPs is explained by using the dispersion curves and electric field distributions. The measured results have a good agreement with the simulated ones, which indicate that the proposed SSPPs will be potentially very useful for microwave applications.**

Keywords—high-efficiency transmission; multi-band; spoof surface plasmon polaritons

I. Introduction

Surface plasmon polaritons (SPPs) are highly localized surface waves [1, 2], which can propagate along the textured conducting surfaces at deep subwavelength scale. Additionally, the SPPs have attracted great attentions on biomedical sensing, near-field microscopy, nano-photonic and optoelectronic technologies [3-5], due to their exotic performance, such as field confinement and nondiffraction limit. However, the nature SPPs cannot be invoked on the metal surface in terahertz (THz) and microwave bands, hence the spoof SPPs (SSPPs) is proposed to produce highly confined surface electromagnetic (EM) wave and its controllability of the performance.

Classical SSPPs are basically designed using periodic gradient grooves etched on the CPW [6] or microstrip line [7]. However, the traditional structures are more or less limited on practical applications owing to their parasitic properties. The periodic gradient grooves structures are antisymmetrical structures, which is difficult for the design of wave separator. Moreover, according to the open literatures, the SSPPs with multi-band characteristic have not been reported.

In this paper, we present a simple SSPPs using periodic holes etched on the traditional 50-Ω CPW, which not only has a high-efficiency transmission, but also realizes multi-band performance. More importantly, the number of the passband can be easily controlled by adjusting the length of the unit cell compared to the conventional SSPPs, which will be very useful at actually applications.

II. Design Considerations

The configuration of the proposed spoof surface plasmon polaritons (SSPPs) is shown in Fig. 1, which is a traditional CPW feeding structure with the middle stripline drilled with periodic holes. The designed parameters of the width of the

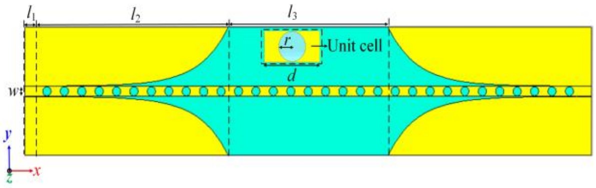

Fig. 1. Configuration of the proposed spoof surface plasmon polaritons.

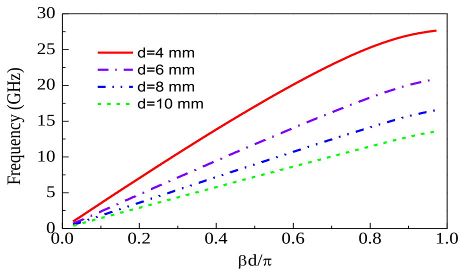

Fig. 2. The dispersion curves for the fundamental mode of the proposed SSPPs for different the unit cell length when the hole radius (r) is fixed as 1.45 mm.

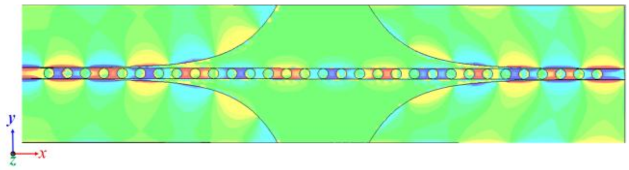

Fig. 3. The electric field distribution on the x-y plane at 10 GHz when d=5 mm.

CPW middle stripline is denoted by w. The length of the CPW feeding part is marked as l_1 and the two gaps of the CPW are 0.125mm and 0.15mm, respectively. The length of the flaring ground and middle transmission part are denoted as l_2 and l_3, respectively. The periodic holes have the radius of r and length of the unit cell is marked as d. The unit cell of the proposed SSPPs is presented in the dashed box in Fig. 1. The Vivaldi curve of flaring ground is expressed in [8]. The initial values of the parameters are selected as w=3 mm, l_1=5 mm, l_2=65 mm, and r=1.45 mm. It should be noted that the value l_3 changes with the length of unit cell d.

The characteristic of the proposed SSPPs is predicted using the full-wave electromagnetic simulation software CST. The dispersion curve for the fundamental mode of the proposed design for different length of the unit cell (d) is presented in Fig. 2. It shows that the dispersion curves significantly deviate to low frequency with the unit cell length (d) increase when the hole radius (r) is fixed as 1.45 mm. Generally, the cut-off frequency of the fundamental mode of the proposed design decreases as the unit cell length (d) raises, indicating tighter confinement of the SSPPs. Additionally, in order to further show the excellent field confinement of the proposed SSPPs, the electric field distribution on the x-y plane at 10 GHz with d=5 mm is plotted in Fig. 3. It is seen that the electromagnetic fields are highly localized on the middle stripline, which indicates that the proposed design can support the modes of SSPPs propagation on its surface.

III. Simulated Results and Experimental Verification

To verify the functionality of the proposed configuration, two samples of the proposed SSPPs are fabricated. The substrate used is F4B with ε_r = 2.65, loss tangent tan δ = 0.0015 and the metallic strips have a thickness of 0.018 mm. The photograph of our fabricated SSPPs are shown in Fig. 4, they have the same physical dimensions except d. The designed dimensions are w=3 mm, l_1=5 mm, l_2=65 mm, and r=1.45 mm.

The simulated and measured S-parameters of the proposed SSPPs with the initial values when d=5 mm and d=12 mm are presented in Fig. 5. From Fig. 5(a), it is obvious that the design achieves single-band within the designed band and its cut-off frequency is about 20 GHz. Additionally, the high frequency high-order modes attenuation dramatically, leading to $|S_{21}|$ just presents single-band characteristic. The highest $|S_{21}|$ is up to -1 dB and the lowest $|S_{21}|$ is about -2 dB between 3.4 GHz to 19.4 GHz, which is wider than the traditionally SSPPs. Moreover, as shown in Fig. 5(b), the proposed design can achieve multi-band transmission performance with the highest $|S_{21}|$ is -1.7 dB and then the high-order modes will be attenuation gradually with d=12 mm. From Fig. 5, we find that the number of bandpass will be increased when the length of unit cell (d) raised, due to the cut-off frequencies of all modes will be decreased as the length of unit cell (d) aggrandized and the pass band will disappear until the high frequency high-order modes attenuation completely. In addition, the measured results of the proposed SSPPs are plotted in Fig. 5, which have a good agreement with the simulated ones and the slight degradation compared to the simulated one is caused by the tolerances in the fabrication and measurement.

IV. Conclusion

The spoof surface plasmon polaritons using periodic holes etched on the metal stripline is proposed, which exhibits high transmission efficiency and multi-band characteristic. The measured results have a good agreement with the simulated ones, which makes it to be very useful in a variety of exciting applications.

ACKNOWLEDGEMENT

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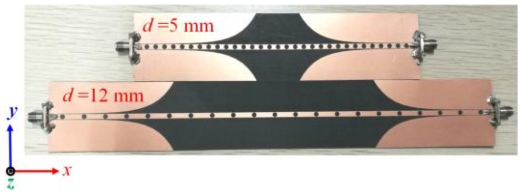
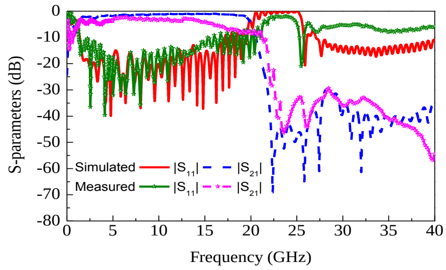
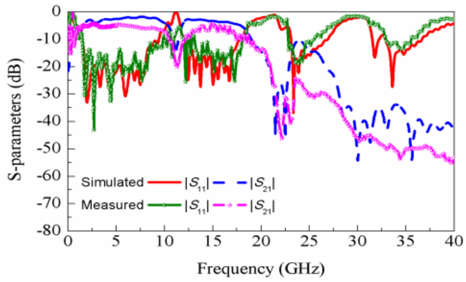


Fig. 4. Photograph of the fabricated SSPPs when d=5 mm and d=12 mm.



(a)



(b)

Fig. 5. Simulated and measured reflection ($|S_{11}|$) and transmission ($|S_{21}|$) coefficients of the proposed SSPPs when (a) d=5 mm and (b) d=12 mm.

References

[1] R. H. Ritchie, "Plasma losses by fast electrons in thin films," Phys. Rev., 106, pp. 874-881, 1957.

[2] W. L. Barnes, A. Dereux, and T. W. Ebbesen, "Surface plasmon subwavelength optics," Nature, 424, pp.824-830, 2003.

[3] E. Ozbay, "Plasmonics: merging photonics and electronics at nanoscale dimensions," Science, 311, pp.189-193, 2008.

[4] S. Kawata, Y. Inouye, and P. Verma, "Plasmonics for near-field nano-imaging and superlensing," Nature Photon., 3, pp.388-394, 2009.

[5] M. Ozaki, J. Kato, and S. Kawata, "Surface-Plasmon Holography with White-Light Illumination," Science, 332, pp.218-220, 2011.

[6] H. M. Ma, X. P. Shen, Q. Cheng, W. X. Jiang, and T. J. Cui, "Broadband and high-efficiency conversion from guided waves to spoof surface plasmon polaritons," Laser Photonics Rev., 8, No. 1, pp.146-151, 2014.

[7] H. C. Zhang, S. Liu, X. P. Shen, L. H. Chen, L. Li, and T. J. Cui, "Broadband amplification of spoof surface plasmon polaritons at microwave frequencies," Laser Photonics Rev., 9, No. 1, pp.83-90, 2015.

[8] L. Zhao, X. Zhang, J. Wang, W. H. Yu, J. D. Li, H. Su, and X. P. Shen, "A Novel Broadband Band-pass Filter Based on Spoof Surface Plasmon Polaritons," Scientific Reports, 6, 36069, 2016.