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A High Gain Endfire Antenna Based on Spoof Surface Plasmon Polaritons

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Abstract— This work presents the design and realization of a high-gain endfire antenna leveraging the unique properties of odd-mode spoof Surface Plasmon Polaritons (SSPPs). The proposed design incorporates a circular monopole to excite the odd-mode SSPPs, resulting in an endfire radiation pattern. The reported antenna operates in 2.3-3.16 GHz with the overall dimension of $3.16\lambda \times 1.13\lambda \times 0.02\lambda$. Validating the designed SSPPs endfire antenna, the measured radiation pattern, gain and return loss are agreed well with the simulated results, with a peak gain of 13.4 dBi at 2.8 GHz. The antenna has the features of high gain and ease of fabrication. Such SSPPs antennas will be highly desirable in endfire radiation application.

Index Terms— SSPPs, high gain, endfire antenna

I. INTRODUCTION

Surface plasmon polaritons (SPPs) is a type of electromagnetic waves, which propagates along the interface between metal and dielectric [1]. SPPs have many various applications due to its unique properties, such as high field confinement and energy localization. However, surface waves can't propagate easily on flat metal surface below optical frequency. In order for SPPs to operate at microwave band, the concept of spoof SPPs (SSPPs) has been proposed [1]. SSPPs are structured surface to imitate the performance of SPPs in optical frequency. Owing to the advantages of SSPPs, such as high field confinement and low loss [2], it has been widely used for designing antenna [3-5], transmission lines [6-8] and filters [9, 10].

SSPPs can be excited by two modes: even- or odd-mode, depending on the orientation of the polarization of the incident electromagnetic waves with respect to the waveguide [2]. For symmetrical SSPPs waveguide structures, there are symmetrical electrical field distributions. The even-mode is the main propagation mode [2]. Many works of even-mode SSPPs antennas have been proposed [11, 12]. For odd-mode SSPPs with an asymmetrical waveguide structure, the incident electromagnetic waves are polarized perpendicular to the waveguide, which results in endfire radiations. This mode of SSPPs can effectively restrain the field bound electromagnetic waves [2]. There are also some reported works on odd-mode SSPPs antennas [13, 14].

In this work, a high gain endfire SSPPs antenna is designed and characterized. The SSPPs antenna is composed of a feeding structure, a circular monopole, SSPPs and reflectors. The odd-mode feature is excited by a monopole antenna. The overall dimension of the proposed antenna is $3.16\lambda \times 1.13\lambda \times 0.02\lambda$. The peak gain of 13.4dBi at 2.8GHz is achieved. In

addition, the radiation efficiency of the proposed antenna is above 80%. The design principle and test results of the proposed antenna are presented in section II. Finally, a conclusion is given in section III.

II. ANTENNA DESIGN

A. Antenna Structure

The configuration of the proposed antenna is shown in Fig.1. The antenna is printed on the FR-4 substrate with permittivity $\epsilon_r = 4.3$, loss tangent of $\tan\delta = 0.025$, and substrate thickness $t = 0.8mm$. The monopole is designed to excite the odd-mode SSPPs. The circular monopole is needed to improve the bandwidth of the antenna. A slot is etched inside the circular monopole to improve the antenna overall gain. In addition, the structure of the circular monopole enhances the electromagnetic field between the monopole and SSPPs structure, in order to improve the overall gain of the antenna. By placing the SSPPs structure close to the circular monopole, the surface currents will be induced along the SSPPs. The odd-mode SSPPs is excited. A slot is etched inside the circular monopole to improve the overall gains of the antenna. A metal strip with two symmetrically corrugated transmission line which has 69 SSPPs units is placed on the right of the circular monopole. Two metal strips are placed on the left of the circular monopole as reflectors to enhance the endfire radiation. All the parameters of the antenna are given in Table.1.

B. Simulation and Measurement Results

The dispersion curve of the SSPPs unit is shown in Fig.2. It is analyzed using Eigenmode Solver in CST Microwave Studio. It can be observed that the dispersion curve is related to the groove depth h . In the case of $h = 11.2mm$, the dispersion curve deviates from the dispersion curve of light. The wave vector is larger than that of the light. The working frequency of the antenna is below the slow wave mode frequency. as increasing the groove depth, the field confinement capacity of the SSPPs antenna gets stronger. On the other hand, when the height increases, the dispersion curve will be far away from the light line, which results in poor phase matching. Therefore, $h = 11.2mm$ is chosen to realize endfire radiation.

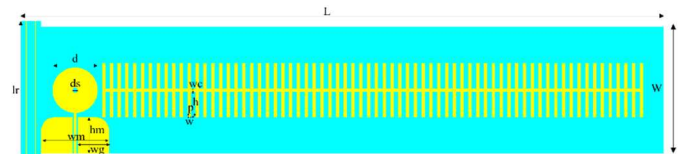


Fig.1. Configuration of the SSPPs antenna

Fig.3 illustrates the electrical field distribution, which indicates the field is well confined and odd-mode SSPPs are excited.

Fig.4 shows the fabricated SSPPs antenna. The simulated and measured S_{11} are presented in Fig.5. The simulated S_{11} is less than -10 dB from 2.3 to 3.16 GHz with the minimum value of -19.6 dB at the central frequency 2.6 GHz. Meanwhile, the measured S_{11} presents an operating frequency range from 2.25 to 2.92 GHz with the minimum value of -20.8 dB at 2.45 GHz, reasonably well agreed with the simulated ones.

Table.1. Dimensions of the proposed antenna

Parameter	L	W	t	wc
Value(mm)	200	55	0.8	1.6
Parameter	h	p	d	ds
Value(mm)	11.2	1.7	20	1
Parameter	lr	ds	hm	wm
Value(mm)	60	1	35	30
Parameter	wg			
Value(mm)	14			

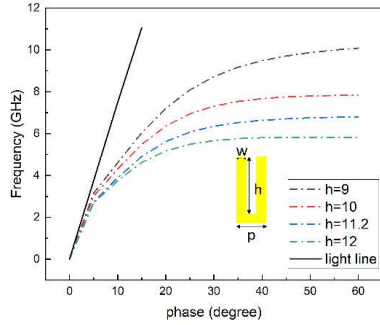


Fig.2. Dispersion curve of the SSPPs unit

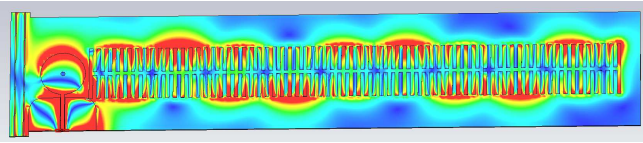


Fig.3. Electrical field distribution at 2.6GHz

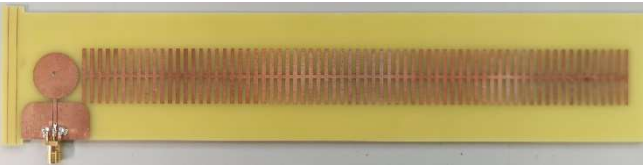


Fig.4. Fabricated prototype of the SSPPs antenna

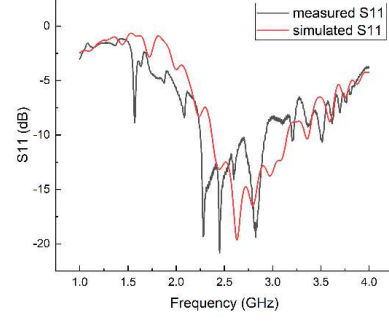


Fig.5. Comparison of simulated and measured S_{11} of the SSPPs antenna

The simulated and measured gains are presented in Fig.7. The measured gains are slightly higher than the simulated results. The simulated and measured gains have the maximum value of 13.4 dBi and 13.6 dBi at 2.8 GHz respectively. Fig.8 shows the radiation efficiency of the proposed antenna. The simulated radiation efficiency within 2.4-3.2 GHz is above 80.8% and achieve 85.07% at 2.8 GHz. The simulated and measured normalized E-plane radiation patterns at 2.6 and 2.8 GHz are shown in Fig.6(a) and (c) and H-plane radiation patterns are shown in Fig.6(b) and (d). Those measured and simulated radiation patterns are in agreement. The simulated and measured beamwidths at 2.3-3.2 GHz are within 33.3° and 29° respectively, with the beamwidths of 30.2° and 28.1° at 2.8 GHz in simulation and 29.4° and 27.6° in measurement related to H-plane and E-plane. The measured results agree well with the simulated results. The comparison with other reported works is listed in

Table 2. In terms of the endfire gain of the listed antennas, this work has the highest gain. In addition, compared the bandwidth to others antenna, the antenna realizes the low profile meanwhile maintains a higher gain performance.

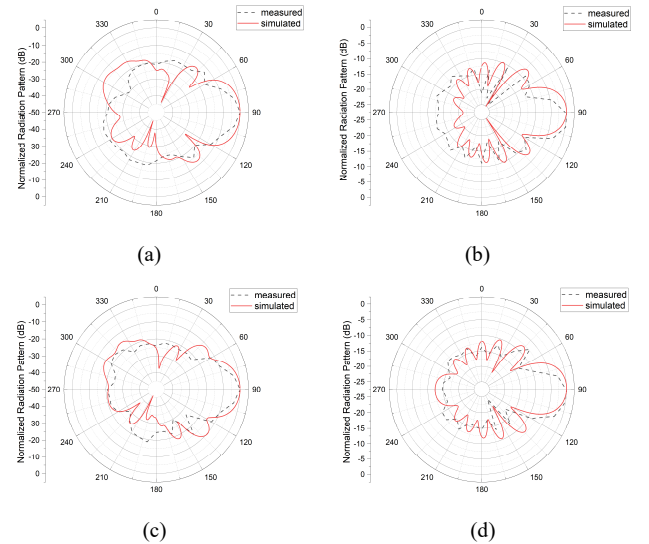


Fig.6. Simulated and measured normalized E-plane and H-plane radiation patterns of the SSPPs antenna at different frequencies. E-plane: (a) 2.6 GHz; (c) 2.8 GHz; H-plane: (b) 2.6 GHz; (d) 2.8 GHz.

III. CONCLUSION

In this work, a high gain endfire antenna based on odd mode SSPPs has demonstrated. The overall dimension of the proposed SSPPs antenna is $3.16\lambda \times 1.13\lambda \times 0.02\lambda$. It generates endfire radiation within 2.3 to 3.2 GHz. A simulated and measured peak gain of 13.4 and 13.6 dBi can be realized at 2.8 GHz. In addition, the simulated and measured beamwidth at 2.8 GHz is 30.2° and 29.4° in H-plane and 28.1° and 27.6° in E-plane respectively. This antenna has the features of high gain, low profile and ease of fabrication, which makes the proposed SSPPs antenna well suited for endfire radiation application.

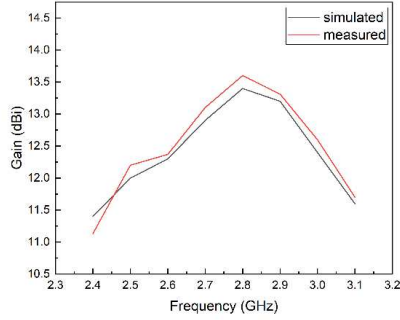


Fig.7. Simulated and measured normalized gains of the SSPPs antenna at different frequencies

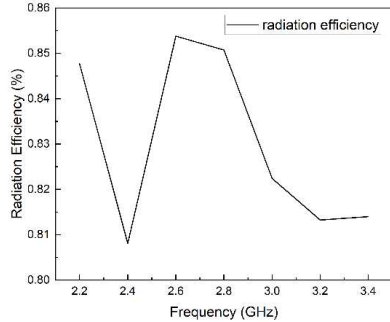


Fig.8. Radiation efficiency of the SSPPs antenna

Table 2. Comparison with other works

Ref.	Gain (dBi)	Size	Gain/Length (dBi/ λ)	BW
[15]	9.2	$4.67\lambda \times 0.55\lambda$	2.3	12%
[16]	9.16	$3.11\lambda \times 0.74\lambda$	2.95	32.1%
[4]	7.86	$3.33\lambda \times 0.74\lambda$	2.36	5.4%
this work	13.6	$3.16\lambda \times 1.13\lambda$	4.2	25%

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