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A Novel Millimeter-Wave Series-Fed Microstrip Line Antenna Array

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***Abstract*— A novel millimeter wave series-fed microstrip line antenna array is designed. The antenna array consists of stepped inverted-cone stub sections placed on both edges of the microstrip line at a guided wavelength spacing. The 5 strip stub sections can alter the surface current cancellation at each guided wavelength in an ideal microstrip line. By properly tuning the length and height difference of the strip stubs, the equivalent surface currents can be focused to the stubbed inverted-cone sections present on the microstrip line edges and results in an effective radiation. The fabricated antenna array has return loss better than 10 dB around 27.3 GHz. Peak realized gain of 10.1 dBi is achieved and measured side lobe levels are better than -15 dB. The proposed antenna array has a very good radiation pattern and low side lobe levels which makes it a suitable direction for future integrated millimeter wave antenna arrays.**

***Index Terms*— antenna array, antenna radiation pattern, microstrip antennas, millimeter-wave (mm-wave) arrayseries-fed array, transmission lines.**

I. INTRODUCTION

Millimeter-wave antennas have been in high demand over the few years as they have been proven to meet the call for fifth generation (5G) and sixth generation (6G) mobile communication systems due to the merits of large capacity and high data rate [1]. Subsequently, the research of mm-wave antennas with good performance but simple and compact structures are immediately required [2].

Due to the easy integration with passive or active microwave devices and easy fabrication process, the microstrip line is a widely used planar transmission line in RF and mm-wave circuits [3]. However, the radiation property of a pure microstrip line is very low, since it is fundamentally a transmission line. To be specific, the equivalent magnetic current along one side of the line and the counterpart along the other have the same amplitudes but opposite directions [4]. To make the microstrip line radiative, it is possible to alternately remove the magnetic currents and to keep only the in-phase magnetic currents. This idea has been used in [5] and [6] to realize all-metal arrays. In [5], L-shaped blocking structures are arranged alternatively beside the microstrip line to remove the magnetic current units. Fabrication of these blocking metallic plates makes the process difficult. Furthermore, the difficulty will considerably increase if the array is designed at mm wave frequencies, owing to the very small dimensions.

Microstrip antennas are more beneficial than other millimeter-wave antennas in terms of their low profile and low cost [7]. On the other hand, the feeding techniques are a significant problem in the array feeding due to the trade-off in parameters such as bandwidth, side lobe levels (SLL) stable gain and desired radiation pattern of the microstrip array. The parallel-fed array usually suffers from complicated design process, bulky size, as well as extra loss due to the corporate feed structure. On the contrary, the series-fed array has a much simpler feeding network and more compact configuration [8].

To achieve a low side lobe level (SLL) and to shape the beam profile, significant research has been carried out on series-fed microstrip arrays [9], [10]. A typical method for realizing nonuniform excitation is to taper the radiation efficiency of each antenna element by adjusting the patch width [11]. Since the radiation patterns of each element are not strictly identical, this method may result in a low gain and is effective only when the tapering difference is not significant. Otherwise, the synthesized radiation pattern would deteriorate significantly.

In this paper, a novel series-fed microstrip linear array is investigated. This array is mainly based on a modified microstrip line by introducing stepped inverted-cone stub sections on both the edges of the microstrip line to make it radiate effectively. In Section II, the design of proposed microstrip line array antenna is discussed. Sections III describes the performance of array antenna. Finally, conclusions are drawn in Section IV.

II. MICROSTRIP LINE ARRAY ANTENNA DESIGN

The proposed series-fed array is a microstrip line-based antenna at 27.3 GHz is illustrated in Fig.1, with a line length lr of 33.12 mm as the radiating element. The microstrip line has a width wr of 2 mm (0.35λ). Stepped inverted-cone stubs are proposed on both edges of the microstrip line with a guided wavelength spacing for effective radiation. Each stepped inverted-cone stub section consists of 5 strip stubs with a stub height difference ds of 0.15 mm and constant stub length ls of 0.5 mm. Stub heights in each section increments in step to a maximum stub height of 0.45 mm and then decreased. A ground layer is placed on the bottom side of the substrate. A thin microstrip line connected to the end of the radiating microstrip line is utilized as the feeding element of the antenna array. The feed line has a width *wf* of 0.4 mm and a length *lf* of 12.2 mm. The feed line is a simple 50 ohm line – the array input being designed for 50 ohms. Two large ground pads with vias to bottom ground layer are also placed on both sides of the feed line with a length *lp* of 10 mm and width *wp* of 10 mm – for mounting a 2.4 mm coaxial end-launch. The proposed antenna is fabricated on a RO4003C substrate of 0.203 mm thickness with a relative dielectric constant 3.55, and tangential loss of 0.0027. The antenna has an overall dimension of 50 mm × 21 mm.

Fig. 2 illustrates the surface current distributions of the pure microstrip line and proposed microstrip line antenna array. For understanding the working principle of the proposed microstrip line array antenna, initially the surface current along the pure microstrip line is observed as shown in Fig. 2 (a). The equivalent surface currents along one $\boldsymbol{\lambda}/2$ section and the consecutive sections are in reverse directions. Hence the resultant surface current cancel outs in each guided wavelength section. Accordingly, the equivalent magnetic current along one side of the line and the counterpart along the other have the same amplitudes but opposite directions [5]. As a result, little energy can be radiated out from an ideal microstrip line.

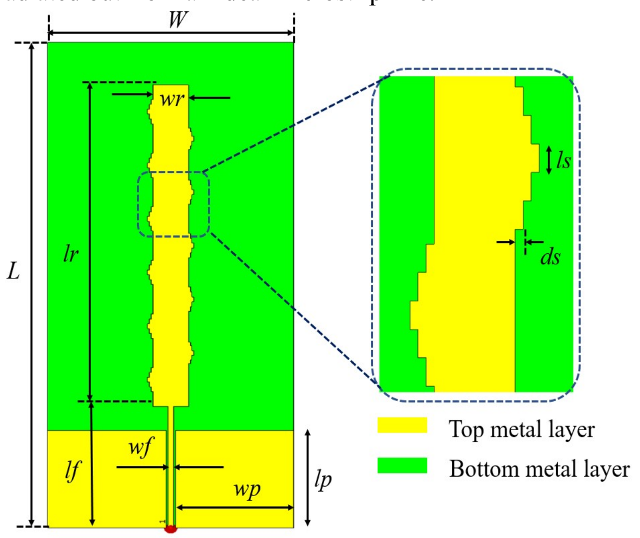

Fig. 1. Microstrip line array antenna

In this paper, a simple configuration is proposed to remove the opposing surface currents of the microstrip line and to make it radiate effectively. Therefore, stepped inverted-cone stub sections are introduced in both edges to remove the cancelling effect of the surface currents. As in Fig. 2(b) it can be observed that the equivalent surface currents are focused to the stubbed inverted cone sections of the microstrip line. Five incremental strip stubs with an overall length slightly less than λ/2 are included in a stepped inverted cone stub section to facilitate an effective radiation. By properly tuning the length and height difference of the stepped stub sections along the microstrip line, a broadside pattern can be achieved with high gain. The proposed antenna has the advantage of being scalable along the length direction. Moreover, the fabrication is relatively simple, as no blocking structures or shorting pins are present in this design.

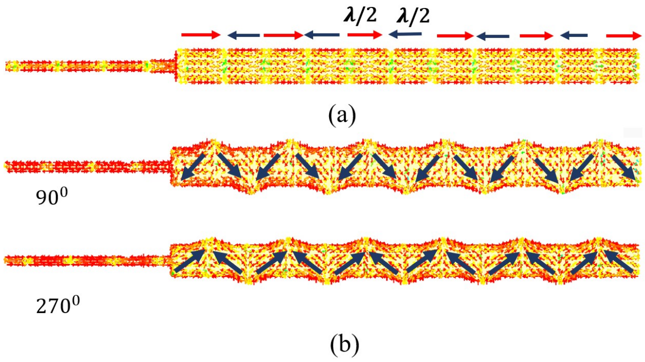

Fig. 2. Surface current distributions (a) conventional microstrip line (b) proposed microstrip line antenna array at 90^0 and 270^0 phases.

III. Results

Results are now presented from EM simulations and subsequent prototype build of the antenna design, on Rogers RO4003C substrate.

A. EM Simulation Results

EM simulations using CST studio are utilized to simulate the design idea of the proposed antenna array. The simulated reflection coefficient of the antenna is shown in Fig. 3. The proposed microstrip line antenna is resonating at 27.3 GHz. It can be observed that more than 10 dB return loss has been achieved over a 330 MHz bandwidth from 27.17 GHz to 27.5 GHz.

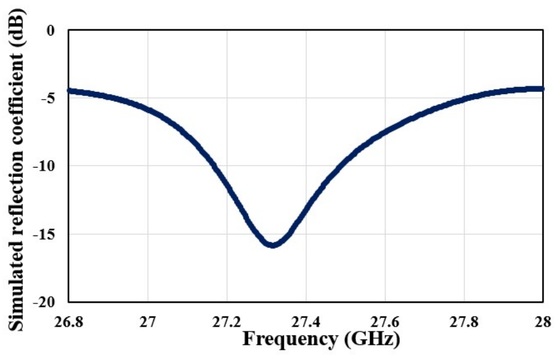

Fig. 3. Simulated reflection coefficient of the proposed antenna array

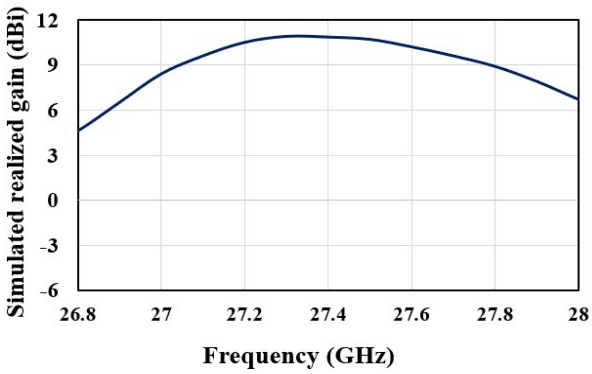

Fig. 4. Simulated realized gain of the proposed antenna array

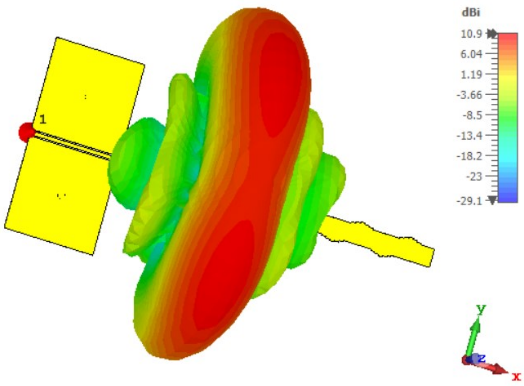

Fig. 5. Simulated 3-D radiation pattern of the antenna array.

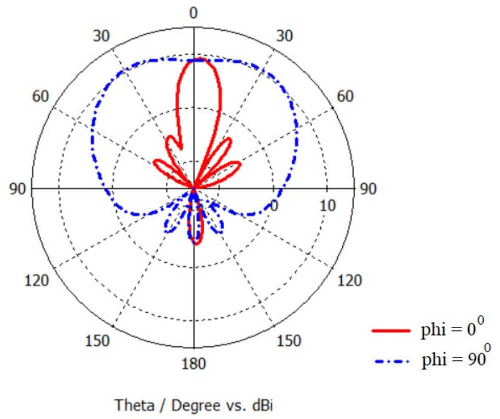

Fig. 6. Simulated E and H plane radiation pattern of the antenna array.

Simulated realized gain of the proposed array antenna is shown in Fig. 4. A peak realized gain of 10.9 dBi is achieved at 27.3 GHz. Fig. 5 represents the 3-D radiation pattern of the microstrip line array antenna. The proposed antenna has a broadside radiation pattern. Fig. 6 shows the simulated radiation patterns of the array antenna at 27.3 GHz. A narrow beam with a 3 dB beam width of approximately 18^0 is obtained in the H-plane (phi = 0^0), and the SLL is around −16 dB. The E-plane (phi = 90◦) pattern has a fan shape, and the 3 dB beam width is approximately 113^0. Simulated efficiency of the antenna is more than 70% at the designed operating band.

B. Prototype Measurement Results

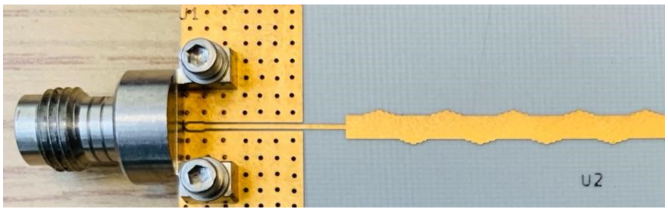

Fig. 7. PCB prototype of the proposed microstrip line antenna array

The fabricated PCB prototype of the antenna is shown in Fig. 7. A 2.4 mm PCB edge launch connector is utilized at the microstrip feed line end. Initially, the reflection coefficient of the fabricated array antenna was measured.

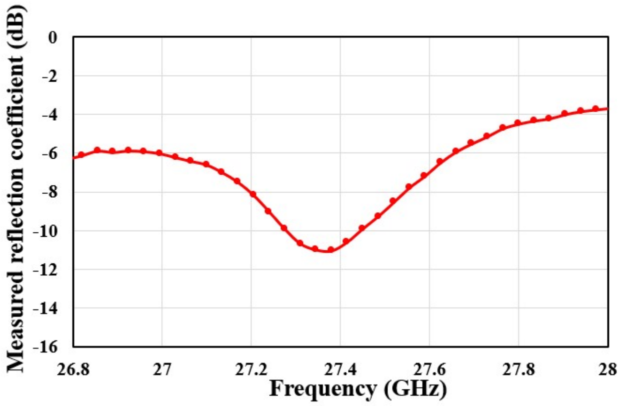

Fig. 8. Measured reflection coefficient of the microstrip line antenna array

Fig. 8 shows the measured reflection coefficient of the proposed microstrip line antenna with stepped inverted cone stub sections. Even though the measured impedance bandwidth is slightly reduced due to fabrication errors, the resonance can be properly observed at 27.3 GHz in the measured results. NSI-MI 700S-360 antenna measurement system in The University of Sheffield EPSRC mmWave Measurement Lab was utilized to evaluate the radiation pattern performance of the proposed antenna array [12]. Broadside radiation pattern with a fan shaped radiation pattern is observed, as expected. Fig. 9 shows the measured 3D radiation pattern of the proposed microstrip antenna array at 27.3 GHz. Side lobe levels in the measured radiation pattern is better than -15.1 dB. A narrow beam in the H-plane and a fan shaped beam in the E-plane is observed. Also, the radiation patterns are found very stable, not only at the resonant frequency but also at other frequencies across the entire operating band. Fig. 10 shows the measured realized gain of the proposed antenna array. A peak gain of 10.1 dBi is achieved at 27.3 GHz, agreeing well with simulation. The observed small reduction in gain and bandwidth could be due to radiated measurement uncertainty, PCB edge launch connector loss or further PCB losses. It is worth mentioning that the proposed array has a different radiation principle compared to the works in [7]-[11]. Furthermore, the realized gain is reasonably high in the proposed array with a compact thin radiating structure.

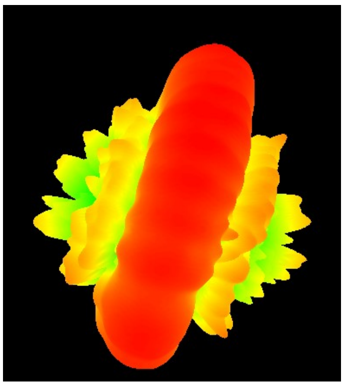

Fig. 9. Measured 3-D radiation pattern of the microstrip line antenna array.

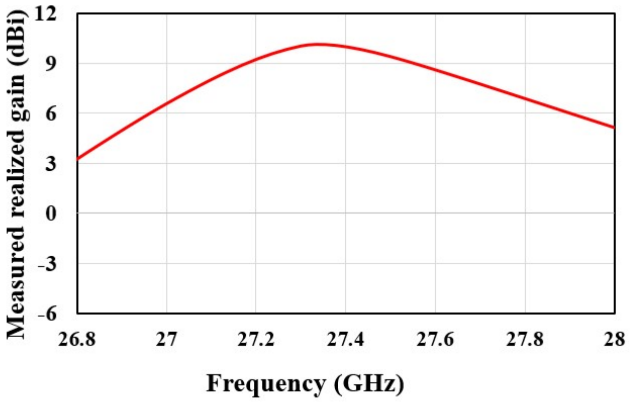

Fig. 10. Measured realized gain of the microstrip line antenna array.

IV. CONCLUSION

A novel series fed microstrip line antenna array has been designed for millimeter wave applications. Stepped inverted-cone stub sections were placed on both edges of the microstrip line at guided wavelength spacing. By introducing the 5 strip stub sections, the surface current cancellation at each guided wavelength in a pure microstrip line would be perturbed and turned into an efficient radiator. For demonstration, a microstrip line antenna array with stepped inverted cone stub sections at 27.3 GHz has been fabricated. A broadside radiation pattern with fan shaped beam profile has been achieved. The microstrip line antenna array achieved a peak realized gain of 10.1 dBi and measured side lobe levels were better than -15 dB. The proposed microstrip line antenna array exhibits low side lobe levels and high gain, along with simple fabrication and easy integration making it appropriate for future 5G and 6G mm-wave communication applications.

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