A high-gain dual-band ESPAR antenna with simple on/off controlling

W.J. Huang, B.H. Sun, Y. Wang, F.F. Zhang and K. He

School of Electronic Engineering, Xidian University, China

hwj_02034@163.com
bhsun@mail.xidian.edu.cn
Jiangzhixd@163.com
shalolo@163.com
hekai1204@gmail.com

***Abstract*— A new type of dual-band ESPAR (Electronically Steerable Parasitic Array Radiator) array antenna is presented. The antenna consists of one feeding radiating element and two-layer parasitic radiating elements. The parasitic radiating element of each layer is composed of 6 parasitic monopoles and placed in the near field of the active radiator. Replacing the reactance-load, the on/off controlling is used, which is easy fulfilled and low cost. The antenna realizes the dual-band performance by using a metal cylinder with a large radius as active radiator and an impedance matching circuit. The designed two-layer parasitic radiating elements make the antenna gain enhanced. A prototype is made and tested, and the result shows that the antenna has a horizontal directivity of 6-7 dBi and VSWR of 3:1 or better at 1.48 GHz and 1.82 GHz.**

I. INTRODUCTION

The theoretical concept of beam-forming using a circular parasitic array was initially introduced by Harrington in 1978 [1]. The ESPAR antenna is a type of reactively steerable array antenna and single-port array antenna with only one central active monopole element surrounded by several reactively controlled parasitic radiating elements [2], [3]. The ESPAR antenna pattern is controlled by adjusting the reactance-load values including capacitance and inductance. A conventional ESPAR antenna has good steerability, but complex circuits for controlling these reactance loads in the ESPAR antenna are needed [4], [5], which lead to a difficult manufacturing process and high cost. In addition, the reactance-load values change against the frequency and thus there appear many combination states, which makes it difficult to realize a dual-band ESPAR antenna [6], [7].

In this paper, further simplification to the ESPAR antenna is proposed. The reactance-load in the controlling circuit is replaced with simple on/off switch. Two states of open or short to the ground are available for each parasitic radiating element. Outer layer parasitic elements are introduced in order to enhance the gain. The active element is a cylinder monopole with a large radius which is connected to the ground skirt. The cylinder monopole as the active element and an impedance matching network are designed to realize the dual-band characteristic. Compared with the antenna with single-layer parasitic radiating elements, the simulated gain of the antenna with two-layer parasitic elements is increased. Simultaneously, the Voltage Standing Wave Ratio (VSWR) of the proposed antenna is improved.

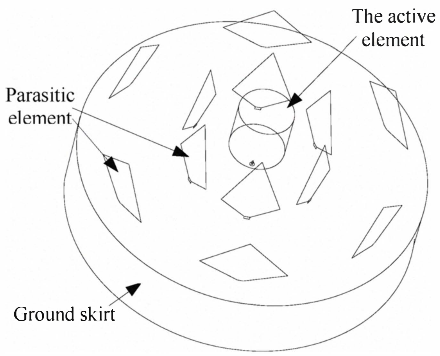


Fig. 1 Dual-band ESPAR antenna structure

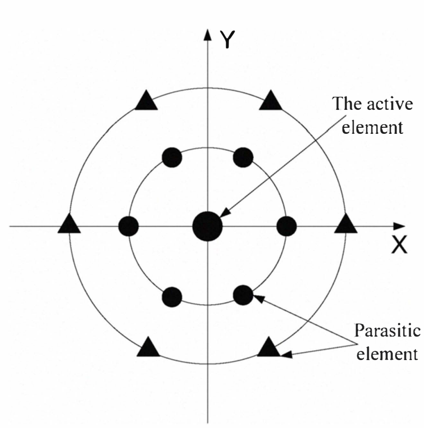


Fig. 2 Dual-band ESPAR with two-layer elements

978-1-4244-6908-6/10/$26.00 ©2010 IEEE

II. ANTENNA CONFIGURATION AND PRINCIPLE

The proposed dual-band ESPAR antenna with two-layer elements is controlled by a simple on / off switched circuit. Through the simple on / off controlling, scanning characteristic of the radiation pattern is achieved. As shown in Fig. 1 and Fig. 2, the single active monopole is placed in the center of the ground plane, encircled by equally spaced, two-layer parasitic radiating elements. The inner layer parasitic elements are loaded with the switched circuit, and outer layer parasitic elements are connected to the ground plane directly. There are six parasitic elements in each layer. In order to achieve good reflectors or directors function and reduce the coupling capacitance between parasitic radiating elements and the ground plane, the two-layer parasitic elements are designed with planar structure in diamond shape. Generally, radiation patterns are synthesised by electromagnetic coupling between one RF excited element and parasitic radiating elements. The electromagnetic coupling is controlled by changing the on/off switch of parasitic radiating elements. In view of this, the inner layer parasitic monopoles control and change the direction of the radiation pattern, and the outer layer monopoles can further enhance the gain.

Fig. 3(a) shows that the central active radiator is a metal cylinder monopole. The variation of input impedance is stable against the frequency. The impedance bandwidth characteristic is improved effectively and the dual-band impedance matching is possible by using a cylinder with a large radius as the active radiator. In order to realize the dual-band characteristic and low Voltage Standing Wave Ratio (VSWR), an impedance matching network is designed. It is connected to the active element and fixed on the back of the ground plane. As shown in Fig. 4, the designed matching circuit includes shunt capacitances and series inductances.

Parasitic elements are located on a hollowed cylindrical ground structure which is composed of a ground plane and a metal skirt. The ground skirt is used to reduce the angle of elevation of the main lobe which exists due to the finite ground plane dimensions [8].

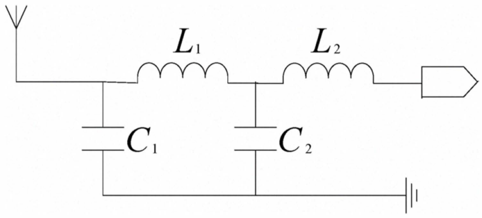


Fig. 4 Impedance matching circuit

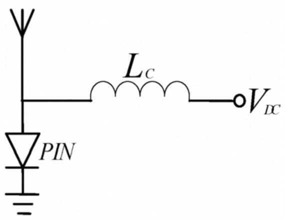
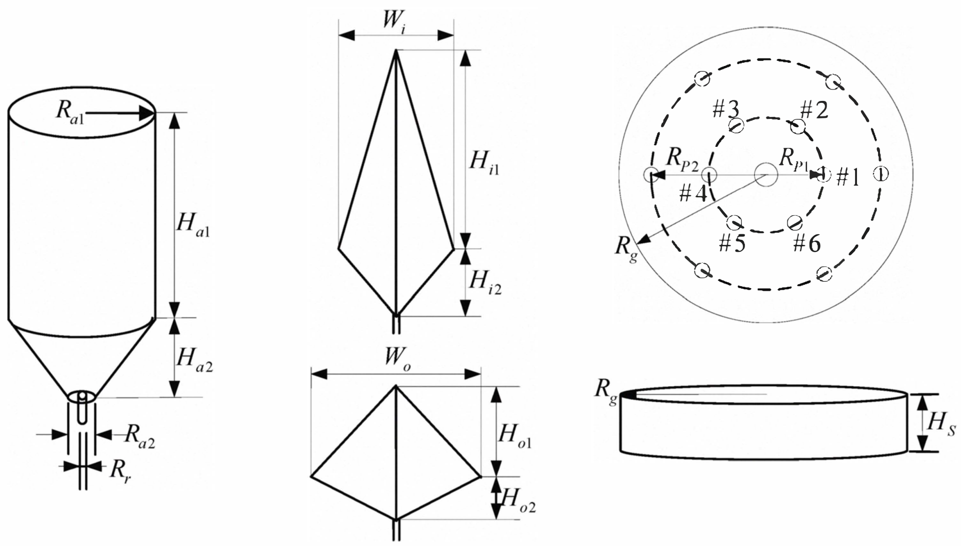


Fig. 5 Switched circuit

As shown in Fig. 5, the switched circuit includes a PIN diode and a choke inductance.



(a) (b) (c)

Fig. 3 Dimensions of the switched ESPAR antenna.
a: the active radiator or the solid cage antenna, b: the parasitic element, c: the ground skirt

There are two types of parameters in the design of the dual-band ESPAR antenna: structure parameters, which define the mechanical structure, and impedance matching parameters, which provide dual-band operation.

Antenna Structure Parameters

The structure of the dual-band ESPAR antenna has a number of parameters which can be separated into three groups as shown in Fig. 3. The parameters of the active element or the cylinder monopole are: the height of the cylinder H_{a1}, the height of the cone H_{a2}, the radii of the upper and bottom bases R_{a1}, R_{a2}, the radius of the cylindrical probe which connects the cylinder monopole to the RF transceiver R_r. The parameters of the parasitic element are: the heights of the inner layer elements H_{i1}, H_{i2} and the outer layer ones H_{o1}, H_{o2}, the widths of the inner layer elements W_i and the outer layer ones W_o. The parameters of the cylindrical ground structure are: the radius R_g, the height H_s, and the radii of parasitic radiating elements around the active element R_{p1}, R_{p2}. The dimensions of the parameters are shown in Table-1.

TABLE 1
ANTENNA DIMENSION (mm)

H_{a1}	H_{a2}	R_{a1}	R_{a2}	R_r
36.2	18	17.8	1.1	0.5

H_{i1}	H_{i2}	H_{o1}	H_{o2}	W_i	W_o
41	15	25	12	37	54

R_{p1}	R_{p2}	R_g	H_s
44	93.6	111.5	46.8

More efforts are made to improve the gain of the proposed dual-band ESPAR antenna. According to the center frequency 1.6 GHz, detailed sizes of the antenna are: the height of the active element 0.298λ, the inner layer parasitic elements 0.30λ, and the outer layer parasitic ones 0.20λ, the distances between the central active monopole and two- layer parasitic monopoles 0.235λ, 0.5λ, the radius and height of the ground skirt 0.595λ, 0.25λ.

Matching Network Parameters

The antenna with the only single active monopole is able to achieve good impedance bandwidth. However, introduction of parasitic radiating elements causes the impedance mismatch. An impedance matching network is designed to solve this problem and realize the dual-band characteristic.

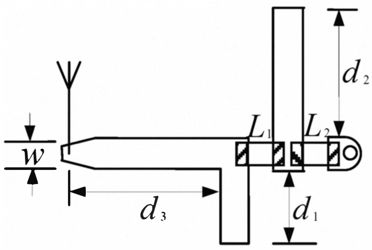


Fig. 6 PCB layout for matching circuit

The PCB layout for the impedance matching network is shown in Fig. 6. It is composed of the microstrip transmission line, equivalent capacitance of the microstrip and chip inductance. The impedance matching circuit is designed and optimized by using the commercial software Advanced Design System (ADS). Taking the impact of the microstrip transmission line into account, the lengths of microstrip line (equivalent capacitance) and transmission line are viewed as new optimization parameters. Detailed optimization values are shown in Table-2.

TABLE 2
OPTIMIZED VALUES FOR MATCHING CIRCUIT

d_1	d_2	d_3	L_1	L_2
7.8mm	13.6mm	11mm	10.2nH	14.8nH

III. EXPERIMENTAL RESULTS

A prototype of the proposed dual-band (1.48GHz / 1.82GHz) ESPAR antenna is shown in Fig. 7. It is made with the dimensions given in table 1.

Fig. 7 The photograph of the fabricated ESPAR antenna

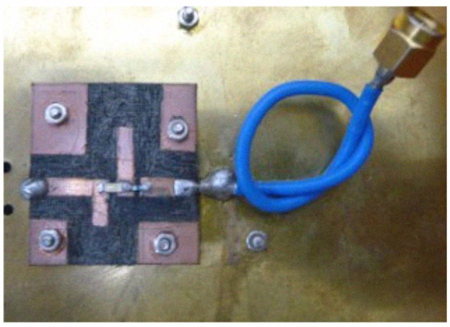


Fig. 8 The photograph of the fabricated matching circuit

Fig. 8 shows a fabricated prototype of the matching circuit. It is connected to the active monopole and fixed on the back of the ground plane.

According to the dimensions listed in table-1 and table-2, the prototype is measured. Fig. 9 shows the simulated and measured VSWR of the proposed dual-band ESPAR antenna. A VSWR of 3:1 or better in the two bands (1.48 GHz and 1.82 GHz) is observed.

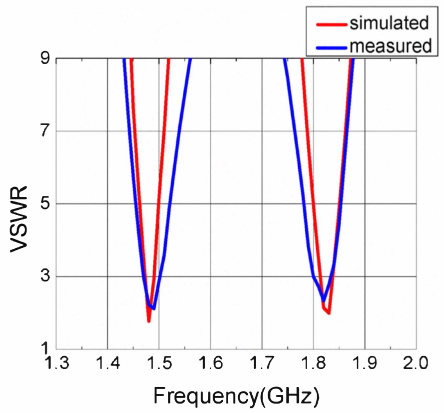


Fig. 9 Simulated and measured VSWR of the proposed antenna

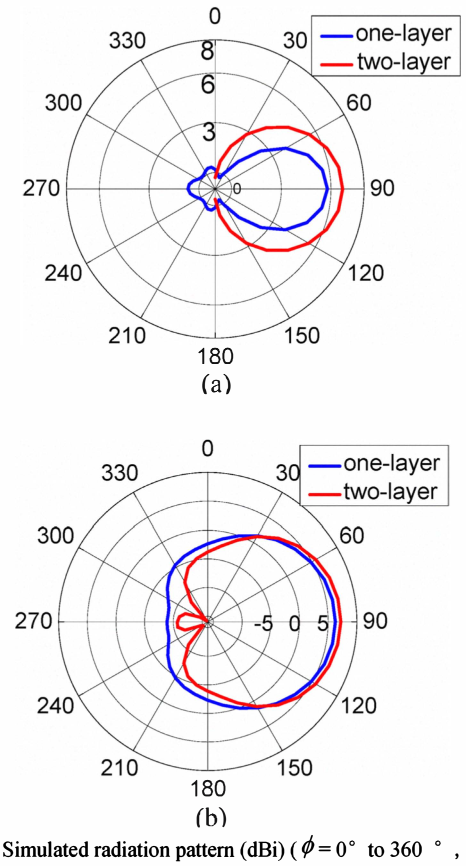


Fig.10 Simulated radiation pattern (dBi) ($\phi = 0°$ to $360°$, $\theta = 90°$) of the switched ESPAR antenna with one-layer and two-layer; (a) is at 1.48 GHz , (b) is at 1.82 GHz.

As shown in Fig. 10, simulated radiation patterns of the proposed antenna with one-layer and two-layer parasitic elements are depicted. It illustrates that the gain of the proposed ESPAR antenna with two-layer parasitic radiating elements is increased by about 1 dBi in the two service bands compared with the antenna with one-layer parasitic radiating elements. The antenna produces a horizontal directivity of 6-7 dBi.

Ⅳ. CONCLUSION

A high-gain ESPAR antenna with simple on / off controlling covering two bands (1.48 GHz and 1.82-GHz band) has been presented. Using two-layer parasitic radiating elements and the on/off switch circuit, the scanning characteristic of the radiation pattern is achieved. Due to the rotational symmetry, the main beam can be steered around the azimuthal plane by sequential rotation of the parasitic loading (on and off). A matching network is designed to realize the dual-band characteristic of the ESPAR antenna. The mean gain in horizontal direction is around 7 dBi and VSWR is less than 3:1 in the two service bands. The proposed antenna is suitable for commercialization in mobile wireless communications system.

REFERENCES

[1] R. F. Harrington, "Reactively controlled directive arrays," *IEEE Trans. Antennas Propag.*, vol. AP-26, no. 3, pp. 390-395, May 1978.

[2] S. Preston, D. Thiel, and J. Lu, "A multibeam antenna using switched parasitic and switched active element for space-division multiple access application," *IEICE Trans. Jpn.*, vol. E82, no. 7, pp. 1202-1210, 1999

[3] T. Ohira and K. Gyoda, "Electronically steerable passive array radiator antennas for low-cost analog adaptive beamforming," in *Proc. IEEE Int. Conf. Phased Array Systems Technology*, May 2000, pp. 101-104.

[4] D. V. Thiel and S. L. Smith, *Switched Parasitic Antennas for Cellular Communications.* Norwood, MA: Artech House, 2002.

[5] J. Lu, D Thiel, B. Hanna, and S. Saario, "Dielectric embedded electronically switched and multiple beam antenna arrays for wireless communications systems," *Electron. Lett.*, vol. 37, no. 14, pp. 871-872, Jul. 2001.

[6] R. Schlub, D. Thiel, J, Lu, and S. G. O'Keefe, "Dual-band six-element switched parasitic array for smart antenna cellular communications systems," *IEE Electron. Lett.*, vol. 36, no. 16, pp. 1342-1343, Aug. 2000.

[7] O. Shibata and T. Furuhi, "Dual-band ESPAR antenna for wireless lan applications," in *Proc. 2005 IEEE Antennas Propag.*, Jul. 2005, pp. 605-608.

[8] Y. Ojiro, H. Kawakami, K. Gyoda, and T.Ohira, "Improvement of elevation directivity for ESPAR antennas with finite ground plane," in Proc. IEEE Antennas Propagat. Soc. Symp., 2001, pp. 18-19.