2x2 Array Design of ESPAR Antenna for IoT Communication System

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***Abstract* – 2x2 array design of ESPAR Antenna is proposed for the better IoT communication system. Compared with the single antenna, the array antenna is widely used in the recent communication systems due to its advantages as like higher gains, and better radiation patterns and power efficiency. Also, it is very important to use the array antennas for the faster data rate in any dense communication systems efficiently and for the sensing any target or sensors. However, it is a big challenge to design this array antenna using optimum radiator. In this paper, 13-elements Electronically Steerable Parasitic Array Radiator (ESPAR) antenna with the array of 2x2 is designed and simulated on the FR-4 substrate with the dielectric constant 4.3. The proposed array antenna efficiently shows good match with the mathematical logic by increasing gain. The gains obtained as 4.56 dBi at the single 13- elements ESPAR antenna, 9.61 dBi at the 2x2 array of 13- elements ESPAR antenna, and the reflection coefficient is measured below -10 dB in the designed array at 2.40 GHz frequency.**

Keywords – ESPAR antenna, Array antenna, High-Gain, communication and sensing.

I. INTRODUCTION

The electronic control panel class unit has an antenna system capable of configuring and managing beam forming and steering by adjusting the signal's amplitude that receives or transmits by each antenna elements [2]. Array antennas special selectivity makes themselves more attractive to be used in many communication devices. Next-generation massive wireless communication systems are involved with array antennas due to its optimum size, luminous weight, larger gain, overall better reliability, mobility, and for highly efficient performance [1-4].

Array antennas used in the center/base stations which increase the channel capacity, higher data transfer without additional bandwidth, reduces multipath fading and co-channel interference in normal ways, minimizes the need for more power transmission in any communication system [5]. Systematic planning of this array also drives decisions forwarding and signal to noise ratio in the system [6]. Special feature of this technique has many advantages in business applications or personal communications. However, the price is confusing and systematic restrictions made on its use. For these the scientists have been focusing on this recently to reduce costs and the design complexity of array antennas. So that it can be used in many places and industries easily. As the system turns into a control circuit, they play an important role in determining maximum revenue and minimum complexity [7-8].

The first array antenna was introduced in the 1940s [9]. This development was significantly used in wireless communications because it improves the reception and transmission of systems with minimum interference. The antenna array consists of N-radiated elements applied to special functions. Feeding can also be done specifically to achieve the goals of increasing or maintaining radiation patterns or maintaining alignment. In this way, the array antenna is widely used in the recent communication systems due to its advantages as like higher gains, and better radiation patterns and power efficiency. Also, it is very important to use the array antennas for the faster data rate in any dense communication systems efficiently and for the sensing any target or sensors. However, it is a big challenge to design this array antenna using optimum radiator. The proposed antenna's gain (9.61 dBi) is much higher than the previously published array antennas like 9.04 dBi [2], 9.50 dBi [4], and 7.16 dBi [10]. As compared to the other parameters i.e., reflection coefficient, radiation pattern, and directivity, the designed array antenna's performance is also exhibited as much better.

In this paper, 13-elements Electronically Steerable Parasitic Array Radiator (ESPAR) antenna with the array of 2x2 is designed and simulated on the FR-4 substrate with the dielectric constant 4.3. The proposed array antenna efficiently shows good match with the mathematical logic by increasing gain. The gains obtained as 4.56 dBi at the single 13- elements ESPAR antenna, 9.61 dBi at the 2x2 array of 13- elements ESPAR antenna, and the reflection coefficient is measured below 10 dB in the designed array at 2.40 GHz frequency.

II. ESPAR ANTENNA ARRAY

The ESPAR antenna consists of one active monopole (numbered as #0) placed in the center of the metal ground plane surrounded by 12- parasitic elements (numbered as #1- #12) printed on FR-4 dielectric substrate. It has a thickness of h = 0.787 mm and exhibits a relative permittivity of ε_r = 4.3, so the antenna can be used in inexpensive in our proposed system. The height of the active element, ha = 30 mm, and the height of parasitic elements, hp = 26 mm. The active monopole is fed by the coaxial connector via the central pin in order to provide 50Ω impedance appropriately. The parasitic elements can be opened (directors that pass through the electromagnetic wave) or shortened (reflectors that reflects the energy) to the ground by the pin diode switching circuits designed on dielectric substrate.

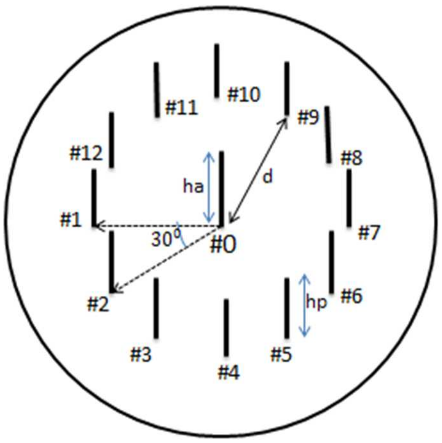

Fig. 1. Structure of 13-elements ESPAR antenna geometry.

The optimum distance, d= $\lambda/4$ (quarter-wavelength) between each parasitic elements and the active printed monopole causes strong mutual coupling effects and provides a reconfigurable radiation pattern to the ESPAR antenna according to which parasitic monopole is connected to the ground plane [10]. The polar radiation pattern which has the main beam direction, φ^{1}_{max} = 90^0 (along the negative y-axis) illustrated in Fig. 2, and is created by shorting the respective switching vectors.

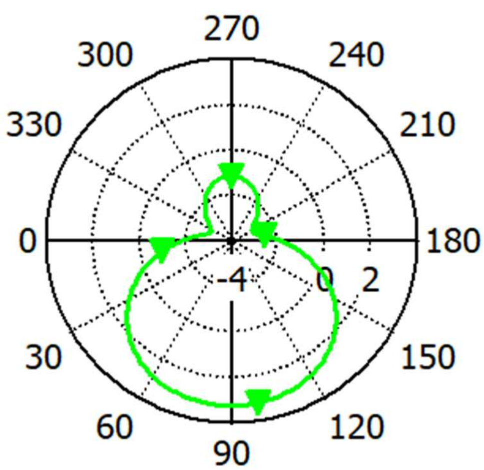

Fig. 2. Polar radiation pattern of the antenna at 2.40 GHz for φ^{4}_{max}= 90^0.

Moreover, there is a very good impedance matching for different considered configurations of this ESPAR antenna. The reflection coefficient below -10 dB in the considered frequency band for the proposed antenna is presented in Fig. 3 at only one case of the switching. From where, it is observed that the antenna exactly resonates at 2.40 GHz for each steering vector with the minimum return loss of 23.286 dB.

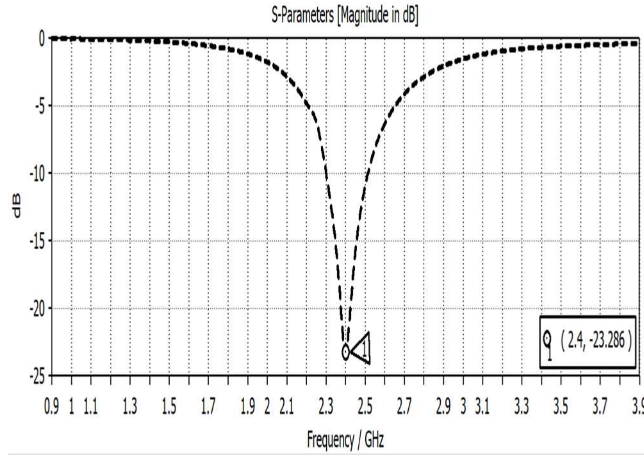

Fig. 3. Reflection coefficient of the 13- elements ESPAR antenna.

In 2x2 array of 13- elements ESPAR antenna, each ESPAR antenna is arranged in such a way that the distance between the antennas is one-half wavelength, λ/2 (= 62.5 mm). The distance between each active elements of this array system will be λ (= 125 mm). To be noted the each parameters like shape, height of the active and parasitic elements, each elements diameter of the single ESPAR antenna will be unchanged. Finally, the 2x2 array antenna configurations are well integrated and optimized to ensure that input is consistent with the best results. The geometrical design specification of the 2x2 array is illustrated in Fig. 4 with four single 13- elements ESPAR antennas.

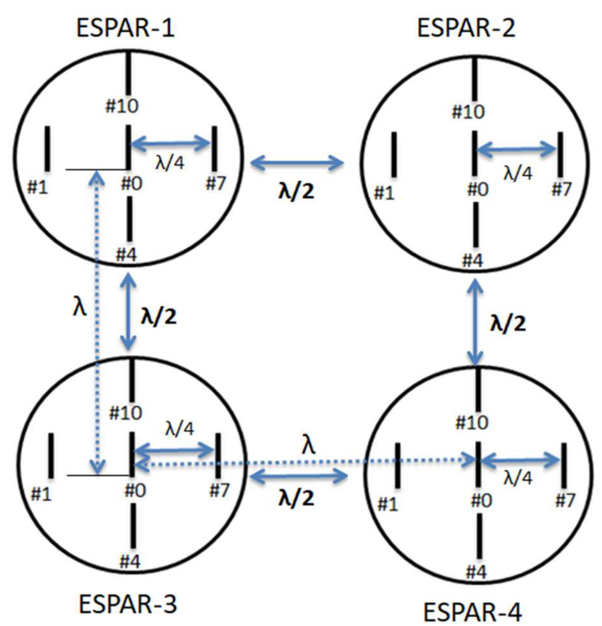

Fig. 4. Structure of 2x2 array of 13-elements ESPAR antenna geometry.

The return loss plot of this array antenna is demonstrated in Fig. 5; moreover the reflection coefficients for S11, S22, S33, S44 of the 2x2 array, 13- elements ESPAR antenna are indicated as circle mark. After combining the farfield results, the final reflection coefficient is also displayed in Fig. 06, which indicates that the array antenna resonates at 2.40 GHz frequency with minimum return loss of – 18.33 dB. The 3-D radiation pattern of the proposed 2x2 array antenna is depicted in Fig. 7, where the value of gain is 9.61 dBi. The polar radiation pattern of the array antenna is depicted in Fig. 8, which could be used to direct the energy to the directions of 0^0, $90^0, 180^0, 270^0$.

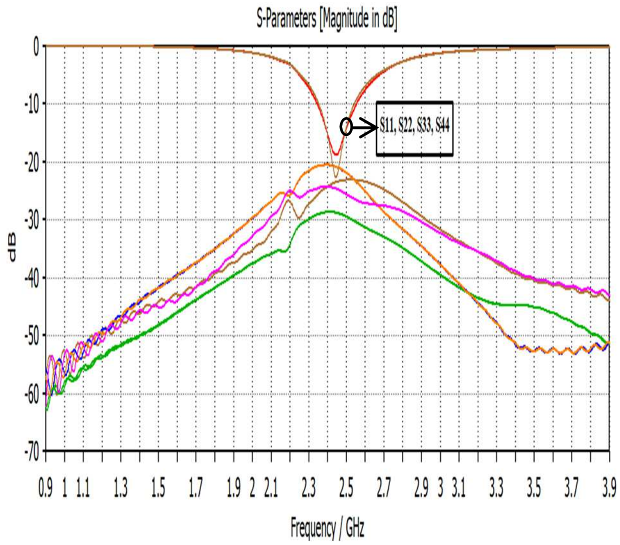

Fig. 5. Reflection coefficient of the 2x2 array 13- elements ESPAR antenna.

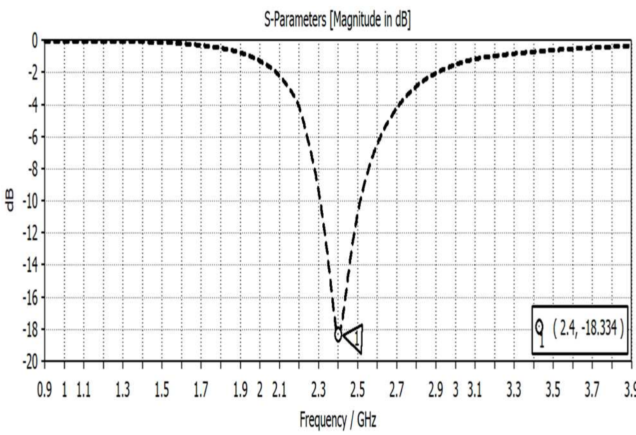

Fig. 6. Reflection coefficient after farfields combination.

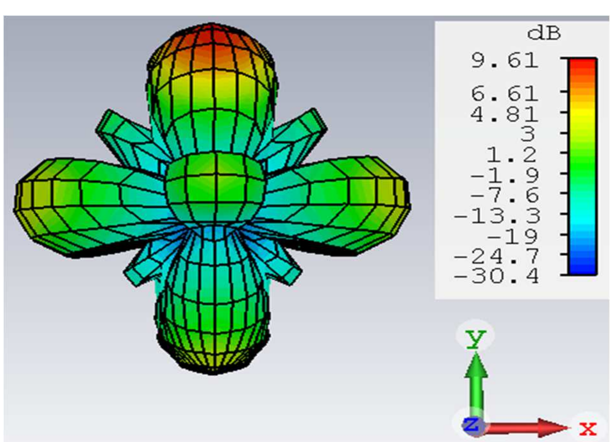

Fig. 7. 3-D radiation pattern of the 2x2 array antenna after farfields combination.

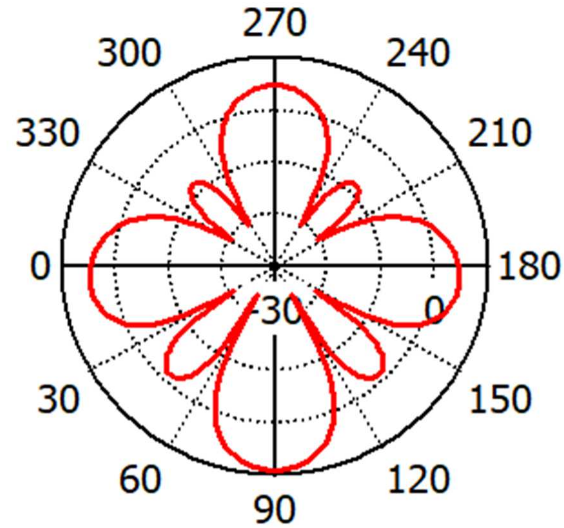

Fig. 7. Polar radiation pattern of the 2x2 array antenna.

The gain is enhanced from single antenna to the array antenna by the following mathematically term as,

$$G\ (\text{dBi}) = G_s(\text{dBi}) + 10\log_{10}(n \times m) \tag{1}$$

where G_s is the gain of the single antenna (= 4.52 dBi), n x m is the array alignment of the system.

For 2x2 array antenna, the gain from equation (1) becomes

$$G\ (\text{dBi}) = 4.52 + 10\log_{10}(2 \times 2) = 10.54\ \text{dBi}.$$

By comparing this mathematical value (10.54 dBi) with the simulation gain's value of 9.61 dBi, it could be reached to a decision that the designed array is well efficient.

III. Conclusions

In this paper, 13- elements Electronically Steerable Parasitic Array Radiator (ESPAR) antenna with the array of 2x2 is designed and simulated on the FR-4 substrate with the dielectric constant 4.3. The proposed array antenna efficiently shows good match with the mathematical logic by increasing gain. The gains obtained as 4.56 dBi at the single 13- elements ESPAR antenna, 9.61 dBi at the 2x2 array of 13- elements ESPAR antenna, and the reflection coefficient is measured below -10 dB in the designed array at 2.40 GHz frequency. The ESPAR array antenna also exhibits very good performance regarding radiation pattern, gain, and the reflection coefficients at each steps. Thus, the proposed design can be considered as a reliable and robust to be used in the respective applications.

Acknowledgments

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TABLE I. REACTANCE SET OF THE SINGLE ESPAR ANTENNA

Direction	Lumped Ports											
	#1	#2	#3	#4	#5	#6	#7	#8	#9	#10	#11	#12
0^0	0.45nH	0.45nH	0.3 pF	0.3 pF	0.3 pF	0.3 pF	0.3 pF	0.3 pF	0.3 pF	0.45nH	0.45nH	0.45nH
30^0	0.45nH	0.45nH	0.45nH	0.3 pF	0.3 pF	0.3 pF	0.3 pF	0.3 pF	0.3 pF	0.3 pF	0.45nH	0.45nH
60^0	0.45nH	0.45nH	0.45nH	0.45nH	0.3 pF	0.3 pF	0.3 pF	0.3 pF	0.3 pF	0.3 pF	0.3 pF	0.45nH
90^0	0.45nH	0.45nH	0.45nH	0.45nH	0.45nH	0.3 pF	0.3 pF	0.3 pF	0.3 pF	0.3 pF	0.3 pF	0.3 pF
120^0	0.3 pF	0.45nH	0.45nH	0.45nH	0.45nH	0.45nH	0.3 pF	0.3 pF	0.3 pF	0.3 pF	0.3 pF	0.3 pF
150^0	0.3 pF	0.3 pF	0.45nH	0.45nH	0.45nH	0.45nH	0.45nH	0.3 pF	0.3 pF	0.3 pF	0.3 pF	0.3 pF
180^0	0.3 pF	0.3 pF	0.3 pF	0.45nH	0.45nH	0.45nH	0.45nH	0.45nH	0.3 pF	0.3 pF	0.3 pF	0.3 pF
210^0	0.3 pF	0.3 pF	0.3 pF	0.3 pF	0.45nH	0.45nH	0.45nH	0.45nH	0.45nH	0.3 pF	0.3 pF	0.3 pF
240^0	0.3 pF	0.3 pF	0.3 pF	0.3 pF	0.3 pF	0.45nH	0.45nH	0.45nH	0.45nH	0.45nH	0.3 pF	0.3 pF
270^0	0.3 pF	0.3 pF	0.3 pF	0.3 pF	0.3 pF	0.3 pF	0.45nH	0.45nH	0.45nH	0.45nH	0.45nH	0.3 pF
300^0	0.3 pF	0.3 pF	0.3 pF	0.3 pF	0.3 pF	0.3 pF	0.3 pF	0.45nH	0.45nH	0.45nH	0.45nH	0.45nH
330^0	0.45nH	0.3 pF	0.3 pF	0.3 pF	0.3 pF	0.3 pF	0.3 pF	0.3 pF	0.45nH	0.45nH	0.45nH	0.45nH

TABLE II. REACTANCE SET OF THE 2X2 ARRAY ANTENNA

SL No.	ESPAR-1												..	ESPAR-4
	#1	#2	#3	#4	#5	#6	#7	#8	#9	#10	#11	#12		#1 - #12
1	0.45nH	0.45nH	0.3pF	0.3pF	0.3pF	0.3pF	0.3pF	0.3pF	0.3pF	0.45nH	0.45nH	0.45nH		Same as ESPAR-1