Developing a Symmetrical Phased Array Antenna with Low Complexity

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Abstract—**Phased array antennas were widely presented by their benefits, especially their capability of electronic beam scanning. Controlling some phase shifters of a phased array antenna without moving the array physically causes the wave-fronts of the antenna element changing, so the main beam of the array be able to scan in space. However, in both series and parallel feeding styles (conventional approach) it is required a number of phase shifters. This paper designs a symmetrical phased array antenna using only one phase shifter at each branch of the array. The analytical and simulation results using ADS (Advanced design system) software demonstrated the advantages of the proposed design.**

Keywords—Phased array antenna; phase shifter; wavefront; ADS.

I. INTRODUCTION

The real demands for various passive phased array antennas having conformal style, electronic scanning in azimuthally plane in real time are ever-increased recently [1-5]. The antenna can be used for air-force radar or high speed communications [6].

The reason for above antenna features are as follows: i) if the antenna is conformal it will be mounted on moving vehicle (air plane, missile, etc.) easily and securely ii) real time beam scanning for increasing target tracking capability iii) electronic scanning in azimuthal plane to ensure seeing targets in front of an object and it is possibly to view overall angle of 360^0 when using both the antenna and the antennas on other sides of the object.

However, in the conventional feeding design (series and parallel feeding) the phase shifters are inserted into antenna elements or into feeding structures. Generally, each antenna element requires one phase shifter [6]. Therefore, the more antenna elements are used the more phase shifters are need. Large phase shifters means a complex controlling system.

The problem is that is there any passive phased array antenna having conformal style, narrow main beam, electronic scanning in azimuthal plane but simple?

In this paper, we propose a symmetrical phased array antenna with only one phase shifter in each of its branch. The proposed design is simple but conformal style, main beam width and electronic beam scanning are reserved. The analytical and simulation results using ADS (Advanced design system) software demonstrated the advantages of the proposed design.

The paper is organized as follows. Part II presents feeding methods of passive phased array including parallel, series and one phase shifter feeding. Developing a branch of passive phased array using one phase shifter is presented next. Simulation results is given in part IV. Finally, we conclude the paper.

II. ONE PHASE SHIFTER FEEDING

A. Parallel feeding

First, a passive phased array using parallel feeding is depicted in Fig. 1. The energy before going to antenna elements is split to two or more at one point using T-junctions, hybrids or couplers [6]. In this case, the errors of the array antenna is equal to maximum error of one phase shifter.

B. Series feeding

The energy from a source is coupled into antenna elements. Phase shifters is inserted in between antenna elements [6]. The phased array using series feeding is presented in Fig. 2.

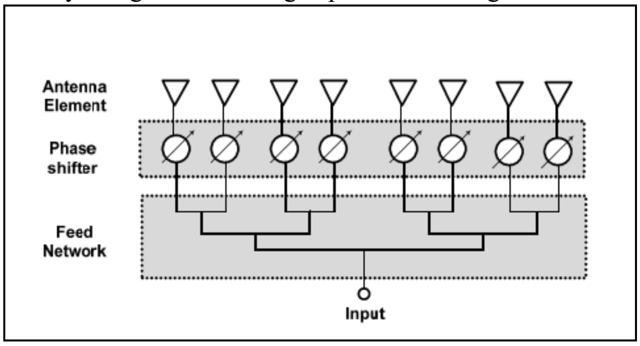

Figure 1. Phased array using parallel feeding

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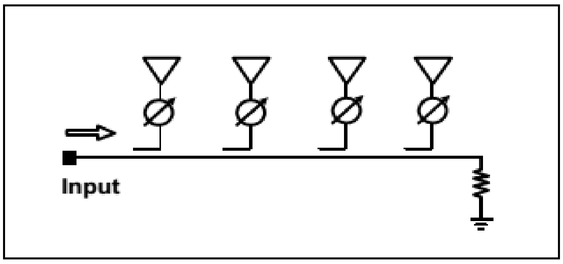

Figure 2. Phased array using series feeding

The array antenna losses of series feeding is accumulated when the phase shifted decreases through the array.

C. One phase shifter feeding

In order to simplify control system of a passive phased array, one phase shifter feeding is proposed [7-8]. In the feeding system, only one phase shifter is used. The principle of the feeding system are as follows: i) The wave at each antenna element is vector sum of two wave components which are called directed wave and indirected wave ii) The waves in direct path are in phase. The waves in indirect path are also in phase iii) However the phase difference between them is controlled by the only phase shifter.

The schematic of the one phase shifter feeding is shown in Fig. 3. Noting that a_i, b_i and E_i are directed paths, indirected paths and inputs to antenna elements respectively. Phase shifted at each antenna element is given in [7] by

$$\theta_i = \arctan\left(\frac{\sin\phi}{\frac{a_i}{b_i}+\cos\phi}\right) \quad (1)$$

where ϕ is phase shifted by the phase shifter.

It can be seen that the phase shifted at each antenna element is a function of phase and the ratio of amplitude of directed element to that of indirected one. The ratio of amplitudes is determined in order to get phase progressively through the array. In this case, directed wave fed into each antenna elements has its amplitudes progressively decreasing whereas the amplitudes of indirected wave progressively increasing, i.e.

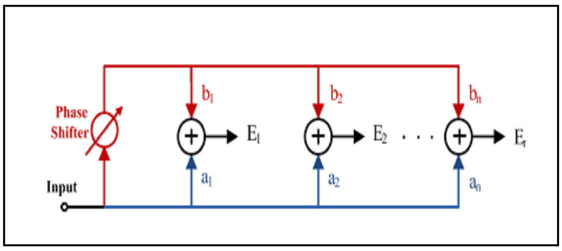

Figure 3. Diagram of one phase shifter feeding

$$\begin{aligned} a_1 > a_2 > \cdots > a_n \\ b_1 < b_2 < \cdots < b_n \end{aligned} \quad (2)$$

The vector diagram is shown in Fig. 4 illustrates how the phase progression is achieved across the phased array.

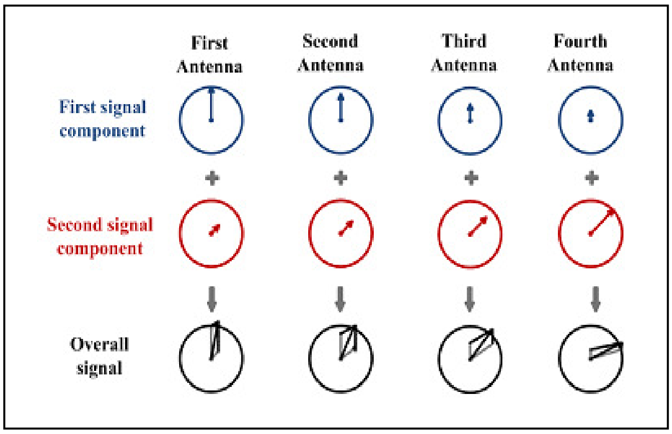

Figure 4. Phase progression in the entire array

III. DEVELOPING A BRANCH OF PASSIVE PHASED ARRAY USING ONE PHASE SHIFTER FEEDING

A. Antenna elements

In order to satisfy the conformal requirement, microstrip patch antenna elements are chosen. For example, the array consists of four antenna elements with center frequency of 27.5GHz is designed using antenna design principles from [9-10] and ADS software. The array is depicted in Fig. 5.

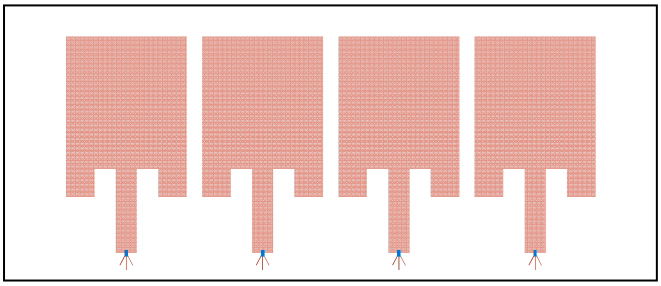

Figure 5. The array of four elements with center frequency of 27.5GHz

B. One phase shifter feeding system

Some devices such as hybrid 90s, power combiners, attenuators, and only one phase shifter are used in one phase shifter feeding system. The designation of one phase shifter feeding using ADS software is carried out. The schematic of the feeding system is shown in Fig. 6.

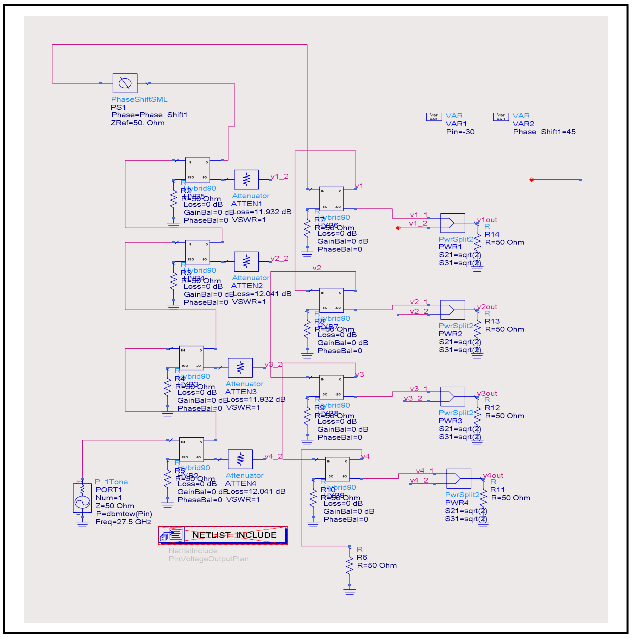

Figure 6. One phase shifter feeding system

C. *The operation of the proposed branch of passive phased array*

Once the one phased shifter feeding system is connected to the four antenna elements, the branch of passive phased array is constructed completely. We assume that the source transmitting in frequency band from 20 to 30 GHz with center frequency of 27.5 GHz. Each hybrid 90 creates two outputs which are direct path and indirect path. The direct path is shifted 90^0 in phase compared to the indirect path. Both the outputs of the hybrid 90 decrease 3dB to the input. Then the power combiner sums two input waves to create the vector output before going to each antenna element.

D. The symmetrical phased array with low complexity

The symmetrical phased array is build from the two identical branches of passive phased array. Therefore, only one more power splitter and phase shifter are added. The reason to make the array symmetrical is that it is more convenient for symmetrical objects such as hemi-sphere or cylindrical.

IV. Simulation Results

A. The far field of a branch of passive phased array

The far field of a branch of passive phase array is obtained using ADS software. It is presented in 3D as in Fig. 7 as follows

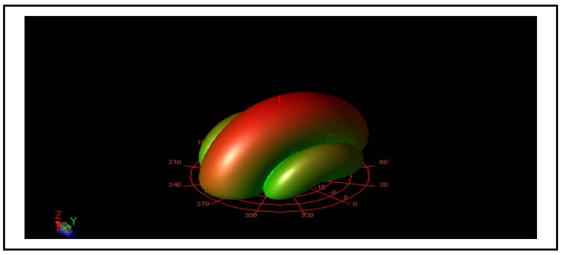

Figure 7. Far field of four microstrip patch antennas

The main beam width of 60^0 is obtained by using four antenna elements. There are two symmetrical side lobes as normal.

B. The phases of the antenna elements

To verify the operation of the branch of the passive phased array we change the phase shifter by step of 22.5^0. The phase shifted values are described in Table I as follows

TABLE I. PHASE SHIFTED VALUES

Step	**1**	**2**	**3**	**4**	**5**	**6**
Phase shifted (degree)	22.5	45	67.5	90	112.5	135

At step 1, the phases at each antenna elements is achieved using ADS software as in Table II as follows

TABLE II. POWER COMBINER INPUTS AND OUTPUTS (AMPLITUDES AND PHASES) AT STEP 1

Frequency (GHz)	**Input of the first power combiner, V1_1 (V/Degree)**	**Input of the second power combiner, V2_1 (V/Degree)**	**Input of the third power combiner, V3_1 (V/Degree)**	**Input of the fourth power combiner, V4_1 (V/Degree)**
27.5	0.056/-67.505	0.040/-67.506	0.028/-67.507	0.020/-67.509
	Input of the first power combiner, V1_2 (V/Degree)	**Input of the second power combiner, V2_2 (V/Degree)**	**Input of the third power combiner, V3_2 (V/Degree)**	**Input of the fourth power combiner, V4_2 (V/Degree)**
27.5	0.020/-90.002	0.028/-90.002	0.040/-90.002	0.056/-90.001
	Output of the first power combiner, V1out (V/Degree)	**Output of the second power combiner, V2out (V/Degree)**	**Output of the third power combiner, V3out (V/Degree)**	**Output of the fourth power combiner, V4out (V/Degree)**
27.5	0.106/-73.382	0.094/-76.800	0.094/-80.778	0.105/-84.180
	Phase difference of V2out and V1out (Degree)	**Phase difference of V3out and V2out (Degree)**	**Phase difference of V4out and V3out (Degree)**	
27.5	-3.417	-3.978	-3.402	

Here *V*1_1, *V*1_2, *V*1out are two inputs, one output of the power combiner into the first antenna element. At step one, there is phase progressively through the array with the phase difference between two consecutive antennas is around 3.4^0.

At step 2, the phases at each antenna elements is achieved using ADS software as in Table III as follows. Here *V*2_1, *V*2_2, *V*2out are two inputs, one output of the power combiner into the first antenna element. The other notation are similarly up to the fourth antenna element. At this step the phase progressively is also obtained but the phase difference is around 7^0.

TABLE III. POWER COMBINER INPUTS AND OUTPUTS (AMPLITUDES AND PHASES) AT STEP 2

Frequency (GHz)	**Input of the first power combiner, V1_1 (V/Degree)**	**Input of the second power combiner, V2_1 (V/Degree)**	**Input of the third power combiner, V3_1 (V/Degree)**	**Input of the fourth power combiner, V4_1 (V/Degree)**
27.5	0.056/-45.005	0.040/-45.006	0.028/-45.008	0.020/-45.006
	Input of the first power combiner, V1_2 (V/Degree)	**Input of the second power combiner, V2_2 (V/Degree)**	**Input of the third power combiner, V3_2 (V/Degree)**	**Input of the fourth power combiner, V4_2 (V/Degree)**
27.5	0.020/-90.003	0.028/-90.002	0.040/-90.002	0.056/-90.001
	Output of the first power combiner, V1out (V/Degree)	**Output of the second power combiner, V2out (V/Degree)**	**Output of the third power combiner, V3out (V/Degree)**	**Output of the fourth power combiner, V4out (V/Degree)**
27.5	0.101/-56.426	0.088/-63.440	0.089/-71.713	0.101/-78.693
	Phase difference of V2out and V1out (Degree)	**Phase difference of V3out and V2out (Degree)**	**Phase difference of V4out and V3out (Degree)**	
27.5	-7.014	-8.273	-6.980	

At step 6, the phases at each antenna elements is achieved using ADS software as in Table IV as follows. By the similar way the branch of the phased array took phase progressively with the phase difference increased up to 26^0.

TABLE IV. POWER COMBINER INPUTS AND OUTPUTS (AMPLITUDES AND PHASES) AT STEP 6.

Frequency (GHz)	**Input of the first power combiner, V1_1 (V/Degree)**	**Input of the second power combiner, V2_1 (V/Degree)**	**Input of the third power combiner, V3_1 (V/Degree)**	**Input of the fourth power combiner, V4_1 (V/Degree)**
27.5	0.056/-44.995	0.040/-44.994	0.028/-44.992	0.020/-44.991
	Input of the first power combiner, V1_2 (V/Degree)	**Input of the second power combiner, V2_2 (V/Degree)**	**Input of the third power combiner, V3_2 (V/Degree)**	**Input of the fourth power combiner, V4_2 (V/Degree)**
27.5	0.020/-90.003	0.028/-90.002	0.040/-90.002	0.056/-90.001
	Output of the first power combiner, V1out (V/Degree)	**Output of the second power combiner, V2out (V/Degree)**	**Output of the third power combiner, V3out (V/Degree)**	**Output of the fourth power combiner, V4out (V/Degree)**
27.5	0.062/-26.269	0.040/-0.007	0.040/-45.718	0.063/-71.565
	Phase difference of V2out and V1out (Degree)	**Phase difference of V3out and V2out (Degree)**	**Phase difference of V4out and V3out (Degree)**	
27.5	-26.276	-45.710	-25.847	

After some controlling steps the phase progressively is verified for the entire array.

C. Beam steering

Here we verify the scanning of the main beam of the branch of the passive phased array electronically. The simulation results of the main beam steering at step 1 and step 3 are given in 3D as in Fig. 8 and Fig. 9 respectively.

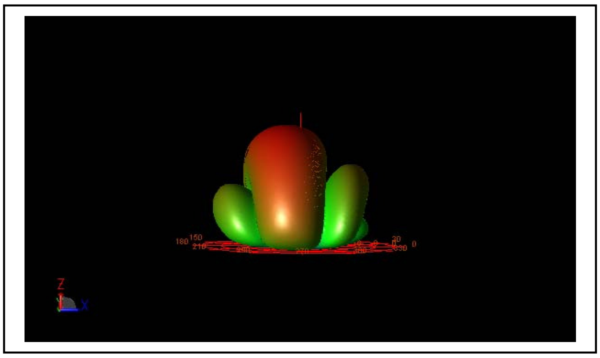

Figure 8. Main beam steering at step 1

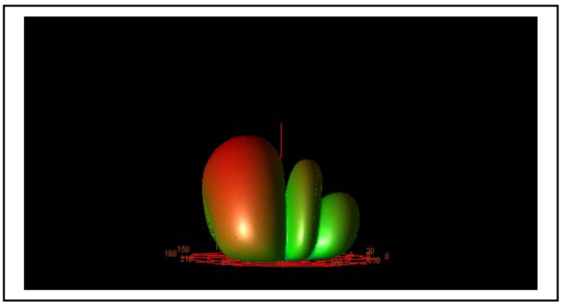

Figure 9. Main beam steering at step 3

Compared the boresight of the array to the vertical axis (red line) in Cartesian coordinate, the beam steering is clearly proved.

D. Simple controlling system

With the four antenna elements array, it is required four phase shifters as normal. The proposed array only using one phase shifters so it simplified the controlling system considerable.

V. CONCLUTIONS

A symmetrical phased array antenna is designed. Only one phase shifter is used for each branch of the array. As a result, the controlling system of the array is more simple than conventional phased array. The others features of the proposed array such as conformal style (using microstrip patch antenna elements), main beam width and electronic scanning are reserved. In view of design, the symmetrical phased array antenna design is successful and it is ready for manufacturing process.

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