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PERFORMANCE ANALYSIS OF QWT FED 8X8 PHASED ARRAY

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ABSTRACT
In this paper, the discussion concentrates on modelling, simulation and performance analysis of a Microstrip Line Quarter Wave Transformer (QWT) - fed 8x8 Circular Patch phased array. The substrate material used for this has thickness of 1.588mm and relative permittivity (ε_r) is 2.2. The design frequency is 2GHz and VSWR $\leq$ 2. The proposed 8x8 Circular Patch phased array is modelled and simulated by using ANSOFT HFSS 15.0. The gain of this array is 24.639 dB, return loss of -16.2810dB and bandwidth is 32.7MHz. The phased array is steered for 10^0, 20^0, 30^0, 38^0 and 45^0. The proposed phased array is very useful for airborne applications.

Keywords: quarter wave transformer, circular patch phased array, gain, returns loss, beamwidth.

1. INTRODUCTION

Microstrip antennas are one of the most popular geometries inexpensive to fabricate and can be easily made conformal to the host body. The attractive features of the microstrip enhanced their application in the recent past and stimulated an ever increasing attention from all around to investigate their performance further. Of all the shapes of the microstrip radiator the circular patch tends to be smaller than other configurations. In some applications, such as arrays, circular geometries provide certain advantages over others, since the feed can be connected at any point along the periphery of the circular microstrip. At first, the circular patch antenna is matched to 50Ω feed line via quarter wave transformer. This configuration has been described earlier [1], [2], [3].

An objective of phased array is to accomplish beam steering without the mechanical and inertia problems of rotating the entire array. In principle, the beam steering of a phased array can be done simply by changing the phase at individual elements in the array. The spacing between the elements are λ/2. The elements of an antenna must be phased in some manner, the term phased array has come to mean an array of many elements with the phase of each element being a variable providing control of the beam direction and pattern shape including side lobes. During the last few years, microstrip patch radiators have received increasing interest as candidates for planar or conformal phased array antennas. Already some complete antennas have been built [4] & [5]. But there is still some critical lack of theoretical / experimental knowledge concerning the fundamental properties of the patch radiators in the phased array environment. In this paper, the design, simulation and analyzation of 8x8 phased array is presented.

2. DESIGN AND MODELING OF SINGLE CIRCULAR PATCH ANTENNA WITH QUARTER WAVE TRANSFORMER

The geometry of the circular microstrip patch antenna is fed by the microstrip line quarter wave transformer as shown in Figure-1. The circular microstrip

patch antenna design can be divided into three stages, namely design of the circular patch; the microstrip feed line and the quarter wave transformer. Each of these stages is presented in detail below.

A. Design of circular patch

Radius of the patch
The radius 'R' of the patch is given by [3]:

$$R = \frac{F}{\left[1 + \frac{2h}{\pi \varepsilon_r F \left[ln\left(\frac{F\pi}{2h}\right) + 1.7726\right]}\right]^{1/2}} \quad (1)$$

Where $F = \frac{8.791 \times 10^9}{f_r \sqrt{\varepsilon_r}}$

R= radius of the patch in mm; h= height of the patch substrate in mm; f_r= resonant frequency in Hz; ε_r = effective dielectric constant of the substrate.

Using the above expression the calculated radius is 28.52 mm for 2 GHz operating frequency, dielectric constant 2.2 and the height of the RTDuorid5880 substrate is 1.588 mm.

B. Design of a microstrip line feed

To excite the circular microstrip patch, a 50Ω microstrip line is used. The width of the microstrip line calculated with the known values of the characteristic impedance Z_o (50Ω) and dielectric constant of the substrate ε_r (2.2) using the standard equations is given below [9].

$$\frac{w_f}{h} = \begin{cases} \frac{8e^A}{e^{2A}-2} & for \frac{w_f}{h} < 2 \\ \frac{2}{\pi}\left[B - 1 - \ln(2B-1) + \frac{\varepsilon_r-1}{\varepsilon_r+1}\left\{\ln(B-1) + 0.39 - \frac{0.61}{\varepsilon_r}\right\}\right] & for for \frac{w_f}{h} > 2 \end{cases} \quad (2)$$

$$Where\ A = \frac{Z_o}{60}\sqrt{\frac{\varepsilon_r+1}{2}} + \frac{\varepsilon_r-1}{\varepsilon_r+1}\langle 0.23 + \frac{0.11}{\varepsilon_r}\rangle \quad (3)$$

$$and\ B = \frac{377\ \pi}{2Z_o\sqrt{\varepsilon_r}} \quad (4)$$

The calculated width of 50Ω microstrip line is 4mm.

C. Design of the Quarter Wave Transformer (QWT)

A quarter-wave transformer is a simple and useful device for matching real load impedance to different source impedance. [8]

However, a single section quarter wave transformer has a length equal to quarter wave in microstrip and its characteristic impedance Z_c is given by [9]:

$$Z_c = \sqrt{(Z_o Z_{in})} \tag{5}$$

Where Z_0 the characteristic impedance of the 50Ω is line and Z_{in} is the input impedance of the circular patch. With the above equation (5) the Z_c of the impedance transformer is 130Ω when Z_o is 50Ω and Z_{in} is 340Ω. The width of the 130 Ω QWT is calculated using (3) and the calculated value is 0.74mm. The geometry of the proposed circular patch antenna is shown in Figure-1.
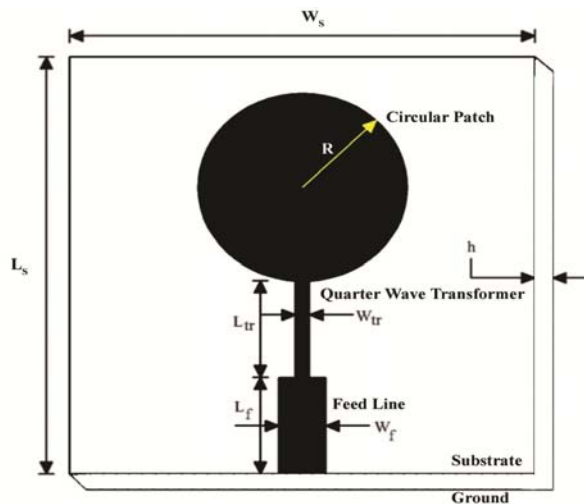
Figure-1. Geometry of the circular patch antenna.

Dimensions of proposed single circular patch antenna is given in Table-1.

Table-1. Calculated dimensions of proposed single CPA.

Parameter	Value
Radius of CPA (R)	28.52mm
Height of the substrate (h)	1.588mm
Length of the substrate (Ls)	138.52mm
Width of the substrate (Ws)	60mm
Length of QWT (Ltr)	28.62mm
Width of the QWT (Wtr)	0.74mm
Length of the feed line (Lf)	10mm
Width of the feed line (Wf)	4mm

The modeled structure of single circular patch antenna is as shown in Figure-2 with a maximum size of antenna as 200mmX350mmX24mm.
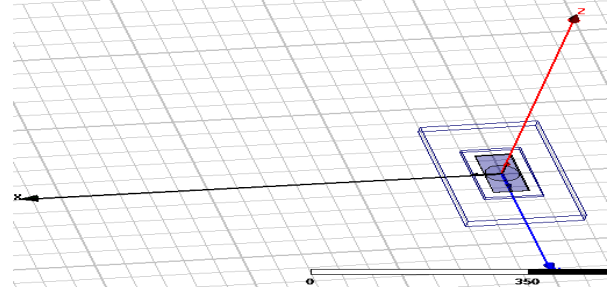

Figure-2. Structure of modeled single circular patch antenna.

3. DESIGN AND ANALYSIS OF 8X8 CIRCULAR PATCH PHASED ARRAY

The array factor for N elements in general is [7]

$$AF = \left[\frac{1}{M} \frac{\sin\left(\frac{M\Psi_x}{2}\right)}{\sin\left(\frac{\Psi_x}{2}\right)} \right] \left[\frac{1}{N} \frac{\sin\left(\frac{N\Psi_y}{2}\right)}{\sin\left(\frac{\Psi_y}{2}\right)} \right]$$

Where

$$\Psi_x = kd_x \sin\theta \cos\phi + \beta_x$$

$$\Psi_y = kd_y \sin\theta \cos\phi + \beta_y$$

The direction of the major radiation from an array can be controlled by changing the phase excitation between the elements. It is then logical to assume that the maximum radiation can be oriented in any direction to form a scanning array.

To accomplish this, the phase excitation ß between the elements must be adjusted. Thus by controlling the progressive phase difference between the elements, the maximum radiation can be squinted in any desired direction to form a scanning array. This is the basic principle of electronic scanning phased array operation. Since in phased array technology the scanning must be continuous, the system should be capable of continuously varying the progressive phase between the elements.

The single Quarter wave transformer fed circular patch antenna is used as the array element for this 8x8 planar array. The spacing between elements in X-direction 100mm and Y-direction 200mm is maintained to get desired radiation characteristics. All the elements are fed with the same amplitude and difference in phase. The phased array is steered for 10^0, 20^0, 30^0, 38^0 and 45^0 by changing the progressive phase between the elements.

The structure of modelled and simulated 8x8 circular patch phased array antenna is shown in Figure-3.
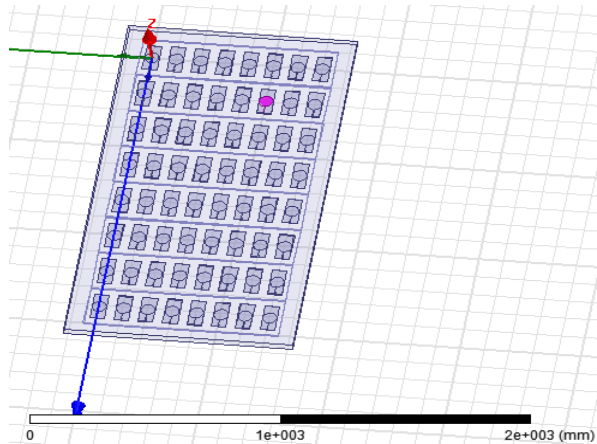
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Figure-3. 8x8 circular patch phased array antenna.

The Return loss, VSWR and Bandwidth of the proposed 8x8 Circular Patch Phased Array at 2GHz are -16.2810dB, 1.7597 and 32.7MHz as shown in Figures 4, 5 & 6 respectively.
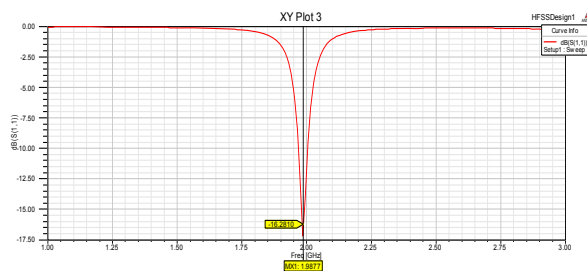

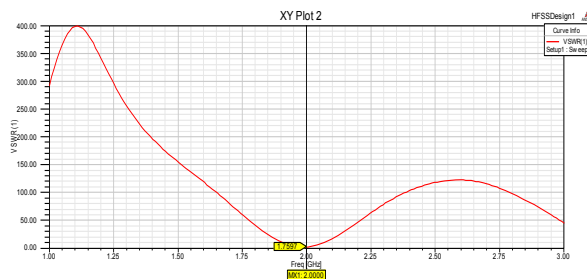**Figure-4.** Return loss of the 8x8 circular patch phased array.
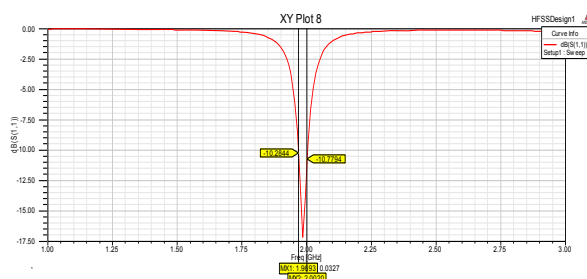

Figure-5. VSWR of the 8x8 circular patch phased array.

Figure-6. Bandwidth of the 8x8 circular patch phased array.

The gain, directivity, and efficiency of the 8x8 Circular Patch Phased Array are 24.6398dB, 24.748dB, 98.5% respectively as shown in Figures 7-10.
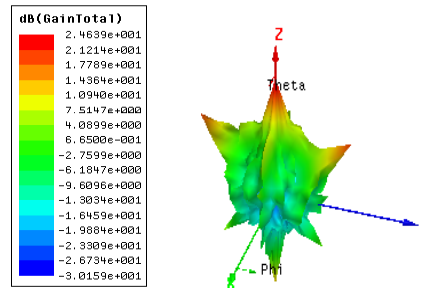
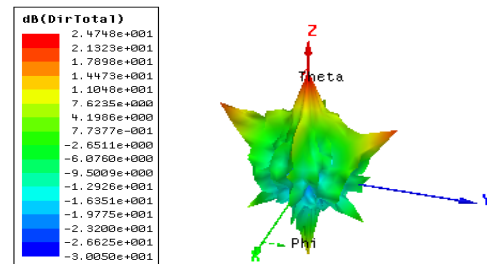**Figure-7.** Gain of the 8x8 circular patch phased array.

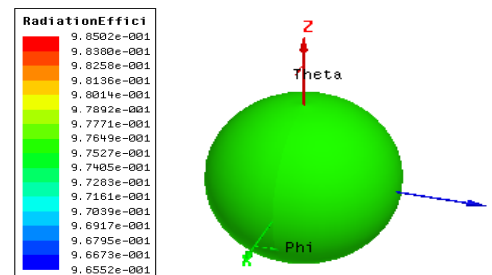**Figure-8.** Directivity of the 8x8 circular patch phased array.

Figure-9. Efficiency of the 8x8 circular patch phased array.

The Half Power Beamwidth(HPBW)s of the 8x8 Circular Patch Phased Array are 9.3543^0 and 4.5866^0 degrees in elevation and azimuth directions respectively as shown in Figures 10 and 11.
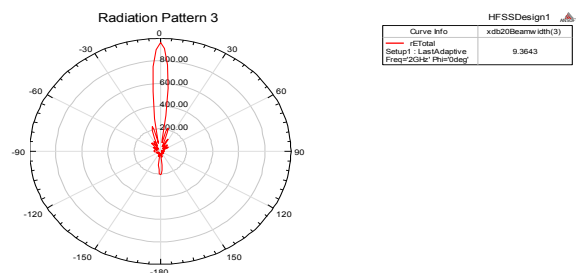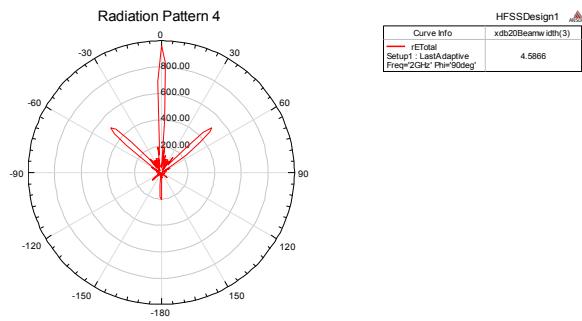

Figure-10. Elevation half power beamwidth (HPBW) of 8x8 patch phased array.

**Figure-11.** Azimuth half power beamwidth (HPBW) of
8x8 patch phased array.

## 4. BEAM STEERING OF 8X8 CIRCULAR PATCH PHASED ARRAY

All the elements in 8x8 planar array are fed with the same amplitude and with different phase angles. The spacing between the elements in the X-axis 100mm and in Y-axis 200mm is maintained.

The phase difference between the elements both the directions is 40^0, the elevation beam is steered at 10^0 with a Half Power Beam Width (HPBW) of 9.5186^0 as shown in Figure-12.
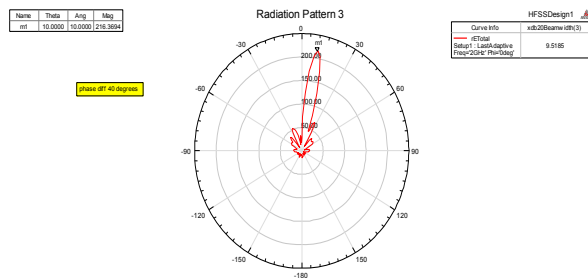
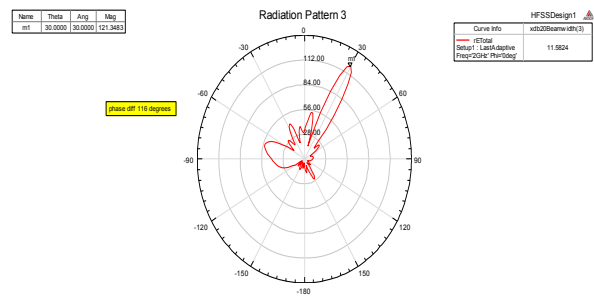**Figure-12.** Elevation beam steered at 10^0.

The phase difference between the elements both the directions is 80^0, the elevation beam is steered at 20^0 with a HPBW of 9.1066^0 as shown in Figure-13.
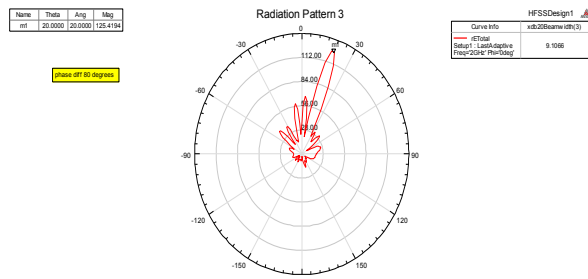
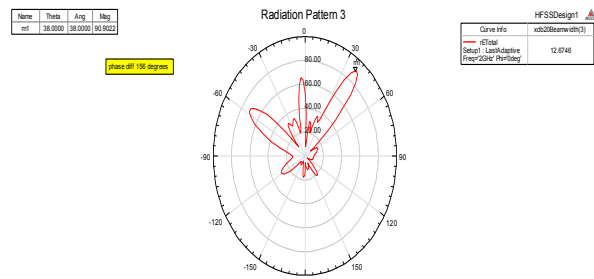**Figure-13.** Elevation beam steered at 20^0.

The phase difference between the elements both the directions is 116^0, the elevation beam is steered at 30^0 with a HPBW of 11.5824^0 as shown in Figure-14.

Figure-14. Elevation beam steered at 30^0.

The phase difference between the elements both the directions is 156^0, the elevation beam is steered at 38^0 with a HPBW of 12.6746^0 as shown in Figure-15.
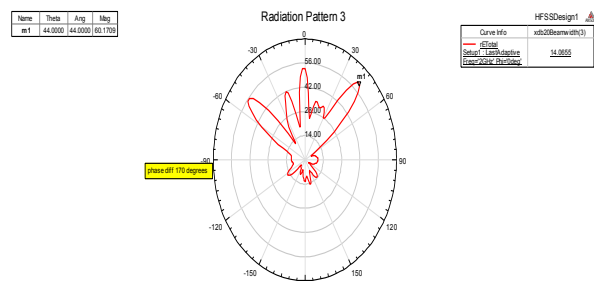

Figure-15. Elevation beam steered at 38^0.

The phase difference between the elements both the directions is 170^0, the elevation beam is steered at 45^0 with a HPBW of 14.0656^0.

Figure-16. Elevation beam steered at 45^0.

5. DISCUSSIONS

The proposed circular patch phased array antenna is successfully modelled, simulated and performance analysed by using ANSOFT HFSS 15.0.

The radiation characteristics Frequency, return loss, VSWR, Bandwidth, gain, directivity, efficiency, elevation HPBW (Half Power Beam Width) and Azimuth HPBW of the proposed 8x8 circular patch phased array antenna are summarized in the Table-2.

Table-2. Radiation characteristics of the proposed antenna.

S. No.	Parameter	Value
1	Frequency	2 GHZ
2	Return loss	-16.2810dB
3	VSWR	1.7597
4	Bandwidth	32.7MHz
5	Gain	24.639dB
6	Directivity	24.7482dB
7	Efficiency	98.5%
8	Elevation HPBW	9.3543^0
9	Azimuth HPBW	4.5866^0

6. CONCLUSIONS

Design of an intensive 8x8 phased array is successfully modeled and simulated. The gain of propose array is 24.639dB, Return loss is -16.2810dB, Elevation HPBW is 9.3543^0, Azimuth HPBW is 4.5866^0, Bandwidth is 32.7MHz and the beams in elevation and azimuth directions are steered in various directions for various phase angles. The radiation characteristics obtained in this proposed array is very much useful for air borne applications.

ACKNOWLEDGMENTS

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