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Design and Simulation Microstrip Array Antenna using Circular Patch in UWB Application

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***Abstract*—In the current scenario the advancement in communication systems requires the development of system with low cost, light weight along with an high performance but a low profile antenna which is capable of maintaining high performance over a wide spectrum of frequencies. Therefore this technological trend has emphasized the effort into the design of a micro strip patch antenna patch array antenna. The aim of this paper is to design and simulate a circular micro strip using ADS software "Advanced Design System" and compare the performance of 2 elements and 4 elements single patch for the operating frequency of 3GHz-10.6GHz. Also comparisons are made between the performances of different substrate dielectric materials. Details of simulated results are presented and discussed. Enhancement in gain, directivity and better return loss performance can be obtained by the use of different dielectric substrate (RT-Duroid 5880, FR4). Our goal is to obtain a high directivity with better gain and radiation pattern, return loss, efficiency to be especially used for satellite communication, radar and other wireless systems.**

***Index Terms*—Microstrip patch antenna, circular patch, array antenna, corporate feed array, return Loss, directivity.**

I. INTRODUCTION

A. Microstrip Array Antenna

Microstrip antennas are used in arrays as well as single elements. By using array in communication systems to enhance the performance of the antenna like increasing gain, directivity scanning the beam of an antenna system, and other functions which are difficult to do with the single element [9].

Rectangular arrays are common type used for antenna arrays. Studies on dual band antennas employing rectangular array were reported [7]. Compared to rectangular patch antenna arrays, there are limited numbers of studies performed on circular patch antenna arrays due to difficulties in fabrication. Advantages of circular antenna array include high gain and narrow beam width [9].

Antenna arrays are widely used in various purposes like missiles, military and satellite communication [6]. There are different form of antenna arrays linear, circular, planar etc. Various arrays are discussed in the following sections.

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B. Two Elements Array

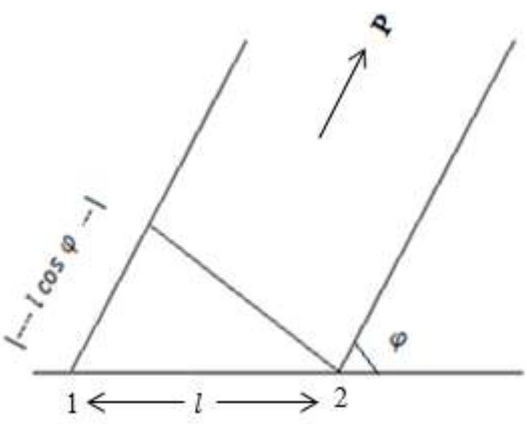

Figure 1: N element array

The point of observation is in the far field, the path length difference is ***lcosα***, where *l* is the distance between the two elements. The radiation of element '1' at P will lead the radiation of element 2 with angle ψ where:

$$\psi = \beta l \cos\phi + \alpha \quad (1)$$

β = phase constant of the transmitted wave.

The total field at P is

$$E = E1[1 + exp(j\,\psi)] \quad (2)$$

Where E_1 is the field at P due to element 1.

The magnitude of the field at P is:

$$|E\phi| = 2E1cos((½)\,\psi)$$

$$= 2E1cos\,((1/2)(\beta l cos\phi + \alpha))$$

$$= 2E1\cos(\frac{\pi l}{\lambda}\cos\phi + \frac{\alpha}{2}) \quad (3)$$

From the above equation we can see that for a given phase difference and a given distance we can change the radiation pattern by changing(l/λ).[1]

C. Linear array

A simple array consist of two elements, linear array is formed by more than two elements and is shown in figure 2.

Field at point P is:

$$E = E_1[1 + ej\varphi + ej2\varphi + ej3\varphi + \cdots ejn\varphi] \quad (4)$$

The magnitude of E is:

$$E = E_o \left| \frac{\sin \frac{n\varphi}{2}}{\sin \frac{\varphi}{2}} \right| \quad (5)$$

$$\varphi = \beta l \cos\phi + \alpha \quad (6)$$

When $\varphi = 0$ so $\beta l \cos\phi = -\alpha$

The phase of each element in this array can be controlled by phase shifter, and the amplitude of the elements is adjusted by an amplifier or attenuator.

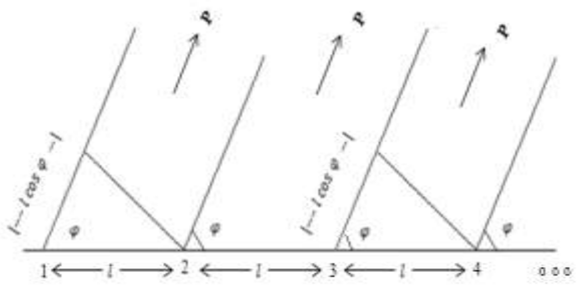

Figure2. Uniform linear array of n elements

D. Array Factor

Array factor determines the overall radiation pattern of the array while the element pattern describes radiation pattern of the individual element [1]. It can also define as the function of the total number of elements, their spacing and the phase difference between each element.

For a uniform circular array with N elements and an equal excitation current amplitude Io And current phase of βn (reference to the central point of the array) for the nth element (and φn=2πn/N),

$$AF = A0 \frac{\sin(\frac{n\varphi}{2})}{N\sin(\frac{\varphi}{2})} \quad (7)$$
$$= A0 \frac{\sin(2\varphi)}{4\sin(\frac{\varphi}{2})}$$

$$\varphi = \alpha + \beta d \sin(\theta)\cos(\varphi), \quad (8)$$
$$\beta d = (\frac{2\pi}{\lambda})(s)$$
$$= \left(\frac{2\pi}{7}\right)(3.8)$$
$$= \pi$$

Array factor (AF) is a sum of the N complex exponentials. The magnitude of each complex exponential is 1. Hence the maximum value of the magnitude of AF is the addition of magnitudes of the complex exponentials, i.e., N. The maximum radiation direction (θmax ,ϕmax) is therefore achieved when:

$$ka\sin\theta_{max}\cos(\phi_{max} - \frac{2\pi}{N}) + \beta_1 = \pm 2q\pi$$
$$ka\sin\theta_{max}\cos(\phi_{max} - \frac{4\pi}{N}) + \beta_2 = \pm 2q\pi$$
$$\vdots$$
$$ka\sin\theta_{max}\cos\left(\phi_{max} - \frac{2\pi}{N}\right) + \beta_N = \pm 2q\pi \quad (9)$$

Where $q = 0,1,2 \ldots$

In order to achieve the above maximum radiation this particular excitation method is used:

$$\beta_N = \pm 2q\pi - ka\sin\theta_{max}\cos\left(\phi_{max} - \frac{2\pi n}{N}\right) \quad (10)$$
$$n = 1,2,..N$$

Thus in the circular antenna the desired maximum radiation direction(θmax , ϕmax) is first choosen. Then the excitation phase βn for each element is determined according to the given formula. The βn so determined may not be equally increasing from one element to the next. Thus this is different from the case of a linear array.

II. Feed Techniques

Microstrip arrays are capable of radiating efficiently only over a narrow band of frequencies and hence they can operate only at the low power levels of waveguide. Using an single element it is difficult to increase th directivity and perform various functions hence antenna arrays are used to scan the beam of an antenna system. In the microstrip array, elements can be fed by a single line or by multiple lines in a feed network arrangement.

The elements can be fed by a single line called the series feed network or by multiple lines called corporate-feed network. Among all the feeding techniques corporate feed is mostly used in scanning, phased array, multibeam and beam arrays. While designing an array the feed point and the distance between each element is kept constant in order to provide equal phase excitation.

Various feed arrangements of feeding method are shown in figure 3.

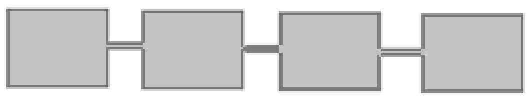

Figure 3 (a) Series feed

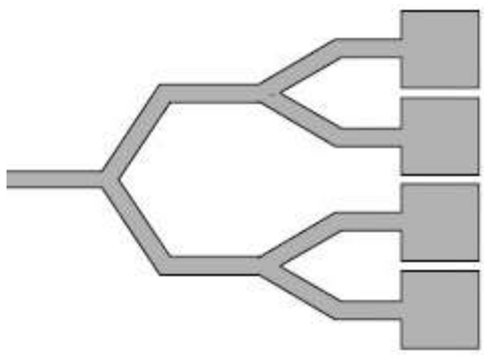

Figure 3 (b) corporate feed

Figure 3. Feed arrangement in microstrip patch array

A. Series feed network

By connecting elements with high impedance transmission line and feeding the power at the first element Series feed microstrip array can be formed. As the feed arrangement is compact the line losses associated with this type of array are lower than those of the corporate feed type. The drawback of series feed arrays is the large variation of the impedance and beam pointing direction over a band of frequencies. [11]

B. Corporate feed network

The corporate feed networks are used to provide power splits of the order 2n (i.e. n=2; 4; 8; 16; etc.,) which can be accomplished by using either the tapered lines or by using quarter wavelength impedance transformers.[5] The quarter wavelength impedance transformer method is used to connect the patch element in this paper.

Corporate feed arrays are general and versatile in nature. This particular method has more control of the feed of each element and therefore it is ideal for scanning phased arrays. Therefore providing better directivity as well as radiation efficiency and hence reducing the beam fluctuations over a band of frequencies compared to the series feed array. The phase shifter is used to control the phase of each element while amplitude can be adjusted by using either the amplifiers or the attenuators.

In this paper we have investigated the performance of the corporate feed array in circular microstrip array antenna.

III. MATERIALS AND METHODS

The main constituent of the microstrip structure is the dielectric substrate, whether it is an antenna or an microstrip line. For an application with an microstrip array antenna, to enhance the fringing fields and hence the radiation thicker substrate with a low dielectric constant is preferred. Another important parameter which must be considered is the loss tangent. In order to have an antenna with higher efficiency, the substrate with a low loss tangent should be used; the dielectric constants are usually in the range of 1.3 to 12 for the microstrip antenna. Dielectric constants in the lower range can provide better efficiency, large bandwidth, loosely bound electric field for radiation into space, but at the expanse of large element space.

In this paper two different substrate materials FR4 and RT Duroid 5880 are used and its performances are analysed. FR4 is an grade designation which is assigned to the glass-reinforced epoxy laminate sheets, tubes, rods and the printed circuit boards. RT Duroid 5880 substrate low loss tangent. They exhibit excellent chemical resistance, including solvent & reagents used in printing and platting, ease of fabrication – cutting, shearing, environment friendly.

The circular array with rectangular patch with 2 and 4 elements are designed and simulated by using ADS software. The performances are analyzed with various substrate materials.

A. Design of Circular Patch

The mathematical analysis of circular polarized antenna involves Bessel functions [2][8]. The electric field of the resonant TMnm mode in the cylindrical cavity under the circular patch is given in cylindrical coordinates as,

$$E_z = E_0 J_n(k_{nm}) \cos(n\varphi) \qquad (11)$$

Where
Jn is the Bessel function of the first kind of order n.

$$k_{nm} = \frac{X_{nm}}{r}$$

with Xnm being the roots of J n' (r) =0

Xnm is the zeros of the derivatives of Bessel function and the first four values are given by

$X^{1}_{11} = 1.8412$
$X^{2}_{21} = 3.0542$
$X^{3}_{01} = 3.8318$
$X^{4}_{31} = 4.2012$

The resonant frequency of the TM_{nm} mode is given by

$$f_{nm} = \frac{X_{nm} C}{2\pi r_e \sqrt{\varepsilon_{eff}}} \qquad (12)$$

C is the speed of light.
$\sqrt{\varepsilon_{eff}}$ is the effective dielectric constant.

Based on the assumption of a perfect magnetic wall along the periphery, the effect of fringing field is accounted for, by taking the effective radius of the circular patch as

$$r_{eff} = r\left[1+\frac{2h}{\pi\varepsilon_r}\left(\ln\frac{\pi r}{2h}+1.7726\right)\right]^{1/2} \qquad (13)$$

where

ε_r - Dielectric constant of substrate.

h - Thickness of dielectric material.

Since the dimension of the patch is treated as a circular loop, the actual radius of the patch is given by [1]

$$a = F\left\{1+\frac{2h}{\pi F\varepsilon_r}\left[\ln\frac{\pi F}{2h}+1.7726\right]\right\}^{-\frac{1}{2}} \quad - (14)$$

where

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

The above equation does not take into consideration the fringing effect. Since fringing makes the patch electrically larger, the effective radius of the patch is used and is given by

$$a_e = a\left\{1+\frac{2h}{\pi\varepsilon_r}\left[\ln\left(\frac{\pi a}{2h}\right)+1.7726\right]\right\}^{1/2} \quad \_(15)$$

B. Circular patch array antenna Design

In this paper a circular patch antenna having two and four elements patches are designed and simulated. The spacing between the patch elements are λ/2, an array of 2 circular patches are designed and is shown in figure 4. The circular array antenna with dimensions of width=2mm, angle=360 degree, Radius=50mil and rectangular patch width=5mm, length=5mm are evaluated and analysed. Corporate feed is through a network of microstrip line in the form of Y- shape excited by source 50Ω.

Figure 4.Circular with 2 elements patch array antenna

In the figure 4 the Circular patch array antenna which is of 4 element design having same dimensions mentioned above and a spacing of λ/2 between the patch elements are shown.

Figure 5.Circular with 4 elements patch array antenna

IV. Simulation Result and Discussions

The FR4 substrate with 2 and 4 elements circular patch array are analyzed and compared. The table 1 shows the performance of comparison with various parameter for 2x1 and 4x1 elements circular patch. From the table 1 we can easily identified that 4 element circular patch is preferable because of its high directivity, gain and efficiency. The return loss for 4 element circular patch is -28db and its efficiency is 99.

Using RT duroid with 2 and 4 elements circular patch is analysed and its performances are compared. Table 2 shows the comparison of various performances for 2 elements as well as 4 elements circular patch array. The return loss, gain & efficiency for 4 elements circular patch array gives best result. From this we can investigate that the number of elements are increased the gain and efficiency are increased.

The return loss for 2×1 patch array antenna using FR4 substrate is -23dB at frequency 3.5GHZ .The gain is 27dB and directivity 7dB. S parameter calculation has been performed for microstrip patch array antenna with 4 elements using corporate feed network. The return loss for patch array antenna using FR4 substrate with corporate feed is -28dB at frequency 3.5GHZ. Circular Microstrip patch array antenna with 4 elements using corporate feed gain value is 36 dB and directivity 6dB.

Table 1: FR4

Parameter	2x1elements	4x1elements
Resonance frequency	4.8GHz	5GHz
Return loss	-24 dB	-20 dB
Gain(dBi)	27 dB	30 dB
Directivity	6 dB	7 dB
Efficiency(dB)	88.98	91.54

Table: 2 RT-Duroid 5880

Parameter	2x1elements	4x1elements
Resonance frequency	3.5GHz	3.5GHz
Return loss	-23dB	-28dB
Gain(dBi)	27 dB	36 dB
Directivity	7 dB	6 dB
Efficiency(dB)	93.46	99.76

The return loss for 2×1 patch array antenna with RT duroid as substrate is -24dB at frequency 4.8GHZ.The gain is 27dB and directivity 6db.S parameter calculation has been performed for microstrip patch array antenna 4 elements using RT duroid as substrate with corporate feed network. The return loss for patch array antenna with corporate feed is -20dB at frequency 5GHZ. Circular Microstrip patch array antenna with corporate feed gain value is 30 dB and directivity 7dB.

From the above table 1 and 2 we can investigate that the efficiency of circular patch with 4 elements using FR4 substrate is maximum. Gain and return loss is 36dB and 28dB respectively for 4 elements circular patch using FR4 substrate. So 4 elements circular patch with FR4 is preferable.

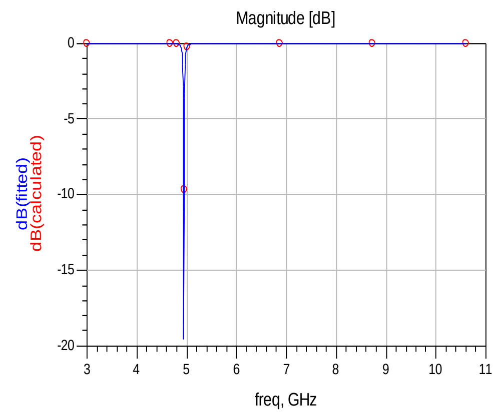

Figure 6.a.Return loss

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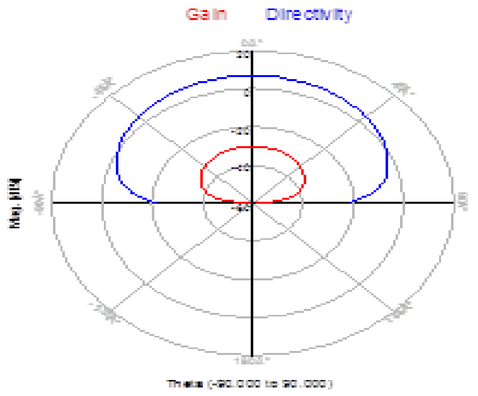

Figure 6.b Gain and Directivity

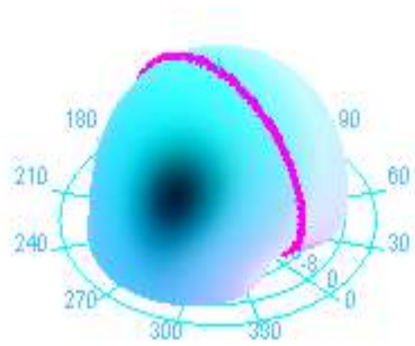

Figure 6.c.Radiation Pattern

Figure 6: Circular patch array antenna with 4 element using FR4

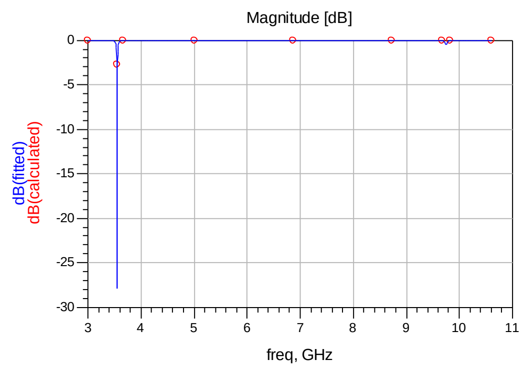

Figure 7a.Return loss

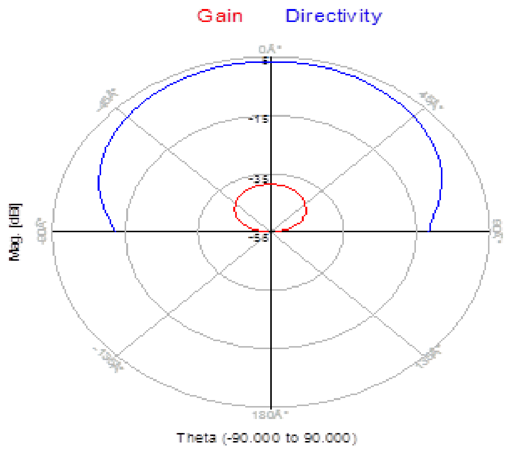

Figure 7b.Gain and Directivity

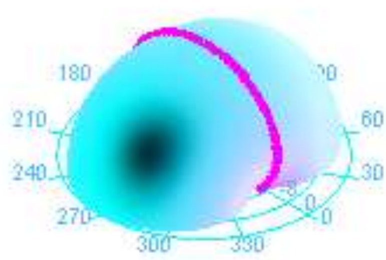

Figure7.C Radiation Pattern

Figure 8 : Circular patch array antenna with 4 element using RT-Duroid 5880

V. CONCLUSIONS

The circular microstrip antenna arrays are designed and simulated at 3GHz to 10 GHz. The two and four elements of circular microstrip antenna with various substrates FR4 and RT Duroid are analysed from the analysis 4 elements circular patch array antenna with FR4 substrate gives good performance characteristics.

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