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Optimized Circularly Polarized Bandwidth for Microstrip Antenna

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Abstract

In very high frequency performances such as spacecraft, satellite & missile applications where the size, weight, cost, performance, ease of installation & aerodynamic profile are constraints microstrip antennas (MA) are used to meet these requirements.

In spite of limitations such as small bandwidth, low gain and low power handling capability, microstrip antenna offers good performance over other type of antennas due to their advantages. Therefore nowadays they have been used in various applications. One of the most interesting applications is their use for transmitting & receiving systems required for circular polarization. Increasing demands for circularly polarized microstrip antenna (CPMA) for communication systems has directed researchers to improve the performance of circularly polarized microstrip antenna. Specifically CP microstrip antenna is used in satellite links, missiles etc.

The manuscript discusses the technique which perturbates a pair of orthogonal slits along the sides of the patch. This technique results into the optimized parameters for MA which is dimensions for MA, impedance as well as circularly polarized bandwidth. It is easy to fabricate. Therefore MA had been designed at 2.4GHz with pair of orthogonal slits along the sides of patch antenna. It is simulated using electromagnetic simulation software IE3D. While simulating for patches of various dimensions, it had been observed that for a particular patch & slit dimension there is only one feed location at which maximum impedance bandwidth can be obtained. It is also observed that for fixed patch dimensions by varying the slit length CPBW can be improved. In this manner the optimized patch had been fabricated and tested. The simulated and experimental results show good agreement.

Keywords: Microstrip antenna, CPBW, Beam width, Gain, IE3D.

Introduction

In very high frequency performances such as spacecraft, satellite & missile applications where the size, weight, cost, performance, ease of installation & aerodynamic profile are constraints microstrip antennas (MA) are used [1] to meet these requirements.

In spite of limitations such as small bandwidth, low gain and low power handling capability, microstrip antenna offers good performance over other type of antennas due to their advantages. Therefore nowadays they have been used in various applications. One of the most interesting applications is their use for transmitting & receiving systems required for circular polarization. Increasing demands for circularly polarized microstrip antenna (CPMA) for communication systems has directed researchers to improve the performance of circularly polarized microstrip antenna [1]. Specifically CP microstrip antenna is used in satellite links, missiles etc. Microstrip antennas are planar resonant cavities that leak from their edges and radiate. We can utilize printed circuit techniques to etch the antennas on soft substrates to produce low-cost and repeatable antennas in a low profile.

An integral concept of microstrip antenna is its polarization. Polarization of a radiated wave is defined as “that property of an electromagnetic wave describing the time varying direction and relative magnitude of the electric field vector”[3]. The manuscript deals with circular polarization for MA. There are various techniques to achieve circular polarization of microstrip antenna. In one of the techniques circular polarization is achieved by cutting of the slits at the four edges of the patch [4]. With the help of various simulations this technique is modified to get proper impedance matching. In these simulations patch & slit dimensions are kept constant. Feed location is changed to get proper impedance matching. Simulations are done with the help of Electromagnetic simulation software IE3D-10.9

The main contribution of the work is in development of an optimally designed circularly polarized microstrip antenna with compactness in size, good impedance matching and large bandwidth. These are the principal requirements for modern mobile and wireless communication systems.

1. Circular Polarization for Microstrip Antenna:

The polarization of an antenna refers to the polarization of the electric field vector of the radiated wave. In other words, the position and direction of the electric field with reference to the earth’s surface or ground determines the wave polarization. The most common types of polarization are linear (horizontal or vertical) polarization, Elliptical polarization and Circular (right hand polarization or left hand) polarization. The manuscript deals with circular polarization (CP) . In a circularly polarized wave, the electric field vector remains constant in length but rotates around in a circular path. A left hand circular polarized wave is one in which the wave rotates counterclockwise whereas right hand circular polarized wave exhibits clockwise motion. The CP for MA can be categorized as Dual Feed and Single Feed which totally depends on number of feed used. Dual feed makes the system more bulky and hence system efficiency reduces. Therefore single feed system is preferred.

The various classes which produces CP with single feed is shown figure1. The approximately square patches have been divided into two groups: type A, fed along the centerline, and type B, fed along the diagonal.

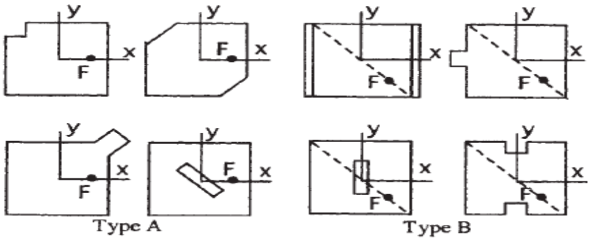


Fig. 1: Classes of perturbed microstrip

2. Polarization for Microstrip Antenna with pair of orthogonal slits:

This design is achieved is by cutting slits in a square patch & by adjusting length of slits, the MA can perform CP radiation with reduced size at fixed frequency [6]. This design also provides a wide CP bandwidth & relaxed fabrication tolerances.

To achieve CP operation slits are cut in orthogonal directions & due to slits, the equivalent excited patch surface current path is lengthened, reducing the resonant frequency of patch.

By further adjusting the slits lengths & feeding the patch using a single feed along the diagonal of the patch, two orthogonal modes with equal amplitude & 90 ^{0} phase difference can be excited, which results in reduced size CP operation at a fixed frequency. Due to slits, quality factor of the patch reduces which increases BW & ease of fabrication tolerances.

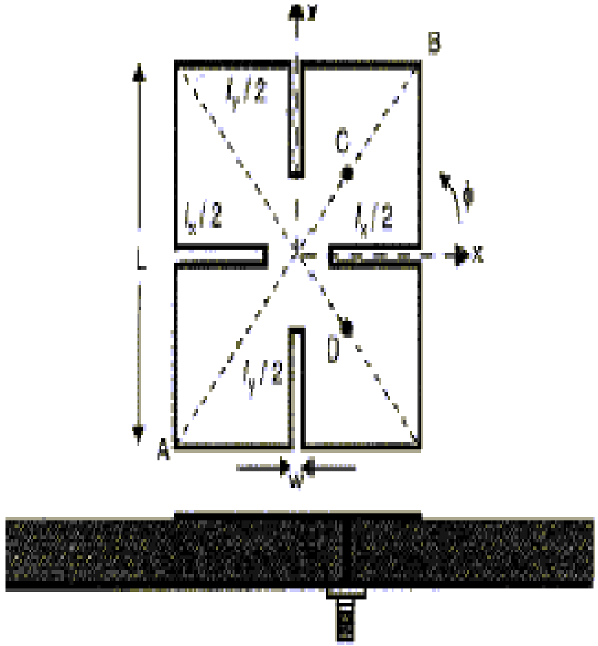


Fig 2: Compact microstrip antenna

3. Antenna design

Referring to geometry shown in figure 3, two pairs of narrow slits are cut in X & Y directions in patch. Each pair of slit is having equal length but the total lengths of two pair's l_x & l_y are not same. This generates two orthogonal modes of interest.

When $l_x > l_y$ & feed point is at point 'C' along diagonal AB then RHCP radiation occurs.

Whereas $l_x > l_y$ & feed point is at point 'D' then LHCP radiation occurs.

It is observed that patch without slits are having higher resonant frequency as compared to patch with slits. It is observed that by increasing slit length resonant frequency of patch reduces which causes reduction in size of it.

3.1. Design of wideband element

The BW of MA depends on the patch shape, the resonant frequency & the dielectric constant & thickness of the substrate [1].

The wider BW is usually obtained by employing a thick substrate with low dielectric constant. However, such an antenna, in general, has two major problems, which should be considered. One concerns the unwanted mode generation. The former may impose a limiting factor on the maximum usable frequency of substrate because a practical MA is usually designed so as not to radiate any surface waves. However. The latter problem cannot be ignored for MA having BW greater than about 6 %. Although a wideband MA has these problems, it has advantage that no balun is required. So the BW can be accurately & analytically estimated. This advantage makes it possible to design MA taking into account not only the resonant frequency but also BW. BW of MA is inversely proportional to quality factor (Q) of MA. By decreasing Q, BW can be increase. To achieve broad BW MA, various perturbation methods are useful [3].

4. Theoretical Design for MA with CP:

4.1 Substrate Material & Parameter Selection:

The propagation constant for a wave in MA substrate must be accurately known in order to predict the resonant frequency, resonant resistance & antenna performance factors. Antenna designers have found that the most sensitive parameter in MA performance estimation is the dielectric constant of substrate material & that the manufacturer's tolerance on ε_r is sometimes inadequate [1].

Thickness variation in substrate material can have effect on operating frequency [5]. Thickness & dielectric constant of substrate material affects the BW of MA. To have a wider BW of MA we can use a thick substrate with low dielectric constant. But it has a problem of surface wave radiation [3].

Thickness of substrate also affects the CPBW as given below [7]

CPBW (%) =36.7* t/ λ =0.16 Where, t= thickness of substrate material, λ=Wavelength

High dielectric constant reduces antenna dimensions but it reduces antenna efficiency. So we can choose the substrate material according to following requirements

1) Antenna dimensions, resonant frequency, gain & BW requirement.
2) Comparative list of available substrates.
3) Thermal characteristics of material.

4.2 About Gain Improvement

In order to achieve a high antenna gain, however, the energy losses from the feeding structure must be reduced significantly [2]. To improve gain, Feed Structure should be properly designed. Gain of MA can be improved by increasing thickness & dielectric constant of substrate material. Super-strate loading of high permittivity material with chip resistor loading increases gain of MA. But this may affect radiation pattern of an MA along with reduction in surface wave radiation.

4.3 About Bandwidth Improvement

The BW of MA depends on the patch shape, the resonant frequency & the dielectric constant & thickness of the substrate [2].

A wider BW is usually obtained by employing a thick substrate with low dielectric constant. However, such an antenna, in general, has two major problems, which should be considered. One concerns the unwanted mode generation. The former may impose a limiting factor on the maximum usable frequency of substrate because a practical MA is usually designed so as not to radiate any surface wave. However, the latter problem cannot be ignored for MAs having BW greater than about 6 %. Although a wideband MA using thick substrate has these problems, it has advantage that no balun is required. So that BW can be accurately & analytically estimated. This advantage makes it possible to design MA taking into account not only the resonant frequency but also BW.

BW of MA is inversely proportional to quality factor (Q) of MA. By decreasing Q, BW can be increase. To achieve broad BW MA, various perturbation methods are useful [3].

For MA there are three essential parameters

1) Resonant Frequency (f_{cp})
2) Dielectric Constant (ε_r): Dielectric Constant (ε_r) selected is 4.4.Though High dielectric constant reduces antenna dimensions but it reduces antenna efficiency.
3) Height of Substrate (h): To avoid bulkiness, height of antenna selected is 1.588 mm.

f_{cp} =2.4GHz, ε_r=2.4, h=1.588 mm

Step 1: Calculation of width

$$W = v_0 \div 2 * f_r \sqrt{\varepsilon_r} \text{ --------------(5.1)}$$

v_0 = velocity of light=3.8*10^{11} mm/seconds, ε_r=4.4

W= 3.8 *10^{11} /[(2* 2.4*10^9) *($4.4^{1/2}$)]

W=29.8 mm -------(5.2)

Step 2: Calculation of Effective Dielectric Constant (ε_{reff}):

$$\boldsymbol{\varepsilon_{reff} = 0.5*(\varepsilon_r+1) + 0.5*(\varepsilon_r-1)*[1+12*h/W]^{-1/2}} \quad \text{------(5.3)}$$

ε_{reff}=2.697 ----------(5.4) **,** $f$cp= 2.4 GHz

Dielectric constant of substrate (ε_r)=4.4

Step 3: Calculation of Length

$$L = v_0 \div (2 * f_r * \sqrt{\varepsilon_{eff}}) - - - - - (5.4-1)$$

$$\therefore L = 3.8*10^{11} \div (2*2.4*10^9 * \sqrt{2.691})$$

$$\therefore L = 38mm$$

Step 4: Calculation of Length Extension (ΔL):

$$\Delta L = 0.412 * h * (A \div B) - - - - - - (5.5)$$
$$A = (\varepsilon_{eff} + 0.3) * ((W/h) + 0.264) - - - - - (5.6)$$
$$\therefore A = (2.11206 + 0.3) * ((40.3435/1.588) + 0.264)$$
$$\therefore A = 61.9157$$
$$B = (\varepsilon_{eff} - 0.256) * ((W/h) + 0.8) - - - - (5.7)$$
$$B = (2.112060 - 0.256) * ((40.3435/1.588) + 0.8)$$
$$\therefore B = 48.5860$$
$$\therefore \Delta L = 0.412 * 1.588 * (61.9157/48.5860)$$
$$\therefore \Delta L = 0.83375mm - - - - - - - - (5.8)$$

Step 5: Calculation of Effective Length (L_{eff}):

$$L_{eff} = L + 2 * \Delta L --------(5.9)$$
$$\therefore L_{eff} = 43.00573 + 2 * 0.83375$$
$$\therefore L_{eff} = 38.83mm -------(5.10)$$

Step 6: Calculation of Ground Plane Dimensions:

The transmission line model is applicable to infinite ground planes only. However, for practical considerations, it is essential to have a finite ground plane. It has been shown that similar results for finite and infinite ground plane can be obtained if the size of the ground plane is greater than the patch dimensions by approximately four times the substrate thickness all around the periphery [1]. Hence, for this design, the ground plane dimensions would be given as:

Lg=4*h+L------------ (5.11)

Wg=4*h+L---------- (5.12)

Step 7: Determination Of Feed point location:

A coaxial probe type feed is used in this design. The feed point must be locatedat that point on the patch, where the I/P impedance is 50 Ω. Hence trial & error method is used to locate the feed point. For different feed points, the return loss (R.L.) is compared & that feed point is selected where R.L. is most negative.

4.4) Patch Design with Slits

f_{cp}=2.4GHz, ε_r=2.4, h=1.6mm

Consider a square patch

Therefore L=W=26 mm

Step 1: Calculation of Effective Dielectric Constant (ε_{reff}):

ε_{reff} =0.5*(ε_r+1)+ 0.5*(ε_r-1)*$[1+12*h/W]^{-1/2}$------(5.3)

Therefore,

ε_{reff}=2.62 --------------(5.14)

$f$cp= 2.4 GHz

Dielectric constant of substrate (ε_r) =4.4

Step 2: Selection of Slit Length:

As described above current path gets lengthened due to slits cut at the edges of patch. Due to this resonant frequency of the patch gets reduced. Till date there is no exact relationship between slit length & resonant frequency of patch. So according to required resonant frequency, axial ratio & proper feed point we can determine the slit length.

Step 3: Calculation of Ground Plane Dimensions**:**

As explained in step 6

Step 4: Determination Of Feed point location:

As explained in step 7

5. Simulated and Experimental Results:

While simulating patches with various feed points it is observed that for particular patch & slit dimension there is only one feed location at which patch resonates with maximum return loss at desired resonate frequency. How to achieve compactness for microstrip antenna is explained in chapter 4.In many of the simulations patch dimensions are kept constant. Only changes in slit dimensions are done. In many simulations patch dimensions are also change. During this process following observations are made

1) For particular patch & slit dimension there is only one feed location that provides proper impedance matching.
2) With change in slit length for fixed patch dimension, resonant frequency of patch changes.
3) Circular polarized bandwidth changes by changing slit dimensions.
4) For certain slit dimensions though patch resonates we will not get circular polarization.
5) Change in radiation efficiency was also observed.

These observations conclude that there may be some empirical relations between following parameters of microstrip antenna

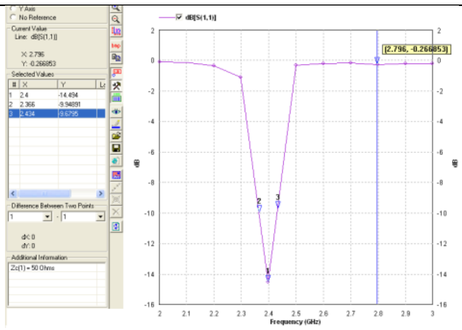
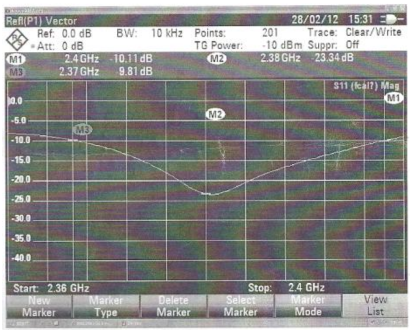
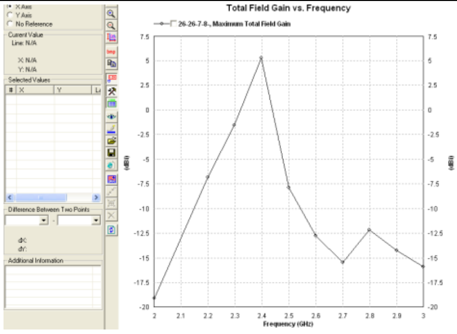
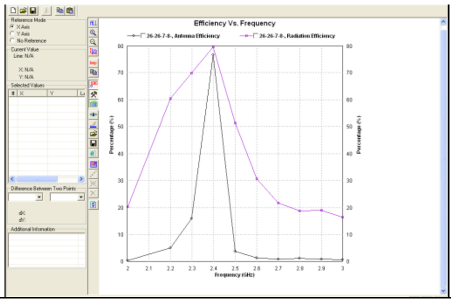
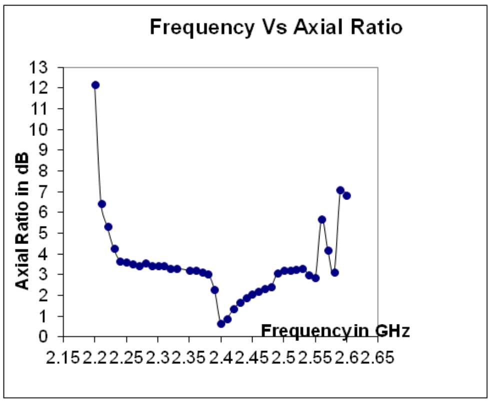
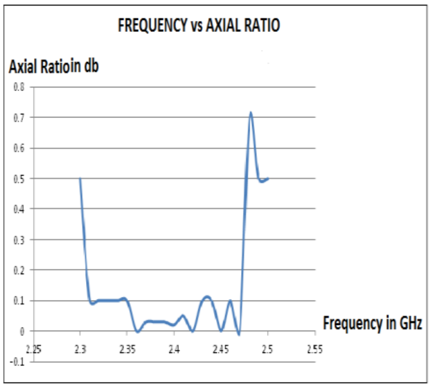
1) Patch & slit dimension with return loss & feed location.
2) Slit dimensions & circular polarized bandwidth.
3) Slit dimension & feed location.
4) For fixed patch dimension there must be some relation between slit dimensions & resonant frequency.

After vigorous simulation the optimized MA for various antenna parameters such as antenna dimensions, impedance and CP bandwidth, directivity and gain was obtained. Antenna with optimized dimensions is fabricated it is tested experimentally. The various simulated and experimental results are tabulated in table1 also preferred snapshots are displayed in table 2.

Table 1

Sr.No.	Parameter	Simulated Results	Experimental Results
1	Resonant Frequency (GHz)	2.4	2.38
2	Return Loss in dB	-14.69	-23.34
3	Impedance Bandwidth (MHz)	700	300
4	V.S.W.R. at Resonant Frequency in dB	1.46	1.46
5	Gain at resonant frequency in dB for $\Phi=45^0$ & $\Phi=135^0$ at an elevation angle $\theta=0^0$	5.29	--
6	Directivity at resonant frequency in dBi	6.45	--
7	Gain in dB at resonant frequency	5.24431	--
8	Antenna Efficiency (%)at resonant frequency	79.4	--
9	Radiation Efficiency (%)at resonant frequency	76.5	--
10	% CPBW	4.425	4.6

Table 2

Sr.No.	Parameter	Simulated Results	Experimental Results
1	Resonant Frequency (GHz)		
7	Gain in dB at resonant frequency		
8	Antenna Efficiency (%)at resonant frequency		
10	% CPBW		

5. Conclusion:

Various techniques to achieve CP are studied. For singly fed MA to achieve CP various perturbations methods are employed. By properly adjusting the location & dimensions of perturbation, RHCP & LHCP radiations can be easily obtained using a single feed and this ease the manufacturing tolerance. The proposed technique gives very compact MA. While simulating the patches of various dimensions, we can conclude that for a particular patch & slit dimension there is only one feed location at which maximum impedance occurs. It is also observed that for fixed patch dimensions by varying the slit length CPBW can be improved. Table 1 shows that experimental reading and simulated are approximately same. The accuracy limits are also within tolerable engineering range.

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