Conformal microstrip printed antenna

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Abstract

In this paper, the comprehensive study of the conformal microstrip printed antenna is presented. The main advantages and drawbacks of a microstrip conformal antenna are introduced. The earlier researches in cylindrical-rectangular patch and conformal microstrip array are summarized. The effect of curvature on the conformal Microstrip antenna patch on conical and spherical surfaces is studied. Some new flexible antenna is given for different frequencies. Finally, simulation software is used to study the effect of the curvature on the input impedance, return loss, voltage standing wave ratio, and resonance frequency.

Keywords: *Microstrip antenna, conformal antenna, Printed antenna, resonance frequency, curvature, input impedance, return loss, and voltage standing wave ratio.*

1. Introduction

Microstrip antennas have been widely studied in recent years. The main reasons are due to a plethora of reasons, such as low profile, lightweight, low cost, high gain and conformability to curved surfaces [1]. Planner microstrip antennas have been extensively studied and the models used to analyze this type of antenna have reached some kind of maturity.

Conformal microstrip antennas are very important in many applications such as mobile communication, airplane, rockets, radar and satellites [2]. Conformal antennas are mainly the following advantages over the planer microstrip antennas [3]:

1. Conformal antennas have little effect of carrier's own aerodynamic properties due to its conformal surface.
2. Conformal antennas can be used to simplify the antenna installation under the conditions of assuring the performance of the antenna.
3. Conformal antennas can eliminate or reduce the error caused by radome. The radome does not need to install; even if the radome is installed, as the microstrip antenna and its close proximity, distortion of the antenna is greatly reduced [4].
4. With planer arrays the radiation pattern changes with the direction of scan, while conformal arrays with rotational symmetry (cylindrical profile) can have scan-invariant pattern [5].
5. Cylindrical conformal gives nearly Omni-directional radiation pattern [6].
6. It gives large angle coverage.

Because of the advantages of conformal antennas, it is very popular in the different flight aircrafts [7].

On the other side, a conformal microstrip antenna has some drawbacks due to bedding [8], those drawbacks are illustrated below:

1. The dielectric material will undergo stretching and compression along the inner and outer surfaces, respectively. Stretching of copper traces will result in phase, impedance, and resonance frequency error.
2. Shaping the material can also result in a change in both the dielectric constant and material thickness. The thickness is an easily measured parameter, and measuring the dielectric constant of a cylindrical shaped substrate can be done using the two microstrip line method [9].
3. Dielectric materials will suffer from cracking due to bending and that will affect the performance of the conformal microstrip antenna.

A better method for creating uniform cylindrical structures would be to roll the material into a cylindrical shape while the outer surface is still completely plated, then pattern and each the material in its cylindrical configuration.

In the next sessions, we will show some earlier research in conformal mirostrip antenna field.

2. Cylindrical-Rectangular Patch Antenna

Cylindrical-rectangular patch is the most famous and popular conformal antenna. The manufacture of this antenna is very easy with respect to spherical and conical antenna especially in the military field. So the research in this type of conformal antenna stared early by 1980's [10].

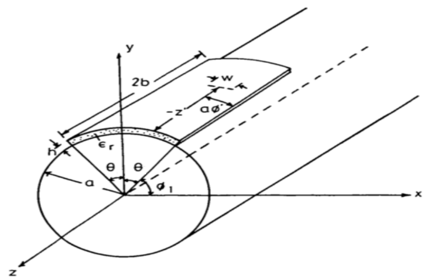


Fig1: Geometry of cylindrical-rectangular patch antenna

Clifford M. Krowne [10] calculated the resonance frequency fr for a cylindrical-rectangular patch and he made a comparison to fr for planar rectangular patch antenna. The field distribution within the antenna has been determined using a cavity model for TEmn (transverse electric) and TMmn (transverse magnetic), where m and n are the modes of operations and indicated that only discrete solutions for the transverse TM and TE.
The resonance frequency is given by [10]:

$$(f_r)_{mn} = \frac{1}{2\sqrt{\mu\varepsilon}}\sqrt{\left(\frac{m}{2\theta a}\right)^2 + \left(\frac{n}{2b}\right)^2} \qquad (1)$$

Where 2b is a length of the patch antenna, a is a radius of the cylinder, 2θ is the angle bounded the width of the patch, ε represents electric permittivity and μ is the magnetic permeability as shown in figure 1 [10].

An approach to the microstrip antennas on cylindrical bodies is presented by Joseph A. et al [11]. In this paper, the printed radiator is replaced by assumed surface current distribution, and the fields are solved taking into account the presence of the dielectric layer around the cylindrical body. Under this assumption, the far electric field is calculated then used to get the radiation patterns of the wraparound antenna. The assumption is valid as long as the radiation is small compared to the stored energy.

Kwai et al. [12] gave a brie analysis of a thin cylindrical-rectangular microstrip patch antenna which includes resonant frequencies, radiation patterns, input impedances and Q factors. The effect of curvature on the characteristics of TM10 and TM01 modes is also presented in this paper. They first obtained the electric field under the curved patch using the cavity model and then they calculated the far field by considering the equivalent magnetic current radiating in the presence of cylindrical surface.

In the cavity model, the region between the patch and the cylinder is considered as a cavity bounded by electric walls on the top and bottom and by a magnetic wall on the side, and this model is valid in case of a small thickness of dielectric with respect to the dimensions of the patch . Also, for much small thickness than a wavelength and the radius of curvature, only TM modes are assumed to exist. In order to calculate the radiation patterns of cylindrical-rectangular patch antenna, they introduced the exact Green's function approach. Using equation (1), they obtained expressions for the far zone electric field components Eθ and Eφ as a functions of Hankel function of the second kind $H_p^{(2)}$. The input impedance and Q factors are also calculated under the same conditions.

Based on cavity model, microstrip conformal antenna on a projectile for GPS (Global Positioning System) devise is designed and implemented by using perturbation theory is introduced by Sun L., Zhu J., Zhang H. and Peng X. [13]. The designed antenna is emulated and analyzed by IE3D software. The emulated results showed that the antenna could provide excellent circular hemisphere beam, better wide-angle circular polarization and better impedance match peculiarity.

Nickolai Zhelev Introduced a design of a small conformal microstrip GPS patch antenna [14]. A cavity model and transmission line model are used to find the initial dimensions of the antenna and then electromagnetic simulation of the antenna model using software called FEKO is applied. The antenna is tested experimentally and he compared the result with the software results. It was founded that the resonance frequency of the conformal antenna is shifted toward higher frequencies compared to the flat one.

3. Conformal microstrip antenna array

Conformal microstrip arrays are used to increase the directivity of the antenna and increase the signal to noise ratio. So, we get a better performance using arrays. The radiation pattern will significantly be affected by putting arrays on a conformal surface to appear as omni-directional pattern, in all directions, which is very useful in the aerospace system [15].

The equations of directivity function of conformal microstrip array on a cylinder and experimental results of pattern of array of 64 elements are given by Mao K. and Xue M. [15]. The coupling between elements is not considered in this paper. In this paper, they calculated the total electric field strength for an array of N elements using the equation:

$$E = \sum_{i=1}^{N} E_i\, e^{-j\varphi_i} \qquad (2)$$

Where, Ei is the field strength of number I radiator and φ i is the phase of equivalent transversal magnetic current source of N radiators.

C. Uou, W. Hwang amd M. M. Tentzeris designed and fabricated a composite antenna array conformed around cylindrical structures [16]. The experimental results showed that the radiation pattern is strongly dependent on the cylindrical curvature for the transverse radiation pattern, while the array also exhibits high side-lobes and wider beamwidth.

Problems associated with Ultra Wide Band (UWB) antennas as phased array elements discussed by Altan M. Ferendeci [17]. In this paper, he introduced various wide bandwidth arrays of antennas that can be conformed and also, problems that arise depending on the physical separation of antennas are discussed. For conformal placement of an antenna either as an individual antenna or as in an array configuration on any arbitrary surface may require very thin antenna. They should be processed preferably on flexible substrates so that they will conform to the surfaces without changing the surface geometry.

4. Conformal Microstrip antenna patch on conical and spherical surfaces

Single and dual patch antenna conformed on a conical surface are studied by W. Gomes and A. Giarola [18], [19]. The radiation electric, using a Green's function, and the radiation loss tangent were calculated in the TM10 mode. The input impedance for this case is also calculated.

The software simulation of 36 GHz conformal rectangular patch antenna on a cone is introduced by Z. Peng, L. Chaowei and W. Qiang [20]. The return loss and voltage standing wave ratio for flat rectangular patch and on a cone were discussed in this paper. Also, the same software was used to design a microstrip antenna array.

The effects of spherical conformity on a wideband circular patch antenna described by B. Piper and N. Shuley [21]. The theoretical design of a wideband circular patch antenna of 2.4 GHz was given and the experimental measurement also given in this paper. The effect of distortion on the spherical antenna is very important and has a great effect on the performance of any spherical antenna. So, they used the air dielectric to overcome the problems come from dielectric cracking. The return loss was measured for a flat antenna and then for spherical antenna for different radii and the result showed the effect of the conformal antenna on the performance.

5. Flexible microstrip antenna

A flexible transparent film ultra wideband antenna (3.1 GHz -10.6 GHz) for curved surfaces was designed and developed by T. Peter and R. Nilavalan [22]. The patch and ground plate are both designed using AgHT-8 material, very flexible materials, while substrate is of a polymer. AgHT-8 material has less impact on performance with bending and consequently improves the performance. The effect of bending was also studied for different radius of curvatures and they noted that the 10 dB bandwidth reduced as the curvature increased.

The performance of flexible printed radio frequency identification tags affixed onto cylindrical containers was measured by S. Leung and D. Lam [23]. Conductive polymeric coil antennas were screen printed onto flexible substrates, and the coil resistance, the inductances, and the S-parameters of the antenna coils were measured and analyzed. The results in this paper showed that the coil inductance decreases slowly with increasing curvature, and the maximum read range of the tag reduced by increasing curvature.

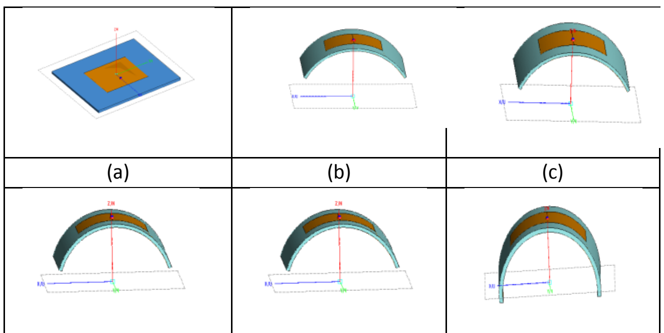
Y. Bayram et al [24] presented a conformal and lightweight antenna technology based on E-textile conductors and polymer-ceramic composites. E-textile conductors are fabricated with single wall carbon nanotube and Ag coated textile. They demonstrate good structural integrity with polymer composites due to their mechanical compatibility. The radiation performance of a simple microstrip antenna when it was flat and conformed on a cylindrical surface was studied. Experiments suggested that the sample patch antenna based on the proposed technique achieved 6 dB gain, which is 2 dB below a patch which has the same dimensions.

A microstrip antenna on liquid crystal polymer multilayer technology of dual frequency (14 and 35 GHz) was presented for the first time by G. Dejena et al [25]. A liquid crystal polymer is a flexible material and a good choice for designing of a low cost antenna. The designed antenna exhibits a return loss of better than 15 dB in both frequency bands. But in this paper, the measured cross-polarizations levels are higher than the predicted ones so they suggested a separate feed layer will increase the measured cross-polarization.

Two dimensional curved electromagnetic bandgap structures were designed, according to the reflection condition of optics Bragg, by L. Tao, C. Xiangyu, Z. Guang and Y. Zhoawei [26]. They applied this structure to the cylindrical conformal microstrip antenna. The simulation results indicated that, the higher harmonics of the antenna with electromagnetic bandgap are perfectly suppressed comparing with the normal cylindrical microstrip patch antenna without electromagnetic bandgap.

6. Results

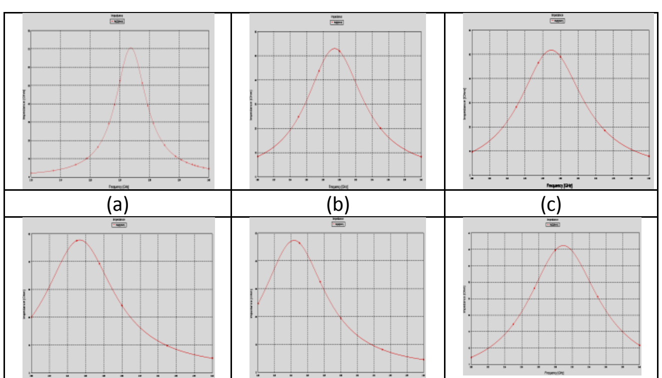
In this section, we introduce some simulation results, using FEKO software, related to the previous work. The effect of radius of curvature on performance of microstrip antenna is studied. For a flat microstrip printed antenna resonate at 2.25 GHz and input impedance is around 52 Ω, the effect of curvature on its shape is shown in fig. 2. For 50 mm, 45 mm, 40 mm, 35 mm, and 30 mm radius of curvature (R), the input impedance (Z) is changed with R as in figure 3(will be summarized in table 1). The voltage standing wave ration (VSWR) and the return loss (S11) are also studied in figures 4 and 5 respectively. The dimensions of the patch are 41.5 mm length and 50.2 mm width, while the dimensions of the ground plat are 83 mm length and 100.4 mm width, and the position of the patch is centered on the ground plat as shown in figure 2.a. The feeding position is 8.25 mm from the center of the patch and along the length of the patch. The dielectric material is Teflon with dielectric constant 2.1 and thickness 2 mm.



(a) (b) (c) (d) (e) (f)

Fig. 2 different radius of curvatures (R) for the same antenna

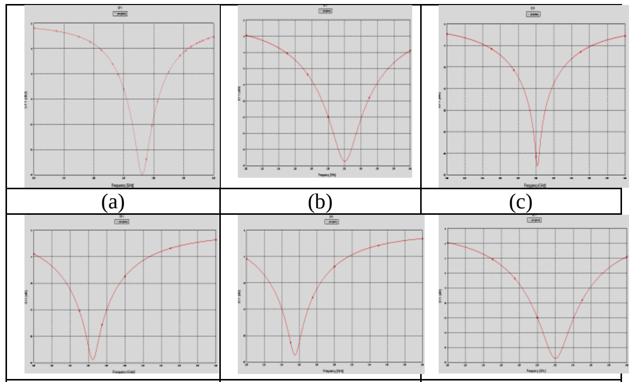
a) Flat antenna	b) R = 50 mm	c) R = 45 mm
d) R = 40 mm	e) R = 35 mm	f) R = 30 mm



(a) (b) (c) (d) (e) (f)

Fig. 3 input impedance (Ω) as a function of frequency (GHz)

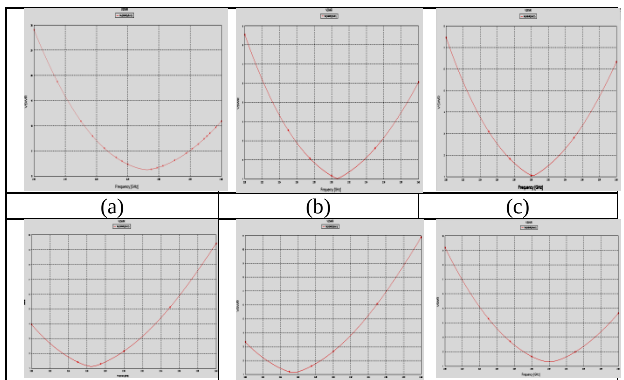
a) Flat antenna	b) R = 50 mm	c) R = 45 mm
d) R = 40 mm	e) R = 35 mm	f) R = 30 mm



(a) (b) (c) (d) (e) (f)

Fig. 4 return loss (S11) as a function of frequency (GHz)

a) Flat antenna	b) R = 50 mm	c) R = 45 mm
d) R = 40 mm	e) R = 35 mm	f) R = 30 mm



(a) (b) (c) (d) (e) (f)

Fig. 5 VSWR as a function of frequency (GHz)

a) Flat antenna	b) R = 50 mm	c) R = 45 mm
d) R = 40 mm	e) R = 35 mm	f) R = 30 mm

We can summarize the result as shown in table 1 for the radius of curvature R (mm), resonance frequency fr (GHz) and input impedance Z (ohm).

Table 1, R as a function fr and Z

R (mm)	f_r (GHz)	Z (Ω)
Flat (infinity)	2.25	50
50	2.23	52.9
45	2.29	51.7
40	2.24	47.7
35	2.23	47.2
30	2.3	41.2

As we can note from table 1, the input impedance decreases with decreasing curvature which is the same result as in previous research [12]. On the other hand, the decreasing in the resonance frequency is slightly different from the resonance frequency for the flat antenna, which is not the case in all of the previous work because all the previous researches assumed the constancy of resonance frequency.

7. Conclusion

The effect of curvature on the performance on a microstrip printed is shown. For cylindrical, conical and spherical microstrip printed antenna, we introduce the earlier studies on calculation of the quality of factor, input impedance, resonance frequency, electric and magnetic fields at a far field, and the gain of that antenna. The radius of curvature affect the input impedance, return loss, and VSWR as shown in simulation results. The resonance frequency is affected by very small amount which can be neglected and we can consider that the resonance frequency is constant with curvature.

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