

New Design of Cylindrical Rectangular Microstrip Antenna (CRMA) By Using The Slots Technique

Nabeel A. Areebi^{1}

Zeki A. Ahmed²

Mahmoud M. Aubais³

¹Qadisiyah University \ Faculty of Education

²Basrah University \ Faculty of Science

³Kufa University \ Faculty of Science.

*Corresponding Author E-mail: nabeelabbasphm@gmail.com

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ABSTRACT

A conformal antennas are plays an important role due to its multitasking possibilities , which have many opportunities in several applications. In this study, a new design of cylindrical rectangular microstrip antenna(CRMA) excited at TM_{01} mode, was achieved in order to operate at the frequency of 5.6GHz. The simulation was done by Finite Difference Time Domain(FDTD) method using MATLAB program. The input impedance , return loss and radiation pattern of antenna were calculated and plotted. By using the slots technique and dual-layers substrate technique , the bandwidth(BW) is increased to 88.88% . Also BW is increased as the dielectric constant value is decreased.

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تصميم جديد لهوائي شريطي اسطواني بمشع مستطيل باستخدام تقنية الشقوق

^٣ محمود مسافر عبيس

^٢ زكي عبدالله احمد

^١ نبييل عباس عربي

¹ جامعة القادسية/ كلية التربية/ قسم الفيزياء

² جامعة البصرة/ كلية العلوم/ قسم الفيزياء

³ جامعة الكوفة/ كلية العلوم/ قسم الفيزياء

الكلمات المفتاحية:

الهوائيات الشريطية غير المستوية

الاقتزان المتبادل

فجوة الطاقة الكهرومغناطيسية

وطريقة الفروق المحددة في مجال

الزمن .

الخلاصة

تلعب الهوائيات الامتثالية دورا مهما وذلك نتيجة لإمكانياتها متعددة المهام وكذلك لما لها من تطبيقات عدة. في هذه الدراسة، انجزنا تصميمًا جديدًا لهوائي شريطي اسطواني بمشع مستطيل يثار بالنمط TM_{01} لكي يعمل عند التردد 5.6GHz. نفذت المحاكاة بطريقة الفروق المحددة في مجال الزمن (FDTD) وباستخدام لغة البرمجة الماتلاب. ان كل من ممانعة الدخل، عامل فقد والهيكلة الاشعاعي للهوائي تم حسابها ورسمها. ازداد عرض الحزمة الى 88.88% باستخدام تقنية الشقوق وتقنية مضاعفة الطبقة العازلة كما لاحظنا زيادة عرض الحزمة مع تناقص قيمة ثابت العزل.

1. INTRODUCTION

Antenna is an essential part of a transferrer of the energy system for multipoint communication purpose for which increased the efficiency and the gain and decreased the wave interference. Nowadays, there is continuous spread in the area of multiband communication system to meet requirement of development. Information can be transfer in the form of video, e- mail, text ,audio, etc. by communication network's users. The development of networks provides users with the services they need. Through the modernization of communication, microstrip antenna exists in several applications, like the spacecrafts, satellite and missile applications [1].

The conformal antennas technique is pertinent with the evolution of space information technique and the evolution of microwave devices technique [2].

A conformal antennas is defined as those antennas that can be constructed to a specific shape or with curved surface by just changing the shape of the antenna ground plane. The patch can also be rolls on the base without getting any unacceptable changes in its radiation characteristics and does not cause an additional drawback. They can be found in a high-speed train, airplane or in defense systems, navigation, various communication systems, equipment landing systems, altimeter radar, wearable devices and so on [3].

The conformal antennas are divided into singly curved (such as cylindrical antennas) and doubly curved (such as spherical antennas), depending on how many curvatures the geometry has [4].

Generally, conformal antennas have some advantages such as special angular coverage ,wide band and lower radar cross section(RCS). However, the conformal antennas are not widespread for many various reasons. For

example, Its technology is more difficult than the planar antennas. In addition, the market lacks of design tools of these antennas. Finally, narrow bandwidth is the major disadvantage of these antennas and the efficiency of their performance have a high sensitivity to any frequency change [5].

2. Theory

2.1 Cylindrical Rectangular Microstrip Antennas(CRMAs)

Antennas on singly curved surfaces are the easiest conformal antennas. It is the most obvious in non-planar geometry. Specifically the cylindrical antennas are commonly used in conformal antenna applications such as aerospace, communication systems and in many experimental radars [4].

These antennas are easy manufacturing compare with conical and spherical antennas. Our study is concentrated on cylindrical conformal microstrip antenna with rectangular patch which is known by the cylindrical rectangular microstrip antenna (CRMA) [6].

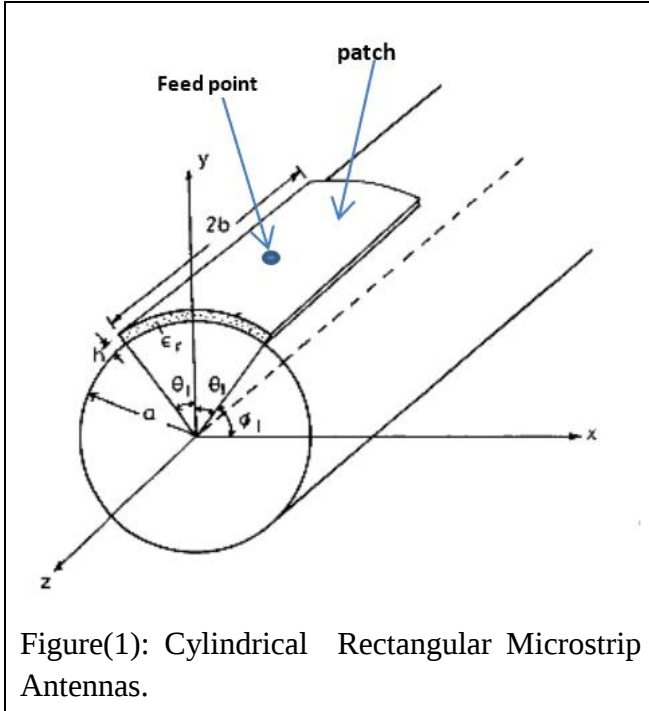
The basic structure of (CRMA) is shown in Figure (1). The excitation was chosen by a probe feed method for several reasons including providing less spurious radiation from the probe current, further to the simplicity in theoretical engineering installation and practical manufacturing. The ground plane of the CRMA is a metal cylinder of radius (a). The dielectric substrate is of relative permittivity ϵ_r and having thickness h extends around the body of the ground plane. The rectangular metal patch is etched on the surface of the substrate [7].

The width and length of the patch are given by $(W = 2(a + h)\theta_1)$ and $(L = 2b)$ [4], respectively. The ground plane have been assumed infinite along z-axis. The probe feed is extends from $(Y = a)$ to $(Y = a + h)$.

The resonant frequency for the TM_{mn} mode is given by[4]:

$$f_{mn} = \frac{c}{2\sqrt{\epsilon_r}} \left[\left(\frac{m}{W} \right)^2 + \left(\frac{n}{L} \right)^2 \right]^{1/2} \quad 1$$

Where c is the light velocity in free space



Figure(1): Cylindrical Rectangular Microstrip Antennas.

2.2 Bandwidth

Bandwidth expansion requisites do not satisfy in pure shape of the microstrip antenna for most wireless communication systems[8]. There are a numerous methods, with different degree of complexity to enhance the bandwidth. The general procedure of most of these techniques is to add elements which may be patches or in the form of slots[9].

Nonetheless, narrow bandwidth is desirable in some applications, such as in government security systems.

Various shapes of cutting slots such as V-shape and L-shape, have been designed[10].

A broader bandwidth of microstrip antenna is possible by choosing a lowest of the dielectric constant ϵ_r [11].

To increase the bandwidth, an additional substrate can be used between the ground plane and substrate. Practical implementation for this

structure is achieved with an air gap ,for example, is placed below the substrate with dielectric constant $\epsilon_r = 1$. In this case, BW will increase because of increasing the thickness of the dielectric medium and decreasing the permittivity. One of the applications of this structure is in a (GPS) system.

An antenna bandwidth is defined as [11]:

$$BW = 200 * \frac{(f_H - f_L)}{(f_H + f_L)} \% \quad 2$$

Where f_H : upper frequency.

f_L : lower frequency.

3. FDTD method

Simulation model of FDTD method in time-domain is obtained by solving Maxwell curl equations. Due to the huge memory capacity of the modern computers, the simulation of electromagnetic problems becomes possible in the time domain [12]. FDTD method provides us with an understanding about the propagation of the electromagnetic waves in microstrip antennas .FDTD method is used in both radiation and scattering problems to obtain the radiation and the scattering patterns , respectively.

In 1966 Kane Yee proposed a modified of Transmission Line Matrix (TLM) method which is today called Finite Difference Time Domain (FDTD) method. This method is used to solve Maxwell's time –dependent equations in the time domain by converting it into finite difference equations. Simulation steps of FDTD method are starts by representing the physical structure depending on material type (conductor, dielectric or boundaries). The second step is applied Gaussian pulse to simulate all the sources. Then all the fields (electric and magnetic) are calculated at any increments of time. These fields are recalculated again after each increment until they decay to zero in the system. Finally, the frequency information are extracted by Fourier transformation. Yee supposed that FDTD space

are cells of a $\Delta x \Delta y \Delta z$ -volume and the components of electric and magnetic fields in 3D space are distributed as shown in figure (2). Every E field component is surrounded by four H field components and every H field component is surrounded by four E field components [11].

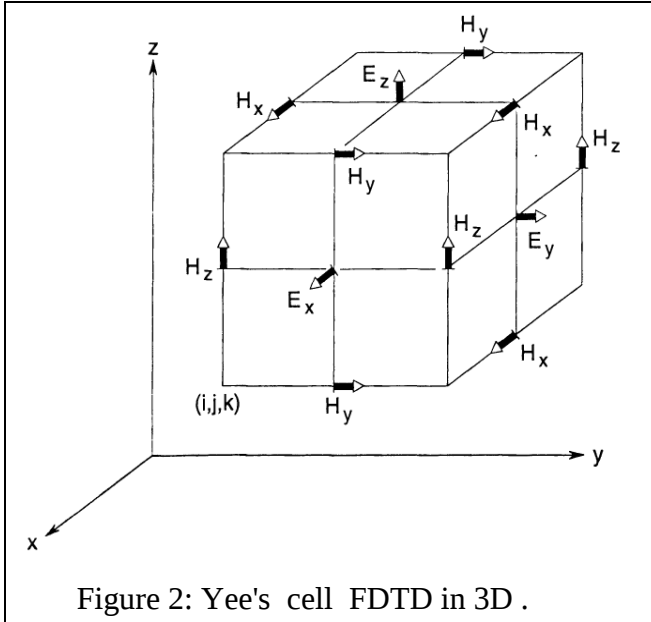


Figure 2: Yee's cell FDTD in 3D .

3.1 Basic Formulation of FDTD

Based on the system of central difference , Maxwell's curl equations can be replaced by a sets of finite difference equations . The curl operator is yield to six coupled scalar equations which are equivalent to Maxwell's curl equations in 3D rectangular coordinate system. These equations can be written as follows[10]:

$$\frac{\partial H_x}{\partial t} = \frac{1}{\mu} \left(\frac{\partial E_y}{\partial z} - \frac{\partial E_z}{\partial y} - \rho' H_x \right) \quad 3$$

$$\frac{\partial H_y}{\partial t} = \frac{1}{\mu} \left(\frac{\partial E_z}{\partial x} - \frac{\partial E_x}{\partial z} - \rho' H_y \right) \quad 4$$

$$\frac{\partial H_z}{\partial t} = \frac{1}{\mu} \left(\frac{\partial E_x}{\partial y} - \frac{\partial E_y}{\partial x} - \rho' H_z \right) \quad 5$$

$$\frac{\partial E_x}{\partial t} = \frac{1}{\varepsilon} \left(\frac{\partial H_z}{\partial y} - \frac{\partial H_y}{\partial z} - \sigma E_x \right) \quad 6$$

$$\frac{\partial E_y}{\partial t} = \frac{1}{\varepsilon} \left(\frac{\partial H_x}{\partial z} - \frac{\partial H_z}{\partial x} - \sigma E_y \right) \quad 7$$

$$\frac{\partial E_z}{\partial t} = \frac{1}{\varepsilon} \left(\frac{\partial H_y}{\partial x} - \frac{\partial H_x}{\partial y} - \sigma E_z \right) \quad 8$$

the FDTD simulation space is bounded, and these radiated or scattered fields will be

reflected back into the simulation space when they are arrived the boundary of FDTD space.

The perfect matched layer(PML) technique is presented by Berenger[13], who proposed an absorbing layer designed to absorb EM waves without any reflections[14]. The excitation of the system can be done by Gauss pulse $p(t) = e^{-\left(\frac{t-t_0}{\tau}\right)^2}$ where τ is a damping factor that has a value depends on the frequency range of problem, t_0 is the time delay. When a FDTD simulation is completed , then, the input and output time functions will be transformed to the frequency domain by using Fourier transform [14].

4. Results and Discussion

4.1 Design of Cylindrical Rectangular Microstrip Antenna(CRMA)

The CRMA is fed by the coaxial probe feed technique, it is excited with the dominant mode TM_{01} . The dimensions of the patch are determined in terms of its resonant frequency formula ($f_r = \frac{c}{2L\sqrt{\varepsilon_r}}$) where (L) is the length of patch. The cylindrical antenna has a radius (R=5cm).

It is very suitable for the wireless local area network (WLAN) applications. WLAN operates at the frequency spectrum (3 GHz – 10 GHz) . In addition, it is used in civilian and military fields , specially ,for unmanned aerial vehicle, which need broadband antennas.

In this study, the standard operating resonant frequency is 5.6GHz. The proposed antenna contains a *RT – Duroid* material as a dielectric layer with dielectric constant $\varepsilon_r = 2.2$ and dielectric substrate of thickness (h=0.795mm). From the equation ($L = \frac{c}{2f_r\sqrt{\varepsilon_r}}$) where C is the light velocity in free space , resonant frequency $f_r = 5.6 * 10^9 Hz$ and $\varepsilon_r = 2.2$, so the patch length obtained is equal (L=18.05mm) and the optimum patch width is ($W = \frac{L}{1.5} = 13.03mm$).

4.2 Input impedance Z_{in} and resonant frequency f_r

The results bellow were obtained after change of feeding point on the patch length (using trying and error method). The optimum feed point was ($\phi_p = 90^\circ, X_p = 3.5mm$). Figure(3) shows the simulation result calculated by FDTD method for the proposed antenna.

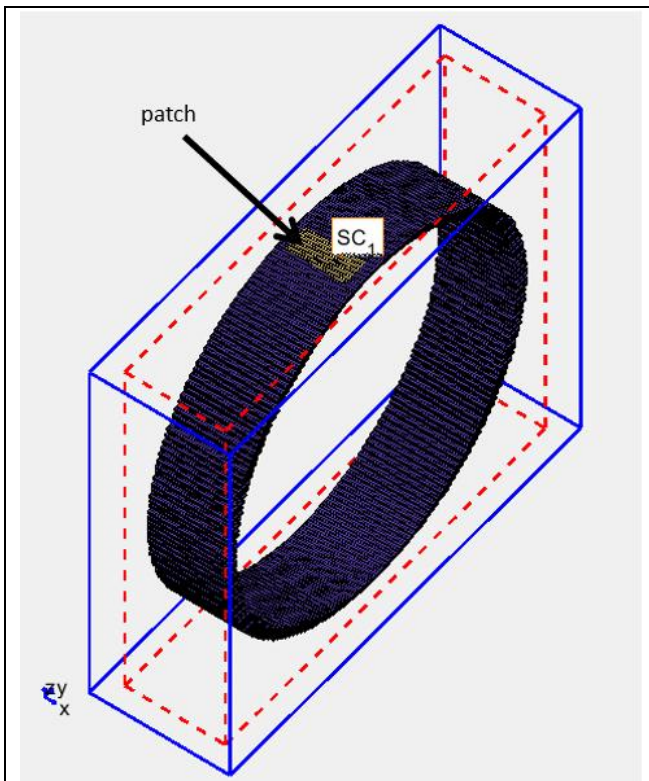


Fig.(3): CRMA by FDTD method

Fig.(4) shows that the value of the input impedance is ($Z_{in} = 50\Omega$) and the calculated resonant frequency is $f_r = 5.44GHz$. Impedance matching between the transmission line and the microstrip antenna is very important to transmit the power from transmission line to the microstrip antenna.

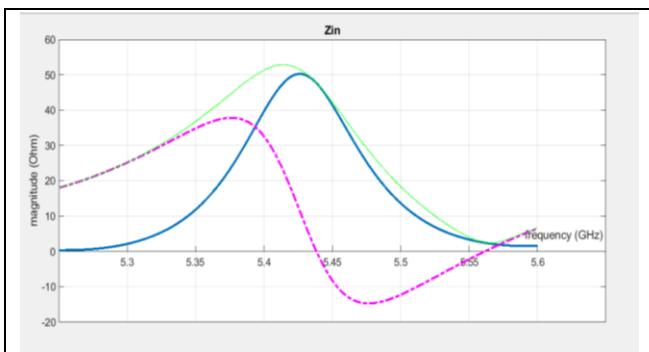


Fig.(4): Input impedance versus frequency by FDTD method.

4.3 Return loss(RL) and bandwidth

Figure(5) shows the calculated result of the return loss is ($-33dB$). Return loss is a measure of the reflected energy at a certain frequency, whereat, the higher the energy radiated versus the less return energy. If the return loss equals $0dB$, this means, all the power will return to the source, while at $RL=-33dB$ very little of the incident energy is returned, and the higher amount of the incident energy will be radiated. The bandwidth of microstrip antenna was calculated from the frequency range at two sides of return loss at $-10dB$. The bandwidth percentage was calculated by eq.(2) and its value is 1.19% .

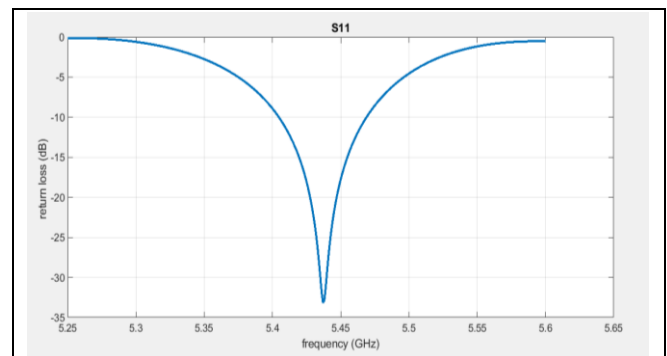


Fig.(5): Return loss versus frequency by FDTD method.

4.4 Effect of low dielectric constant ϵ_r

The result bellow was obtained using foam material as a dielectric layer in the design of the antenna. Foam material have a relative permittivity at ($\epsilon_r = 1.07$). At the remaining thickness ($h=0.795mm$), the bandwidth increased from 1.19% to 12.43% and the resonant frequency from $5.44GHz$ to $5.9GHz$ as shown in figure(6). So, the thickness of the substrate and the dielectric constant are plays an important role on performance of antenna. It is shown clearly that low dielectric constant will increase fringing fields and radiated energy from microstrip antenna.

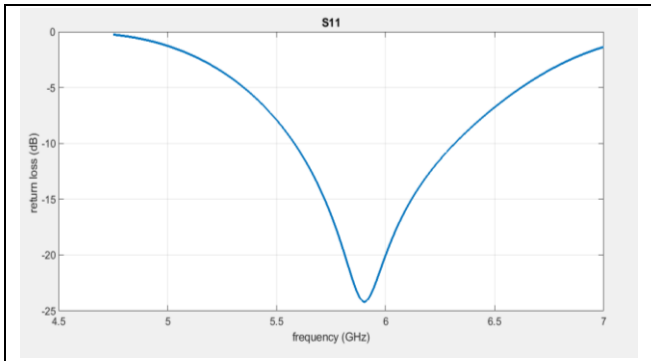


Fig.(6): Return loss by FDTD method, $\epsilon_r = 1.07$.

4.5 Design of Meandering-slotted CRMA

In this section, we presents the slot technique model for the enhancement of the performance of the microstrip antenna. There are different shapes of cutting slots to reduce patch size. These slots are embedded in microstrip antenna to increase the surface current. The proposed slot is a meandering slot in rectangular patch. The dimensions of the proposed meandering slot are determined by using the try and error method as shown in the table (1). The new dimensions of patch with slot are shown in figure (7).

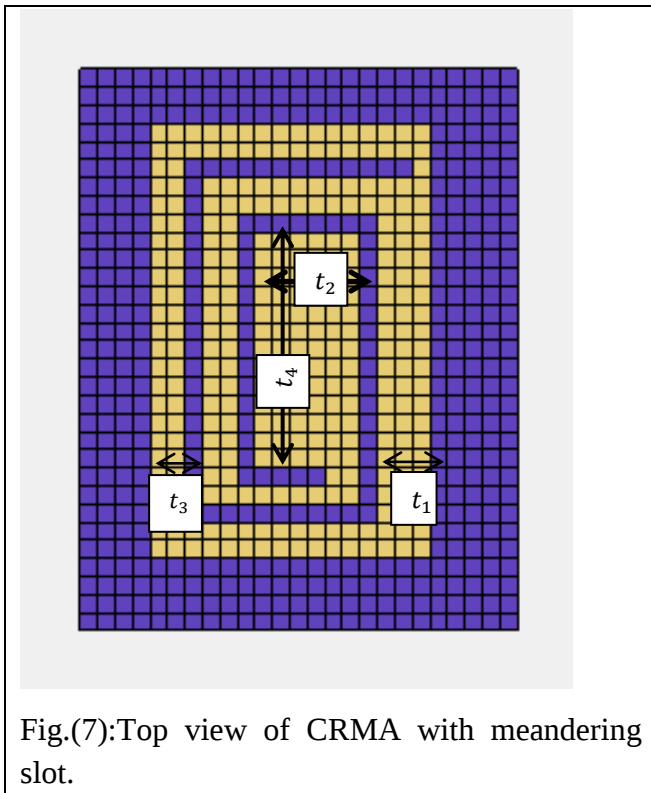


Fig.(7):Top view of CRMA with meandering slot.

Table(1): The optimum values of meandering slot dimensions.

Dime nsion	Value(mm)
t_1	2.256
t_2	4.512
t_3	1.504
t_4	9.776

Figure(8) shows that the result calculated of the return loss is (-28dB) at the resonant frequency of $f_r = 6.09\text{GHz}$. The bandwidth of the microstrip antenna was increased from 1.19% to 28.57% as calculated from eq.(2) for the frequency range (5.19 GHz-6.92 GHz).

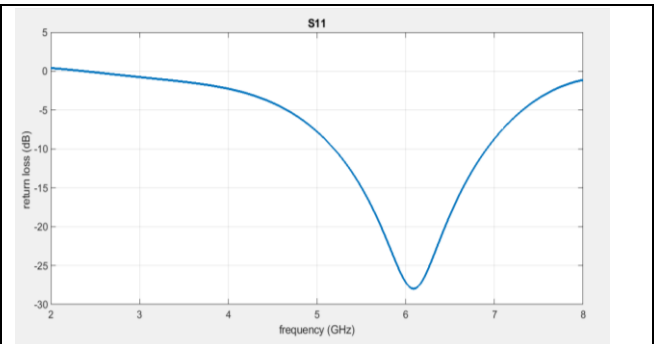
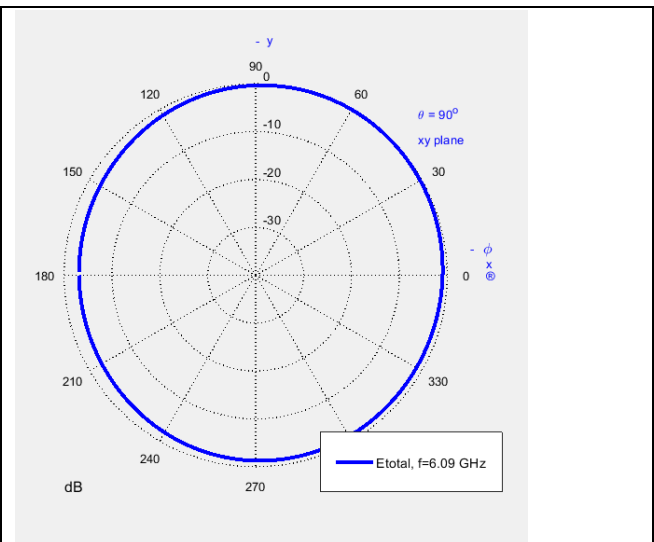


Fig.(8): Return loss versus frequency of CRMA with the meandering slot.

The polar distribution of the electric field for E-plane and H-plane is shown in figure(9a) and (9b) respectively. This figure shows that the radiation pattern is broadside and without side lobes. A 3D plot of radiation pattern in E-plane and H-plane is shown in figure(9c).



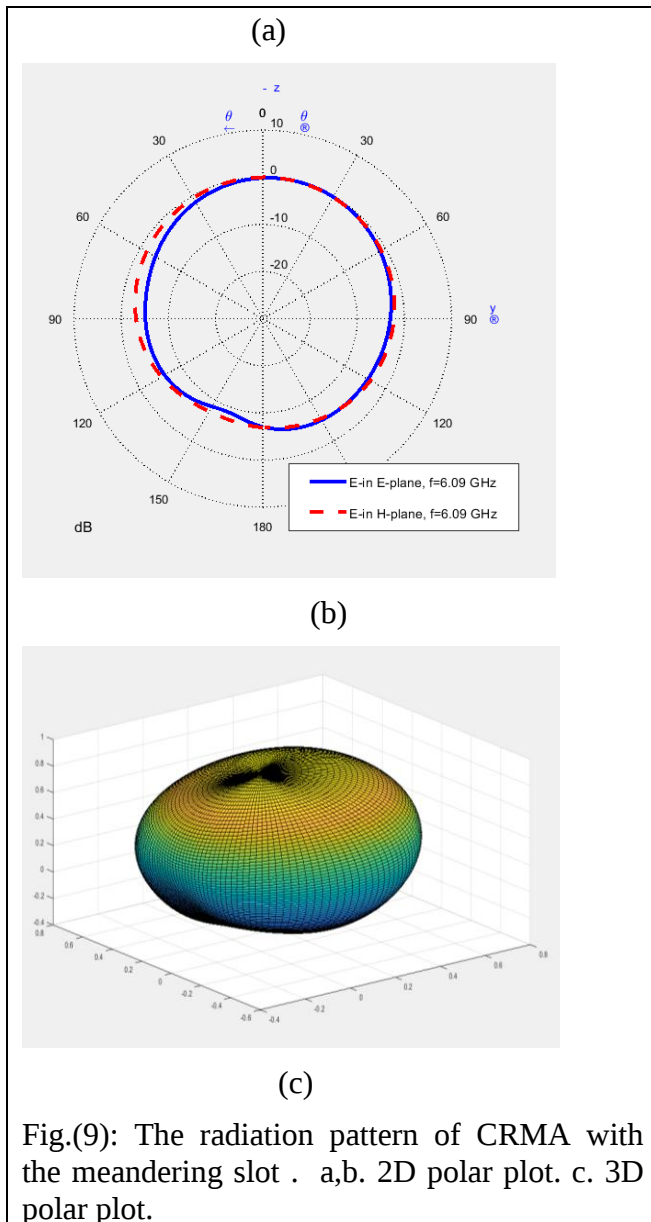


Fig.(9): The radiation pattern of CRMA with the meandering slot . a,b. 2D polar plot. c. 3D polar plot.

4.6 Dual-layers substrate

The cylindrical rectangular microstrip patch with modified U-shaped slot is consists of a single dielectric substrate (*RT – Duroid* type, $\epsilon_{r1} = 2.2$, and $h_1 = 0.795\text{mm}$). Currently, the proposed design includes adding a second dielectric substrate under the first substrate, which describe as (air type, $\epsilon_{r2} = 1$, and $h_2 = 0.795\text{mm}$).

Figure(10) shows the broadband frequency range (2.7 GHz to 7.07 GHz) with percentage bandwidth that increased from 28.57% to 88.88%. The resonant frequency is $f_r = 4.865\text{GHz}$

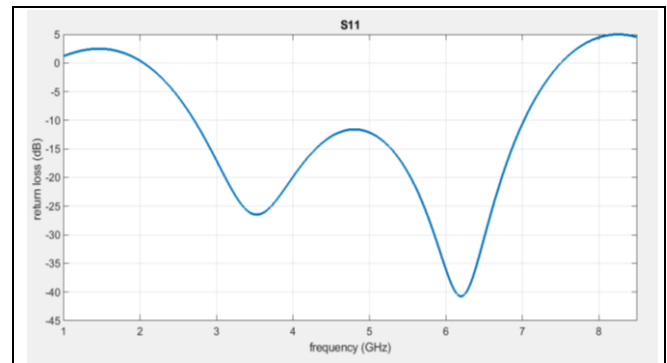


Fig.(10): Return loss of rectangular microstrip patch with meandering slot with dual-layers substrates.

5. Conclusions

The slot technique plays an important role for improving the performance of CRMA. Bandwidth is increased due to cutting slots in antenna's patch and by using lower dielectric constant. Dual-layers substrate is a good technique to increase the bandwidth.

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