Design Of A Planar Spiral Antenna In The 5.5-6.8 Ghz Frequency Range Using Moment Method .

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Abstract
A new objective of this project is to design spiral antenna at frequency range 5.5-6.8 GHz .For spiral antenna simulation ; the MO (microwave office) software is utilized .A prototype of spiral antenna is fabricated and tested for radiation patterns and reflection factor (S11)and presented in this paper. The shape of the antenna is similar to that of the traditional Archimedean spiral antenna. However, this design allows to feed the antenna on the same plane, which is useful to conform the antenna on various surfaces. Antenna behavior is studied using the software FEKO which is based on Method of Moments (MoM). This antenna shows the same characteristics as a traditional spiral antenna while being fed outside with coplanar feeding solution. The antenna is studied without a ground plane.

1-Introduction
A Spiral antenna is well known to be suitable for many applications requiring a large bandwidth, circular polarization (RHCP and LHCP) like WLAN communications, Differential global Positioning system (DGPS) ground station .Generally this type of antenna is studied by various authors [2-6].In this paper , the fundamental principal of theory with spiral antenna is demonstrated .The same design is simulated using Method of Moments (MoM) and simulated on Ansoft_ HFSS_ software [1]. In most cases, the spiral antenna is fed at the center point of spiral graph. However, it is not always possible for the feed to be at the center of the antenna. Thus, it could be interesting to feed the device on the same plane. A 3-arm spiral antenna with coplanar feeding solution has been proposed in research[7] and a 2-arm with a outer feed in research[6]. In both cases, the lower frequency is around twice that of the theoretical lower frequency limit. Moreover, the shapes of the far field pattern doesn´t remain constant over the frequency range.

In this paper, a new spiral antenna with a band range is proposed.

2-Antenna Design (Basic Theory)
The spiral for two arms was constructed as shown below in Fig.(1) and also can be represented by the equation $r= ro\times e^{a(\varphi-\varphi o)}$, where r and *ro* are the radial distance and initial radial distance for each arm of the spiral, respectively; φ and φ_0 represent the angular position and initial angular position, respectively, and a is the expansion rate. The concept of active region states that the far-field radiation is mainly contributed from the region of about one-wavelength circumference and balanced feed is required for mode 1 operation.

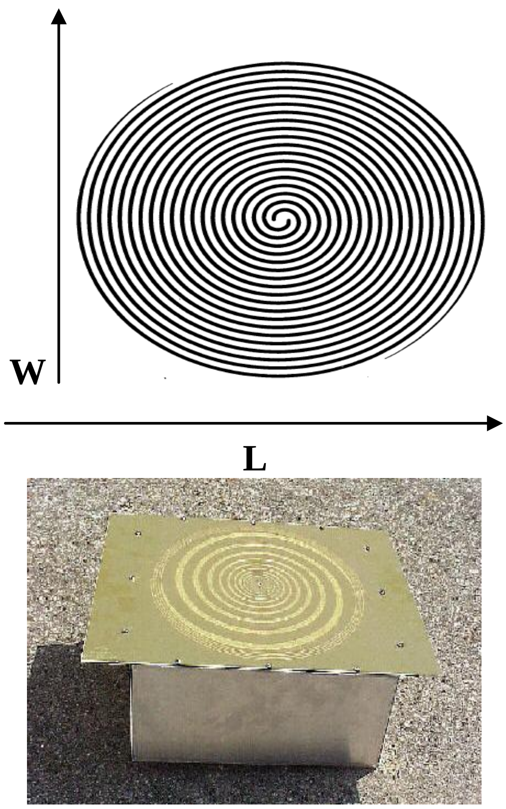

Figure (1) Archimedean spiral antenna

The current and phase distributions are the figure of merits to identify the traveling wave characteristics of spiral antennas. The total arm length was chosen for optimization of polarization and impedance bandwidth for the lower end frequency, while the other parameters were also optimized for bandwidth through simulation. When the spiral arm length equals approximately one wavelength, the impedance begins to match the feed line and the radiated wave achieves circular polarization (CP), which is desirable for optimal reception [2]. The chosen spiral arm length theoretically enables CP and impedance matching at 6 GHz and higher; however, the simulated and measured results indicated a better match at approximately 6 GHz. This is most likely due to the grounding effects of the spiral slot antenna, which reduce the bandwidth.We can consider the equiangular spiral curve, which is shown in Figure (2) representing the polar coordinates of a point from the origin [1] as shown :

$$r(\varphi)=r_0\tau(\varphi)$$

where $\tau(\varphi)=\exp(a\varphi)$ and a is the flare rate of the spiral. The equiangular spiral curve can be used to achieve the angular structure of equiangular spiral antenna[1,2]. For any q there is a ψ such that $qr(\varphi)=r(\varphi+\psi)$. It is seen that $q=\tau(\psi)$. where q is a factor ranging from 1<q<2; Thus, if a region of the spiral corresponding to a frequency f1 radiates for the condition $k_1r(\varphi)=1$ where $k_1=2\pi/\lambda_1=2\pi f_1/c$, when the frequency is reduced to f_2, there is an exactly similar region on the spiral for which $k_2r=1$.

Also $k_1r(\varphi)=k_2r(\varphi+\psi)=1$ gives $k_1/k_2=\tau(\psi)$ or $\psi=(1/a)\ln(k_1/k_2)$ in other words the similar region at f_2 is reached by rotating ψ degrees from φ on the spiral. It is also evident that the radiated field has also rotated by ψ. Far field expression for an antenna can be given by,

$$E(\theta,\varphi,r)= e^{-jkr}/r\ [a_\theta F_\theta(\theta,\varphi)+a_\varphi F\varphi(\theta,\varphi)]$$

where a_θ and a_φ are the unit vectors, $F_\theta(\theta,\varphi)$ and $F\varphi(\theta,\varphi)$ are the patterns. When the frequency is decreased by a factor of $\gamma= k_1/k_2$, the pattern rotates according to,

$$F\theta,\varphi\ (\theta,\varphi+1/a\ \ln\gamma\ ,\ f/\gamma)= F\theta,\varphi(\theta,\varphi,f)$$

If the field is almost uniform with φ then the pattern rotation cannot be observed. The radiation field is circularly polarized which may be explained using the traveling wave nature of the current distribution and that the radiation region of the spiral corresponds to $kr(\varphi)=1$ i.e. $2\pi r(\varphi)=\lambda$; two space orthogonal regions are separated by $\lambda/4$ and radiating elements are 90° out of phase results in circular polarization. The radiation mechanism of the spiral antenna can be explained on the basis of the traveling wave current model [3]. Figure (3-b) shows the two arms of a spiral antenna. The points M and Q are diametrically opposite with respect to the center 0. For anti phase feeding at A and B, the phase of the traveling wave currents at M and Q are also opposite. The phases of the currents at Q and P are out of phase by $\Delta\varphi=\beta(L_{PA}-L_{QB})+\pi$, where $\beta=k$ for TEM traveling wave currents. The phase difference becomes 2π at some point on the spiral and the currents in the vicinity of this point radiate constructively. The radius r where

$$\Delta\varphi=2\pi \text{ can be found from } \Delta\varphi=kL+\pi=2\pi.$$

$$L=(1+a^{-2})^{1/2}(r_P-r_Q)$$

$$\text{Where ; } r_P= r_0\, e^{a\varphi},\ r_Q= r_0\, e^{a(\varphi-\pi)} = r_P e^{-a\pi}$$

$$k(1+a^{-2})^{1/2}\, r_P(1-e^{-a\Pi})=\pi$$

$$k_{rP}=\pi/[(1+a^{-2})^{1/2}(1-e^{-a\pi})]$$

The usual expansion rate may be a=0.01 rad^{-1} for which $k_{rP}=1.016$. It is seen that for this value of "a"; $2\pi r_P=1.016$, i.e. the diameter of the active region $2r_P=\lambda/\pi$. The radiation mechanism of a planar spiral antenna hence becomes apparent from Figure (3-c). In-phase currents Iy<0° radiate constructivelytowards the bore sight direction as a broadside array. The space orthogonal currents Iy<90° radiate also into the bore sight direction, but with a 90° phase difference 90° phase difference comes from the traveling wave nature of the current and the fact that the circumference is one wavelength. The resultant bore sight field is thus circularly polarized. The sense of polarization depends on the direction of spiraling. In Figure (3-a), the spiraling is in $+\varphi$ direction and for a wave radiated into +z direction the wave is right hand circularly polarized wave. The radiated field rotates with the frequency by $\psi=(1/a)\ln(f_1/f_2)$ where if $f_1>f_2$, rotation is ψ degrees towards the center and vice versa occurs if f1<f2. The current distribution is decaying slowly up to active region (kr=1) and there is a small amount of radiation. After the active region the currents magnitude rapidly attenuates as a result of the radiation. The radiation pattern is bi-directional and almost rotationally symmetrical for a<0.2 rad^{-1}. For larger "a" pattern shows asymmetry and its rotation with frequency can be observed. The beam width is about 76° for a<0.2 rad^{-1} .

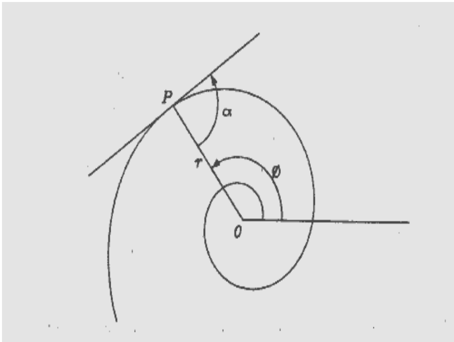

Figure (2) Basic Spiral Curve [1]

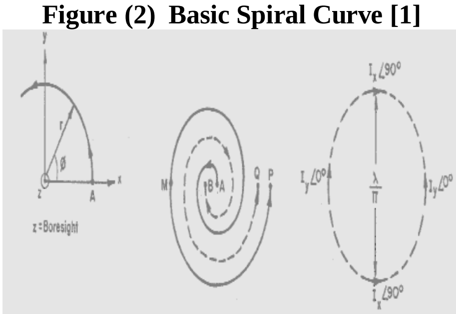

Figure (3-a) (3-b) (3-c)
Explaining the radiation mechanism by the radiating ring current[1]

2-1 Planar Archimedean Spiral Antennas

This type of spiral antenna is characterized by the polar equation $r=r_0(1+a\varphi)$ which is the first two terms of the Taylor's expansion of the equiangular spiral $r=r_0\exp(a\varphi)$ for small values of "a". The Archimedean spiral also exhibits all the main characteristics of the equiangular spiral. The operation of this spiral has been explained by Kaiser [8] using the radiating band concept. For small a<0.1 Archimedean and Equiangular spiral antennas are almost equivalent as far as the principle of operation is concerned and they both radiate from a diameter of about λ/π[2,6]. For a given diameter of the antenna greater bandwidth is obtained with more tightly wounded spirals (i.e. for small "a" values). So Archimedean spiral has a wider bandwidth with a given antenna diameter. However, the feed region of

Archimedean spiral is more tight and for this reason, equiangular spirals are better for higher frequencies especially for f>18 GHz. The circular polarization characteristics of Archimedean spirals at the low frequency end are better compared to than of Equiangular spirals. The azimuthal symmetry and axial ratio of the Archimedean spiral is also better than that of equiangular spiral. Further improvement of the axial ratio can be obtained by resistive loading of spiral arms at the exterior terms. Making the last half turn of the spiral resistive or by absorptive painting aqua dag between the two wires of last turn can either do this. The loading will reduce the end-reflected currents that radiate opposite sense of polarization. A disadvantage of the Archimedean spiral is that due to the large number of turns, the ohmic RF loss-resistance is large and this reduces the gain of the antenna [2].

2-2 Radiation Patterns and Polarization

Spiral antennas radiate Right Hand Circular Polarization to one side and Left Hand Circular Polarization to the other side. The radiating currents along the arms are traveling wave currents and their paths are clock-wise when considered from one side and counter clock-wise when considered from the other side. The radiated field from these traveling currents will also rotate in the direction same as the exciting currents.Therefore, the fields will be LHC polarized for clock-wise orientation of arms and RHC polarized for counter clock-wise orientation of arms [1,2].

3-Backing Cavity Design

It was stated that the spiral antenna has a bi-directional radiation pattern theoretically but in practical applications a unidirectional radiation is required. This can be achieved by mounting the spiral element onto the aperture of a cylindrical metallic cavity. The diameter of the cavity dc is slightly larger than the 15 diameter of the spiral antenna at the lowest operating frequency. At $f=f_{low}$,$d_c=q\lambda/\pi$ where q is a factor ranging from $1<q<2$. The gain of the antenna considering the end loading of spiral arms approaches +4 dBli (relative to linear isotropic source) and the bore sight axial ratio approaches to 1.5 dB at the same time, as the cavity diameter approaches to half wavelength ($d_c=0.5\lambda$). For $d_c=\lambda/\pi=0.318\ \lambda$ gain of the antenna G=-4 dBli and the axial ratio is 5 dB. This implies an active radiating region of 0.18 λ wide. The depth of the cavity should be ideally $\frac{\lambda}{4}$ so that the wave reflected from the bottom of the cavity are in phase with the wave in the desired direction. Note that during the reflection an extra _ radians phase shift is acquired in addition to $\pi/2+\pi/2=\pi$ radians path-length phase shift with the conclusion of the image principle. The cavity depth is a characteristic dimension dependent upon the wavelength so the frequency independent characteristics of the antenna are destroyed. Consequently, empty cavities are appropriate only for narrow band spirals. For wide band applications (40:1 for instance), cavity should be loaded with a microwave absorber. Disadvantage of this method is the reduction of the gain approximately 3 dB since the half of the radiated power is fully absorbed [3,2].

4-Feed Circuit

A feature of complementary structures concerning their input impedance is as follows [2,5]. Consider a metal antenna with input impedance Z metal. A complementary structure can be formed which is an antenna with air replacing the metal and metal replacing air and its input impedance will be Z air. Using Babinet's principle that the impedance of complementary antennas are related as follows

$Z_{air} \times Z_{metal}=\eta^2/4$ (η is the free space intrinsic impedance) If an antenna and its complement are actually same, they are called self complementary and their impedances are equal.

$$Z_{air} = Z_{metal} = \eta/2 = 188.5\ \Omega$$

This relationship is frequency independent, and also holds true for the impedance matrix of the n-arm spiral antenna. On the other hand, it turns out that many frequency independent antennas are not ideally self-complementary and still have relatively constant impedance [1]. Since the spiral antenna with anti phase feeding presents a balanced load, the feeder should be a balanced transmission line with the characteristic impedance nearly about $60\pi=188.5$ ohms ideally. But this value cannot be easily obtained practically. Due to the loading effect of dielectric substrate the impedance of the antenna reduces to $188.5/\sqrt{\epsilon_r}$ =130 Ohms approximately for a dielectric constant of 2.3. In practice, we almost always need an unbalanced 50 ohms coaxial input connector to the antenna. Thus, a wide-band 130 ohms to 50 ohms balun becomes an essential component of the antenna. The most popular baluns are printed circuit version of Marchand's balun and the tapered coaxial balun [2,4]. Second one has the advantage that, it is simple to realize and transforms the impedance at the same time, disadvantage is that the length of the balun should be 0.5 at the lowest operating frequency. Short baluns cause an unbalance at the feed point of the antenna, which has an adverse effect on axial ratio and produces beam squint (departure of electrical bore sight from geometrical bore sight). The beam squint is about 3° for good baluns and may increase to about 10° for poor baluns [2].

5-antenna specifications under study

The spiral has been designed from copper patch deposited on a substrate ($\epsilon_r=2.33$) with h=20 mil and size $4000\times4000\ mil^2$ with infinite waveguide boundaries. The spiral patch with W=1400 mil and L=1600 mil were used. The spiral was designed with an expansion rate of 0.3, initial inner radius of 60 mil, total arm length of 5000 mil, outer radius of 800 mil and arm slot ratio of 0.65.

6-Simulation Results

The MOM (Method of Moment) is to analyze this antenna with MWO (Microwave Office) software.

Figure (4) descript the S11 as the input impedance and reflection coefficient factor. VSWR (Voltage stand wave ratio) could be calculated from :

$$\mathbf{VSWR = (1+\ S11\ )/(1-\ S11\ )}$$

Figure (5) and figure (6) shows how input impedance (resistance R and reactance X) varied with frequency in the range under study.

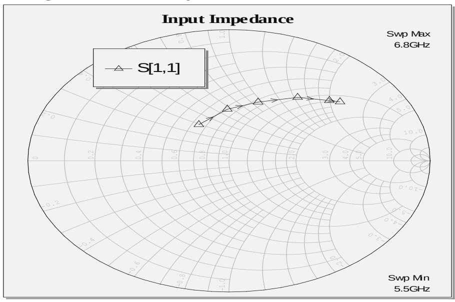

Figure (4) Input impedance and S11 Variations

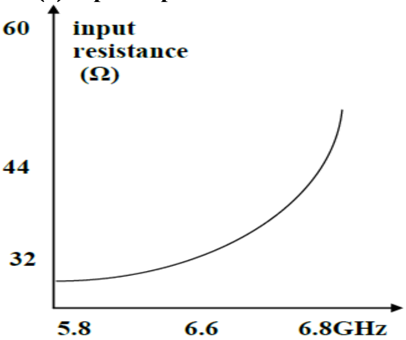

Figure (5) the variation of input resistance.

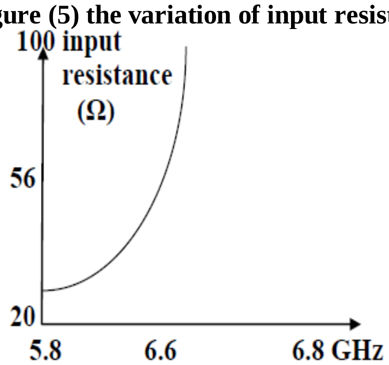

Figure (6) the variation of input reactance.

As shown in these figures (4,5,6) that the radiation spiral input impedance (within a range) is suitable for moderate match (VSWR between a and 2 units).

Figure (7) and figure (8) shows below ; depict PPC-RHCP (principal plane cut-right hand circular polarization) and PPC-LHCP (principal plane cut-left hand circular polarization) at φ =0 ,30º as a principal radiation patterns at center frequency 6 GHz.

RHCP and LHCP are obtained from following formulae :

RHCP=0.707 × (Eθ + j E φ)

LHCP=0.707 × (Eθ - j E φ)

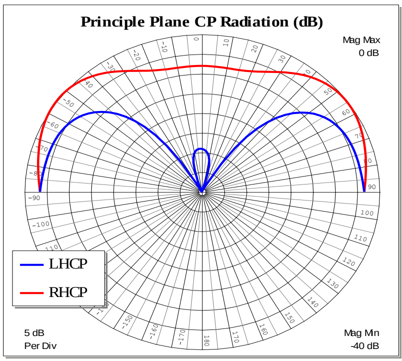

Figure (7) LHCP and RHCP at φ =0 .

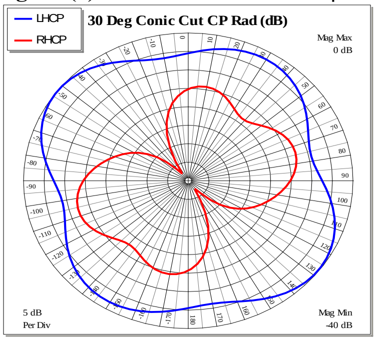

Figure (8)LHCP and RHCP at φ=30.

These radiation patterns give suitable gain and directivity as shown and look like Omni directional dipole . LHCP at φ =0 º and RHCP at φ = 30 º give two side lobes.

Conclusion

A spiral microstrip antenna with internal port, fed to antenna has been successfully designed and tested at frequency band 5.5-6.8 GHz. Such type of antenna may be used for wide band applications and found the experimental results and goals approaches theoretical ones.

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تصميم الهوائي الحلزوني المسطح في حزمة الترددات 5.5-6.8 كيكاهيرتز وباستخدام طريقة العزم

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الملخص

إن الهدف الجديد لهذا البحث هو الغرض منه تصميم هوائي حلزوني في حزمة الترددات 5.5-6.8 كيكاهيرتز . ولغرض تمثيل الهوائي الحلزوني رياضيا فان برمجيات المكتب المايكروي استخدمت لهذا الغرض وتم تصميم نموذج أولي للهوائي الحلزوني وتم اختباره لأغراض عمل منحنيات الانبعاث ومعامل الانعكاس الخاصة فيه على متن هذا البحث.إن شكل هذا الهوائي هو شبيه لذلك الهوائي التقليدي الارخميدي وبإعادة هذا التصميم الذي يسمح لتغذيته على نفس المستوى المصمم عليه حيث يمكن اعتبار مثيله مفيدا لتصميمه على عدة مستويات /أسطح . إن دراسة سلوك هذا الهوائي تم فحصها بواسطة برمجيات شركة فيكو(FEKO) التي استخدمت طريقة العزم (Mom.) .إن خواص هذا الهوائي بهذه الطريقة يبين نفس خواص الهوائي التقليدي الذي يتم تغذيته بطريقة متحد المستوى .تم اعتبار هذا الهوائي مسطح ودراسته على أساس دون استخدام الأرضي.