Multilayer Circularly Polarized Circular Annular Ring Patch

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ABSTRACT
This paper presents the effect on circular polarization of multilayer circular annular ring patch (CARP). A CARP have been fabricated on FR4 substrate of dielectric constant 4.2 and thickness 1.52mm. Experimental resonant frequency impedance bandwidth and Axial ratio of simple CARP, covered CARP, spaced dielectric CARP and CARP with two superstrates have been measured and simulated using full wave analysis methods. The Simple CARP is fed diagonal to the radiating patch by a 50Ω coaxial probe for determining circular polarization (CP) and 3dB Axial Ratio (AR) bandwidth. The simple CARP has been designed and fabricated and found to have a CP-3 dB axial ratio bandwidth of 15MHz at the center fundamental resonant frequency of 1.5514GHz. Covering the simple CARP with various dielectric material of varying thickness shows a 4% increase in 3dB AR bandwidth. Covering the CARP with constant thickness material but with varying dielectric material, both the 10dB impedance bandwidth and 3dB AR bandwidth shows 1.9% and 15% increase with respect to the simple CARP. This type of study is useful for wideband, high gain antenna and to calculate the radome and environmental effect on resonant frequency.

General Terms
Design, Experimentation Measurement, Performance, Perturbation, Verification.

Keywords
Circular Annular Ring patch, Axial Ratio bandwidth, Circular polarization, Resonant Frequency, Superstrate, spaced dielectric.

1. INTRODUCTION
Microstrip antennas are in great demand for wireless communication system in space and navigation applications. Various types of microstrip antennas have been studied so far like rectangular microstrip antenna, circular microstrip antenna, triangular microstrip antenna and annular microstrip antenna etc [2-3]. The serious limitations of microstrip antennas are their narrow bandwidth, low gain and poor efficiency. To enhance the bandwidth and gain of microstrip antenna, multilayered structures are required. In this regard several research papers have been reported [1] [4-5] [10-11]. The extensive study of multilayer rectangular microstrip antenna and multilayer circular microstrip antenna has been done in detail by present author [8-9]. For circular annular ring patch several research papers have been reported [6-7] in open literature, but the detail study of multilayer CP annular circular ring has not been reported for covered, spaced dielectric and annular ring with two superstrates. Perturbation techniques such as stubs, notches or embedded slit in the patch or ground plane are used for square and circular patch antenna to achieve CP [12-13]. Due to these perturbations, two degenerate orthogonal modes are exited having equal amplitude and in phase quadrature. For given resonant frequency an annular ring microstrip antenna has a smaller size compared to a square or circular patch antenna. If the circular annular ring is added with a strip in the inner circle then this antenna will exhibit circular polarization characteristics. In this paper a detail study of multilayer circularly polarized CARP have been presented for the resonant frequency, 10dB impedance bandwidth 3dB AR bandwidth and directive gain. Such type of study is useful to calculate the plastic effect on resonant frequency of portable antenna, environmental effect, improvement in gain and bandwidth of CARP with CP purity.

2. DESIGN OF CIRCULAR ANNULAR RING PATCH
Fig.1 shows the CARP. Circular annular ring microstrip antenna is printed on FR4 substrate of dielectric constant ε_r=4.2, thickness h=1.52mm and loss tangent tanδ=0.02 with ground plane size of 60mm x 60mm. This CARP consists of the ground plane, substrate and radiating patch with dimensions of outer radius ‘b’equal to 24.8mm and inner radius ‘a’ equal to 7.4mm. The feed position is optimized and located diagonally on the edge of inner circle fed by coaxial probe SMA connector. The feed position is optimized using the 3D EM commercial software. In order to provide circular polarization characteristics for the annular ring antennas, a microstrip line of width ‘w’ is embedded in the inner circle to obtain good matching at the low frequency. It is expected that, due to the embedded-slot perturbation, the effective excited patch surface current path in the y-direction is slightly shorter than that in the x-direction which gives the y-direction resonant mode frequency slightly larger than that of the x-direction resonant mode. That is, the fundamental mode TM_{10} can be split into two orthogonal near-degenerate modes for CP radiation. By selecting the probe feed at point P, left-hand CP operation can be obtained. Fig.2 shows the annular ring multilayer structure. The air spacers of various heights are introduced to create an air cavity between the actual radiating patch and the superstrates. The superstrates material is chosen for varying dielectric constants and varying thickness placed above each other denoted as ε_{r2}, ε_{r3}, h_2, h_3

respectively. From this multilayer annular ring structure various configurations of patch antenna can be studied like simple, covered, spaced dielectric and two superstrates. All the fabricated CARP are tested using R&S ZVA40 Vector Network Analyzer. In this paper, the multilayer effect on resonant frequency, 10dB impedance bandwidth, 3dB axial ratio bandwidth and directive gain is studied and compared for simple CARP, covered CARP, spaced dielectric and two superstrates placed on the simple CARP.

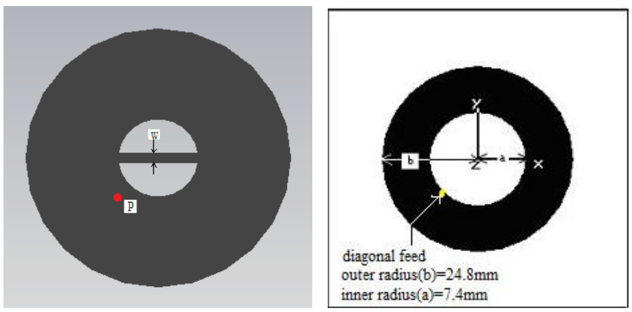

Figure 1: Structure of circular annular ring patch with 'a' radius of inner disc and 'b' radius of outer disc.

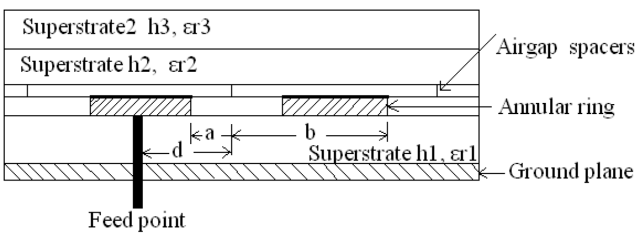

Figure 2: Multilayer Circular Annular Ring Patch

3. DESIGN EXPRESSION OF CIRULAR ANNULAR RING PATCH

For an Annular ring MSA with an inner radius 'a' and outer radius 'b', the expression for resonant frequency is given by

$$f_{nm} = \frac{k_{nm} c}{2\pi\sqrt{\varepsilon_r}} \quad (1)$$

where k_{nm} are the roots of the characteristic equation;

$$J_n^{'}(k_{nm}a)Y_n^{'}(k_{nm}b) - J_n^{'}(k_{nm}b)Y_n^{'}(k_{nm}a) = 0 \quad (2)$$

Where 'n' is order of the Bessel function and 'm' is m^{th} zero of the function $J_n'(ka)$ and; $J_n(x)$ and $Y_n(x)$ are the Bessel function of order n of first and second kind respectively, and the prime denotes derivatives with respect to x. To account for the fact that a small fraction of field exists outside the dielectric, it is common to use an effective permittivity ε_e in place of ε_r in equation (1)

$$\varepsilon_e = \frac{1}{2}(\varepsilon_r + 1) + \frac{1}{2}(\varepsilon_r - 1)\left(1 + \frac{10t}{W}\right)^{-1/2} \quad (3)$$

Where; $W = (b - a)$

4. RESULTS AND DISCUSSION

The circular annular ring patch is studied with simple, various superstrate cover material, varying air gap thickness for spaced dielectric and multilayer superstrates to determine the effect on resonant frequency, impedance bandwidth, axial ratio bandwidth and gain.

4.1 Simple Circular Annular Ring Patch

In the Simple CARP, the substrate size is 60 x 60mm^2 with h_1=1.52mm and ε_{r1}=4.2. The dimensions of annular ring are optimized for outer radius=24.8mm and inner radius=7.4mm. The feed position is also optimized along the diagonal with coordinates of (-7.6,-7.6) mm. In order to provide circular polarization characteristics for the annular ring antennas, a microstrip line of width 1mm is embedded in the inner circle and this antenna is named as simple CARP.

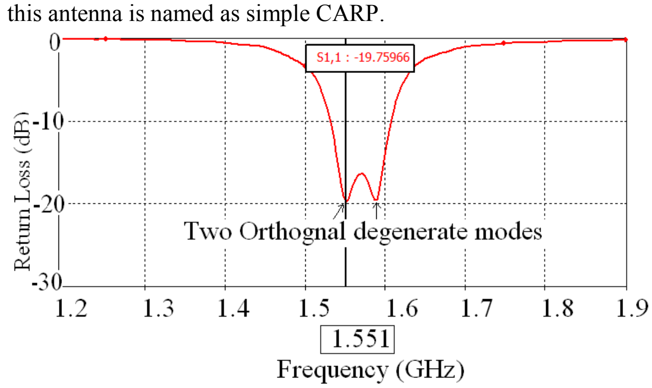

Figure 3: Return Loss characteristics of Simple CARP

Figure.3 shows the return loss characteristics of the simple CARP. By embedding the CARP with a microstrip line of width 1mm,the fundamental mode is split into two orthogonal near degenerate modes as indicated with equal amplitudes and 90° phase shift between them. This simple CARP resonates at the fundamental frequency of 1.551GHz. As the size of the CARP decreases, it is observed that the resonant frequency of dominant mode shifts towards the higher side. As the dimensions of CARP increases, the resonant frequency is lowered, because the effective current path for large size patch increases. It is also found that the resonant frequency of circular annular ring is shifted towards lower side in comparison to solid circular patch of same dimension which resonated at centre frequency of 1.69GHz. The %shift in fundamental resonant frequency of Simple CARP in comparison to a solid circular patch of equivalent outer radius 'b' is 8.22%. This is because of the current path in case of annular ring become more than that of the solid circular patch. The measured 10dB impedance bandwidth, 3dB axial ratio bandwidth and directive gain for the simple CARP is found to be 76.1MHz, 15.0MHz and 6.398dBi respectively. Such type of study is useful in estimating the exact dimensions of annular ring as well as to reduce the size of antenna. As inner radius 'a' increases, the resonant frequency reduces since current path through patch increases.

4.2 Circular Annular Ring with Cover

In this, the covered circular annular ring patch has been studied with substrate h_1=1.52mm, ε_{r1}=4.2 and cover thickness h_2 varying from 0.5mm to 5mm for five different cover material ε_{r2} =2.08(Teflon PTFE), 2.33(RT Roggers), 3.48(Rogers RO4350), 4.3(FR4),and 5(Porcelain).

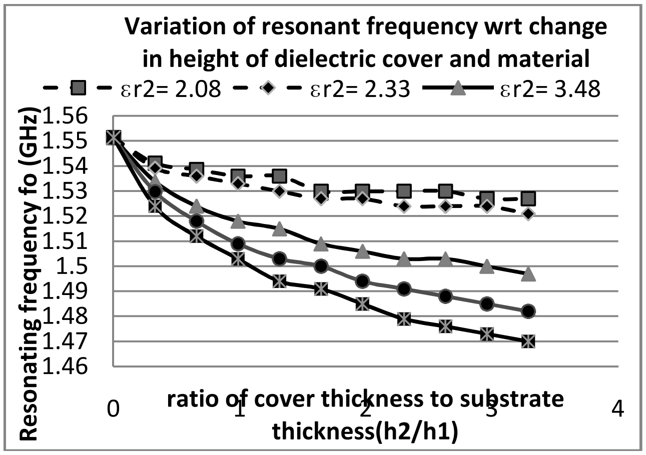

Figure 4: Effect of superstrate material thickness and dielectric constant on the centre frequency of CARP.

respect to change in cover thickness for all five different dielectric constant material. It is observed that as the simple annular ring patch is covered with dielectric; the resonant frequency is shifted towards lower side. This is because the effective dielectric constant of the radiating patch increases in comparison to simple annular ring patch. From figure4 it is seen that as the dielectric material constant increases the shift in the resonant frequency is more towards the lower side for a thicker cover. The average percent shift in resonant frequency due to cover in comparison to simple CARP is 0.97%, 1.35%, 2.32%, 3.09% and 3.67% for the cover of ε_{r2}=2.08(Teflon PTFE), 2.33(RT Roggers), 3.48(Rogers RO4350), 4.3(FR4),and 5(Porcelain) respectively. It is observed that percent shift increases with increase in cover thickness and dielectric constant. Figure5a and 5b compares the 10dB impedance bandwidth and 3dB axial ratio bandwidth of a simple CARP covered with ε_{r2} =2.08, 2.33, 3.48, 4.3 and 5 each of constant thickness h_2=2mm. In comparison to simple CARP the 10dB impedance BW is slightly reduced when a cover is introduced. As the ε_{r2} value increases the 10dB impedance BW still decreases. But the 3dB axial ratio bandwidth increases as the ε_{r2} value decreases. For ε_{r2} = 5 3dB AR BW = 13.7 MHz, indicates that circular polarization is impure for high dielectric constant values of the cover material. Such type of study is useful to calculate the effect on resonant frequency due to radome, effect of plastic cover on portable antenna and to enhance the gain of antenna.

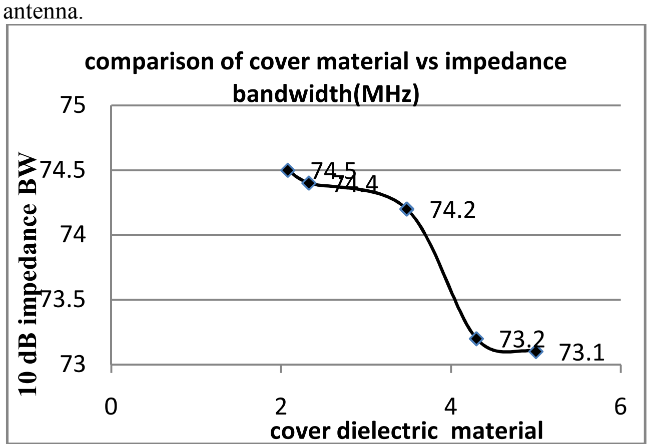

Figure 5a: Effect on 10dB imp. BW due to change in cover dielectric material

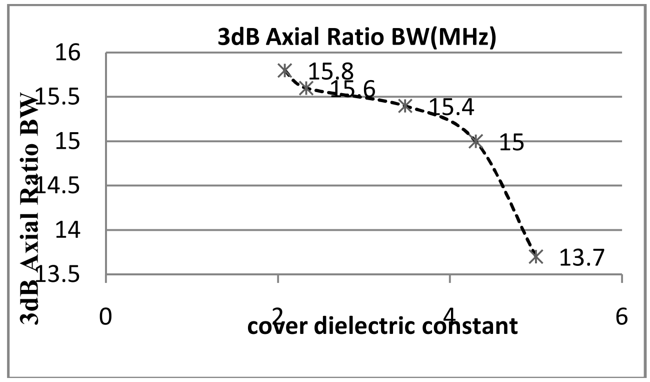

Figure 5b: Effect on 3dB AR BW due to change in cover dielectric material

4.3 CARP with Spaced Dielectric

In this, the spaced dielectric CARP has been achieved by substituting h_2=air gap varying, ε_{r2}=1; ε_{r3}=2.08 and h_3=2mm of Teflon material. Spaced dielectric increases the resonant frequency of covered CARP. As the air gap increases, the resonant frequency tends towards the resonant frequency of simple CARP. The incremental percent change with respect to air gap is small. This configuration is useful to calculate the effect on resonant frequency due to intentional or unintentional air gap over covered CARP. Basically plastic cover over the portable antenna is not very far from patch. It is useful to account the plastic with air gap effect on resonant frequency for portable antenna for wireless communication systems. Table 1 includes the measured resonant frequency, 10dB impedance bandwidth, and 3dB axial ratio bandwidth and directive gain of spaced CARP. The comparison has been carried out for air gaps varying from h_2=0.1mm to 3mm for spaced dielectric material of Teflon ε_{r3}=2.08, h_3= 2mm. The resonant frequency reduces due to spaced dielectric in comparison to Simple CARP. The percent shift in resonant frequency of spaced dielectric in comparison to simple CARP for air gap 0.5mm, 1mm and 2mm is, 0.77%, 0.52% and 0.13% respectively. This indicates as air gap increases the resonant frequency approaches towards Simple CARP. The comparison has been carried out for various air gaps varying from h_2=0.1mm to 3mm for spaced dielectric material of Teflon ε_{r3}=2.08, h_3= 2mm. The resonant frequency reduces due to spaced dielectric in comparison to Simple CARP. The percent shift in resonant frequency of spaced dielectric in comparison to simple CARP for air gap 0.5mm, 1mm and 2mm is, 0.77%, 0.52% and 0.13% respectively. This indicates as air gap increases the resonant frequency approaches towards Simple CARP.

Table1. Effect on resonant frequency, 10dB impedance BW, 3dB axial ratio BW and directive gain of spaced CARP

Substrate of h_1=1.52mm; ε_{r1}=4.2				
h_2/h_3 (airgap/cover)	f_o(GHz)	10dB impedance BW(MHz)	3dB AR BW (MHz)	Gain(dBi)
0.0(covered)	1.536	74.4	14.8	6.256
0.05	1.536	74.4	14.9	6.251
0.1625	1.536	74.6	15.0	6.23
0.275	1.539	76.0	15.3	6.263
0.3875	1.542	76.5	15.8	6.267
0.50	1.543	75.9	15.7	6.27

0.75	1.548	75.3	15.5	6.26
1.00	1.549	74.1	15.5	6.256
1.25	1.55	74.7	15.1	6.255
1.50	1.551	74.6	16.3	6.257

4.4 Circular Annular Ring Patch with Two Superstrates

This configuration of patch can be achieved by having substrate h_1=1.52mm, ε_{r1}=4.2 and two superstrates of dielectric constant ε_{r2}=4.3(FR4) and ε_{r3}= 2.08(Teflon). The simple CARP patch has been loaded with two superstrates. The effect of superstrate on resonant frequency, 10dB impedance bandwidth, 3dB AR bandwidth and gain has been measured. The second superstrate further decreases the resonant frequency of covered CARP. The percent decrease in resonant frequency in comparison to covered CARP and simple CARP is 0.78 % & 1.74% respectively. Table 2 shows the resonant frequencies, 10dB impedance bandwidth, 3dB axial ratio bandwidth and directive gain of two superstrates of Teflon material having h_2=2mm, ε_{r2}=2.08 and another superstrate of FR4 with h_3=1.53mm, ε_{r3}= 4.3 above the simple CARP. It is observed that the CARP covered with a single material of Teflon has the highest gain of 6.256dBi whereas the CARP covered with two materials of different dielectric constant has the minimum gain of 6.091dBi.

Table2. Effect on resonant frequency, 10dB impedance BW, 3dB axial ratio BW and directive gain of two covered CARP

Substrate of h_1=1.52mm; ε_{r1}=4.2				
Two superstrates	f_o(GHz)	10dB impedance BW(MHz)	3dB AR BW(MHz)	Gain(dBi)
h_2=2mm, ε_{r2}=2.08 (Teflon covered CARP)	1.536	74.4	14.8	6.256
cover1 of h_2=2mm, ε_{r2}=2.08; cover2 of h_3=2mm, ε_{r3}=2.08	1.53	73.8	16.0	6.127
cover1 of h_2=2mm, ε_{r2}=2.08; cover2 of h_3=1.53mmε_{r3}=4.3	1.524	74.5	15.4	6.091
h_2=1.53mm, ε_{r2}=4.3 (FR4 covered CARP)	1.509	73.8	14.6	6.240
cover1 of h_2=1.53mm, ε_{r2}=4.3; cover2 of h_3=2mm, ε_{r3}=2.08	1.503	74.0	15.9	6.110
cover1 of h_2=1.53mm, ε_{r2}=4.3; cover2 of h_3=1.53mm, ε_{r3}=4.3	1.494	73.7	14.8	6.099

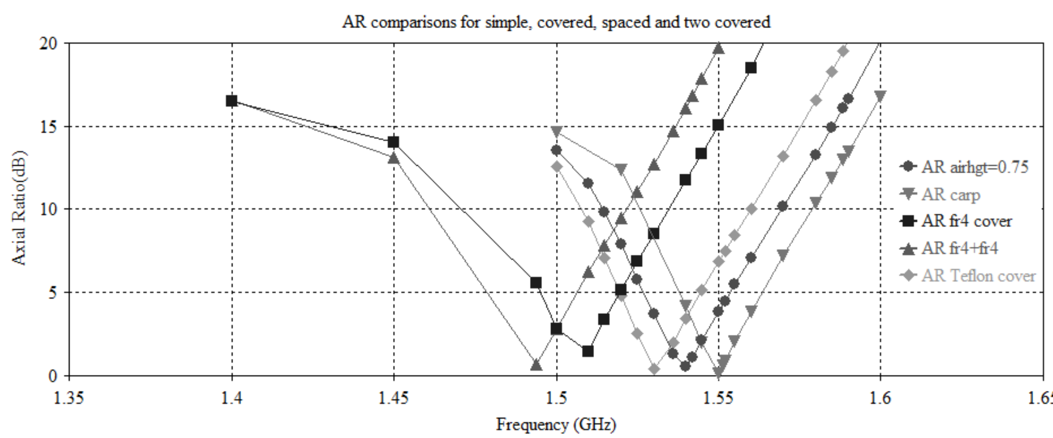

Figure 6: Axial ratio comparison of simple, covered spaced and two superstrate covered CARP

The CARP is analyzed by interchanging the superstrates as well as for two superstrates of same material above it. This type of configuration is useful to improve the gain of antenna as well as bandwidth by proper selection of superstrate thickness. This is also useful to estimate the effect on resonant frequency due to snow because sometimes antenna may be used in snowfall region. Figure 6 shows the comparison of axial ratio in dB with respect to frequency for all types of CARP. It is observed that along with the shift in the fundamental resonating frequency the axial ratio center frequency also shifts toward the lower side for spaced and covered carp in comparison to simple CARP. Also the 3dB axial ratio is highest which is 16 MHz when both covers are of ε_{r2}=2.08 and ε_{r3}=2.08. This gives improved CP purity. It is clear from figure 6, covered dielectric resonant frequency shifts towards lower side in comparison to simple annular ring patch, but spaced dielectric resonant frequency lies in between of simple and covered dielectric annular ring patch.

5. CONCLUSION

The CARP was analyzed using the FIM Method and compared for simple, covered dielectric and spaced dielectric configuration. The resonant frequencies of circular annular ring microstrip antennas are analyzed for various configurations of simple, covered, spaced dielectric and two superstrate loading. All the types of CARP are fabricated and a comparison is made between the experimental and calculated values of the resonant frequencies, 10dB impedance bandwidth 3dB axial ratio bandwidth and directive gain. The percent incremental change in resonant frequency for spaced dielectric is less than 0.2%. The percent incremental change due to second substrate in comparison to covered dielectric is less than 0.5%. The 3dB axial ratio bandwidth for circular polarization is achieved by diagonal feeding the CARP with embedded microstrip line of width 1mm at the inner circle. It is found that the 3dB axial ratio BW improves with multilayer CARP covered with a lower value of dielectric material. Also this type of configuration shows an increase in the directive gain in comparison with CARP covered with a higher value of dielectric constant material. Such type of study is useful for calculating the effect on resonant frequency, improvement of gain and bandwidth of portable antennas. Additionally, the CARP is suitable for covered antenna devices and is directly applicable for the integration of microstrip antennas beneath plastic covers or protective dielectric superstrates in portable wireless equipments.

6. ACKNOWLEDGMENTS

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