DOUBLE FEED WRAPAROUND MICROSTRIP ANTENNAS ON CYLINDRICAL STRUCTURES FOR CIRCULAR POLARIZATION

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ABSTRACT - *The circular polarization for a wraparound microstrip antenna on a thin cylindrical substrate excited at higher order modes and require different feed arrangements for different mode excitations has been studied. The theoretical study is based on the model-expansion theory, which is valid for the thin-substrate case. Numerical results for the aspect ratio of the wraparound patch, the optimal feed points for optimal voltage standing-wave ratio, minimum cross polarization level, and the 3-dB bandwidth for circularly-polarized radiation are analyzed. Effects of the curvature on the circular polarization condition are also discussed.*

I. INTRODUCTION

WRAPRAOUND Microstrip Antennas find many applications in high-speed aircrafts, missiles and spacecrafts, because of their conformity with the aerodynamical structure of such vehicles. Recently, there has been some progress in the theoretical study of such antennas [1-6]. The curvature effects on the resonant frequency, radiation pattern, input impedance, quality factor, directivity, radiation efficiency, and cross polarization level have also been investigated.

In this paper, we extend the study, and report on the results, of a double feed circular polarization for such wraparound microstrip antenna which do not appear to be available in the literature. The thin-substrate condition is assumed in this study, which allows the use of model-expansion approximation [4,5,6,7,9]. By calculating the equivalent magnetic current along the edges of the wraparound patch, the far-zone electric fields are determined [5,6]. The aspect ratio and the operating frequency of the wraparound patch antenna are then adjusted for circularly-polarized radiation. The optimal feed points are also studied for optimal voltage standing wave ratio(VSWR), minimum cross polarization level [5], and the 3-dB bandwidth of circular polarization. The results for a wraparound patch with various curvatures are also analyzed. Details of the theoretical formulation are presented in section II. The numerical results and discussion are given in section III. Conclusions are drawn in section IV.

II. THEORETICAL FORMULATION

The geometry of a wraparound microstrip patch antenna placed on a cylindrical body is shown in Fig.(1). The structure consists of infinitely thin metallic strip wrapped around a dielectric-coated cylinder of radius "b". The strip width is "2ℓ" and its length $L=2\pi b$, where $b=a+h$, where the metallic cylinder is of radius " a " and the dielectric layer has a thickness "h" with a relative permittivity ε_r. The curved patch is also assumed to be probe fed at point (ϕ', z'). 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. For a value of " h" much smaller than the wavelength, the cavity model or model-expansion can be adapted for analyzing the patch antenna on a thin substrate. In this case the resonant frequencies of the TM_{mn} modes, under the additional condition that $h \ll a$, are given as [6]

$$f_{mn} = \frac{c}{2\sqrt{\varepsilon_r}}\sqrt{\left(\frac{m}{a+h}\right)^2 + \left(\frac{n\pi}{2\ell}\right)^2} \quad (1)$$

Where m, n = 0, 1, 2,.. each, and c is the velocity of light in free space.

In order to calculate the far-zone fields, we model the probe feed to be a $\hat{\rho}$-directed unit-amplitude current ribbon. In this case the electric fields under the patch have only an $E\rho$ component, which is independent of ρ. This expression for $E\rho$ can be written as [5,6]

$$E_\rho = j\omega\mu \sum_n \sum_m C_{mn} \cos(\phi - \phi') \cos\frac{n\pi}{2\ell}(z - \ell) \quad (2)$$

where the quantity ω is the wave angular frequency, μ is the free-space permeability, and C_{mn} is the expansion coefficient for the TM_{mn} mode and is given in [5,6].

From the results of (2) the equivalent magnetic currents along the edges of the wraparound patch can then be calculated [5,6]. The expressions for the far-zone electric fields for the TM_{mn} modes excited by a single coax feed, can then be written as [5,6]

$$E_\theta = \frac{\omega\mu h}{\pi r} e^{-jk_0 r} \frac{e^{jk_0 \ell\cos\theta}}{\sin\theta} \sum_n \sum_m C_{mn}$$

$$\left(1-(-1)^n e^{-2jk_0\ell\cos\theta}\right) \frac{j^{m+2}\cos m\phi}{H_m^{(2)}(k_0 a\sin\theta)} e^{-jm\phi'} \quad (3)$$

$$E_\phi = \frac{\omega\mu h}{\pi r a} e^{-jk_0 r} \frac{\cos\theta\, e^{jk_0\ell\cos\theta}}{k_0 \sin^2\theta} \sum_n \sum_m C_{mn}$$

$$\left(1-(-1)^n e^{-j2k_0\ell\cos\theta}\right) \frac{j^{m+2} m \sin(m\phi)}{H'^{(2)}_m(k_0 a\sin\theta)} e^{-jm\phi'} \quad (4)$$

where $H_m^{(2)}(..)$ is the Hankel function of the second kind and m_{th} order, and $H'^{(2)}_m(..)$ is the derivative with respect to the argument of the Hankel function.

For circular polarization excitation [8], two feeds with proper angular spacing are needed as shown in Fig. (2) with this spacing, the fields generated from the two feeds are orthogonal to each other under the patch as well as outside the patch. In addition, with this angular spacing, one probe is always situated in the null field region of the other probe, thus, causing very little mutual coupling between the probes. Certainly, as is conventionally done, the two probes are required to be fed 90° out of time phase for achieving circular polarization. The angular spacing between two feed probes is different for each different mode. Some of these angular spacing are tabulated in Table I (see Fig. (2)and(3)). In order to preserve beam symmetry and to keep cross polarization low, especially for relatively thick substrate radiators, the unwanted modes need to be suppressed. Generally, the two neighboring modes of a resonant mode have the next highest magnitudes. one way to suppress these adjacent modes is to employ two additional feed probes located diametrically across from the two original feeds. Together, these four feeds should have a phase arrangement of 0°, 90°, 0°, 90° for the even-order modes and 0°, 90°, 180°, 270° for the odd-order modes so that the fields of the unwanted modes from the two opposing fields cancel. Some examples of the feed angular and phase arrangements are illustrated in Fig. (3). The total radiated fields from these four-feed excited the patch can be written as follows:

$$E^t_\theta = E^1_\theta(\phi',\theta) + jE^2_\theta(\phi'+\alpha,\theta) + \text{sgn}(n)\{E^3_\theta(\phi'+180°,\theta) + jE^4_\theta(\phi'+180°+\alpha,\theta)\} \quad (5)$$

$$E^t_\phi = E^1_\phi(\phi',\theta) + jE^2_\phi(\phi'+\alpha,\theta) + \text{sgn}(n)\{E^3_\phi(\phi'+180°,\theta) + jE^4_\phi(\phi'+180°+\alpha,\theta)\} \quad (6)$$

where superscripts 1, 2, 3, and 4 indicate the four feeds with their individual E-fields obtained from (5) & (6), α is the feed angular spacing and is given in Table I, sgn(n) = +1 if n is even and sgn(n) = -1 if n is odd.

TABLE I

FEED PROBE ANGULAR SPACING FOR CIRCULAR POLARIZATION AT DIFFERENT RESONANT MODE

	TM_{11}	TM_{21}	TM_{31}	TM_{41}	TM_{51}
α	90°	45°	30°	22.5°	15°

In order to produce circularly-polarized radiation the following two conditions need to be satisfied:

$$\angle E^t_\theta - \angle E^t_\phi = \pm 90° \quad (7.a)$$

and

$$\left|E^t_\theta\right| = \left|E^t_\phi\right| \quad (7.b)$$

The above conditions can be achieved by carefully selecting the aspect ratio R (= $\frac{b}{2\ell/\pi}$) of the curved patch and the corresponding operating frequency. Another important factor to be considered is the impedance matching of the patch antenna with coax cable feed with Z_0=50 ohms. That is, the optimal selection of the feed point is required to aviod any mismatch. Following the above theoretical treatment, the numerical results and analysis for the circular polarization design of a wraparound patch antenna are given below.

III. NUMERICAL RESULTS AND DISCUSSION

For the following numerical calculations the substrate thickness is selected to be 1.59 mm and its relative permittivity is 2.32. The radius of the cylinder is chosen to be 10 cm and the strip width is varied, which allows for using different aspect ratios. We first consider the case of feeding the wraparound patch at point $(\phi' = 10°, z' = \ell)$. Figures (4), and (5) show the axial ratio and absolute phase difference for E_θ and E_ϕ versus both resonance frequencies and the aspect ratio for TM_{11}, and TM_{13}- modes, respectively. The results for three different operating frequencies, f=5.32, f=5.73, and f=6.24 GHz, are shown in Fig.(4), while the results for three other operating frequencies, f=5.8, f=6.36, and f=7.07 GHz are shown in Fig.(5). It can be seen that each operating frequency has a corresponding aspect ratio to satisfy the 90° phase difference of the radiated fields. In practical cases there are still many other operating frequencies having an aspect ratio to satisfy the 90° phase difference requirement for circular polarization. We select the one with minimum axial ratio (=20 log $|E_\theta / E_\phi|$) to be the optimal aspect ratio and optimal center frequency. The optimal aspect ratio studied here is found to be 5.64 for TM_{11} -mode and 5.92 for TM_{13} -mode. The corresponding 3-dB bandwidth is found to be about 160 MHz for TM_{11} -mode and 166 MHz for for TM_{13} -mode. The phase difference within the operating bandwidth is found to be in the range from about 65° to 90° for both TM_{11} and TM_{13} modes

The cross polarization level for wraparound patch antennas is found and its expression has been given [5]. The obtained results for TM_{11}-mode are drawn in Fig.(6). It can be noticed that the antenna has minimum cross polarization at this optimal selection.

The VSWR values inside the operating bandwidth has also been analyzed for TM_{11}-mode by calculating the input impedances of the wraparound patch whose expression has been given in [6]. The variations of the VSWR versus the frequencies within the 3-dB bandwidth is shown in Fig.(7). The results are calculated for a wraparound patch fed at the optimal feed point. It is found that the VSWR values inside the operating bandwidth are within the range 1.03 to 1.43. That is, within the operating bandwidth, the VSWR is quite stable and shows a reasonably good matching condition.

The 3-dB bandwidth versus the curvature radius are also analyzed. It was found that the effect of the curvature radius within the range 5-30 cm on the bandwidth is very small.

IV. CONCLUSIONS

The circularly-polarized radiation from a wraparound patch antenna excited at higher order modes has been studied. Different feed arrangements are required for different mode excitations. It is found that the 3-dB bandwidth increases at higher order modes. The curvature effect on the bandwidth has been found negligible. It is noted that this technique for generating circular polarization may have only limited applicability because of its narrow bandwidth (≅3.5 %), but it is considerably better than using the rectangular-cylindrical microstrip patch.

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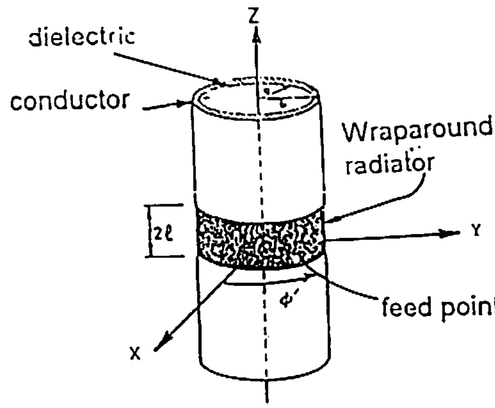

Fig.1 Geometry of wraparound microstrip antenna.

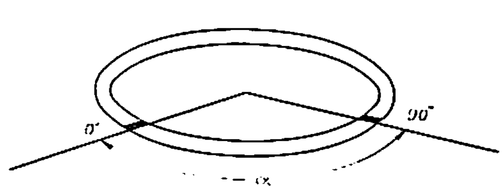

Fig.2 Two-probe feeds with proper angular spacing for exciting circular polarization.

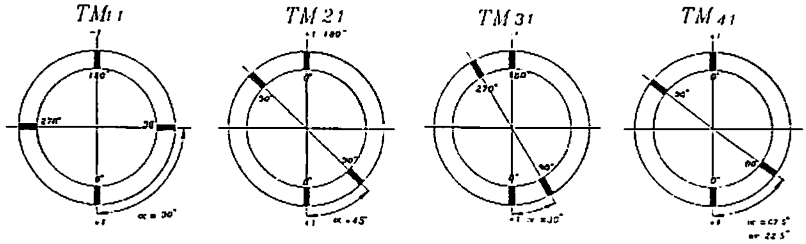

Fig. 3 Four-probe feeds with proper angular and phase arrangements for exciting different resonant modes with circular polarization for wraparound microstrip patch.

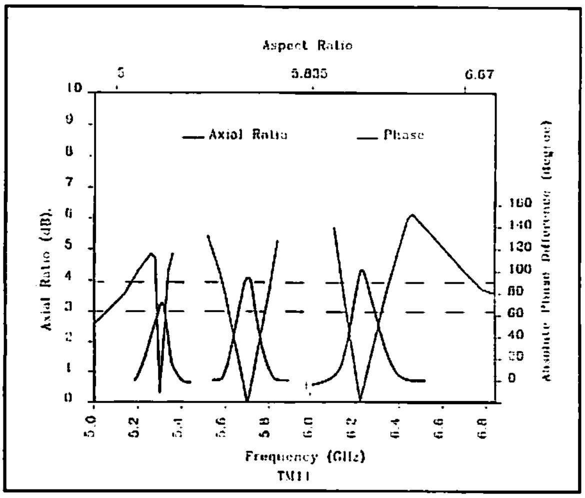

Fig. (4) Axial ratio and phase against frequency and aspect ratio of TM_{11}- mode, for wraparound patch, a = 10 cm, ε_r=2.32, h = 1.59 mm, in the plane $\phi = 90°$.

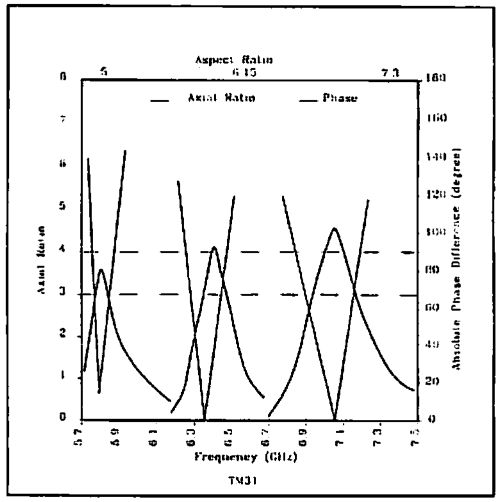

Fig. (5) Axial ratio and phase against frequency and aspect ratio of TM_{13}- mode, for wraparound patch, a = 10 cm, ε_r=2.32, h = 1.59 mm in the plane $\phi = 90°$.

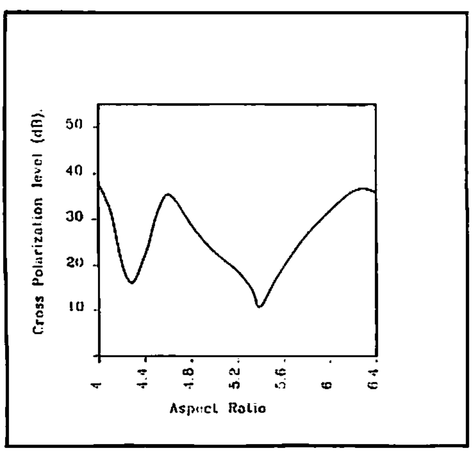

Fig. (6) Cross polarization level as a function of aspect ratio,for the wraparound patch with a = 10 cm, ε_r=2.32, h = 1.59 mm, $\phi' = 10°$, $z' = \ell$, in the plane $\phi = 90°$.

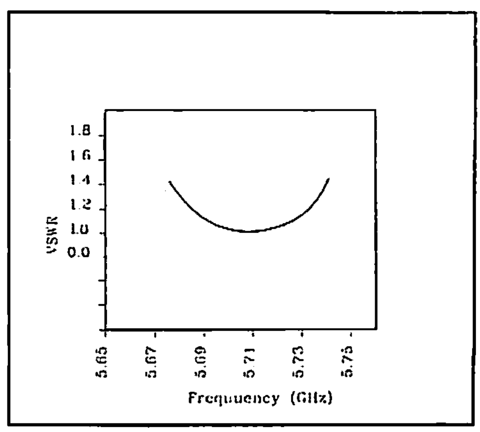

Fig. (7) VSWR versus 3- dB operating bandwith for the wraparound patch with a = 10 cm, ε_r=2.32, h = 1.59 mm, $\phi' = 10°$, $z' = \ell$, for TM_{11}- mode.