Circularly Polarized Broadband Antenna with L-shaped Probe and Partially Covered Circular Wide-slot

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Abstract- A novel type of circularly polarized broadband antenna consisting of a modified circular wide-slot aperture and an L-shaped feed probe is introduced. The modified circular wide-slot is partially covered to generate circular polarization with broadband characteristics in the axial ratio. Variations in both the axial ratio and the $S_{11}$ characteristics of the device are investigated and radiation patterns at several frequencies are presented.

Index Terms - Broadband, Wide-slot antenna, Circular polarization, Axial ratio, L-shaped probe

I. INTRODUCTION

Circularly polarized broadband antennas and polarizers have been investigated [1] - [4] for use in satellite communications and pulse radars, primarily due to their ability to handle large volumes of information. For these applications, broadband characteristics are required in both input impedance matching and radiation characteristics, such as the axial ratio (AR) and gain.

A typical type of broadband circular polarization antenna would be a spiral antenna. A monofilar spiral antenna provides an AR bandwidth of 23% by use of a metallic reflector [3]. In [4], a circularly polarized horn antenna using a waveguide and an L-shaped feed probe exceeds the 2.5 GHz band, and the antenna’s axial ratio and gain characteristics demonstrate broadband characteristics capable of maintaining a high gain level of 16 dBi from 8.3 to 10.5 GHz (23%). Furthermore, it utilizes a very simple circular-polarization (CP) generator in the waveguide. However, a planar structure is still required for the circularly polarized broadband antennas for mobile terminal applications.

Planar wide-slot antennas have also been investigated [5]. These antennas utilize a sliced waveguide-coaxial cable transformer resulting in lightweight, low-profile antennas that are easy to fabricate by printing techniques.

For the purpose of fabricating a planar antenna with broadband circular polarization, this paper deals with a wide-slot antenna fed by an L-shaped probe (L-probe). The results of simulated input and far-field characteristics are compared along with experimental results.

II. STRUCTURE

Figure 1 shows the structure of the proposed antenna. A partially covered circular wide-slot is fabricated on a dielectric substrate (Arlon 522, $\varepsilon_r = 2.5$, $\tan \delta = 0.002$) (see Fig. 1(a)), and an L-shaped probe is fabricated on the other side of the dielectric (see Fig. 1(b)). The black areas in the figures indicate 18-μm-thick metallic parts on the substrate. However, the metallic parts in our simulations (created using Ansoft HFSS Ver. 10) are assumed to be perfect conductors with zero thickness. The current phase on the horizontal component with $L_h$ length lags behind that of vertical component with $L_v$, which causes the 90° out of phase orientation between $E_x$ and $E_z$ of the polarization.

In relation to the feed probe, the input impedance at the edge of slot is capacitive. In order to nullify this, the probe is extended outside to the substrate edge through an inductive microstrip line structure with a characteristic impedance of 116 Ω (width of 0.4 mm), resulting in matching to 50 Ω feed line. This simple matching structure is available for the antenna structure even though the bandwidth exceeds 50% of the current structure. The opposite end of the L-probe has been extended in the x direction from the slot edge by approximately one quarter of a wavelength at 3.2 GHz (center frequency of −10-dB $S_{11}$ band) and has been opened.

The dimensions of the probe are discussed in the next section.
Fig. 1 Geometry of the proposed antenna.

Fig. 2 Behavior of electric field with respect to phase.
The wide-slot was initially designed as a full circle; however, the circular slot was subsequently partially covered, resulting in the shape as shown in Fig. 1(a). To explain the reason for this modification, Fig. 2 shows the behavior of an electric field in a fully circular wide-slot as a function of phase. The vectors in the figure indicate the electric field rotating to the right in the second quadrant (Q2, x<0 and z>0), third quadrant (Q3, x<0 and z<0), and fourth quadrant (Q4, x>0 and z<0). These behaviors combine to generate right-hand circular polarization propagating in the +y direction. However, the field vectors in Q1 (x>0 and z>0) rotate in the opposite direction to the rotations in the other quadrants. The behavior in Q1 causes a deterioration in AR. In order to improve this, the Q1 area of the circular wide-slot has been covered to prevent the electric field from having an effect in this quadrant. As a result, the structure was modified to the present configuration.

### III. PARAMETER STUDIES

The fixed structural parameters shown in Figs. 1, 3 (a) and 3(b) show the variation in both simulated $S_{11}$ and AR characteristics in the boresight direction (see next section) with $L$ and fixed parameters of $L_v = 18$ mm and $L_h = 41.5$ mm. With an increase in the $L$ from 46 mm to 50 mm, the $S_{11}$ around 2.5 to 3.0 GHz increases and approaches -10 dB (Fig. 3(a) $S_{11}$ and Fig. 4(a) $S_{11}$ with $L_v$).

![Graphs showing $S_{11}$ and AR variations](image1)

Fig. 3 Variation in $S_{11}$ and AR with $L$.

![Graphs showing $S_{11}$ and AR variations](image2)

Fig. 4 Variation in $S_{11}$ and AR with $L_h$. 
(a)), while the AR decreases sensitively below 3 dB reducing the AR bandwidth (Fig. 3 (b)). Consequently, $L$ was chosen to be 48 mm, which is longer than the slot radius, in order to obtain the widest bandwidth in $S_{11}$ and AR.

The axial ratio is also sensitive to the structural parameters on the L-shaped slot. Therefore, the effect of $L_{h}$ and $L$ on both $S_{11}$ and AR was investigated (see Figs. 4 and 5).

An increase in $L_{v}$ from 41.5 mm with fixed parameters of $L_{h}=20$ mm and $L=48$ mm shifts the -10-dB $S_{11}$ band lower in frequency (see Fig. 4(a)) because the imaginary part of input impedance increases around the serial resonance frequency of 3.7 GHz. However, $S_{11}$ around 2.5 to 3 GHz increases because the real part of the input impedance decreases. At the same time, $S_{11}$ around 3.5 to 4 GHz decreases. This is because the impedance of parallel resonance at around 4.5 GHz increases approaching to $50+j0 \Omega$. On the other hand, the lowest frequency of the AR band shifts lower, as shown in Fig. 4(b). Consequently, $L_{v}$ was chosen to be 43.5 mm so as to yield the widest bandwidths possible in both $S_{11}$ and AR band.

Similarly, as shown in Fig. 5, when the $L_{v}$ increases from 18 mm with the fixed parameters $L=48$ mm and $L_{h}=43.5$ mm, the $S_{11}$ around 2.5 to 3 GHz increases while the $S_{11}$ around 3.5 to 4 GHz decreases at the same time. The AR band is sensitive to the $L_{v}$, because the phase differences between the vertical and horizontal components of the polarization depend mainly on this pa-
(a) 2.5 GHz in x-y plane.

(b) 2.5 GHz in y-z plane.

(c) 3.0 GHz in x-y plane.

(d) 3.0 GHz in y-z plane.

(e) 4.1 GHz in x-y plane.

(f) 4.1 GHz in y-z plane.

Fig. 8 Radiation patterns.
rameter. As the result of the variation in both $S_{11}$ and AR in Fig. 5, $L_v$ is chosen to be 20 mm in order to obtain the widest bandwidth in both $S_{11}$ and AR band.

IV RESULTS

A. $S_{11}$ and AR bandwidth

Using the structural parameters of $L = 48$ mm, $L_h = 43.5$ mm, and $L_v = 20$ mm, the 57% (from 2.4 GHz to 4.3 GHz in the experiment) of -10 dB $S_{11}$ bandwidth is obtained as shown in Fig. 6. Good agreement was obtained between simulated and measured results within 100 MHz difference in the $S_{11}$ bandwidth. However, the magnitude of $S_{11}$ differs for the frequencies in the range from 3.5 to 4 GHz. The main reason for this difference is probably fabrication errors with respect to the width of the inductive microstrip line, on which the current density is relatively high.

Figure 7 shows simulated and measured AR characteristics. The measured AR bandwidth of 58% (from 2.3 to 4.2 GHz in the experiment) is obtained in the direction of boresight fitting with simulated results. Compared to the circular waveguide using the similar L-shaped probe [4] the present structure shows broader characteristics by 30% in both $S_{11}$ and AR. This is probably because higher-order modes, which limit the AR band in the waveguides, are unable to exist in the present wide-slot structure.

B. Radiation patterns

Figure 8 shows simulated (S) and measured (M) radiation patterns at different frequencies. The azimuth angles in each pattern start from the $+x$ or $+z$ direction shown in Fig. 1 for the x-y plane and the y-z plane, respectively. Good agreements between measured and simulated patterns were obtained at 2.0, 3.0, and 4.1 GHz for co-polarization. There are small differences in the cross-polarization, primarily resulting from a fabrication error with respect to choosing $l$. This indicates that cross-polarization should be reduced further, even though the axial ratio is less than 3 dB.

Regarding the beam direction, the main beam in the y-z plane is aimed at around 70° and 290°. As for x-y plane, the main beam is aimed at 80° and 280° at each frequency. This main beam direction shows the AR characteristics with respect to frequency as shown in Figs. 3-5 and 7. This tilt is probably due to the unsymmetrical slot shape of the modified circular structure. Finally, the antenna gain is almost constant at 5 dBiC in the main beam direction.

V. CONCLUSIONS

The novel structure of a unique circularly polarized broadband antenna that combines an L-shaped probe with a partially covered circular slot has been presented. A principle that can be used to generate CP using the proposed structure has been presented using an L-shaped probe and a modified circular wide slot. Using the above, a 3-dB AR bandwidth of 58% and matching bandwidth of 57% were obtained at 3.2 GHz.

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REFERENCES


