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An L-band, Circularly Polarized, Dual-Feed, Cavity-Backed Annular Slot Antenna with Wide-Angle Coverage

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Abstract

An L-band, circularly polarized, dual-feed, cavity-backed annular slot antenna has been investigated. The investigations comprise parametric studies of design parameters and measurements with different ground planes. The antenna has an impedance bandwidth of 6 % around 1.59 GHz and a maximum directivity of about 7 dBi.

Introduction

This paper presents results from an investigation of a circularly polarized cavity-backed annular slot (CBAS) antenna. The antenna operates in the L-band around a center frequency of 1.6 GHz and yield wide-angle coverage. It is possible to obtain circular polarization with only a single feed by employing various perturbations to the slot [1] or by shorting the slot [2], however, such solutions are usually associated with low axial ratio bandwidths and instead two feeds in phase quadrature are used. Similar antennas, though of different implementation, were previously reported in [3, 4]. Initial design investigations comprise extensive numerical computer simulations using Ansoft's HFSS ver. 9.2. Subsequently, an antenna prototype has been constructed and measured at the DTU-ESA Spherical Near-Field Antenna Test Facility. Three different ground planes were used to investigate the influence of these on the wide-angle performance of the antenna. A comprehensive documentation of the work on this antenna can be found in [5].

Antenna Design and Impedance Characteristics

The CBAS antenna is shown in figure 1. It consists of an annular slot, with mean radius ρ_s and width w_s, which is etched in the single copper layer of a copper-clad Rogers RO-4003 substrate with the relative permittivity ϵ_r and thickness t. The annular slot is backed by a circular metallic cavity with interior radius ρ_c and depth h_c and mounted on a small circular ground plane. The annular slot is excited by two 50 Ω coaxial cables, denoted feed 1 and feed 2, respectively. Feed 2 is phased with a 90º lag with respect to feed 1 resulting in right-hand circular polarization in the boresight direction. The harmonic time dependence $e^{j\omega t}$, with t and ω being the time and angular frequency, respectively, is assumed and suppressed.

The values of the above design parameters were chosen on basis of extensive numerical simulations and are summarized in figure 1. The simulations have led to the following observations on the qualitative behavior of the resonance frequency f_{res} and impedance bandwidth BW.

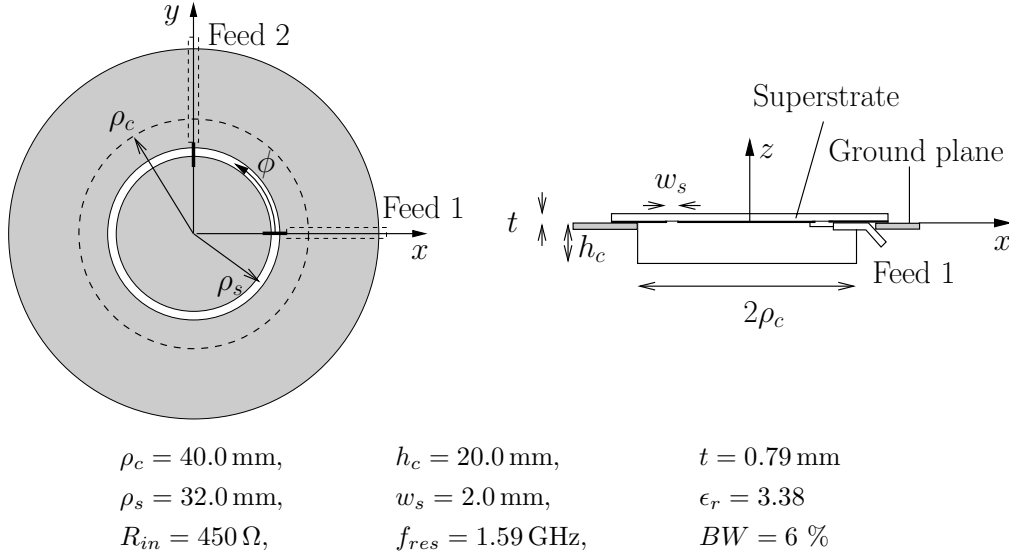| $\rho_c = 40.0\,\text{mm},$ | $h_c = 20.0\,\text{mm},$ | $t = 0.79\,\text{mm}$ |
| $\rho_s = 32.0\,\text{mm},$ | $w_s = 2.0\,\text{mm},$ | $\epsilon_r = 3.38$ |
| $R_{in} = 450\,\Omega,$ | $f_{res} = 1.59\,\text{GHz},$ | $BW = 6\,\%$ |

Figure 1: Geometry of the CBAS antenna and the chosen design parameters. For simplicity the dielectric superstrate is not shown on the top view.

- f_{res} decreases for increasing values of the cavity dimensions ρ_c and h_c as well as slot parameters ρ_s, ϵ_r, and t. It increases for increasing values of w_s.

- BW increases for increasing values of ρ_c, h_c, and w_s but has been found to be independent on ρ_s. It decreases for increasing values of ϵ_r and t.

The input impedances $Z_{in,i} = R_{in,i} + jX_{in,i}$ and input reflection coefficients $\Gamma_{in,i}$ at the two ports, $i = 1, 2$, can be determined from the antenna scattering matrix $\overline{\overline{\mathbf{S}}}$,

$$Z_{in,i} = Z_0 \frac{(1 + S_{ii})(1 - S_{jj}) + S_{ij}S_{ji} + 2S_{ij}\frac{V_j^+(1-S_{jj})-V_i^+S_{ji}}{V_i^+(1-S_{ii})-V_j^+S_{ij}}}{(1 - S_{ii})(1 - S_{jj}) - S_{ij}S_{ji}}, \tag{1}$$

$$\Gamma_{in,i} = \frac{Z_{in,i} - Z_0}{Z_{in,i} + Z_0}, \qquad j = 3 - i, i = 1, 2, \tag{2}$$

where V_i^+ is the incident voltage wave at the i'th feed port (defined at the intersection of the slot and coaxial cable). Equation (1) can be slightly reduced since $S_{12} = S_{21}$, and even further if perfect phase quadrature between the incident voltage waves is assumed, i.e., $V_2^+ = -jV_1^+$, but, with (1) a non-ideal feed network can be taken into account.

In the left part of figure 2 the input impedances of the two ports are plotted assuming $V_2^+ = -jV_1^+$ for both simulated and measured scattering parameters. At the resonance frequency (defined at $X_{in} = 0$) they are approximately $450\,\Omega$ for the simulation result, whereas they are slightly larger for the measurements. By assuming a $50\,\Omega$ to $400\,\Omega$ matching network the corresponding reflection coefficients have been calculated and are shown in the right part of figure 2. The resonance frequency is approximately $1.59\,\text{GHz}$ with a bandwidth of $6\,\%$ with respect to $\Gamma_{in} < -10\,\text{dB}$. The results from the simulation and measurement are generally in good agreement although slight deviations are seen for port 2.
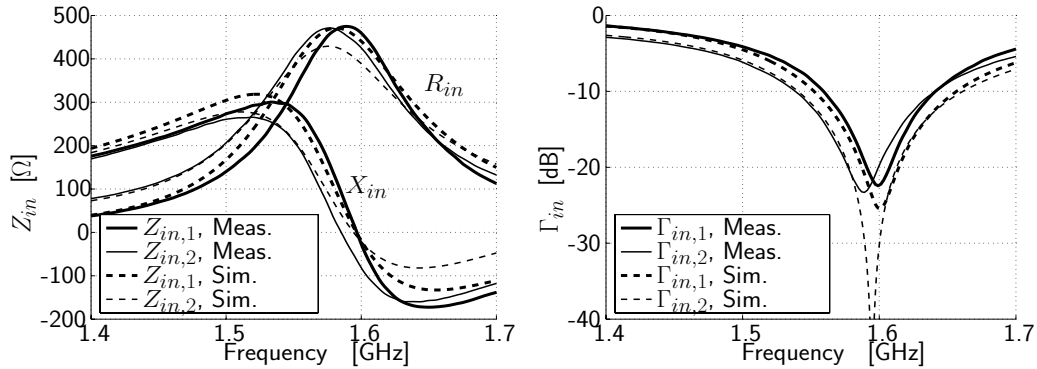
Figure 2: Input impedances $Z_{in} = R_{in} + jX_{in}$ and reflection coefficients Γ_{in} of the two input ports, assumed matched to $400\,\Omega$.

Radiation Characteristics for Different Ground Planes

The antenna, fed using a quadrature hybrid, has been measured with three different ground planes attached behind the small circular one shown in figure 1. The changeable ground planes are denoted GP 1-3 and comprise a square one with side lengths of 250 mm and two circular ones with diameters of 360 mm and 1500 mm, respectively. For the two small ground planes (GP 1-2) the simulations were carried out with HFSS, however, the large problem size for GP 3 rendered this approach impossible with the available computer resources. Instead a Method of Auxiliary Sources (MAS) [6] code was developed with the annular slot represented by a magnetic ring current. In figure 3 the radiation patterns are shown for GP 1 and GP 3 for $\phi = 0^{o}$ together with the maximum directivity and boresight axial ratio as functions of frequency. In general the agreement between the measurements and simulations is good for both the co- and cross-polar components, both for HFSS and MAS simulations. As expected the amount of ripples present in the radiation patterns increases with the ground plane size, however, the maximum directivity and half power beam generally attain values around $7\,$dBi and 100°, respectively. The fact that the axial ratio is nowhere lower than $1\,$dB implies that coupling between the feeds deteriorates the phase quadrature of the feed currents.

Conclusion

An L-band, circularly polarized, dual-feed, cavity-backed annular slot antenna has been developed. The antenna was equipped with three different ground planes and simulated using HFSS and a MAS code. Corresponding measurements have been conducted at the DTU-ESA Spherical Near-Field Antenna Test Facility and good agreement resulted. The antenna has an impedance bandwidth of $6\,\%$ around a resonance frequency of $1.59\,$GHz and an input impedance of approximately $450\,\Omega$. The maximum co-polar directivity is about $7\,$dBi and the half power beam width around 100°. Both, however, vary slightly for different ground planes.
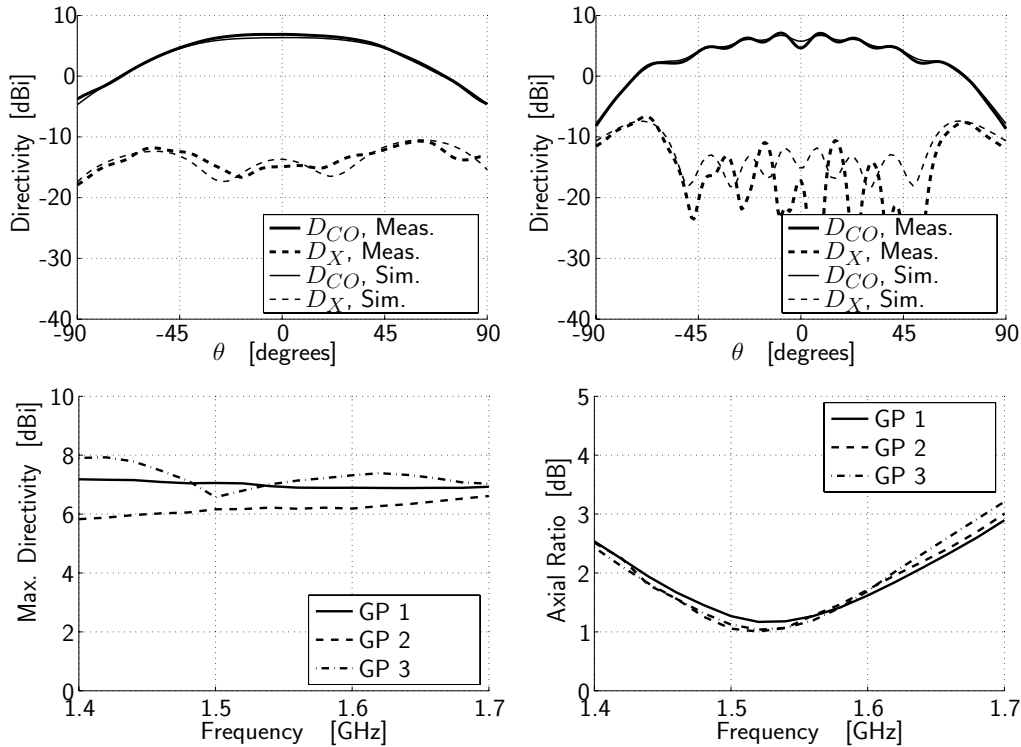
Figure 3: Top: directivity of the CBAS antenna for $\phi = 0^{\circ}$ as function of θ for GP 1 (left) and GP 3 (right) at $1.58\,\mathrm{GHz}$. Bottom: maximum directivity (left) and axial ratio at boresight (right) as function of frequency for GP 1-3.

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