94 GHz Zonal rings reflector for helicopter collision avoidance

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Abstract — A single-layer reflector antenna combining eight and four correcting Fresnel zones is presented. The progressive phase shift is achieved by circular and annular patches. The choice of a quarter-wavelength thickness substrate provides naturally 0° and 180° correcting zones that simplifies the reflector design. A prototype of reflector antenna working at 94 GHz has been designed, built and measured. Measurement results show 70% improvement of antenna aperture efficiency compared to the half-wave Fresnel zone plate reflector [1].

I. Introduction

Millimeter-wave radars are commonly used as complementary systems for preventing helicopters crashes. The antenna of the radar requires high gain. Recently, printed reflectors or reflectarrays [1-5] have become competitive solutions against parabolic reflectors or lenses, due to their low cost, low profile and fabrication facilities. The critical point in their design is to obtain a reflection phase range varying over 360°. It might be achieved by using rectangular or annular patches elements combined with multilayer structures [3, 5], but is not easy to fabricate at millimetre wavelengths. A single-layer alternative solution is the use of a concentric ring array structure [5]. Nevertheless, dimensions are still critical for classical printed circuit fabrication techniques at high frequencies because of fabrication tolerances and limited number of possible correcting zones.

In this paper, we present a single-layer ring reflector using circular, annular or combined patches placed in classical Fresnel zones. Furthermore, a quarter-wavelength substrate was used to simplify the design. The aperture radiation efficiency at 94 GHz is of 34%. Two zonal ring reflectors were made, measured and compared with the classical half-wave Fresnel zone plate reflector (FZP) showing an improvement of 50% aperture radiation efficiency for the smallest one (four correcting Fresnel zones) and 70% for the largest (combined eight and four correcting Fresnel zones).

II. Design of the reflector

Fig.1 shows the design principle of a quarter-wave zonal ring reflector from the substrate top side. The other side of the substrate is a ground plane. The radius of each zone is calculated with the classical Fresnel formula, where f is the focal length, n the order of the zone, λ the wavelength and P the number of correcting zones (here P=4).

\[ r_n = (nf\lambda + n\lambda/P)^{1/2} \]  (1)

The dedicated space for each zone is given by \((r_e-r_m)\). The use of a quarter-wavelength substrate provides naturally 0° and 180° zones. Zones of 90° and 270° are filled with three basic elements (a), (b) and (c) described in Fig 2. As an example to show the reflection phase range, we choose to fix the external radius \(r_e\) of (b) and (c) and to vary \(r\) (Fig. 3). Reflection phase range -180°/180° is covered. Simulations were made by means of HFSS software using the periodic structure module. As the space for each zone decreases when n increases, the external radius \(r_e\) in (b) and (c) has to be recalculated. Internal radius \(r\) is then adjusted in order to provide the desired reflection phase. The 270° zone of Fig.1 is achieved with (c) and \(r\) about 0.33mm. The choice of the type of basic element on several factors, the priority is given to the easiest to etch (e.g. (a), circular patch). It is suitable for up to the 90° zone but has to be replaced by (b) or (c) for higher phases. The \(\lambda/8\)-wave zonal rings reflector is based on the same principle with \(P=8\). It is important to note that an increase in \(P\) is possible only by using element (c) that provides phases between 180° and 360° in a limited space. Owing to computation limits, only 23 mm diameter with \(P=4\) was simulated using HFSS to verify the improvement in antenna aperture radiation efficiency compared to classical FZP.
reflection phase. We have to reduce \( P = 4 \). Therefore, the fabricated reflector has 9 zones with \( P = 8 \) and 24 with \( P = 4 \). For performance comparisons, half-wave FZP reflectors of the same diameters were fabricated. All reflectors are made on Duroid of dielectric constant 2.2 and 0.508mm thickness. The primary source is a standard open ended WR-10 waveguide. The design frequency is 94 GHz. In Fig. 4, E- and H-planes radiation patterns are plotted for the largest zonal rings reflector antenna. Beamwidth at -3 dB is 1.5° in both planes and side lobes levels are of -18 dB in the E-plane and -19 dB in H-plane. Figure 5 shows measured gain against frequency. It is 3 dB higher than FZP for the small zonal ring reflector and 4.5 dB higher for the largest one at 94 GHz. Table. 1 gives performances in terms of gain and antenna aperture efficiency (\( \eta \)) for the four investigated reflectors. We note that \( \eta \) is the same for the 56 and 130 mm zonal rings' reflectors. This is due to inadequate measurement conditions for the largest reflector in our anechoic chamber. Indeed, dimensions of the chamber limit the distance used for measurements to 4.65 m whereas the minimum distance required for far-field measurements is about 10 m at 94 GHz for a 130 mm diameter antenna. Gain and radiation pattern measurements are affected, i.e, real gain and \( h \) should be higher [6]. Nevertheless, half-wave FZP of 130 mm diameter was measured under the same conditions. Antenna aperture efficiency improvement is of 70%.
<table>
<thead>
<tr>
<th>Type of reflector</th>
<th>Gain (dBi)</th>
<th>η(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rings reflector (56 mm)</td>
<td>30.2</td>
<td>34</td>
</tr>
<tr>
<td>Half-wave FZP (56 mm)</td>
<td>27.4</td>
<td>17.3</td>
</tr>
<tr>
<td>Rings reflector (130 mm)</td>
<td>37.5</td>
<td>34</td>
</tr>
<tr>
<td>Half-wave FZP (130 mm)</td>
<td>33</td>
<td>12.3</td>
</tr>
</tbody>
</table>

**TABLE I**
GAIN AND APERTURE EFFICIENT OF REFLECTORS AT 94 GHZ

**IV. CONCLUSION**

We have developed a reflector antenna combining metallic correcting zones with smaller circular or annular patches providing up to 8-Fresnel correcting zones. The choice of the substrate thickness corresponding to a quarter-wavelength provides naturally 0° and 180° zones. It reduces the sensitivity to manufacturing tolerances and simplifies the design. Furthermore, the phase correction has been increased up to 360° by using three types of basic elements. Preliminary measurements show a good performances and an improvement of 70% comparing to half-wave zonal reflector antenna.

References


