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Optimal Patch Antenna Placement for an Efficient Aperture Sharing with a Reflector Antenna

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Abstract

In this work, we present the theory to construct a shared aperture antenna consisting of a high-frequency reflector and a low-frequency patch antenna. We propose an equation for the surface on which placing the patch antennae results in a minimal performance loss of the reflector antenna. We test the concept using a full-wave solver and investigate the effects of patch placement on both the reflector and the patch antennae.

1 Introduction

With the newest generation of the telecommunication networks, the millimeter wave band was introduced to support high data rates [1, 2]. However, the sub-6 GHz bands are still used [2], creating a need for antenna solutions covering both frequencies. While both frequency bands could be covered by separate antenna solutions, this can result inbulky structures which is not always possible to integrate with the rest of the system.

Previous works have bridged this gap with the concept of a shared aperture, where multiple antennae share the same aperture while minimizing the disturbances to one another. Multiple designs have been proposed using different antenna technologies, for example arrays [3, 4], reflectarrays [5] and reflectors [6, 7].

In this paper, we address the problem of integrating patch antennae, operating at a lower frequency with a reflector antenna, operating at a higher frequency, as introduced in [7]. We derive an analytical solution for the equation that determines the optimal patch location to minimize the impact of the patches on the performance of the reflector antenna. This results in a simple and compact antenna system with improved radiation performance compared to the reference work [7]. Additionally, we analyze the key properties of the designed antenna.

2 Derivation of the patch surface

Consider the problem of a shared aperture between a higher frequency reflector antenna and lower frequency patch antennae using the reflector as ground plane, as depicted in Fig 1(a). The reflector antenna operates at higher frequency f_{H} and the patch antennae at lower frequency f_{L}. When the reflector antenna is illuminated, the patch antennae (orange) placed inside the reflector antenna (blue) prevent some of the rays (in gray) reaching the reflector. The reflected rays (in dashed orange) may be reflected in such a way to introduce a disturbance in the electrical field at the aperture of the parabola, resulting in a lower directivity and higher sidelobe level (SLL).

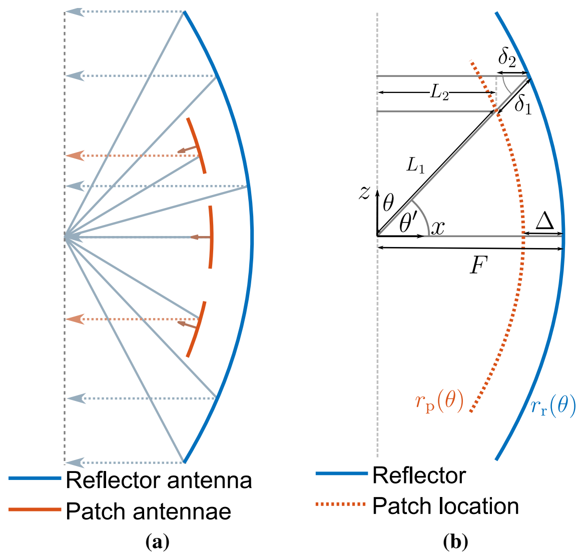

Figure 1. (a): Appropriate integration of patch antennae with a reflector antenna. (b): Solving the problem with geometric optics.

In [7], this effect was mitigated by placing the patches on a curved surface obtained by shifting the reflector curvature by $\lambda_{\mathrm{H}}/2$, where λ_{H} is the wavelength of the higher-frequency wave. However, this means that the patches are placed on a surface with a different focal point than the reflector antenna, leading to a reduced antenna performance [8]. Here, we propose a different approach. In Fig. 1(b), the radius of the reflector antenna corresponds to the one of a parabola with the focal distance F [8].

$$r_{\mathrm{r}}(\theta') = \frac{F}{\cos^2(\theta'/2)}\,, \tag{1}$$

which has the property that any rays launched from the focal point will travel the same distance to the aperture for any angle θ', defined as $\pi/2 - \theta$ (see Fig. 1(b)).

Now, let us consider the appropriate choice of the patch surface. First, the travel distance of the raysreflected at the patch and those reflected at the reflector should differ by an integer multiple n of λ_{H}:

$$L_1 + L_2 + n\lambda_{\mathrm{H}} = L_1 + \delta_1 + \delta_2 + L_2 \,. \tag{2}$$

This yields:

$$\delta_1 + \delta_2 = n\lambda_{\mathrm{H}} \,, \tag{3}$$

which allows us to express δ_1 as a function of the angle θ':

$$\delta_1 = \frac{n\lambda_{\mathrm{H}}}{1 + \cos(\theta')} = \frac{n\lambda_{\mathrm{H}}}{2\cos^2(\theta'/2)} \tag{4}$$

Then, we can write the equation for the radius of the patch location:

$$r_{\mathrm{p}}(\theta') = r_{\mathrm{r}}(\theta') - \delta_1 = \frac{F - n\lambda_{\mathrm{H}}/2}{\cos^2(\theta'/2)} \,. \tag{5}$$

Therefore, as conclusion, the patches should be located on a parabola with a focal distance $F - n\lambda_{\mathrm{H}}/2$.

3 Numerical analysis

Here, we provide some preliminary results of the performance of the geometry described in Fig. 2. The frequencies of interest are $f_{\mathrm{H}} = 28$ GHz for the reflector antenna and $f_{\mathrm{L}} = 3.5$ GHz for the patch antenna. The patch antenna is constructed as the intersection of the parabolic shape defined in (5) with the square block of width w related to the resonance frequency of the patch f_{L}. The reflector feed antenna is the same as the one described in [7].

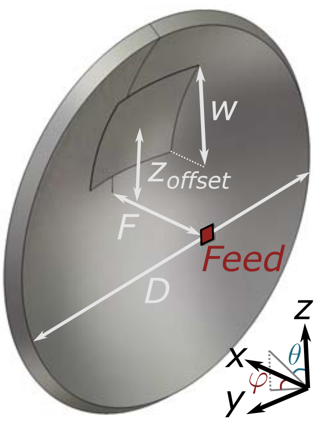

Figure 2. Geometry under analysis. The reflector antenna is defined with a parabola diameter of $D = 11.2\lambda_{\mathrm{H}}$ and a focal distance $F = 3.73\lambda_{\mathrm{H}}$.

3.1 Effect of patch location on the reflector antenna performance

First, we study the effect of the patch location on the performance of the reflector antenna at the design frequency f_{H} for a fixed value of $w = 38.5$ mm. Figs. 3 and 4 present the directivity for different locations of the patch.

First, we note that the performance of the reflector when the patches are defined by either the proposed method or the one in [7] is similar when the patch is located at $z_{\mathrm{offset}} = 0$ mm. This is because in this region, the definitions for the two surfaces are almost identical. However, when the patch is located at maximum $z_{\mathrm{offset}} = 30$ mm, the proposed method achieves performance comparable to the reference case of the reflector without the patch. In contrast, the approach used in [7] results in a directivity decrease of approximately 1.5 dB and an SLL increase of about 7 dB.

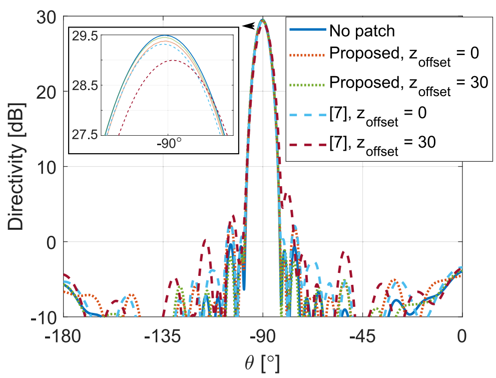

Figure 3. Reflector directivity cut at fixed $\varphi = 0°$.

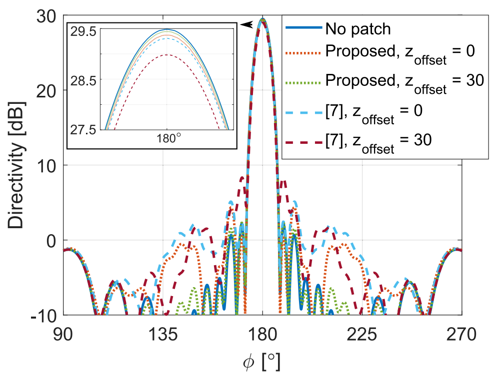

Figure 4. Reflector directivity cut at fixed $\theta = 90°$.

The impact of patch displacement on the peak directivity and the SLL is more clearly illustrated in Figures 5 and 6. The figures suggest that making the conformal patch following equation (5) is always better than using the approach proposed in [7]. An interesting observation is that introducing the patch appears to always increase the SLL. However, when using eq. (5) as curvature for the patch, the SLL tends

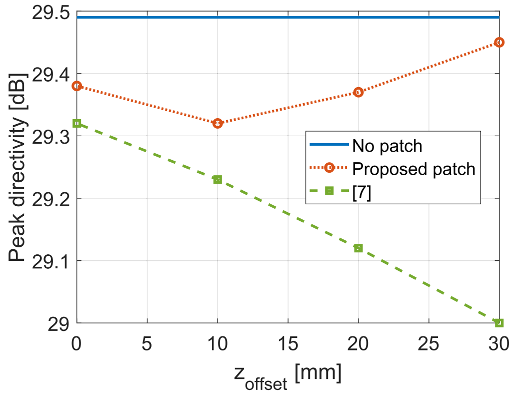

Figure 5. Peak directivity as a function of patch location.

to the reference case (reflector without patch) as z_{offset} is increased. The reason is that the origin of this higher SLL is the diffraction at the edges of the patch. This effect becomes less significant in the radiation pattern of the reflector when the patch is moved away from the center since, the closer it is to the reflector edge, the less it will be illuminated by the feed. As a result, the diffraction at the patch edges will have a reduced impact on the reflector's radiation pattern. Conversely, the SLL is increased when increasing z_{offset} when using the procedure from [7] as, in this case, the increase on the SLL is mainly due to the patch out of focus reflection and not to the diffraction on its edges.

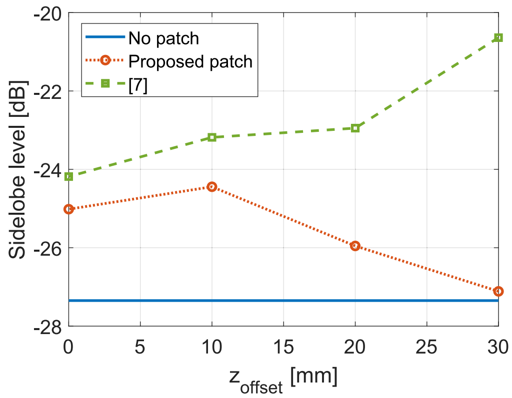

Figure 6. SLL as a function of patch location.

To further study the effects of the introduction of the patch, we present the directivities of a reflector with equal size to the analyzed one but with the focal distance defined by eq. (5), and the one of the two defined patches but without the reflector on the back. The results are presented in Fig. 7. As demonstrated by the figure, the reference reflector has the highest gain and lowest SLL. This is expected, as it is bigger than the patches. In addition, the gain and the SLL of the two patches are approximately the same. However, the proposed patch has the same main direction of the beam as the reference reflector, while the patch designed following [7] directs the beam 4° away from the main lobe. From this, we can conclude that the slight increase on SLL in Fig. 6 when the proposed patch is introduced is caused by

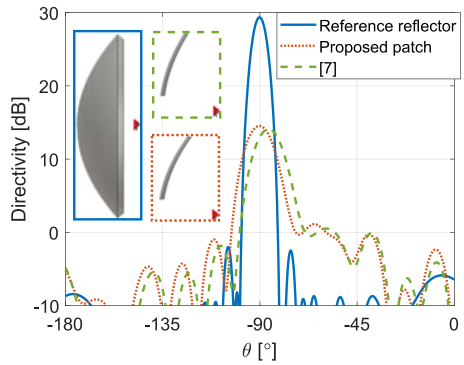

Figure 7. Directivity $\varphi = 0°$ cut of only the reference reflector, the proposed patch and the patch defined in [7]. The patch parameters are $w = 38.5$ mm and $z_{\text{offset}} = 30$ mm. The geometries used for the simulation are presented in the inset.

edge diffraction in the patch. However, the further increase of the SLL for the patch proposed in [7] is caused by the redirection of rays as the patch is feed outside of its focal point.

3.2 Effect of patch location on the patch performance

Now, we study the effect of the patch location on the patch performance as low frequency antenna. Due to the curvature of the patches, for each value of z_{offset}, the w and the location of the feed θ_{feed} must be adjusted to obtain a good matching at f_{L}. The feed always lies on the xz-plane ($\varphi = 0$). These dimensions are given in Tab. 1, where λ_{L} is the wavelength at f_{L}.

z_{offset} [mm]	w/λ_{L}	θ_{feed} [rad.]
0	0.43	0.375
10	0.42	-0.1
20	0.41	0.2
30	0.4	0.43

Table 1. Patch parameters to match the patch at z_{offset}.

As the patch location is shifted, its orientation changes. This results in shifting of the main lobe direction of the patch antenna, as can be seen in Fig. 8. This direction depends as well on the F/D of the main reflector and this behavior may be exploited to implement multiple beams at low frequency without the use of phase shifters.

4 Conclusions and future work

In this work, we presented preliminary results for a solution to the problem of integrating a low frequency patch antenna into a high frequency reflector antenna with minimal effect on the high frequency reflector performance. By

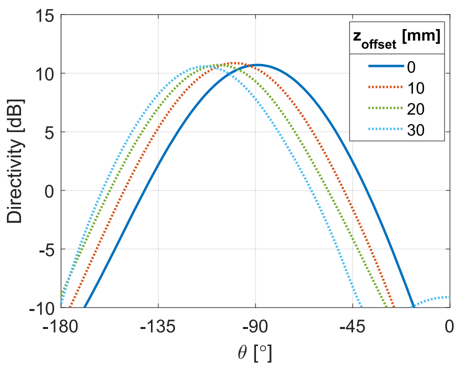

Figure 8. Patch directivity for cut $\varphi = 0$.

using geometrical optics, we have derived the optimal location surface for the patch antenna placement and curvature. We validated the derivation with a full-wave solver, demonstrating the improvement in performance when compared to the reference work [7] in terms of both the directivity and the SLL. In a future work, we aim to further investigate the performance and possible improvements for this antenna. Finally, we will design, manufacture and test a prototype to demonstrate the concept.

5 Acknowledgements

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