Design of complementary reflectarray

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A novel solution for the manufacture of a reflectarray antenna is presented. The unit cell simply consists of dielectric foam inserted between two thick metallic plates. The plate illuminated by the feeder is a 0.5 mm-thick stainless steel sheet into which the C and the reverse C slots are laser cut. This solution allows one to obtain an efficient, robust and compact antenna with low-cost manufacturing process even for no mass production. Preliminary measurements show the feasibility of the proposed solution and its performances.

Introduction: Owing to the recent advancement of lightweight and low-profile printed antennas, such as microstrip patches, printed reflectarrays have become physically more realisable, and several different versions have recently been developed [1]. Among them single-layer reflectarrays are much more attractive for low-cost manufacturing. Recently, Ethier *et al.* [2, 3] have shown that, by using sub-wavelength coupled-resonant elements, not only can one improve the reflectarray bandwidth as suggested in [4], but also it is possible to reduce the losses in the dielectric and, thus, employ cheaper substrates. However, for large (i.e. high gain) reflectarrays, when no mass production is considered and a mechanically robust solution is required, the latter technology could still be at not a negligible expense.

In this Letter, we present an alternative solution that allows us to obtain an efficient, robust and compact antenna with manufacturing process that is low cost even when few antennas are manufactured. Specifically, each reradiating element of the reflectarray, that we denote complementary reflectarray, is composed of two slots, a C slot and a reverse C slot, facing one another, that are laser cut into a metallic thick stainless steel plate (Figs. 1 and 2). The laser cutting process is very low cost although, for structural reasons, a thickness $t \geq 0.5$ mm is required to maintain a sufficient planarity after the cut. The slotted plate sits on a dielectric substrate, with low relative dielectric constant, backed by a flat metallic ground plane. No adhesive is used and the three layers are fastened by using some rivets on the reflectarray rim (consequently several holes are also laser cut on the edges of the antenna).

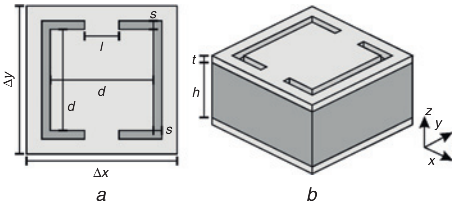

Fig. 1 *Element geometry*

a Top view
b Three-dimensional view

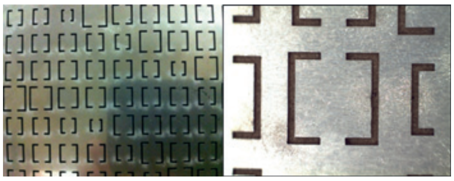

Fig. 2 *Photograph of reflectarray surface (left) and microphotograph of reflectarray element (right)*

Results: By acting on the distance d of the C and the reverse C arms, but maintaining fixed both the distance l between the slots and the slots width s, it is possible to change the phase delay in a range of almost 360°. This is evident in Fig. 3. Indeed, it shows the reflection coefficient phase and the magnitude against the element dimension d at 16.85 GHz, when the element is supposed to be embedded in a periodic lattice. Three different conductors have been considered: perfectly electric, aluminium with a conductivity of $\sigma = 3.8 \times 10^7$ S/m and stainless steel with a conductivity of $\sigma = 1.1 \times 10^6$ S/m. In all the three cases, a 4 mm-thick Divinycell HCP100 with a measured relative dielectric constant $\varepsilon_r = 1.549$ and a dielectric loss tangent of 6.466×10^{-3} has been used. It can be noted that the maximum attenuation at the element resonance due to only the dielectric losses is better than 0.5 dB. For the aluminium plates, the attenuation increases to 0.7 dB, whereas for the stainless steel plates it increases to almost 1.5 dB. These values are comparable with those obtained in [3] by employing sub-wavelength copper loops with lattices of $\lambda/6$ and $\lambda/4$, respectively, printed on an FR4 substrate.

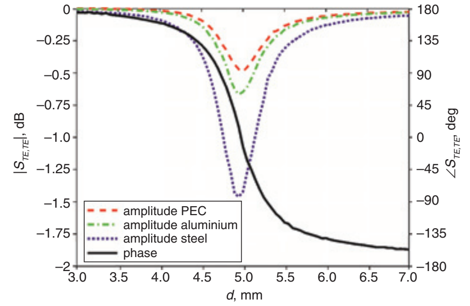

Fig. 3 *Phase and magnitude of reflection coefficient ($S_{TE,TE}$) against size d of C and reverse C element at 16.85 GHz, when plane wave with electric field polarised along $\hat{x}$ impinges orthogonally on element embedded in periodic lattice with $\Delta_x = \Delta_y = 8.722$ mm*

By using this type of radiating element, we have designed a medium-size linearly polarised reflectarray prototype, mainly with the goal of verifying its performance when a very low-cost dielectric material is used. Specifically, the reflectarray has been designed by using a computational procedure similar to that described in [5], which has been proven to yield accurate patterns and absolute gains. The obtained reflectarray is shown in Fig. 4*a*: it consists of 34 × 34 elements laser cut into a $t = 0.5$ mm-thick stainless steel plate that leans against a dielectric panel of thickness $h = 4$ mm, backed by a 2 mm steel plate that also acts as an antenna base. The laser cut tolerance is ±60 µm. We have chosen to use a stainless steel plate since it represents the worst case from the losses point of view. Hence, better performance is expected when an aluminium plate is used.

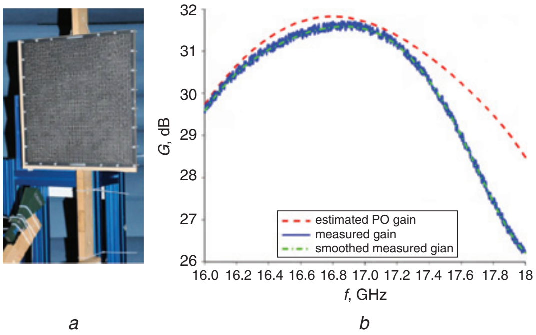

Fig. 4 *Manufactured prototype, and estimated and measured gains*

a Manufactured prototype
b Estimated and measured gains

The element grid spacing is 8.722 mm, so that the reflectarray measures 315 × 315 mm (i.e. about $17.5\lambda_0 \times 17.5\lambda_0$ at the central frequency of 16.85 GHz). As a dielectric substrate, we used a Divinycell HCP100, which is a very low-cost substrate and presents very good mechanical characteristic, but also anisotropy due to the fibrous conformation of the constituent composite material. However, this negative aspect can be taken into account in the numerical analysis and mitigated by aligning the fibres along the direction orthogonal to the central side of the C slots (i.e. along $\hat{x}$). The reflectarray is illuminated by a standard horn (FLANN Microwave 19240-15) located offset at $x = 0$, $y = -0.19$ m and $z = 0.19$ m with respect to the reflectarray centre, with a focal ratio of about 0.6, and radiates broadside a horizontal polarised electric field.

Fig. 4*b* shows both the measured and the simulated gains against the frequency for the reflectarray of Fig. 4*a*. The simulated gain has been calculated by using the PO approximation [6]. The measured maximum is about 0.3 dB lower than that predicted by the PO approximation and it presents a frequency shift of about 50 MHz. A gain reduction of only 0.3 dB is justified by the fact that only 40% of the elements are working in the range of $d = 4.8/5.2$ mm where the losses are more effective. The measured 1 dB bandwidth is about 7%, sufficient for the radar applications. The frequency shift and the bandwidth difference between the simulated and the measured curves are due to the manufacturing process: a microphotograph measurement of the slots dimensions revealed that the average dimensions of the slots are slightly larger (about 0.7%) than the theoretical values. However, once the laser cutting machine and its controller are chosen, the dimensions of the slots can be properly tuned.

Conclusion: We have demonstrated that the use of slots in a metallic plate, achieved by a laser cutting process, can be adopted to synthesise a reflectarray antenna. The discussed technology allows the design of an efficient, robust and compact antenna with low-cost manufacturing process.

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One or more of the Figures in this Letter are available in colour online.

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