A Folded Reflectarray Antenna with Sidelobe Reduction

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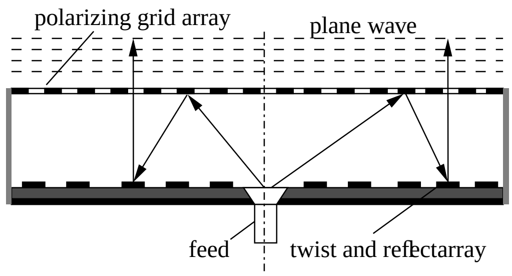
A single-polarization quasi-optical bandpass filter is used as a polarizer in a folded reflectarray antenna. The filter suppresses the sidelobe level of the antenna by up to 15 dB in the range outside of $\pm 20°$. The three resonator filter for Ka-band consists of four slot arrays. It is designed, fabricated and tested with the antenna and compared to a folded reflectarray antenna with a simple grid array as polarizer.

INTRODUCTION

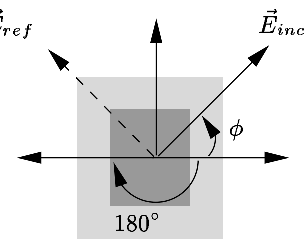
Periodic and quasi-periodic structures find an increasing interest in microwave applications. In [1–4], quasi-periodic structures have been used to build antennas on the basis of reflectarray, even as folded antennas using dual-polarization properties of the planar structures [3, 4]. For some applications, far-off sidelobes of the antenna are too high. In [5], an FSS structure has been proposed for sidelobe suppression. In [6] and [7], this technique is demonstrated using quasi-optical filters. If such a quasi-optical filter for sidelobe reduction is realized using slot arrays–providing the filter function for an electric field perpendicular to the slots and reflecting the other polarization–it can, at the same time, be used as a polarizer in a folded reflectarray antenna [4], giving a very compact setup.

BASIC IDEA OF A PLANAR FOLDED REFLECTARRAY ANTENNA

The basic concept of a planar folded reflectarray antenna [3, 4] is indicated in Fig. 1a. The antenna consists of a feed horn, a planar polarization filter and a printed reflectarray. The polarization filter may be a grid or a slot array printed on a dielectric substrate. The reflector consists of a printed array of patches of different sizes typically rectangular in shape, but they may have any other shape. All the patches are tilt by $45°$ with respect to the incident electric field. Fig. 2 shows the layout of one quarter of the reflecting array of the antenna. The reflectarray of this antenna has two functions; first, it twists the polarization of an incident wave by $90°$, second, it focuses the reflected wave. The radiation from a feed is a spherical wave and is polarized in such a way that it is reflected by the grid or slot array at the front of the antenna. The reflected wave is then incident on the printed array of patches. The electric field vector can be decomposed into the two components parallel to the patch axes (Fig. 1b), and the reflection properties can be determined separately.



(a)



(b)

Fig. 1. Folded reflector antenna: (a) Basic principle, (b) a single cell with a patch of the reflectarray and the vector decomposition of the incident and reflected electrical field. The difference in phase angle of reflection is 180 °.

The dimensions of the patches are selected in such a way that a phase difference of 180° occurs between the reflection phase angles of the two components. Superposition of the reflected field components then leads to a twisting of the polarization of 90°. The necessary 180° phase angle difference between the two field components of the reflected wave can be achieved for a large number of combinations of lengths and widths of patches differing by their absolute reflection phase angle. This degree of freedom now is used to adjust the required phase angles to transform the incident spherical wave into an outgoing plane wave. This plane wave with twisted polarization can now pass the grid or slot array.

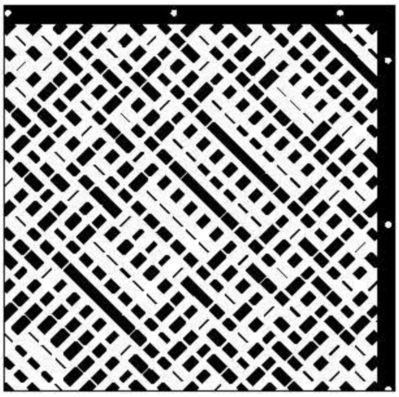


Fig. 2. Layout (one quarter) of the 27.6 GHz reflecting array. The reflector size is 150 mm ×150 mm.

PRINCIPLE AND DESIGN OF A QUASI-OPTICAL FILTER

The basic structure of the quasi-optical filter is shown in Fig. 3. The filter is symmetrical and consists of four slot arrays printed on dielectric substrates. The substrates are separated by distances d_1 and d_2. The structure reflects an incident wave with the electric field parallel to the slot length and acts as a filter for the electric field orthogonal to the slot length. Such a filter can be regarded in two different ways; in a first interpretation, the filter acts as a bandpass filter for a defined frequency range. In a second interpretation, the filter is an angular filter transparent for an incident wave within a specific range of angles of incidence (± 20° in this case) [8].

For the design of the filter, standard filter design and mode matching techniques were applied, taking into account the thickness of the metalization.

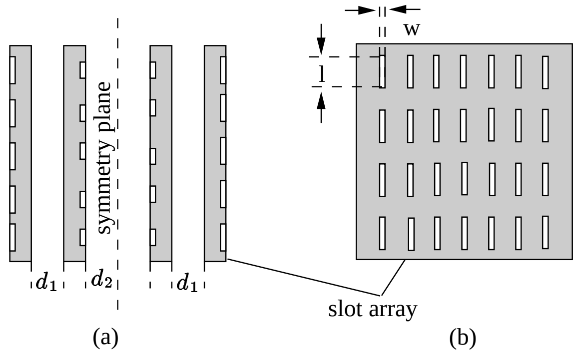


Fig. 3. Quasi-optical filter consisting of four slot arrays: (a) side view, (b) top view.

To enable an easier fabrication, an improved lateral alignment and a better control of the layer distances, the filter was optimized in order to make the distance d_1 between neighboring substrates equal to zero. In this manner, the filter consists of only two dielectric substrates metalized on both sides. Furthermore, the slot periodicity was selected to be $\lambda/2$ in order to reduce wave propagation inside the dielectric area [9]. The final filter was designed for Ka-band having a dielectric constant of $\varepsilon_r = 2.2$, a thickness of 3.18 mm and a metalization thickness of 35 µm. The quasi-optical filter was measured as a function of frequency and over a range of angles of incidence of the wave. In Fig. 4, the transmission characteristic of the filter as a function of frequency is shown. The center frequency is 27.6 GHz, and a -3 dB attenuation is found at 26.8 GHz and 28.4 GHz, resulting in a bandwidth of 1.6 GHz. Furthermore, the filter was tested with respect to the angle of incedance for a frequency range. In the range between ± 20° of angle of incidence of a wave, the signal can pass, and outside this range, the wave is reflected.

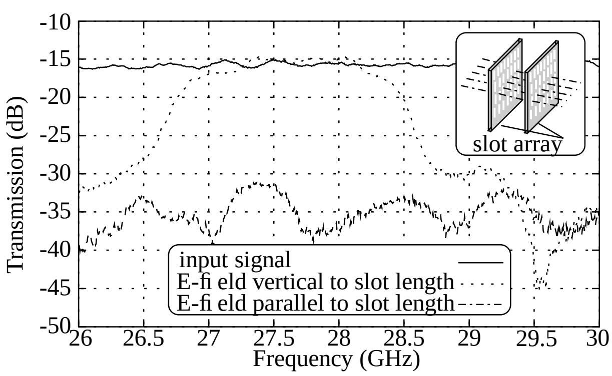


Fig. 4. Broadside transmission characteristic of the quasi-optical filter for an incident electrical field parallel and vertical to the slot lengths.

RESULTS

According to the principles of the antenna and the quasi-optical filter as shown in Fig. 1 and Fig. 3, respectively, a folded reflectarray antenna with both a simple grid array and a quasi-optical filter was designed, fabricated and tested. A view on the opened antenna with the reflectarray, the simple grid array, and the quasi-optical filter is given in Fig. 5. The antenna size and height were 150 mm $\times$150 mm and 25 mm, respectively. For the reflectarray, a substrate with a dielectric constant of $\varepsilon_r = 2.2$ and a substrate height of $h = 0.254$ mm, and for the grid array, a substrate with a dielectric constant of $\varepsilon_r = 2.33$ and a substrate height of $h = 1.57$ mm were chosen. Fig. 6 shows the E- and H-plane radiation pattern of the antenna using the grid array and the quasi-optical filter.

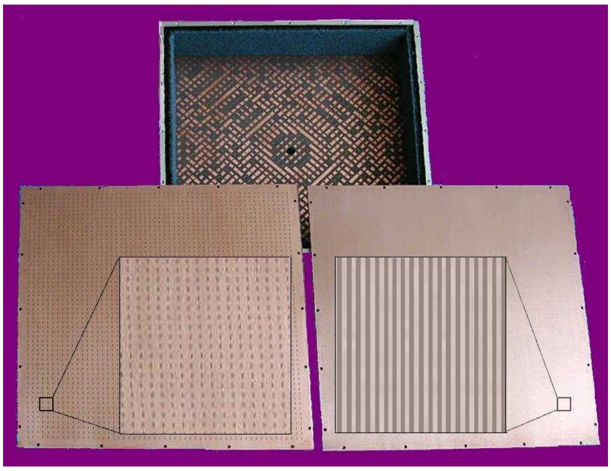
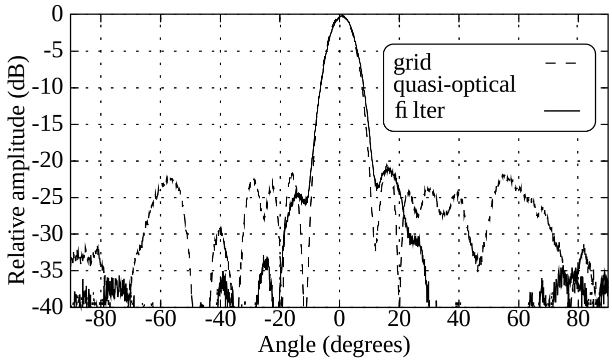


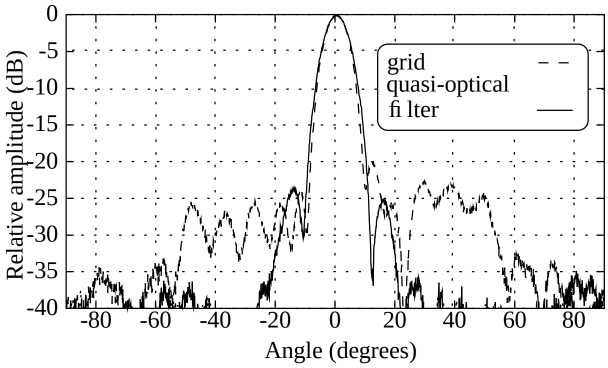
Fig. 5. Photograph of a folded reflector antenna with a simple grid and a quasi-optical filter. The fine structures surrounded by the two small boxes are scaled up and placed in front of each configuration.

Best performance was achieved at a frequency of 27.6 GHz. Beamwidths are 8° in both planes. For the antenna with a grid array, the E-plane and H-plane sidelobe levels for the first sidelobe are -21 dB and -20 dB, respectively, whereas for the antenna with the quasi-optical filter the sidelobe level is -21 dB in E-plane and only -24 dB in H-plane. Furthermore, it can be seen that in the range outside $\pm 20°$, the sidelobes are suppressed by up to 15 dB.

Antenna gain has been measured between 26.5 GHz and 29.0 GHz and is shown in Fig. 7. Maximum gain is 30.8 dB and 29.5 dB for the antenna with the grid array and the quasi-optical filter respectively. The antenna with the simple grid has a higher gain than that with the quasi-optical filter. This is due to the losses of the filter shown in Fig. 4. Due to the filtering properties of the quasi-optical filter, the antenna bandwidth is reduced, too. A 3 dB-gain bandwidth of about 800 MHz (3 %), however, is efficient for most system applications.



(a) E-plane



(b) H-plane

Fig. 6. Radiation diagram of the folded reflector antenna with grid and quasi-optical filter at 27.6 GHz.

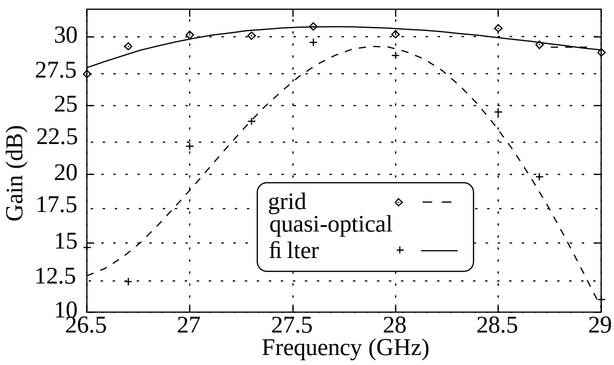


Fig. 7. Gain of the folded reflector antenna with grid and quasi-optical filter. Dots represent measured values; the dashed and solid lines are the least squares polynomial approximation of the measured values.

CONCLUSION

This contribution demonstrates the design of a compact folded reflectarray combined with a quasi-optical bandpass filter. The antenna and filter were designed for a frequency of 27.6 GHz. In this way, an additional sidelobe reduction of up to 15 dB in a range outside $\pm 20°$ has been achieved. The size of the antenna and filter were $150\,\text{mm} \times 150\,\text{mm}$. The height of the antenna was 25 mm. A quasi-optical bandpass filter is more complicated in design and structure than a simple grid or slot array filter. It is also larger in thickness but it adds a very good far-off sidelobe performance to the folded reflectarray antenna.

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