PLANAR AND QUASI-PLANAR ANTENNAS

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Abstract:

Two different approaches of narrow-beam antennas will be presented, based on printed circuits and exhibiting low feed-line losses. Firstly, a waveguide feed network is applied to planar microstrip arrays; examples will be given for 10 and 24 GHz. A second type of antenna is based on printed reflector antennas, using quasi-optical feeding and, partly, folded arrangements to achieve low-profile, low-loss, and high-gain antennas. Antennas of this kind already have been demonstrated at 28, 60, and 77 GHz.

I. Introduction

Today, many systems for communication and sensor applications, e.g. [1], require low profile, low-cost antennas. With increasing frequency, narrow beamwidth/high gain antennas can in principle be realized within a small antenna aperture size. Antenna arrays with a *printed* feed network typically suffer from high losses of the feed network [1]. For a microstrip antenna array with a corporate feed network, for example, a maximum gain of 25 ... 30 dB can be achieved; for larger antenna sizes, gain even is decreasing (Fig. 1). Some improvements in feed line losses are possible employing a series type feeding network, this however, is done at the expense of antenna bandwidth. Waveguide slotted arrays [2] or other waveguide based antennas [3] exhibit lower loss, but are more complicated and expensive in fabrication.

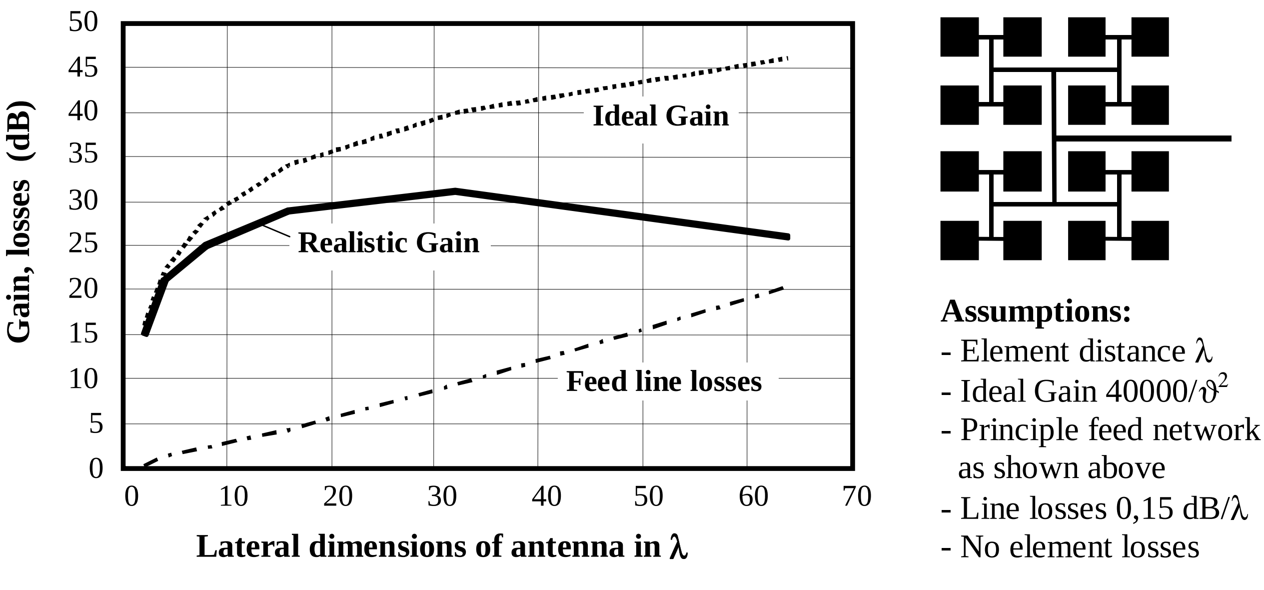

Fig. 1: *Gain of an antenna array using a microstrip corporate feed network.*

A direct way to reduce losses is found using metal waveguide for the feed network of planar microstrip arrays. To this end, four microstrip patches are combined by a small planar network, and these then are slot-coupled to a corporate waveguide feed network. Although this seems to be complicated from a point of view of fabrication, plastic injection-molding for the waveguide structures gives an easy and low-cost way out of this problem.

A second solution to achieve low-loss, high gain antennas is the application of quasi-optical principles combined with printed structures. To this end, printed periodic and quasi-periodic structures are presented which are capable of focussing waves (planar reflector antennas). The combination of a polarizing grid or slot array and a unique quasi-periodic printed structure - which is able to focus an incident wave and to twist polarization at the same time - forms a printed, relatively low-profile and low-loss folded antenna, ideally suited for mm-wave communication and sensor applications. As an example, a 77 GHz antenna with 100 mm diameter and a depth of 25 mm will be presented.

II. Antennas with waveguide feed network

Metal waveguide exhibits much lower losses compared to planar transmission line, but at the same time, it requires a much wider cross section. Therefore, four element planar subarrays where designed. In this case, feed line losses still are low (Fig. 1). Each of the subarrays then is fed from waveguide via slot coupling [5]. The waveguide feed network in principle is a very simple, single layer H-plane network which may finally be fabricated using plastic injection molding and electroplating [4]. For a 10 GHz antenna, a reduced height waveguide, for a 24 GHz antenna, a ridge waveguide was chosen due its smaller width. The complete antenna is assembled simply by fixing the printed substrate on top of the waveguide block with silver epoxy. This requires a homogeneously glued contact along the waveguide edges; this principally is possible, but for the test antennas described here, the required assembly technology was not available. Therefore a modified arrangement was chosen for the realization of the waveguide network based on two separate parts screwed together (Fig. 2). In this way, a good contact is necessary only around the slot areas; in addition, this easily can be inspected from below.

The planar subarrays (Fig. 3) were designed using a commercial CAD program and a 2½-D field solver [6]. For better impedance match of each patch, these include an inset feed structure.

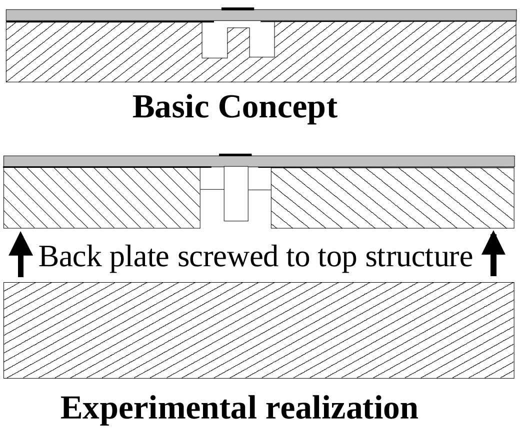

Fig. 2: Basic concept and experimental realization of microstrip antenna with waveguide feed network.

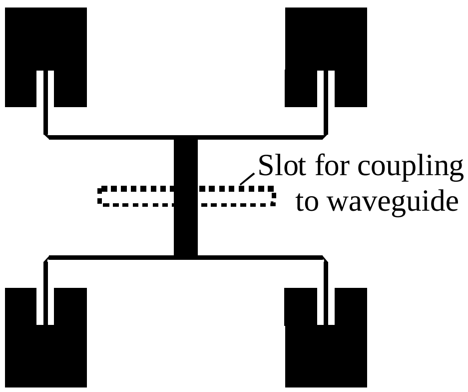

Fig. 3: Layout of planar two by two microstrip subarray.

The design of the slot coupling – and an optimization of the complete slot coupled subarray - was done using an in-house FDTD code [7], [8], mostly based on [9]. The reduced height waveguide network for the 10 GHz antenna was designed employing mode matching techniques, the ridge waveguide feed network using again FDTD. Figs. 4 and 5 show the waveguide structures for the 10 and 24 GHz antennas, respectively.

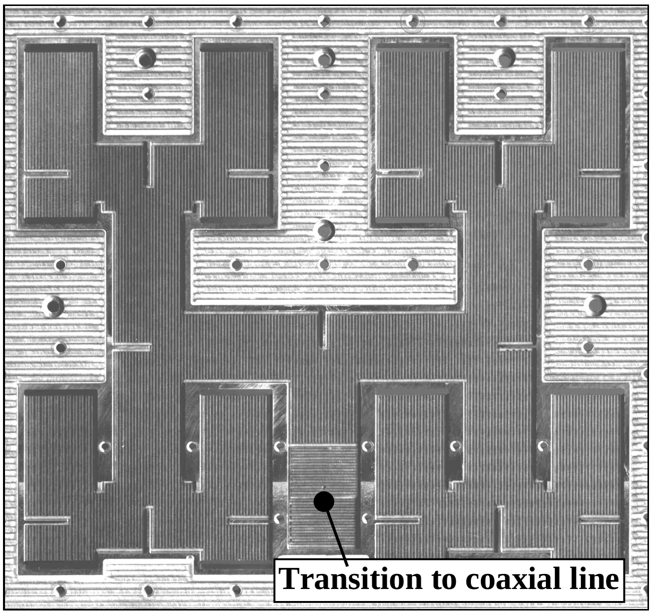

Fig. 4: *Waveguide feed network for the 10 GHz antenna.*

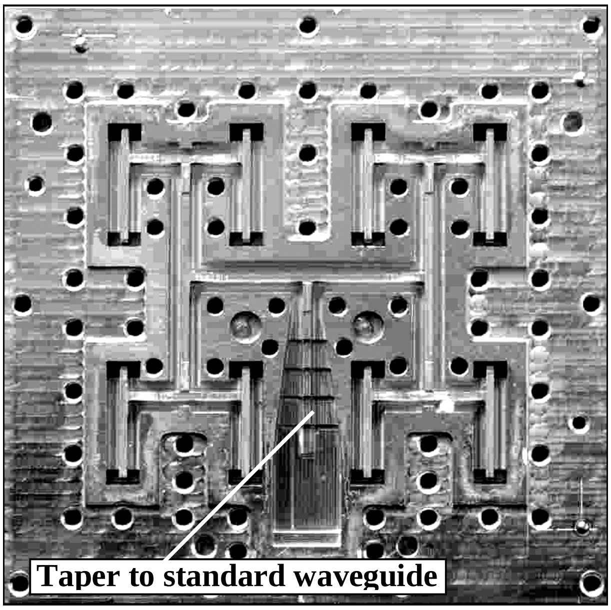

Fig. 5: *Waveguide feed network for the 24 GHz antenna.*

As can be seen from Fig. 4, the reduced height waveguide with a width of 20 mm takes much space, resulting in a wide spacing of the planar elements. This problem is reduced with the ridge waveguide as shown in Fig. 5. The planar structures look very similar for both antennas, therefore, only the 24 GHz antenna is displayed in Fig. 6. At 10 and 24 GHz, 1.56 and 0.5 mm thick substrates, respectively, were chosen.

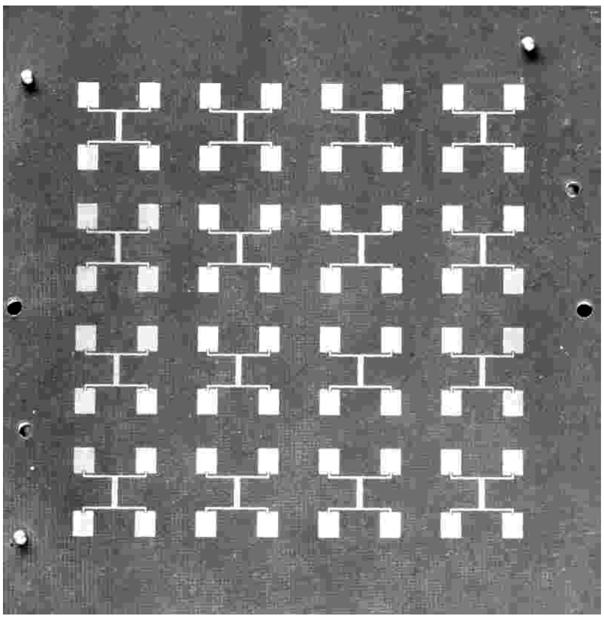

Fig. 6:Planar structure of the 24 GHz antenna.

To test this type of feeding, a constant amplitude distribution was applied in both cases, resulting in a relatively high side lobe level. In Figs. 7 and 8, the radiation diagrams of both antennas in E- and H-plane are plotted. At 10 GHz, some problems occurred with the rather large element spacing as discussed before and with surface waves - the substrate was slightly too thick [10], [11]. Both antennas show some effects on the E-plane diagram due to parasitic radiation of the coupling slots.

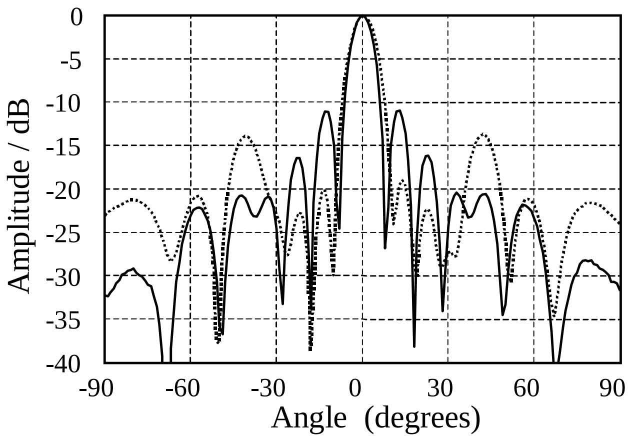

Fig. 7: *H-plane (—) and E-plane (····) radiation diagram of the 10 GHz antenna.*

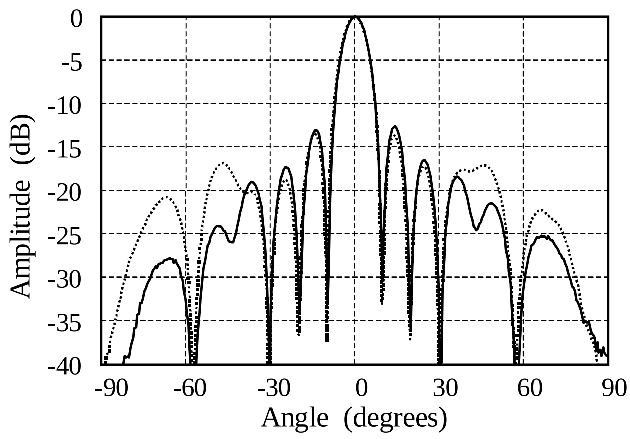

Fig. 8: *H-plane (—) and E-plane (····) radiation diagram of the 24 GHz antenna.*

Planar reflector antennas

A periodic array of dipole structures printed on one side of a dielectric carrier substrate with backside metallization can be used to adjust the reflection phase angle of a plane wave as a function of the size of the elements. An example of the dependence of the reflection phase angle as a function of element length and width is given in Fig. 9, calculated using a spectral domain method [12], [13].

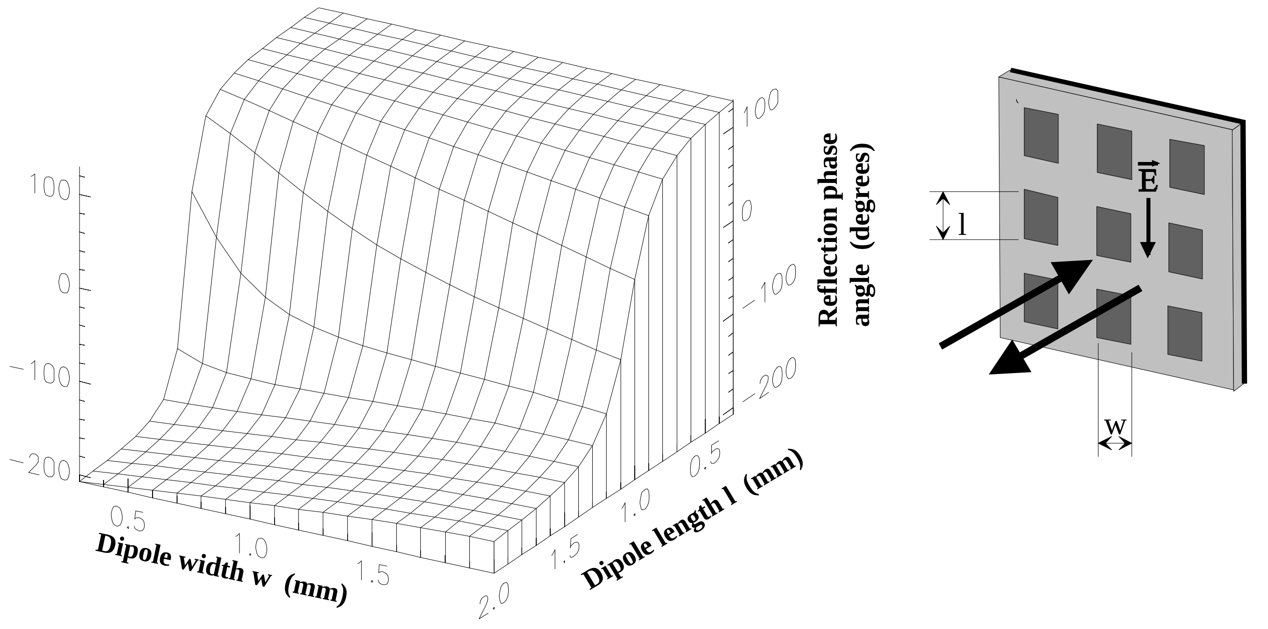

Fig. 9: *Example of reflection phase angle of a periodic arrangement of printed patches as a function of length and width.(Broadside incidence of plane wave, f = 76.5 GHz, substrate height 0.245 mm, ε_r = 2.22, cell size 2.2 mm by 2.2 mm).*

Maintaining a periodic grid, on which the elements are arranged, but modifying the element geometry as a function of coordinates, quasi-periodic structures result which can be used to locally control the reflection phase angle. For example, such elements can act as local phase shifters to realize a planar reflectarray [14] - [16]. Fig. 10 shows the metallization pattern of a 24 GHz, offset-fed printed antenna with horizontal polarization, together with the basic antenna arrangement. All dipoles have the same width. The dipole lengths were calculated according to the required phase shift assuming a broadside incidence of a plane wave. In addition, the complete structure was calculated as a whole with a special spectral domain technique [13], [17]. Both measured and computed radiation diagrams (Fig. 11) agree quite well, only for the far-off sidelobes, some discrepancies due to effects not included in the computation can be seen (finite size of the reflector substrate, direct feed radiation).

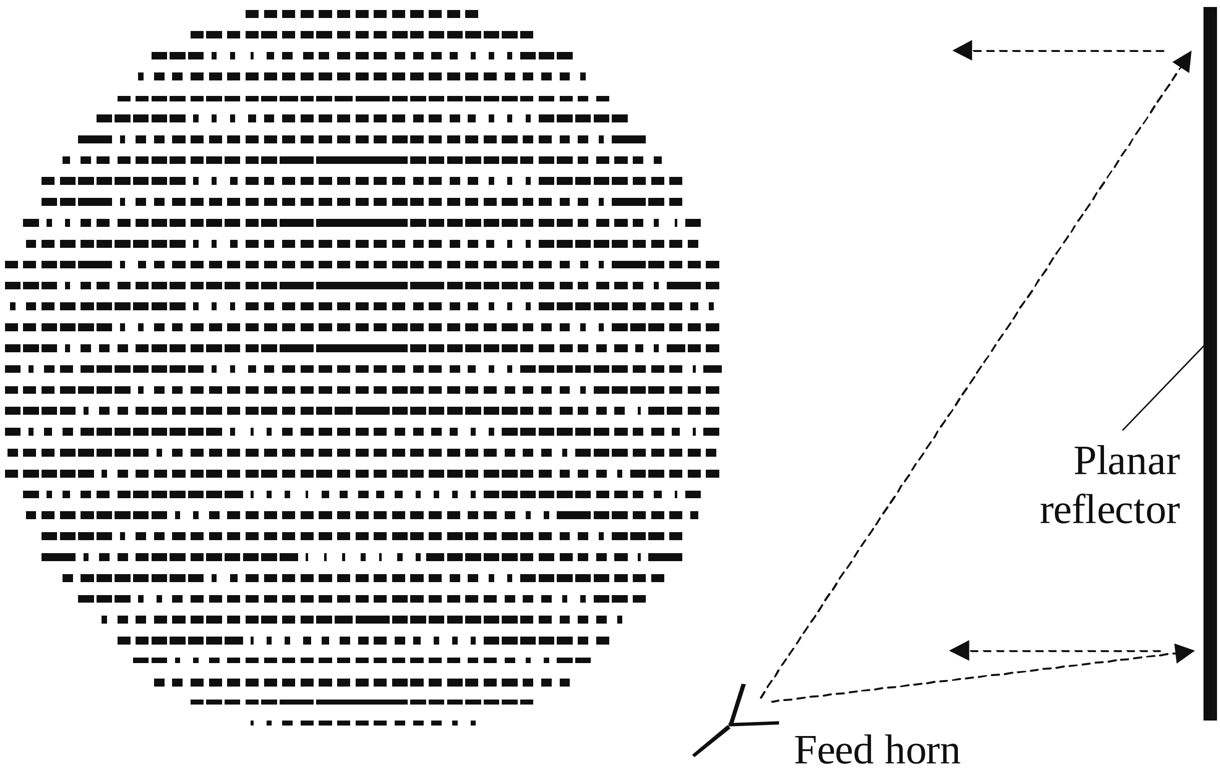

Fig. 10: *Principle layout of planar reflector and basic arrangement of the offset-fed printed reflector antenna.*

Different phase angles can be adjusted mostly independently for both linear polarizations (Fig. 9). For periodic structures, for example, a 90° angle difference between the two polarizations can be used to realize a polarizer from linear to circular polarization, or a 180° phase difference to perform a polarization twisting (90° rotation of the polarization direction), [16]. Furthermore, independent radiation characteristic of planar reflector antennas can be achieved for the orthogonal polarization, like two different diagrams with the same or different feed points or antennas for two different frequencies in different polarizations [16]. Making proper use of both the polarization twisting and, at the same time, of the focussing properties of quasi-periodic structures, folded printed reflector antennas with high gain, low profile, low-weight, and low loss can be realized [18], [19]. The principle cross section of such an antenna is shown in Fig. 12. The field radiated by the feed is reflected at a printed grid or slot array at the front of the antenna. Then the wave is incident on a special array of rectangular metal patches (Fig. 13). The incident electric field is tilted by 45° with respect to the patch axes. The dimensions of the patches are designed in such a way that, on the one hand, a phase difference of 180° occurs between the two components of the reflected wave – giving the twisting performance. On the other hand, an overall phase shift is adjusted according to the focussing (phase shifting) requirements. The outgoing plane wave then can pass the grid or slot array. Antennas of this type have already been built at different frequencies from 20 to 77 GHz. Fig. 13 shows part of the layout of the reflectarray of a 77 GHz antenna of this type. Fig. 14 presents the radiation diagram of this antenna with a diameter of 100 mm and a depth of 25 mm at 76.5 GHz, resulting in a beamwidths of 2.7° and a gain of 35 dB. Sidelobe level is in the range of 24 dB. The radiation characteristic shows equal performance at 75.5 and 77.5 GHz, the actual bandwidth is even higher.

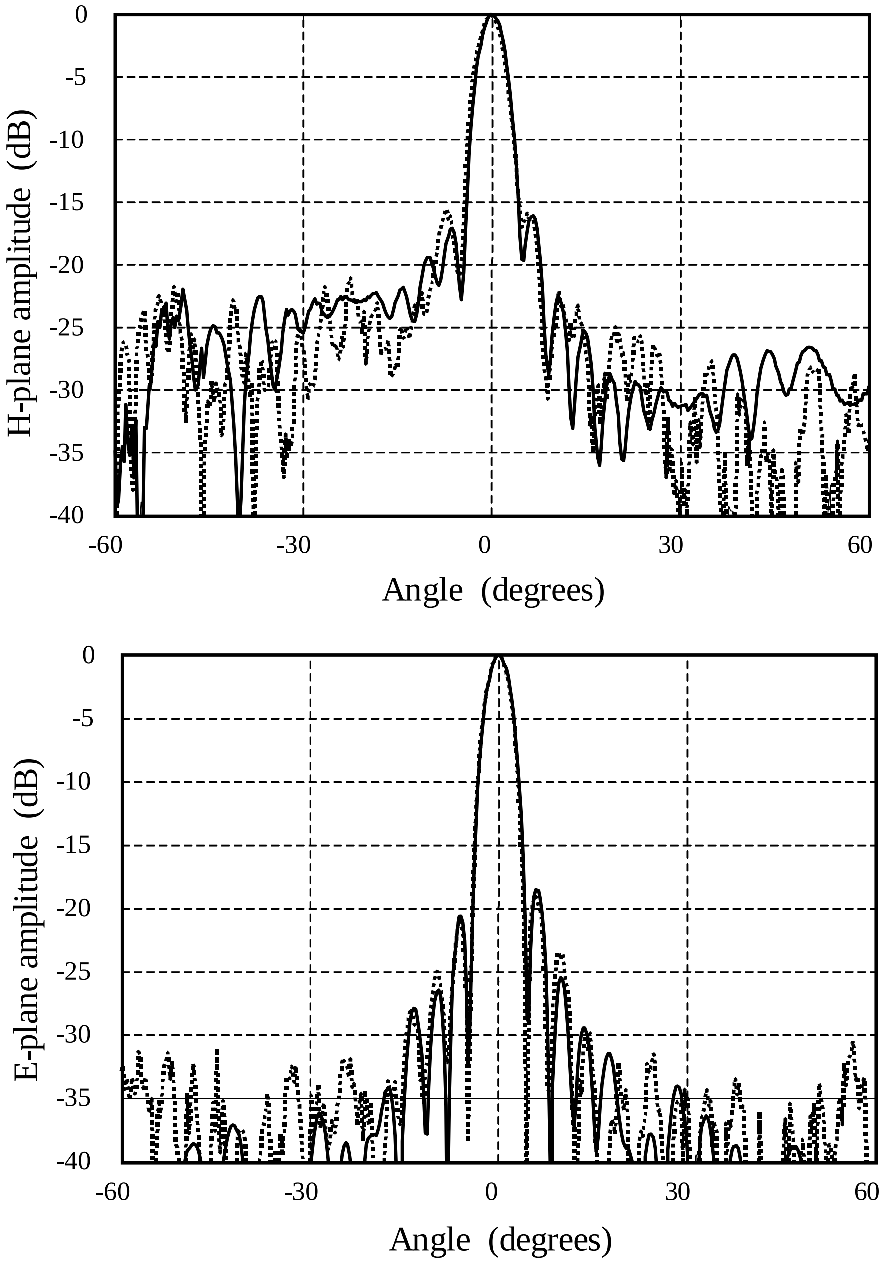

Fig. 11: *H- and E-plane radiation diagrams of offset-fed planar reflector antenna (f= 24 GHz; —— theory, ···· experiment).*

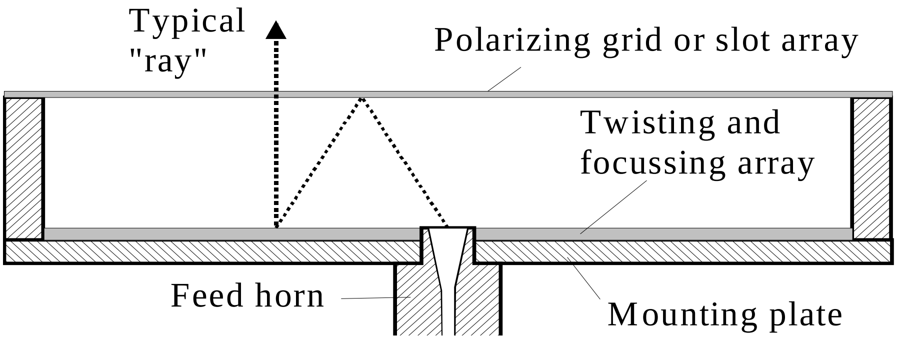

Fig. 12: *Principle cross section of folded planar reflector antenna.*

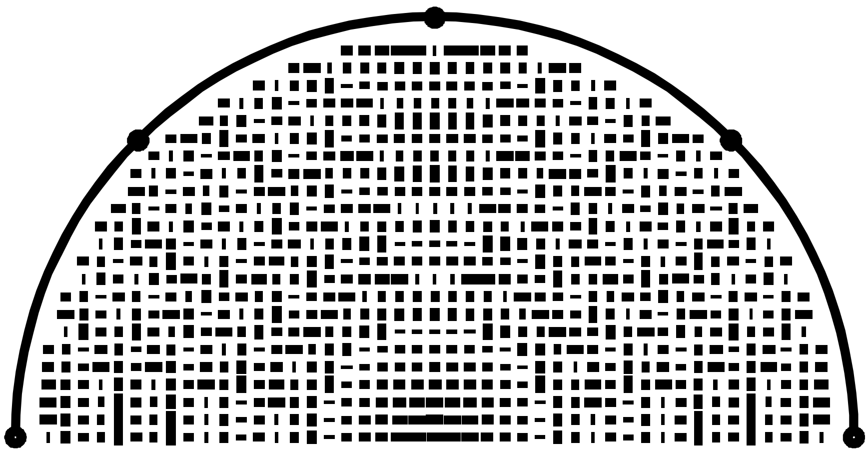

Fig. 13: *Layout of top half of the 77 GHz folded planar reflector antenna (diameter 100 mm).*

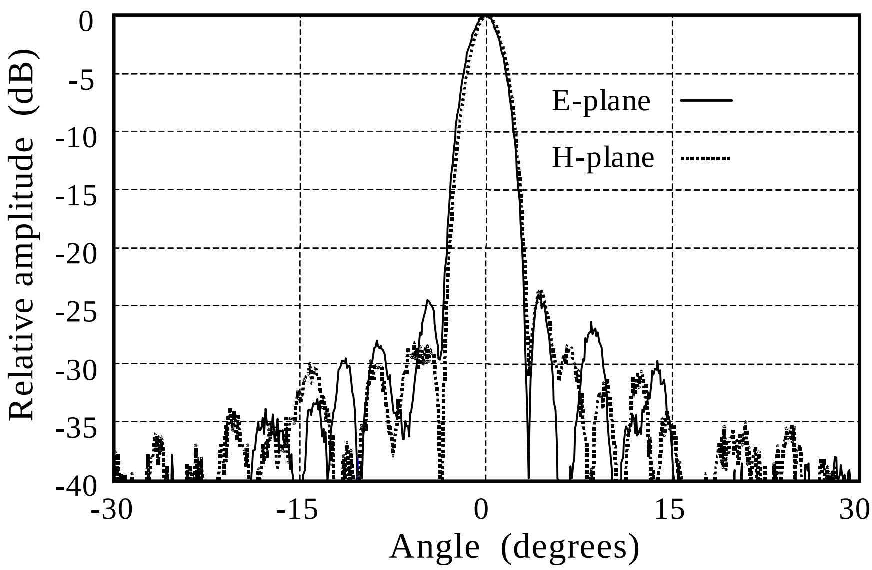

Fig. 14: *Radiation diagram of the 77 GHz folded planar reflector antenna.*

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