A NOVEL MM-WAVE DUAL REFLECTOR ANTENNA WITH OMNIDIRECTIONAL RADIATION PATTERN

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Abstract
A mm-wave antenna with omnidirectional azimuth coverage and narrow beamwidth in elevation is presented, using a conical and a planar reflector. The antenna feed is a open circular waveguide operating in the fundamental TE_{11}-mode with linear polarization. Beam forming and polarization control is performed by the planar reflector. Two different antennas radiating with omnidirectional characteristic in the azimuth and small 3-dB width in the elevation have been designed for circular and linear polarization; results are given for both types of antenna.

Introduction

In recent years, commercial communication applications in the mm-wave region have found an increasing interest. For point to multipoint applications, antennas with omnidirectional radiation characteristic are required. Different efforts have been undertaken to generate omnidirectional radiation, partly with narrow beam width in the elevation. This partly was done using planar antennas [1 - 3]; these antennas, however, are difficult to employ in the mm-wave frequency range due to increased losses and tolerance problems. Circular waveguides with mode transducers and slot arrays to create an omnidirectional pattern are presented in [4]. The small dimensions of the slots in the waveguide and difficulties in fabricating these slots increase the costs of these antennas. As alternative solutions, shaped reflectors illuminated by waveguide horns or dipoles can be effectively used at mm-wave frequencies [5 - 9]. Additional beam forming in the elevation can be made by modifying the reflector shape. A critical point is the required polarization control of these antennas. To achieve a vertical polarization, either a TEM type feed [5, 7], a monopole [9] or the TM_{01} mode in circular waveguide [6] has to be used; and for horizontal polarization, the TE_{01} mode in circular waveguide [6] is necessary. All this provides additional requirements and problems for design and realization of the antenna.
In this paper, a low loss antenna with a planar and a conical reflector is presented. The arrangement is excited by an open circular waveguide simply operating in the TE_{11}-mode with linear polarization. The key component of the antenna is the planar reflector which is used to form a plane phase front and to transform the linear polarization of the feed to either a circular polarization for an antenna with circular polarization or to twist the field components in such a way that vertical or horizontal linear polarization is radiated in all directions. While the planar reflector can be fabricated with standard planar circuit techniques, the cone reflector may be produced using plastic injection molding and electroplating.

Antenna design

The basic antenna setup of the antenna is sketched in Fig. 1. A circular waveguide operating in the fundamental TE_{11} mode with linear polarization is located in the center of the two reflectors and radiates towards the planar reflector. At this reflector, the wave is focused, and, at the same time, the necessary polarization control is performed.
The planar reflector consists of printed patches with backside metallization. The size of the rectangular patches on the substrate determines the phase of the reflected wave (Fig. 2); the overall phase angle range amounts to about 320°, thus, with some gap of ±20°, all reflection phase angles can be adjusted by the size of the elements ([10, 11]). For generating circular polarization, the patch axes of the reflectarray are tilted by 45° with respect to the incident electric field vector. The electric field can be decomposed into two components parallel to the patch axes (Fig. 3, top). The dimensions of the patches then are selected in such a way that a phase difference of 90° occurs between the reflection phase angles of these two components. Superposition of the reflected field components leads to a circular polarized wave. Depending on the sign of the phase difference a right circular or a left circular polarized wave is obtained. A large number of length-width-combinations for the patches can be found, each with a different absolute phase value. This degree of freedom is used to adjust the required phase angles to transform the incident spherical wave into an outgoing plane wave. Consequently, the antenna radiates circular polarization into all directions.

For a linear polarization of the antenna, the electric field of the incident wave must be rotated by an angle depending on the position on the reflector. For vertical polarization of the overall antenna, for example, the direction of the electric field in the E-plane of the feed can be maintained on one side and has to be inverted on the other side. In the H-plane of the feed, twisting by +90° or -90° is necessary, and in between, a continuous twisting of the electric field between -180° and +180° is required. To perform a rotation of the electric field vector for a required angle 2φ, the patch axes must be tilted by the angle φ. The electric field vector once again can be decomposed into the two components along the patch axes. If the patch dimensions are chosen that way that a phase differences of 180° occurs between the reflection phase angles of the two components, the electric field vector is rotated as shown in Fig. 3, bottom. Once again, different combinations of such dimensions can be found, leaving the freedom for adjusting the overall phase angle necessary for focusing the feed radiation. Finally, a quasi-optical reflection of the wave occurs at the conical reflector to the side (Fig. 1). Cutouts of the two reflectors for circular and linear polarization are shown in Fig. 4.

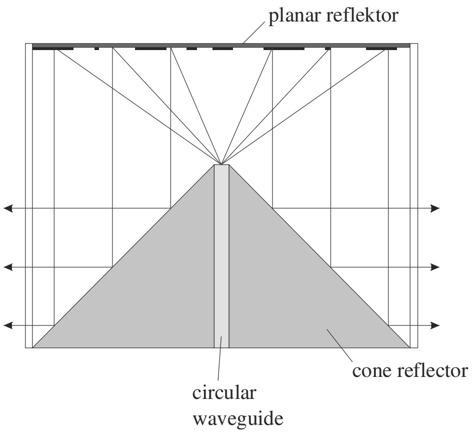

Fig. 1 Basic principle of the dual reflector antenna.

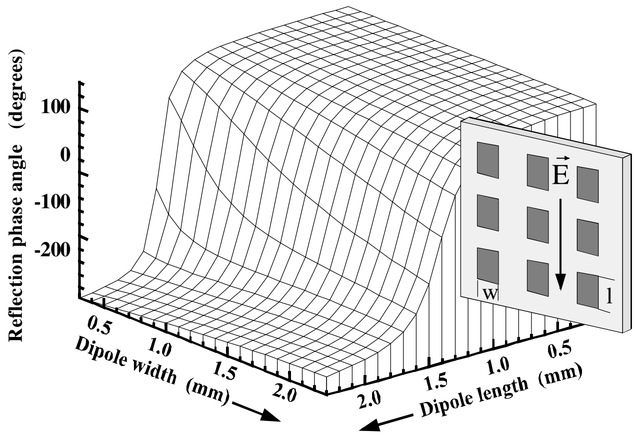

Fig. 2 Reflection phase angle of a plane wave reflected from a periodic array of printed dipoles. (Frequency 58 GHz, substrate thickness 0.254 mm, dielectric constant 2.2, dipole grid spacing 2.4 mm, normal incidence of the wave).

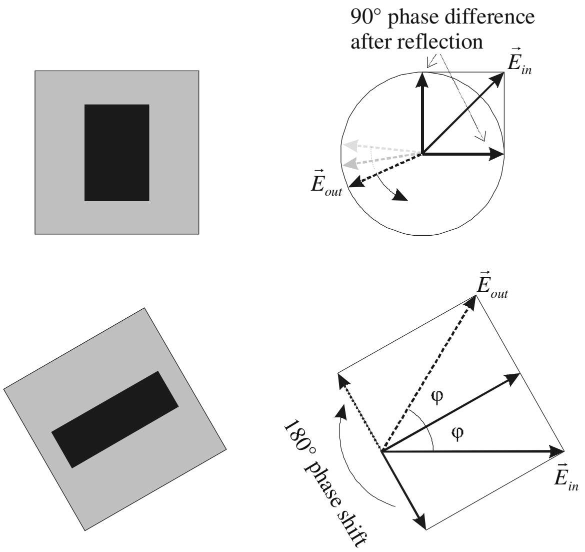

Fig. 3 Single cell/patch and vector decomposition of incident and reflected electric field for 90° (top) and 180° (bottom) of reflection phase angle difference.

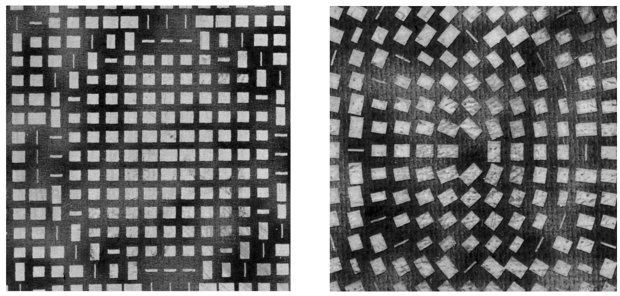

Fig. 4 Cutout of the planar reflectors for circular polarization (left) and linear polarization with polarization rotation (right).

Experimental results

Antennas with different focal lengths have been designed, fabricated and tested. A photograph of one of the antennas is shown in Fig. 5. The diameter is 100 mm, and the focal length (distance between feed and planar reflector) is 35 mm. The conical reflector with the circular waveguide feed was machined from aluminum. The two reflectors were combined by a 5 mm thick plexiglass tube. The reflector substrates are 0.254 mm thick and have a dielectric constant of 2.2. The feed has a diameter of 3.8 mm. In Fig. 6 and 7, azimuth and elevation radiation patterns of two antennas, one with circular polarization, the other one with linear polarization are shown. A side lobe level of -12 dB in elevation is achieved for both antennas. The 3 dB-beamwidth is 6.1° for the circular polarization and 6.7° for the linear polarization. Due to unsymmetries in the feed radiation, there is a variation of ±1.8 dB for both antennas in azimuth where omnidirectional radiation occurs.
For the antenna with circular polarization, the sense of the polarization simply can be changed by changing the polarization of the feed (twisting by 90°), for the linearly polarized antenna, switching from vertical to horizontal polarization can be achieved in the same way.

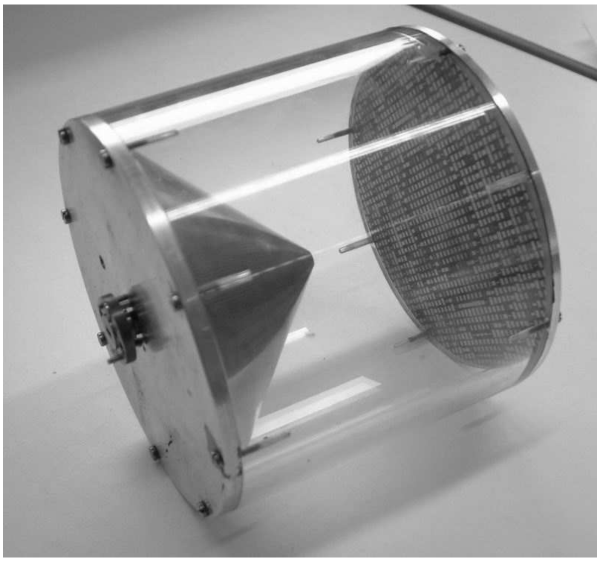

Fig. 5 Photograph of a dual reflector omnidirectional antenna.

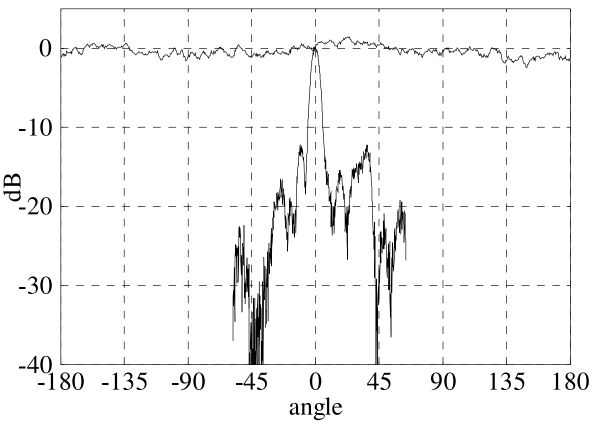

Fig. 6 Far field radiation diagram of the omnidirectional antenna with circular polarization.

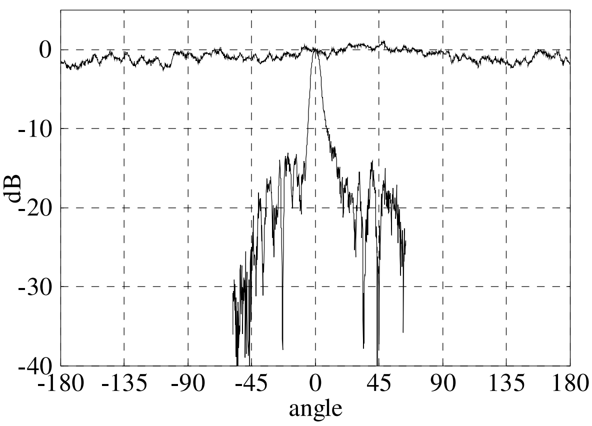

Fig. 7 Far field radiation diagram of the omnidirectional antenna with linear polarization.

Conclusion

A novel configuration of a dual reflector antenna for omnidirectional radiation in azimuth and narrow beamwidth in elevation has been presented. Both circular and linear polarization is possible without complex feed arrangements, just using the TE_{11} mode in circular waveguide. Fabricating the cone reflector with integrated feed using plastic injection molding, the antennas can be fabricated easily and cost-effective. Measured results for both antennas at 58 GHz have been presented. Further improvement of both the omnidirectional and elevation pattern can be expected by shaping the feed radiating characteristics.

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