# MILLIMETER-WAVE FOLDED LENS ANTENNAS

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**Abstract** - A folded lens antenna for mm-wave frequencies is presented providing a compact setup and a possible wideband performance. The wave radiated by the feed is incident on a grid. Firstly, the polarization is oriented parallel to the grid, and the wave is reflected and partly focused a first time by a lens. A twist polarizer behind the lens reflects the wave and twists polarization by 90°. Following this, the wave passes the lens a second time, emerges as plane wave, and now passes the grid. Measured results are given for a first antenna design and an improved antenna with surface matching and an integrated twist polarizer. Alternatively, an extremely wideband printed twist polarizer is demonstrated which will be implemented into the antenna later on.

## Introduction

Millimeter-wave systems today are finding increasing commercial application both in communication [1] for point-to-point or -multipoint links or in radar for industrial or automotive sensors [2, 3]. These systems require compact, low-loss and low-cost antennas. One solution, especially in the mm-wave range, is found in lens antennas. To further reduce their depth, folded arrangements have been proposed, e.g. [3, 4]. This contribution reports a different approach similar to a folded reflectarray as described in [5]; in this case, the focusing of the feed radiation is not done by a reflectarray, but by the double use of a dielectric lens. While reflectarrays provide some limitation in bandwidth due to a partly strong frequency dependence of the reflection phase angles of the elements and a limitation of reflections phase range to about 360°, lenses in principle can provide a very wide frequency operation. This may be of importance with respect to the recently opened frequency bands for ultra-wideband communication in the 60 to 70 GHz band.

## First antenna design

The basic setup of a folded lens antenna as reported here is shown in Fig. 1. The wave radiated by the feed is incident on a (printed) grid. As the polarization firstly is oriented parallel to the grid, the wave is reflected and partly focused a first time by a lens. A twist polarizer behind the lens reflects the wave and twists polarization by 90°. Following this, the wave passes the lens a second time, emerges as plane wave, and now passes the grid. The twist reflector, too, is a printed structure. The principle of this reflector is indicated in Fig. 2. The dipole axes are tilted by 45° with respect to the incident electric field. The dimensions of the dipoles are selected in such a way that a phase difference of 180° occurs between the two components of the reflected wave. Thus, the polarization of the total reflected wave is twisted by 90° compared to the incident one. Conventional twist reflectors using a grid with a quarter-wave spacing in front of an electric conductor must maintain a substrate thickness of $\lambda/4$. In contrast to with our design substrate thickness can be selected in a wide range. As will be shown later on, this can be used to optimize bandwidth.

The design of the lens itself starts with approximate selection of the lens contour. For simplicity, the arrangement is de-folded for this purpose. This first approach typically does not lead to the desired focusing properties (Fig. 3, left side). The contour then is approximated by a polynomial, and an optimization procedure, together with ray tracing is applied to modify the lens contour to provide a good focus at the desired position (Fig. 3, right side).

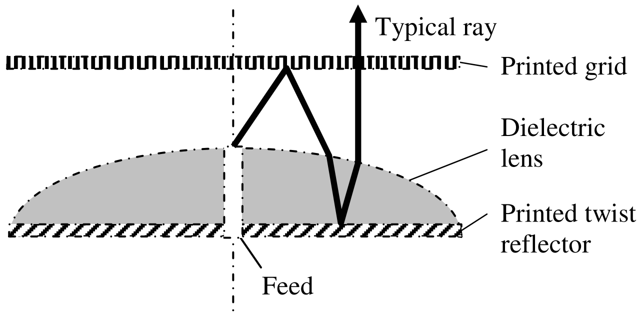


**Fig. 1:** Principle setup of the folded lens antenna.

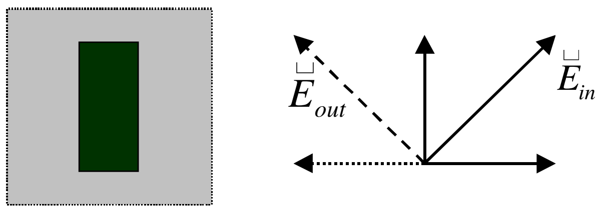


**Fig. 2:** Principle of twist reflector with single cell/patch and vector decomposition of incident and reflected electric field for 180° of phase difference.

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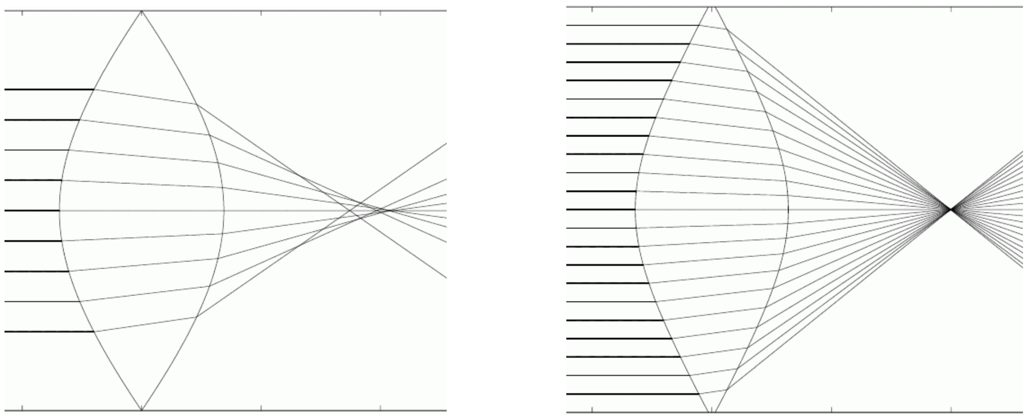

**Fig. 3:** Rays for start-up (left) and optimized design (right) of the lens.

Fig. 4 shows E- and H-plane radiation diagrams for a realized antenna at 60 GHz (left side). Diameter is 100 mm, distance between grid and twist reflector is 33 mm, the maximum thickness of the lens (polyvinylchloride, $\varepsilon_r = 2.84$) amounts to 19.4 mm. The diagrams shows slight shoulders at about -15 dB, the remaining sidelobes are below -25 dB. Beamwidths are 3.8° and 3.5° in the E- and H-plane, respectively. On the right side of Fig. 4, E-plane diagrams are shown from 58 to 62 GHz. Except for a slight change of the shoulders, all diagrams look very similar, proving the principle possibility for wideband antennas.

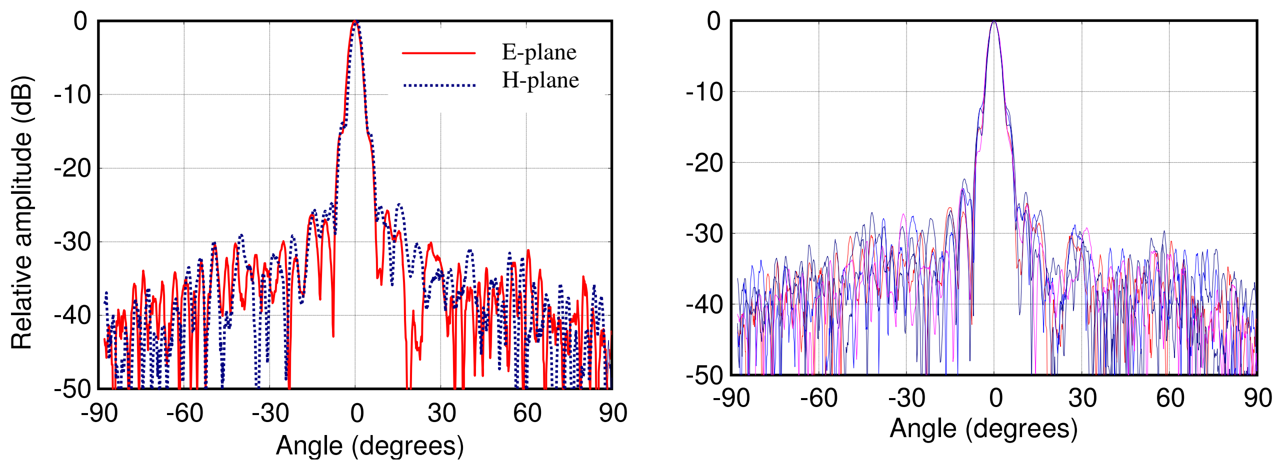


**Fig. 4:** E- and H-plane radiation diagrams of the folded lens antenna at 60 GHz (left side) and E-plane radiation diagrams from 58 to 62 GHz (right side).

Based on the ray-tracing procedure, not only the desired performance could be checked, but also the behavior of the first reflection on the lens surface (Fig. 5). This indicates that some additional radiation occurs and superimposes to the desired radiation at approximately the level of the shoulder in the radiation diagram.

## Improved antenna design

To overcome this problem, groves were machined into the curved lens surface such that a layer with an effective dielectric constant of $\sqrt{\varepsilon_r}$ and a thickness of λ/4 is achieved for matching (Fig. 6). Furthermore, the twist reflector was replaced by groves in the flat backside of the lens, in our approach filled with metal (Fig. 7). One again, the groves are arranged at 45° with respect to the incident electric field, and the depth was adjusted such that a reflection phase difference of 180° occurs between the field component parallel and vertical to the groves. This solution finally would allow a fabrication of the lens by plastic injection molding together with electroplating of the antenna backside; such avoiding the use of an expensive microwave substrate. The radiation characteristics of this antenna are plotted in Fig. 8 for a frequency of 60 GHz. Sidelobe level now is better than -20 dB.

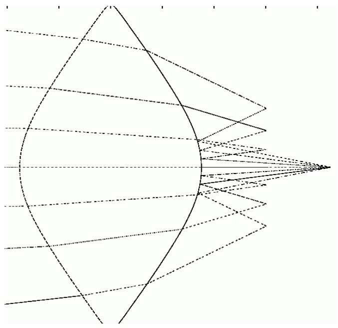

**Fig 5:** Rays reflected at lens surface.

**Fig. 6:** Surface matching of the lens using milled groves.

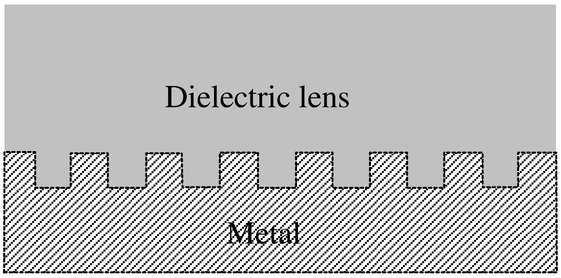


**Fig. 7:** Principle of twist reflector using metal-backed groves in the lens.

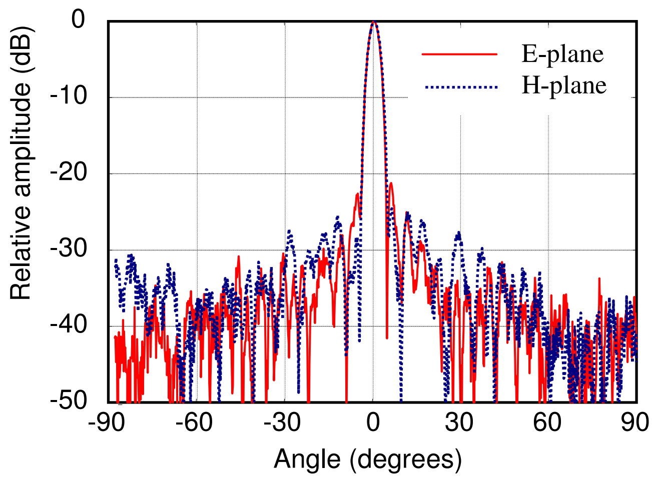


**Fig. 8:** E- and H-plane radiation diagrams of the folded lens antenna with surface matching and integrated twist reflector (60 GHz).

## Wide-band printed twist reflector

As indicated earlier, the substrate properties of a printed twist reflector can be selected arbitrarily within a wide range of parameters. Therefore, together with appropriate patch dimensions, an optimized twist reflector was designed for maximum bandwidth. Fig. 9 shows reflection phase angles for the electric fields parallel to the two patch axes, i.e. for the two orthogonal polarizations. Over a 20 GHz range, a phase difference close to 180° can be adjusted. In a next step, this twist polarizer with be combined and tested with the folded lens antenna. It is expected that bandwidth then is limited mainly by the surface matching of the lens, while the grid in front of the antenna printed on a half-wavelength thick substrate already provides a bandwidth of 17 GHz at -15 dB return loss for a polarization of the wave normal to the strips.

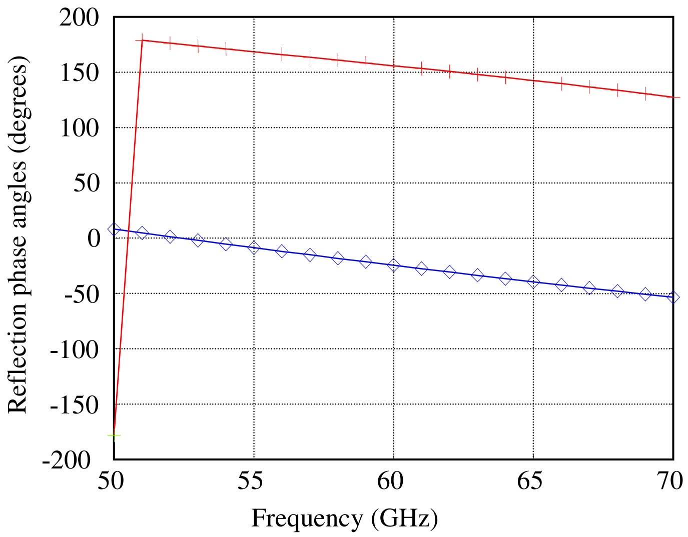


**Fig. 9:** Reflection phase angle for the two polarizations for an optimized twist reflector. Phase difference is close to 180° over a very wide frequency range. (Substrate thickness 0.79 mm, patch size $1.8 \times 0.58$ mm, patch distances 1.9 mm in both directions, dielectric constants of substrate and lens 2.2 and 2.84, respectively).

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