Single-Layer Dual-Frequency Reflectarray

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ABSTRACT: The design and first experimental results for a single-layer, dual-frequency reflectarray for arbitrary polarization is presented. The underlying reflector element is a double square ring structure where the inner ring is folded to cover all necessary phase angles at two frequencies individually. In this work, an antenna for the VSAT frequencies of 20GHz and 30 GHz has been taken as an example. With a 150 mm × 150 mm large reflector, beamwidths of 5.6° and 3.8° have been realized in the 20 GHz and 30 GHz range, respectively.

INTRODUCTION

A number of microwave systems use different frequencies at the same time, e.g. VSAT links with the downlink and uplink in the 20 GHz and 30 GHz frequency range, respectively. A low-cost realization of dual-frequency reflectors can be done by simple printed reflectarrays. Dual-frequency reflectarrays have already been realized based on multilayer structures [1, 2], by arranging separate elements for the two frequencies side by side [3], or using elements working at different frequencies in the two polarizations [4]. In [5], composed split-ring reflector elements are investigated, but working only in one linear polarization, and no antenna is demonstrated. Finally, in [6], the reflector elements are switched between operating frequencies by PIN diodes.
In several efforts, double circular or square rings have been used, e.g. [7]. In these cases, the resonant frequencies of the two sub-structures are arranged relatively close together such that a phase angle behavior (as a function of element size) as monotonically as possible results, giving a flat response with an increased phase angle range. Such structures, however, can also be used in a different way. The resonant frequencies are intentionally selected further away from each other, resulting more or less in two phase range sections usable for two different frequencies (Fig. 1 and 2).

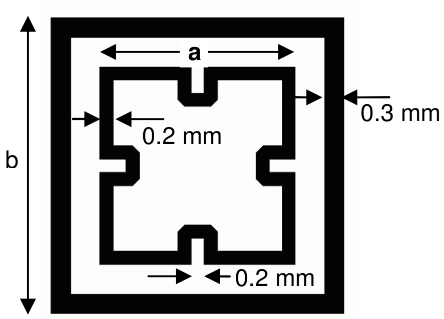

Fig. 1: Reflectarray element for dual-frequency operation

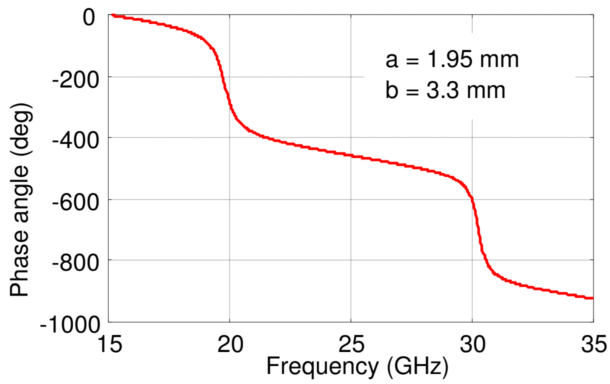

Fig. 2: Principle phase angle behavior of dual element.

REFLECTOR ELEMENT AND ARRAY DESIGN

The antenna described in this paper shall work at 20 GHz and 30 GHz independent of polarization (also enabling circular polarization); accordingly, a double symmetric reflector element has to be used. As substrate material, a Duroid material with a thickness of 0.508 mm and a dielectric constant of 2.22 has been selected; unit cell size is

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6 mm, only slight larger than half a wavelength at the upper frequency. To achieve, in the extreme case, the lowest possible phase angle at 30 GHz (maximum size of inner structure) and the maximum possible one at 20 GHz (minimum size of outer structure), the inner ring was folded, resulting in the overall element structure as shown in Fig. 1. The performance of this double ring was simulated using the CST Microwave Studio (frequency domain solver) based on a unit cell approach and normal incidence of the incoming wave. It could be stated that the phase angle behavior at 20 GHz depends nearly completely on the dimension of the outer ring; the same is true for the inner structure at 30 GHz, except for the case where the gap between the rings becomes very narrow. The phase angle performance of the overall structure is plotted in Fig. 3 as a function of the two ring dimensions (Fig. 1) for the two frequency ranges. These data sets then were used as the basis for the reflector design.

The antenna itself is an offset antenna (see Fig. 4) with a reflector size of 150 mm × 150 mm and a single feed point for both frequencies (in principle, separate feed points are possible with this approach). As feed horn, a circular horn with 18 mm aperture diameter designed for K-band is employed. At 20 GHz, the reflector is illuminated with an edge taper of 4.5 dB, at 30 GHz with about 3 dB. The required phase angles to be adjusted by the reflector elements at both frequencies were determined in the usual way compensating the free space path lengths from the feed horn to the respective reflector cell. Fig. 5 shows a section of the final reflector, and a photograph of the complete antenna is presented in Fig. 6.

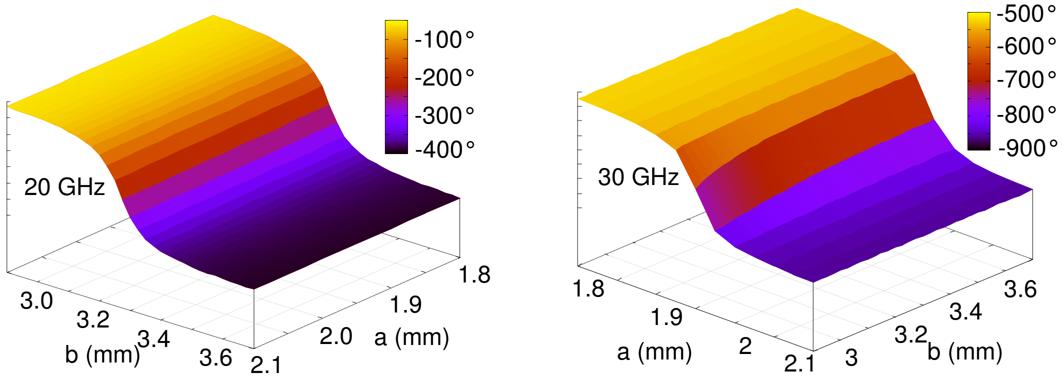

Fig. 3: Phase angle behaviour of the double ring as a function of ring sizes (see Fig. 1). Left: 20 GHz, right: 30 GHz.

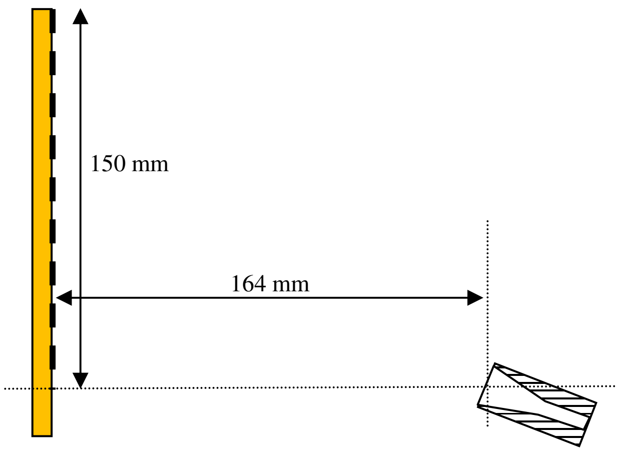

Fig. 4: Structure of the reflectarray antenna with feed horn.

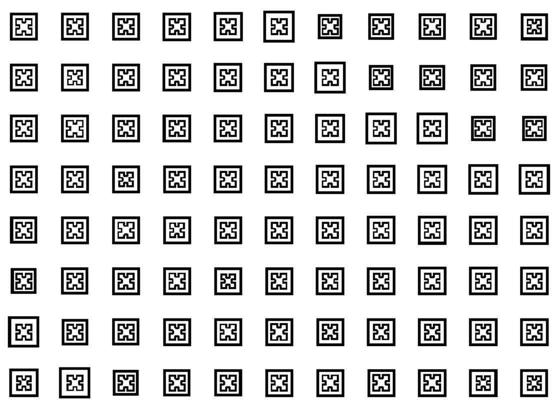

Fig. 5: Section of the antenna layout .

MEASUREMENT RESULTS

The fabricated antenna (AuT) was placed on the turntable in our anechoic chamber using a pyramidal horn for illumination. In a first step, the antenna was adjusted for maximum amplitude (main beam), and the transmission between transmitter and the antenna under test was recorded as a function of frequency using a Rohde and Schwarz

ZVA50 network analyzer (Fig. 7). Due to unknown system attenuation, the curves around the frequencies of operation are normalized to 0 dB. The 20 GHz band was well met, while the higher frequency band was shifted to 31 GHz. This probably is caused by some tolerances in fabrication. The 3 dB bandwidth in both cases is approximately 1 GHz.

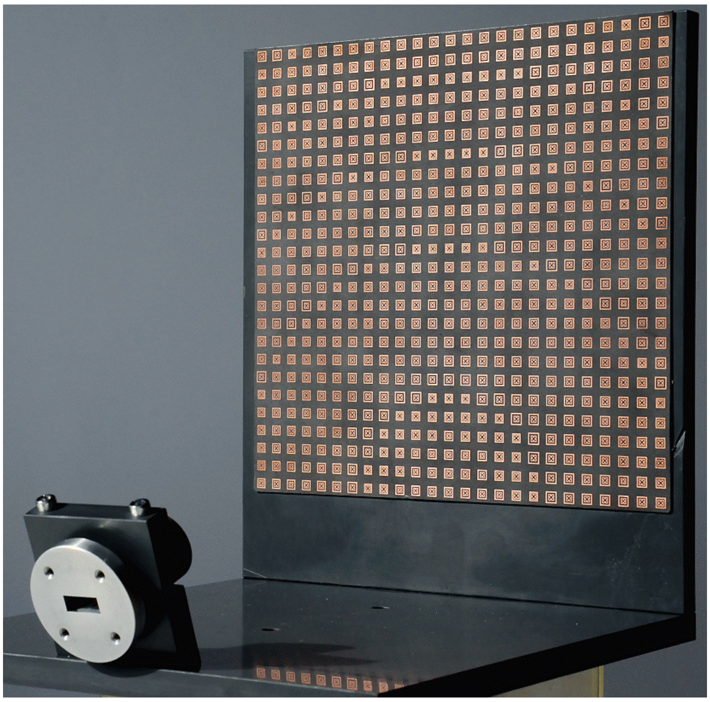

Fig. 6: Photograph of the complete antenna.

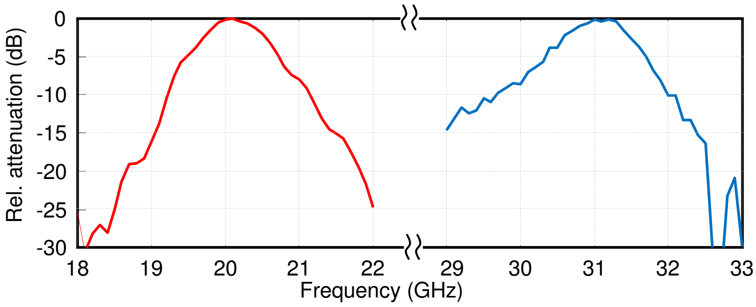

Fig. 7: Relative path attenuation for the reflectarray antenna around the two operating frequencies.

Another set of transmission curves was recorded replacing the AuT by a K- and Ka-band horn, respectively. Although these were not calibrated as standard gain horns, their gain values are estimated to be around 20 dBi, resulting in absolute maximum levels of the AuT (gain of the AuT) of 27 dBi at 20 GHz and 30.6 dBi at 31 GHz.

In the next step, the radiation diagrams of the AuT were measured in H- and E-plane for different frequencies and for orthogonal polarizations of the feed horn. Very similar diagrams were achieved for different polarizations. H- and E-plane diagrams of the antenna (vertical polarization of the feed horn according to Fig. 4) are displayed in Fig. 8 for 20 GHz and 31 GHz. Beamwidths are 5.6° and 3.8° at 20 GHz and 31 GHz, respectively, and sidelobe level is -15 dB at 20 GHz in both planes and –15 dB and -17 dB for H- and E-plane at 31 GHz. Some slight asymmetry can be observed in the H-plane (where the antenna should be symmetric); this is due to the fact that the substrate first was glued to the carrier plate in a wrong orientation, had to be removed and re-glued to the plate, resulting in some uneven antenna surface; this also slightly increases the sidelobe level. Radiation diagrams around the frequencies of operation show a very similar behavior, except for a reduction in amplitude according to the amplitude variation as shown in Fig. 7. Additionally, as reported in a number of cases, e.g. [8], some increase of radiation occurs opposite to the feed horn position (specular reflection).

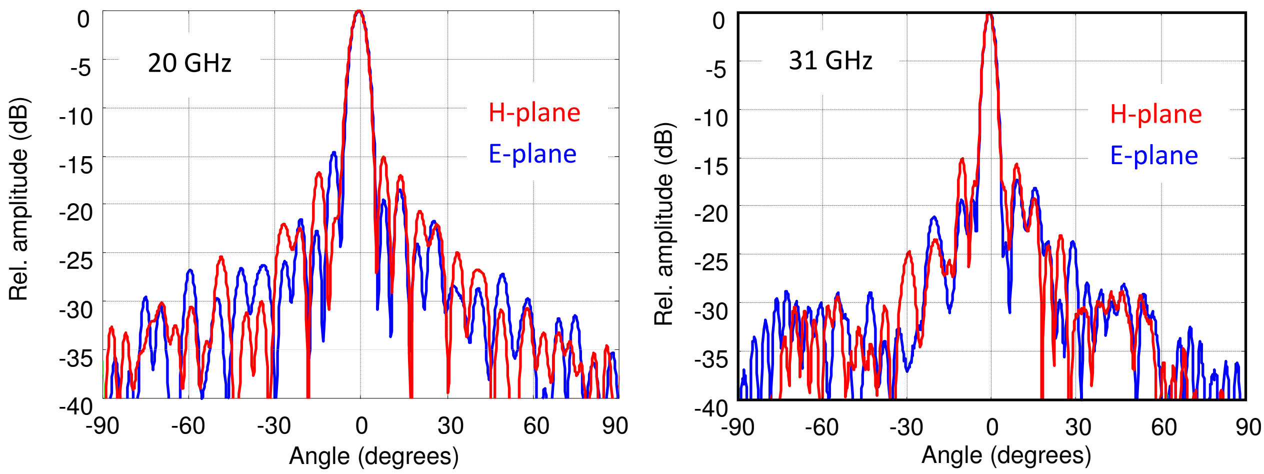

Fig. 8: H- and E-plane radiation diagram of the reflectarray antenna (polarization vertical with respect to Fig. 4) at 20 GHz (left) and 31 GHz (right).

OUTLOOK

This contribution has shown the feasibility of a very simple structure for a dual-frequency, single-layer reflectarrays which can be operated at arbitrary polarizations. While this work has been performed as a student work (Bachelor thesis) within a very limited time, some improvements will be possible, like

- correcting the frequency of operation for the upper band
- investigating modifications of the element dimensions to improve bandwidth
- selecting a smaller unit cell size which is expected to reduce the specular reflections away from the center frequency and potentially to increase bandwidth as well.

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