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# A 24 GHZ MICROSTRIP ANTENNA ARRAY WITH A NON-RADIATIVE DIELECTRIC WAVEGUIDE (NRD-GUIDE) FEEDING NETWORK

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*Abstract* — **A major restriction of high gain microstrip antenna arrays is found in their high losses, mainly due to the feeding network. In this contribution, design and results of a 24 GHz microstrip array antenna with low loss, low cost and low profile NRD-guide feeding network are presented. Interconects between planar structures and NRD-guide feeding network are done by slot coupling. The feeding network for this antenna was implemented as NRD-guides, but in a later phase, it might be implemented as substrate integrated (SI) NRD-guides [1] with even lower production cost.**

## I. Introduction

The goals for modern mm-wave antennas are low loss, low profile, and cheap production. Antennas based on planar structures like microstrip patches are optimal with respect to low profile and price but often suffer from excessive losses due to the feeding network. In former investigations this drawback has been circumvented by a feeding network based on rectangular waveguide machined from metal, [2], [3]. This results in increased production cost and a bulky and heavy setup. Although production cost and weight can be reduced significantly using plastic injection molding and electroplating, the disadvantage of a bulky setup still remains.

In this work the feeding network has been realized by non-radiative dielectric waveguide (NRD-guide) made of high density polyethylene (HDPE) with low loss, low cost and low profile. Figure 1 shows the basic setup of the antenna. Smaller subarrays of microstrip patches have been used where feed losses still are low. The subarrays are coupled to the NRD-guides via slots in the ground plane of the planar substrate (figure 2). Using the planar subarrays, an NRD-guide network with larger distances between the guides can be used, thus ensuring a considerable reduction of spurious coupling within the feeding network. The total height of the antenna is 6.3 mm only, plus the backsided aluminium plate.

## II. Subarrays

The subarrays consist of a setup of 9 rectangular microstrip patch antenna elements which are connected by microstrip lines (see figure 3). Coupling between the planar structures and the backsided NRD-guide feeding network is done by a slot in the common ground metallization. To avoid spurious radiation by the slot

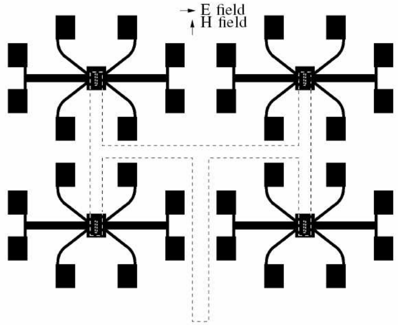


Fig. 1. Sketch of the antenna (top view) with the slot coupled NRD-guide on the backside (dashed lines).

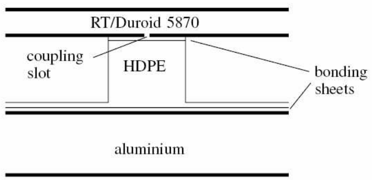


Fig. 2. Setup of the antenna with the principle of the NRD-guide feeding of the planar structure (cross section).

coupling, the coupling slots are covered by a microstrip patch. This approach has been first proposed by [4]. The position of the patches and the feeding microstrip lines are adjusted for equal phase excitation with a compact setup. The substrate is RT/Duroid 5870 ($\varepsilon_\mathrm{r} = 2.33$, thickness = 0.51mm). The outer 8 patches are side fed where matching is done by adjusting the position of the feeding point. Simulations have been done with a commercial 2 1/2 dimensional frequency domain solver [5] which uses the spectral domain technique and the method of moments.

Figure 4 shows the simulated radiation diagrams of the subarray in the E- and H-plane, respectively.

Simulated return loss of one subarray fed by an LSM mode excited NRD-guide is shown in figure 5.

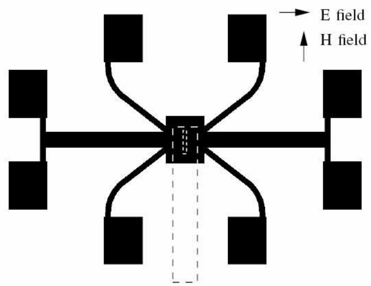


Fig. 3. Sketch of the subarray (top view) with the slot coupled NRD-guide on the backside (dashed lines).

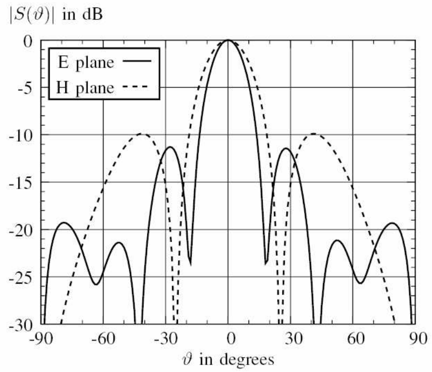


Fig. 4. Simulated radiation diagrams of the subarray in the E-plane and H-plane.

## III. Feeding network

The corporate feeding network consists of a set of NRD-guides (high density polyethylene (HDPE) $\varepsilon_\mathrm{r} = 2.3$, $\tan\delta(@24\,\mathrm{GHz}) = 0.00053$, $H_\mathrm{nrd} = 5.8\,\mathrm{mm}$). For ease of production and in order to circumvent alignment problems, the feeding network has been realized as engraved NRD-guide (ENRD-guide, [6], figure 2). A dielectric block of high density polyethylene (HDPE) is glued on an alumium plate using a bonding sheet. Then the block is milled so as to remove the dielectric material around the guide. A small thickness of dielectric material (60 µm) is left below the air region to ensure that the guide is not moved aside by the milling force. The planar structure including the microstrip patch antenna subarrays is glued on top of the NRD-guide feeding network. The backside metallization of the substrate serves, at the same time, as the top metallization of the NRD-guides. T-junctions are used to split the power. NRD-guide T-junctions always produce mode conversion

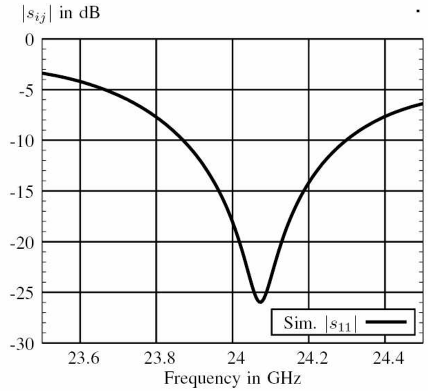


Fig. 5. Simulated return loss of a subarray fed by an LSM mode excited NRD-guide.

between the fundamental longitudinal section electric (LSE) mode and the longitudinal section magnetic (LSM) mode [7], [8]. In the feeding network, the T-junctions have been optimized to maximize the conversion. This results in two types of T-junctions (figure 6). Type 1 is excited by the LSM mode which is converted to the LSE mode at the output branches. Type 2 is excited by the LSE mode which is converted to the LSM mode at the output branches . Optimization of the T-junctions have been done with a commercial finite integration time domain simulator [9]. The simulated S parameter results of the two T-junction types are shown in figures 7 and 8, respectively. The losses due to imperfect di-

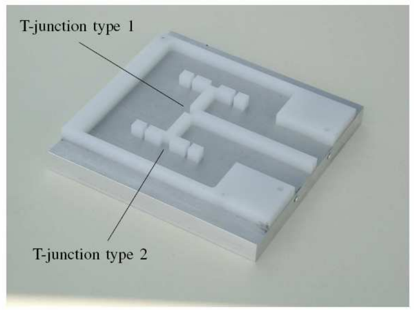


Fig. 6. Photo of the NRD-guide feeding network.

electric materials have been calculated with the formulas given in [10]. For the NRD-guides with the LSM mode ($W_\mathrm{nrd,LSM} = 4.76\,\mathrm{mm}$) the expected attenuation is 2.5 dB per meter. For the NRD-guides with the LSE mode ($W_\mathrm{nrd,LSE} = 3.86\,\mathrm{mm}$) the expected attenuation is 2.7

dB per meter. This results in a theoretical insertion loss for the whole feeding network of only 0.2 dB due to dielectric loss in the NRD-guides.

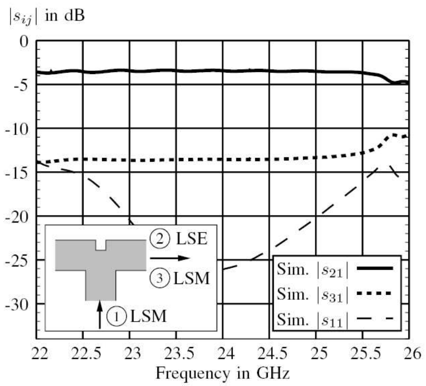


Fig. 7. Simulated S-parameters of T-junction type 1 from LSM mode to LSE mode.

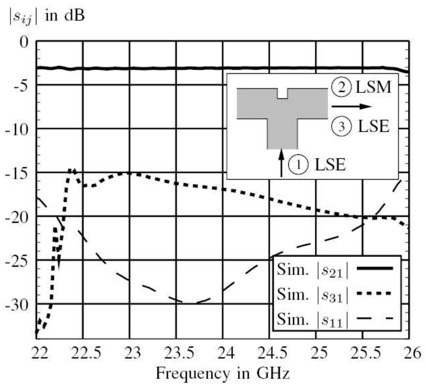


Fig. 8. Simulated S-parameters of T-junction type 2 from LSE mode to LSM mode.

## IV. Complete antenna array

With the subarrays of section II, a 2 by 2 antenna array has been designed (figure 9). Figures 10 and 11 show the calculated radiation diagrams of the complete antenna (subarray multiplied by array factor) in H- and E-plane, respectively. Distances between the subarrays are 40 mm in the E-plane and 28 mm in the H-plane. As the radiation

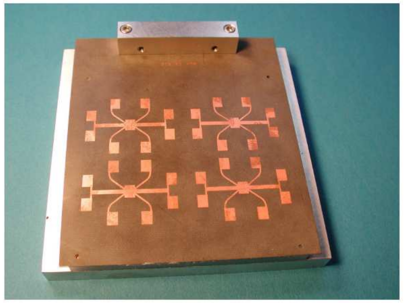

Fig. 9. Photo of the whole NRD based pencil beam antenna.

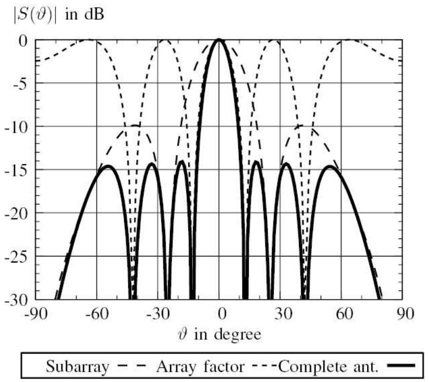


Fig. 10. Theoretical array factor, simulated radiation diagrams of single subarray, and of the 2 by 2 array in H-plane.

diagram of the complete antenna is given by the radiation diagram of one single subarray multiplied by the array factor, the farfield characteristics of the complete array strongly depend on the distances between the subarrays in the E- and H-plane. In the H-plane all 3 side lobes are set to a minimum level of about -14 dB. In the E-plane the level of the first side lobe is at -12.5 dB, 2nd and 3rd side lobes are at a level of -17 dB.

The radiation diagrams have been measured in the H-plane (figure 12) and in the E-plane (figure 13) and compared to the theoretical radiation diagrams. The half power beam width is 7° in the E-plane and 11.2° in the H-plane. A -11.5 dB side lobe level is observed at -31° in the H-plane. This is higher than the expected value of -14 dB.

In the E-plane there is a very small difference between the measured radiation diagram and theory. The level of the first side lobe is at -13.3 dB, further side lobes are at a level of -17 dB or lower.

The slight differences in the radiation diagrams between theory and measurement are probably due to misalignment. The measured gain at 24 GHz is 21 dB.

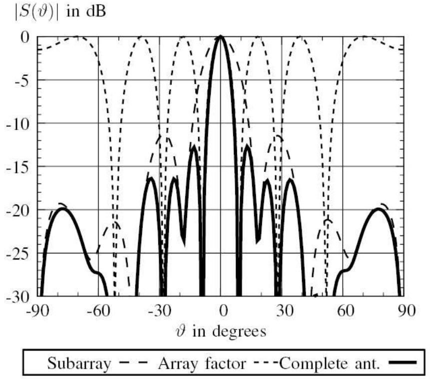


Fig. 11. Theoretical array factor, simulated radiation diagrams of single subarray, and of the 2 by 2 array in E-plane.

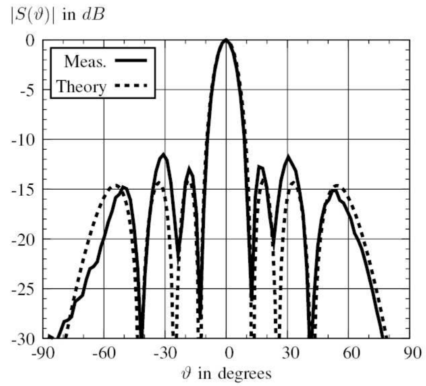


Fig. 12. Simulated and measured radiation diagrams in the H-plane.

## V. Conclusion

A 2x2 array of microstrip patch subarrays has been presented. Each subarray consists of 9 patches which are connected by a small microstrip feeding network. The subarrays are fed by an ENRD-guide feeding network. The half power beam width is 7° in the E-plane and 11.2° in the H-plane. Highest side lobe level of -11.7 dB

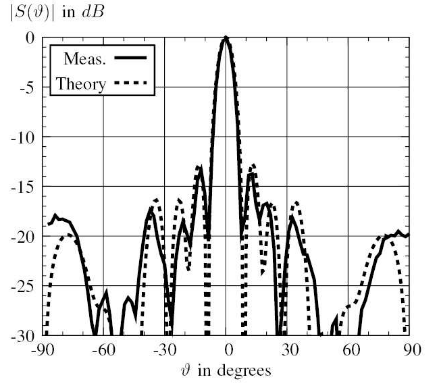


Fig. 13. Simulated and measured radiation diagrams in the E-plane.

is observed at -32° in the H-plane. The measured gain at 24 GHz is 21 dB.

In a final version the feeding network could be implemented in SINRD-guide technique further reducing the fabrication cost. The principle of this antenna can easily be extended to a bigger array (e.g. 4x4 or 8x8) with higher gain. Using unsymmetric T-junctions an amplitude taper function could be realized for lower side lobe levels.

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