A Novel Dual Polarization Antenna Array Fed by a Dual Mode Non-Radiative Dielectric Waveguide

Ulf Schmid*, Dayang Lin†, and Wolfgang Menzel†

*Cassidian, Ulm, 89077, Germany, †Ulm University, Ulm, 89081, Germany

***Abstract*—This paper presents the design and implementation of a dual polarization antenna with a low loss, planar feeding structure applicable for both, communication and radar applications at mm-wave frequencies. The array and feed network efficiency is approximately 50%. Radiation patterns are given and discussed in detail. A higher gain can be achieved by duplicating the feed structure and the antenna subarrays.**

***Index Terms*—Antenna arrays, antenna feeds, planar arrays, radar polarimetry, wireless communication.**

I. Introduction

Typical goals for mm-wave antennas are low loss, low profile and low production cost. 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. The nonradiative dielectric (NRD) waveguide is known to be a low loss waveguide especially for increased frequencies, while allowing for low profile and low cost applications [1]. Some applications require the capability of dual polarization operation. A dual polarization antenna can double the capacity of communications by means of polarization diversity [2], increase the transmit-receive isolation of transceivers or transponders and provide more information for synthetic aperture radars, collision warning radars or other safty applications based on radar [3]. The NRD-guide is a multimode waveguide. But in former approaches, the NRD-guide has been used only in single mode configuration. Typically, one of the fundamental modes (the longitudinal section electric, LSE_{01} or the longitudinal section magnetic, LSM_{01} mode) was desired, while the other one was regarded to be spurious, [4] - [5]. But since these two fundamental modes are orthogonal to each other, they can coexist on the same NRD-guide without interference as long as there is no laterally asymmetric discontinuity that would generate mode conversion problems [6]. This characteristic can be used to feed a dual polarization planar patch antenna array where each linear polarization is associated to one mode [7]. Fig. 1 shows the setup of the proposed antenna array with two microstrip feedings (one for radiation in horizontal polarization and one for radiation in vertical polarization). It consists of two substrate layers mounted on an aluminum plate serving as a support (as depicted in the inset of Fig. 1). The front side substrate (RT Duroid 5870) includes the microstrip feedings and two antenna subarrays consisting of 4 square patches and a small microstrip feeding network. The intermediate substrate (TMM-6) includes the corporate NRD-guide feeding network. The backside metallization of the front side substrate serves, at the same time, as the top metallization of the NRD-guides. The total height of the antenna is 3.5 mm only, plus the backside aluminum plate.

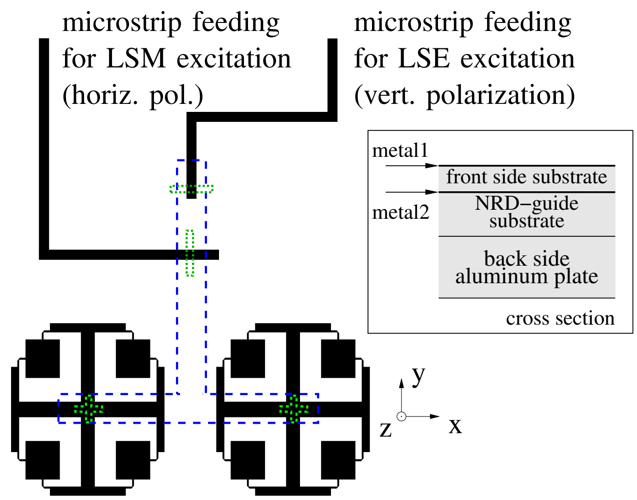

Fig. 1. Sketch of the dual polarization antenna array (top view) with slot coupled NRD-guide feeding network on the backside (dashed lines). The inset shows the cross section with metal1 including feeding microstrip lines and antenna elements and metal2 including coupling slots.

II. NRD-guide circuit elements

The dual polarization antenna array consists of several NRD-guide and hybrid circuit elements. The key component of the antenna is a microstrip to NRD-guide transition which can excite the longitudinal section electric (LSE_{01}) mode and the longitudinal section magnetic (LSM_{01}) mode independently. For matching the transitions from NRD-guide to microstrip line, it is necessary to influence the propagation of the LSE_{01} mode and LSM_{01} mode independently. This can be achieved by using a step in width of the NRD-guide (as depicted in the inset of Fig. 2) which has a strong influence on the LSM_{01} mode but virtually no influence on the LSE_{01} mode. The position of the longitudinal coupling slot relative to the step in NRD-guide width can thus be used to control the impedance matching for the LSM mode excitation. For the LSE mode excitation the commonly used technique of an NRD-guide stub is used to control the impedance matching. Simulations with a commercial finite integration time domain simulator of such a transition from dual mode NRD-guide to microstrip line show a good performance in the frequency range from 23 GHz to 25 GHz (Fig. 2 and Fig. 3).

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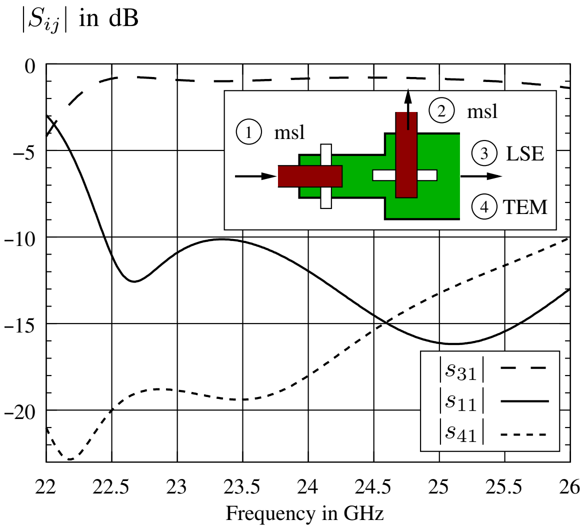


Fig. 2. Simulated S-parameters (insertion loss, return loss, excitation of the parallel plate mode (TEM)) of the transition microstrip line to the NRD-guide (LSE_{01} mode).

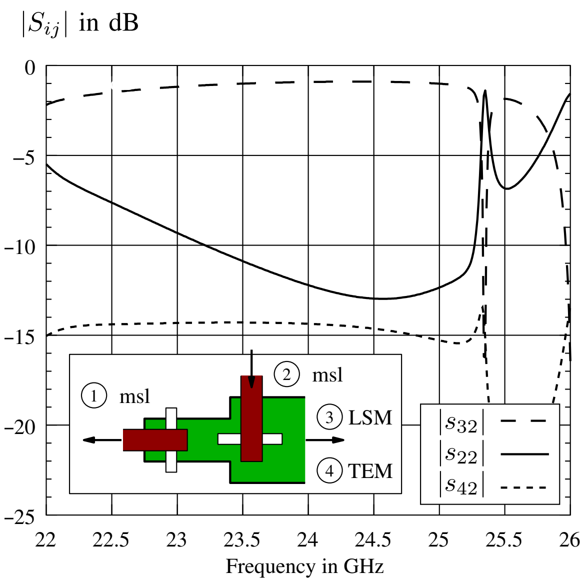


Fig. 3. Simulated S-parameters (insertion loss, return loss, excitation of the parallel plate mode (TEM)) of the transition microstrip line to the NRD-guide (LSM_{01} mode).

The transitions from NRD-guide to crossed microstrip lines at the subarray ends of the feed make use of the same matching principle, but are not described in detail here.

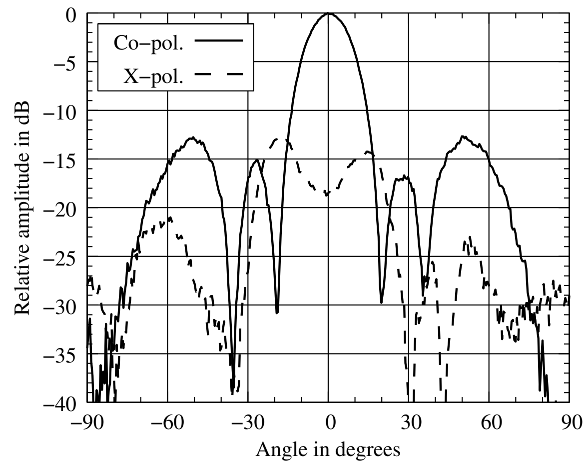
III. Measurements of the Radiation Diagramms

Using the components described before, an antenna array consisting of two 2x2 subarrays has been implemented as shown in Fig. 1. The radiation diagrams of the antenna array have been measured at 22.7 GHz in the E-plane and in the H-plane for both excitations (Fig. 4 and Fig. 5). The notation with x-y-z coordinates is according to the definition in Fig. 1.

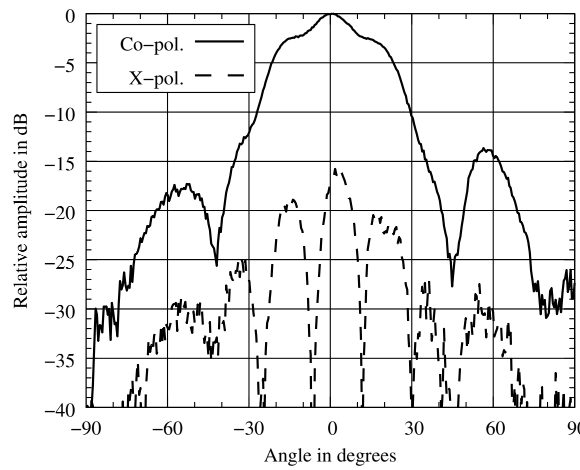
When the array is excited with the LSE_{01} mode, the first side lobes in the x-z-plane (H-plane, Fig. 4(a)) are below -15 dB and the second side lobes are below -12 dB. Cross polarization is -18 dB at boresight and reaches a peak value of -13 dB at the notches of the main lobe where cross polarization is usually not as critical. In the y-z-plane (E-plane, Fig. 4(b)), the relative level of the side lobe at $-60°$ is -17 dB and the side lobe at $+60°$ is -14 dB.

When the array is excited with the LSM_{01} mode, the first side lobes in the x-z-plane (E-plane, Fig. 5(a)) are below -11 dB and the second side lobe at $-75°$ is at -24 dB. The cross polarization at boresight is below -20 dB and reaches a peak value of -17 dB at the edge of the main lobe, where again cross polarization is not as critical. In the y-z-plane (H-plane, Fig. 5(b)) the radiation diagram is asymmetrical with the side lobe at $-60°$ with a level of -17 dB and the side lobe at $+60°$ with a level of -12 dB.

The antenna gain of the dual polarization antenna array when excited with the LSE_{01} mode was measured over a frequency range from 22 GHz to 23 GHz. The peak value is 11.24 dBi at 22.4 GHz including microstrip line feed loss (0.88 dB) and mismatch loss (0.12 dB). Exclusive of these losses, the gain is approximately 12.2 dBi. The theoretical

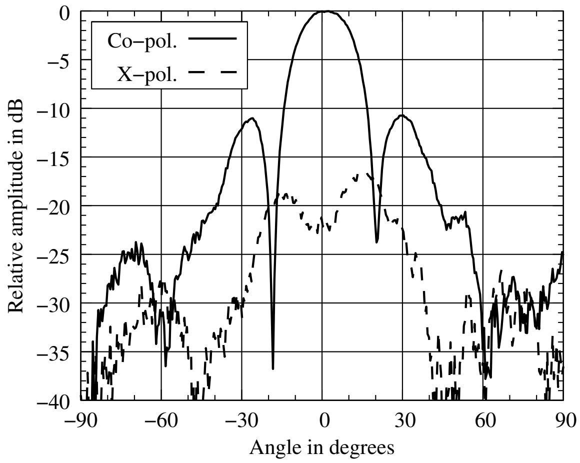


(a) Radiation diagrams in the x-z-plane (H-plane).

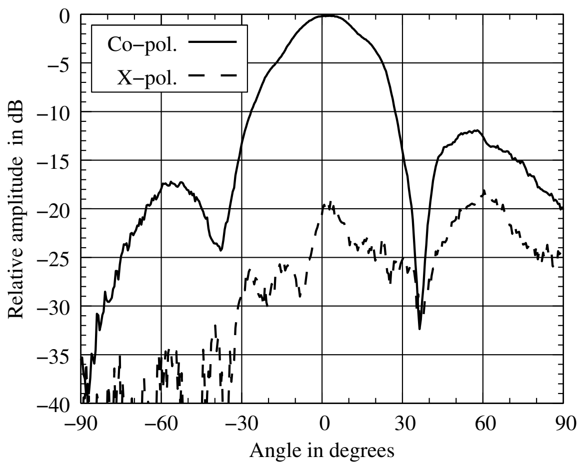


(b) Radiation diagrams in the y-z-plane (E-plane).

Fig. 4. Measured radiation diagrams of the antenna array excited with the LSE_{01} mode.



(a) Radiation diagrams in the x-z-plane (E-plane).



(b) Radiation diagrams in the y-z-plane (H-plane).

Fig. 5. Measured radiation diagrams of the antenna array excited with the LSM_{01} mode.

directivity for this array based on the aperture area is 15.1 dBi at 22.4 GHz. Thus the array and feed network efficiency is approximately 51% (measured gain minus ideal gain). When excited with the LSM_{01} mode, the maximum measured gain of this array is 10.2 dBi at 22.7 GHz including microstrip line feed loss (1.1 dB) and mismatch loss (0.82 dB). Exclusive of these losses, the gain is approximately 12.1 dBi. The theoretical ideal gain is 15.3 dBi at 22.7 GHz. Thus the array and feed network efficiency is approximately 49%. The remaining losses are partly due to spurious emissions of the microstrip feeding, partly due to ohmic and dielectric losses in the NRD-guide feeding (approximately 1.1 dB for LSM_{01} mode excitation, 1.4 dB for LSE_{01} mode excitation). So, the array and feed network efficiency of approx. 50% could be further increased by using a low loss, low permittivity dielectric material such as high density polyethylene (HDPE).

This antenna array can be easily extended to a bigger array with higher gain by duplicating the existing structure.

IV. Conclusion

The nonradiative dielectric (NRD) waveguide is used as a dual mode waveguide for feeding a dual polarization antenna array. The antenna array has a very low profile of only 3.5 mm plus the backsided supporting aluminum plate. The production cost is low. Radiation diagrams and gain measurements of the antenna array are given and discussed in detail. The radiation patterns suggest a duplication of the feed structure which will result in a bigger antenna array with higher gain. The array and feed network efficiency of approx. 50% could be further increased by using a low loss, low permittivity dielectric material. As an example, using high density polyethylene (HDPE) for the feed network would result in an array and feed network efficiency of approx. 60%. Similar efficiency numbers have been shown with a fixed beam antenna for point-to-point applications based on an NRD-guide feeding network [1].

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