Dual polarization antenna fed by a dual mode substrate integrated NRD-guide

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Abstract — The non-radiative dielectric (NRD) waveguide is used for the first time as a dual mode waveguide. The LSE_{01} and LSM_{01} modes are excited independently via a novel microstrip to NRD waveguide dual mode transition. The transition is connected to a new NRD waveguide fed planar patch antenna array where each linear polarization is associated to one mode. Using this circuit, circular and elliptical polarizations may be generated, too, by applying a specified phase shift and amplitude ratio of the two modes.

I. Introduction

Up to now, the NRD-guide has been used only in single mode configuration. Typically, one of the modes (LSE_{01} or LSM_{01}) was desired, while the other one was regarded to be spurious, [1], [2], [3]. 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 asymmetric discontinuity that would generate mode conversion problems [4]. Here we propose a new dual linear polarization antenna fed by a dual mode NRD waveguide circuit. The antenna could also be used for circular and elliptical polarizations by controlling the phase shift and amplitude ratio of the LSE_{01} and LSM_{01}. The key component of this circuit is a microstrip to NRD-guide transition which can excite the two modes independently. The antenna part is made of a dual mode double T-junction from NRD-guide to microstrip line feeding four square microstrip patch antennas. All NRD-guide components are implemented in substrate integrated NRD (SINRD) waveguide technique [5], Fig. 1 top, using TMM-6 material with $\varepsilon_r = 6$, $H_{nrd} = 3.18\,\text{mm}$, $W_{nrd} = 5.25\,\text{mm}$, $D_1 = 1.5\,\text{mm}$, $D_2 = 0.5\,\text{mm}$, $b_{cell} = 1.75\,\text{mm}$. The holes are blind holes with $d_{drill} = 60\,\mu\text{m}$ and $\alpha_{drill} = 118°$ which makes sure that the backside metallization is not damaged. This arrangement produces a small asymmetry along the height of the NRD-guide but is unsufficitent to generate significant leakage losses [6]. Simulation is done with a commercial finite integration time domain simulator [7], using a simplified NRD-guide model [5], Fig. 1 bottom, with $W_{eq} = 5.1\,\text{mm}$ and $\varepsilon_{eff} = 2.79$.

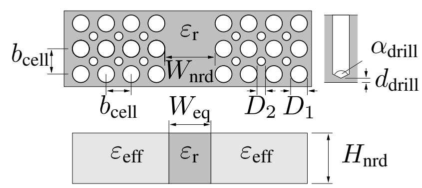


Fig. 1. SINRD-guide topology: at the top drilling hole pattern, at the bottom equivalent NRD-guide for faster simulations.

II. Transitions

A. Dual mode transition from NRD-guide to microstrip line

The dual mode transition from NRD-guide to microstrip line (Fig. 2 left) is a combination of two separate conventional transitions from NRD-guide to microstrip line [1], [2] with one important modification. The NRD-guide stub of the transition from the LSM_{01} mode to microstrip line is implemented by a set of longitudinal slots ($L_{slot} = 4.7\,\text{mm}$, $W_{slot} = 0.2\,\text{mm}$, represented by dashed rectangles in Fig. 2 left) in the backside metallization of the NRD-guide which does not effect the LSE_{01} mode, but act as a highly reflective discontinuity for the LSM_{01} mode. Length of the coupling slots is $L_{slot,LSM} = 4.2\,\text{mm}$ for the LSM_{01} mode excitation and $L_{slot,LSE} = 4.0\,\text{mm}$ for the LSE_{01} mode excitation, and the width of both slots is $W_{slot} = 0.2\,\text{mm}$. The length of the microstrip line stubs is $L_{stub,LSM} = L_{stub,LSE} = 2.2\,\text{mm}$. Fig. 2 right shows the simulated S-parameters of the dual mode transition from NRD-guide to microstrip line. Port 3 and port 4 are for the LSM_{01} and LSE_{01} mode, respectively. Port 5 is defined as the power that is lost by radiation and the excitation of spurious modes in the NRD-guide substrate.

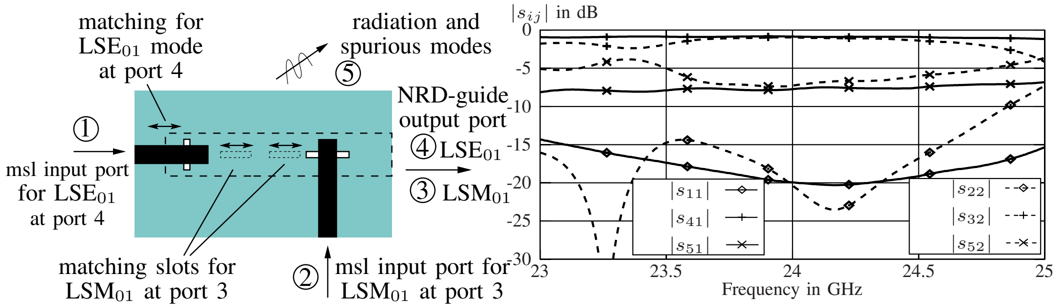
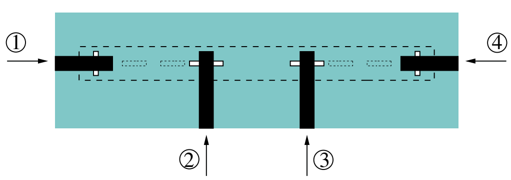


Fig. 2. Simulation of the dual mode transition from NRD-guide to microstrip line: left setup, right S-parameters.

The transition has been fabricated as a back-to-back transition (Fig. 3 left) with 53.8 mm distance between the LSE_{01} mode excitation slots and 27.8 mm distance between the LSM_{01} mode excitation slots. Length of the LSE_{01} mode exitation microstrip lines is 11 mm, and length of the LSM_{01} mode exitation microstrip lines is 16 mm. The wavelength at 24 GHz for a 50 Ω microstrip line made of RT/Duroid 5870 ($\varepsilon_r = 2.33$, thickness = 0.51mm) is about 9 mm. Since the attenuation of the microstrip line is about 0.2 dB per wavelength, we have 0.7 dB insertion loss for the LSM_{01} mode excitation lines, and 0.5 dB for the LSE_{01} mode excitation lines. Fig. 3 right shows the measured S-parameters of the dual mode back-to-back transition. Insertion loss for the LSM_{01} mode with about 4 dB to 5 dB is higher then the simulation results. This is due to the fact that the dielectric losses in the SINRD-guide substrate and the microstrip lines were not included in the simulation. Furthermore the TMM-6 substrate used for the SINRD-guide structures showed impurities which we believe lead to higher insertion losses. We also note a difference between the simulation and the measurement results for the matching level of both modes. Part of this difference is attributed to the dielectric constant of the TMM-6 substrate, which was not exactly known, again because of the impurities found in it.
The other reason of the difference is related to the simplified model in Fig. 1, which does not consider the asymmetry caused by the blind holes.



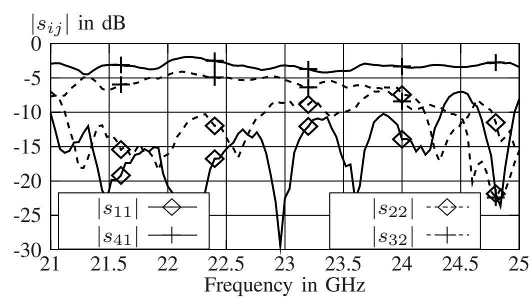


Fig. 3. Measurement of the dual mode transition from NRD-guide to microstrip line: left setup, right S-parameters.

B. Dual mode double T-junction from NRD-guide to microstrip line

The coupling from the NRD-guide to the dual polarization antenna array is done by a coupling cross (see Fig. 4 left). The dimensions of the coupling crossed slots are the same as the dimensions for the coupling slots of the dual mode transition in section II-A. Matching of the LSM_{01} mode is achieved by a longitudinal slot in the backside metallization of the NRD-guide ($L_{\text{slot}} = 5.0$ mm, $W_{\text{slot}} = 0.12$ mm, represented by a dashed rectangle) at the distance $L_{\text{stub,LSM}} = 2.2$ mm from the center of the coupling cross. Note that this longitudinal slot does not effect the LSE_{01} mode. The resonance for the LSE_{01} mode matching is tuned by the NRD-guide stub length $L_{\text{stub,LSE}} =$ 3.0 mm. Fig. 4 right shows the simulated S-parameters of the double T-junction. Power inserted at port 1 and port 2 is transfered to port 4 and port 3, respectively. Port 5 is defined as the power that is lost by radiation and the excitation of spurious modes in the NRD-guide substrate. For

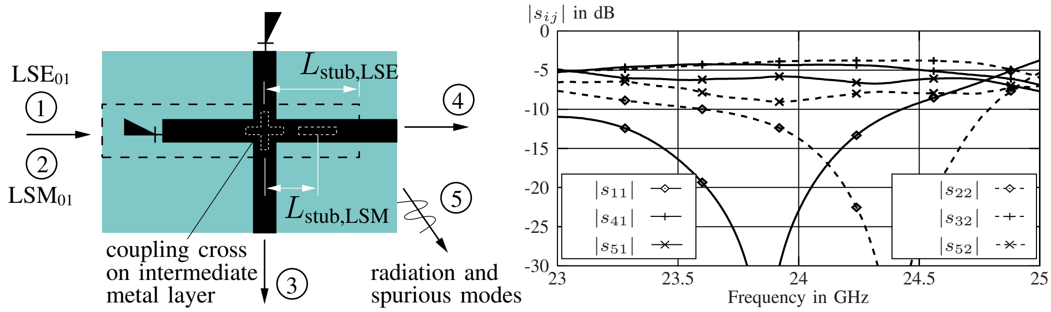
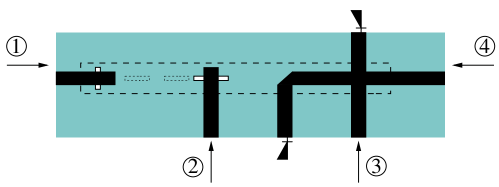


Fig. 4. Simulation of the dual mode double T-junction from NRD-guide to microstrip line.

measurement purpose the transitions for dual mode excitation (Fig. 2 left) and the dual mode double T-junction (Fig. 4 left) have been combined to the measurement setup in Fig. 5 left. Compared to theory, the measured S-parameters (Fig. 5 right) show a slight shift towards lower frequencies. Around 23 GHz the set works well for both excitations.



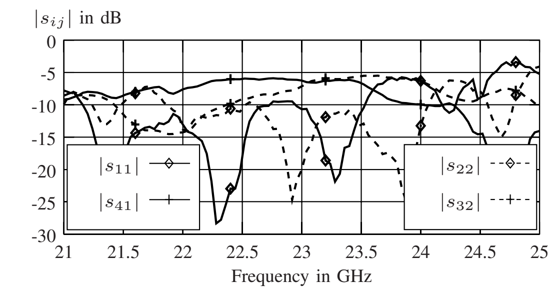


Fig. 5. Measurement of the dual mode double T-junction from NRD-guide to microstrip line: left setup, right S-parameters.

III. Radiating Element

The radiating structure (Fig. 6) consists of four square microstrip patch antennas and is excited by a network including the dual mode double T-junction described in section II-B, Fig. 4 left. LSM_{01} mode on the backside NRD-guide (represented by a dashed rectangle) excites the horizontal microstrip line and makes the four rectangular patches radiate in the horizontal polarization. LSE_{01} mode makes them radiate in the vertical polarization. The planar structure is symmetrical in both planes. Dimensions are $L_1 = 7.6\,\text{mm}$, $W_1 = 1.5\,\text{mm}$, $L_2 = 8.4\,\text{mm}$, $W_2 = 0.9\,\text{mm}$, $W_3 = 0.2\,\text{mm}$, $L_\text{p} = 3.8\,\text{mm}$, $D_\text{p} = 10\,\text{mm}$.

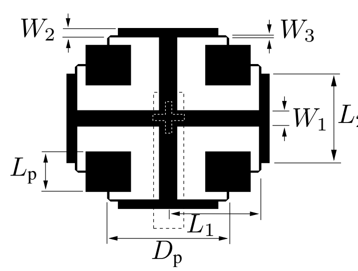


Fig. 6. Setup of the dual polarization radiating element.

IV. Dual Polarization Antenna

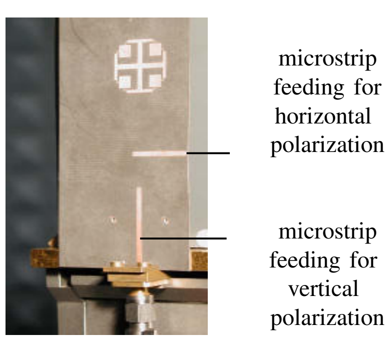


Fig. 7. Photo of the dual polarization antenna.

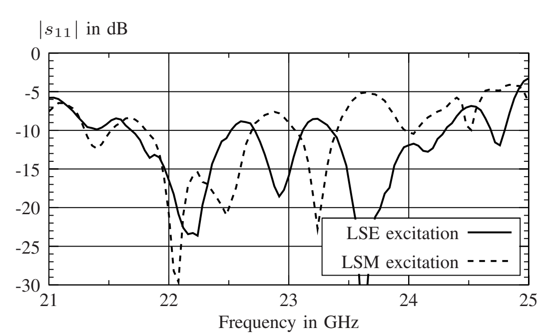


Fig. 8. Measured matching of the antenna.

Fig. 7 shows the dual polarization antenna mounted on the turntable for antenna measurements. In this case, the antenna is excited for vertical polarization by a coaxial connector.

The matching of the dual polarization antenna (Fig. 8) for both excitations is best between 22 and 22.5 GHz. The radiation diagrams of the antenna have been measured in the E-plane and in the H-plane for both excitations (Fig. 9). For LSE mode excitation, the cross polarization and the sidelobes of the co-polarization are below -15 dB. For LSM mode excitation, the cross polarization and the sidelobes of the co-polarization are below -10 dB.

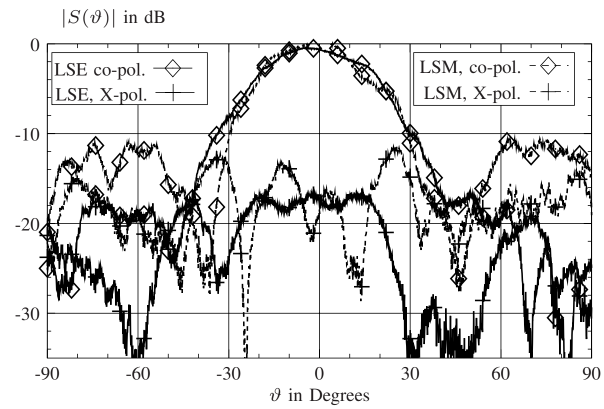


Fig. 9. Measured radiation diagram of the dual polarization antenna.

V. Discussion

The difference between simulation and measurement of the NRD-guide components has several reasons. The dielectric constant of the TMM-6 substrate is not exactly known, the TMM-6 substrate used for the SINRD-guide structures showed impurities which lead to higher insertion losses. Simulation was done with the simplified model in Fig. 1, which does not consider the unsymmetry caused by the blind holes.

VI. Conclusion

The non-radiative dielectric (NRD) waveguide is used as a dual mode waveguide for feeding a dual polarization antenna array. LSE_{01} and LSM_{01} mode are excited independently by seperate transitions from microstrip line to NRD-guide. Each of the modes causes the planar patch array to radiate in one linear polarization. By a respective phase shift and amplitude relation of the two modes, circular and elliptical polarizations may be generated. This even may be achieved with a modified transition using a single microstrip line and exciting both modes in the necessary phase relation.

References

[1] A. Bacha and K. Wu, “Lse-mode balun for hybrid integration of nrd-guide and microstrip line,” *IEEE Microwave and Guided Wave Letters*, pp. 1188–201, 1998.

[2] ——, “Toward an optimum design of nrd-guide and microstrip-line transition for hybrid-integrated technology,” *IEEE Transactions on Microwave Theory and Techniques*, vol. 46, pp. 1796–1800, Nov. 1998.

[3] J. Tang and K. Wu, “Integrated microstrip to nrd-guide transition using a spurious mode suppressing technique,” in *IEEE Transactions on Microwave Theory and Techniques Symposium*, vol. 3, June 2000, pp. 1805–1808.

[4] F. Boone and K. Wu, “Mode conversion and design consideration of integrated nonradiative dielectric (nrd) components and discontinuities,” *IEEE Transactions on Microwave Theory and Techniques*, vol. 48, no. 4, pp. 482–491, Apr. 2000.

[5] Y. Cassivi and K. Wu, “Substrate integrated non-radiative dielectric (sinrd) waveguide,” *accepted for publication in IEEE Microwave and wireless components letters*.

[6] H. Shigesawa, M. Tsuji, P. Lampariello, F. Frezza, and A. A. Oliner, “Coupling between different leaky-mode types in stub-loaded leaky waveguides,” *IEEE Transactions on Microwave Theory and Techniques*, vol. 42, no. 8, pp. 1548–1560, Aug. 1994.

[7] CST, *CST Microwave Studio, Version 4.3*. CST-Computer Simulation Technology.