A NOVEL PLANAR TRAVELING WAVE ANTENNA WITH OMNIDIRECTIONAL RADIATION CHARACTERISTICS

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Abstract -- A linear polarized slot array with stripline feed and good omnidirectional radiation characteristics in the azimuthal plane and narrow beamwidth in the elevation plane is developed. A completely symmetrical setup was chosen to minimize the excitation of parallel-plate-modes and to guarantee a symmetrical radiation pattern. A planar slot-array with six slots on each side of the printed structure is presented. Effects of the geometrical dimensions on the performance of the proposed antenna are studied. For excitation of the TEM-stripline-mode, a simple low-cost coaxial-to-stripline-transition was designed at 24 GHz using a standard SMA-connector. Measured results of the combination of transition and antenna are presented to validate the simulated results.

I. Introduction

With increasing number of wireless local area networks and other point to multipoint applications, the demand for low-cost broadband antennas with omnidirectional radiation pattern in the azimuthal plane and usually narrow beamwidth in the elevation plane and sufficient gain increases. Recently a planar antenna with omnidirectional pattern using a printed dipole array has been presented [1]. An omnidirectional radiation with gain ripple in the azimuthal plane about 2 dB at 2.4 GHz has been obtained. In [2] the omnidirectional characteristic was attained wrapping a microstrip patch around a cylinder, which increases the complexity of the antenna explicitly. The wide beamwidth of a single radiator in the elevation was reduced using an axial array of patches. The unsymmetrical setup, however, reproduces an unsymmetrical radiation pattern. An axially symmetric setup was chosen in [3] where a center-fed corrugated disk antenna with a complex mode transformer was implemented, having low ripple in the azimuth but bad side lobe level in the elevation. Finally, the solution presented in [4] is qualified for small beamwidth and good side lobe level in the elevation plane in the mm-wave range, but for lower frequencies the size of the antenna gets bulky.
The antenna type presented in this paper can be designed for a wide range of frequencies, both for the 2.4 GHz band used for the WLAN-standard IEEE 802.11g and for frequencies up to 60 GHz which are available for future broadband indoor networks. The realized antenna was designed for a center frequency of 24 GHz and has almost perfect omnidirectional characteristic, using a low-cost, easy to fabricate planar structure which can be easily installed inside a cylindrical tube as a radome.
The planar antenna consists of a stripline structure with symmetrical slots in the upper and lower ground plane conductors, whose widths are only slightly wider than the slots (fig. 1). By the finite ground plane the radiated power distribution in the x-z-plane has only a very low ripple. At first a single slot pair as shown in fig. 1 is investigated. Afterwards a serial fed six-element-array with narrow beam width in the elevation is presented.

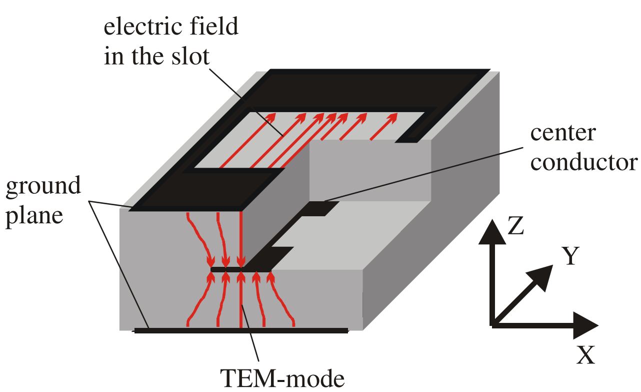

Fig. 1 Structure of a single slot pair

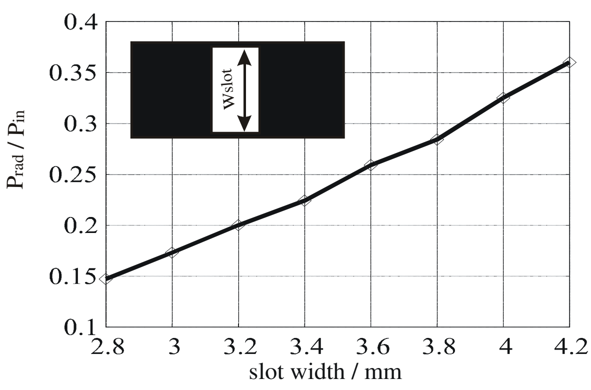

Fig. 2 Radiation efficiency of a matched single slot pair

II. Antenna Design

For the design of a one-dimensional array, it is necessary to adjust radiated power from each slot to obtain the desired amplitude distribution. If a single element as shown in fig. 1 is terminated with a matching load, the ratio of radiated power to the input power can be expressed as follows.

$$\frac{P_{rad}}{P_{in}} = 1 - |S_{11}|^2 - |S_{21}|^2 \tag{1}$$

A commercial time-domain simulator (CST, Microwave Studio 5.0) was used to evaluate the ratio. Fig. 2 shows the calculated values of a matched radiator as a function of the slot width for a substrate with a permittivity of $\varepsilon_r = 2.33$, height $h_s = 0.79$ mm of a single layer, a ground plane width 200 µm wider than the slot and width $w_n = 0.5$ mm of the center conductor. A matching structure is included reducing the width of the center conductor (fig. 1). The constriction depth, length and position are optimized for each slot size to minimize the return loss.
It can be found from this result that the power radiated through the slot and the power transported by the waveguide to the next radiating slot can be controlled mainly by the width of the slot. As the slot width also affects the far field pattern, especially in the azimuthal plane, it is chosen to be smaller than 4 mm to reduce the azimuth ripple. As can be seen from fig. 2, the maximum power radiated by a single slot pair is lower than one third of the input power. In a low loss antenna array with equal amplitude distribution or any taper for low side lobe level, radiation levels of more than 50% are needed. To reach such high radiation level without further increasing the slot width an additional impedance junction was added behind the respective slots (fig. 5). Increasing the effective electrical width of the slot by introducing such capacitive stripline elements, radiation levels of over 60% are achieved. The last radiator in the array was designed to radiate all input power, which was achieved with a stub line ending in the center of the slots, as can be seen in fig. 5. Thus no absorber material has to be used to cancel the power which is not radiated at the end of the array, what would increase losses and complexity of the antenna.
In fig. 3 further effects of the geometrical dimensions on the azimuth ripple are shown. With increasing width of the ground plane and width of the metallization bridges on the sides of the slot, respectively, more power is radiated perpendicular to the slot aperture (along z-direction) than in the direction left and right of the slot (x-direction, fig. 3, left). In the following design process, the bridge width was chosen to be 100 µm as a compromise between the ripple in the azimuth and fabrication complexity. Varying substrate height changes the effective distance between the two slots on the front- and backside of the stripline and varies the ripple in the superposed radiation pattern (fig. 3, middle). In case of the substrate being wider than the ground metallization, the power density radiated in *x*-direction is reduced too (fig. 3, right). As the fabrication process required a substrate width wider than the ground metallization width, a substrate being about 0.5 mm wider than the ground plane at the widest slot width was chosen.
For a low return loss level over a wide frequency range the behavior of a single slot pair as a function of geometrical dimensions was investigated. The characteristic impedance of the stripline changes the 15 dB- and 20 dB-bandwidth only marginally (fig. 4a). As expected the return loss is improved using thicker substrates (fig. 4b) and substrate with lower permittivity. A small ground plane does not only improve the far field-ripple in the azimuth plane, it also improves the bandwidth significantly (fig. 4c). The bandwidth can be improved most effective by increasing the slot length (fig. 4d). When the slot length gets close to a half effective wavelength a second mode in the slot is excited and the cross polarization suppression is getting worse. Thus a slot length of 3 mm was chosen.

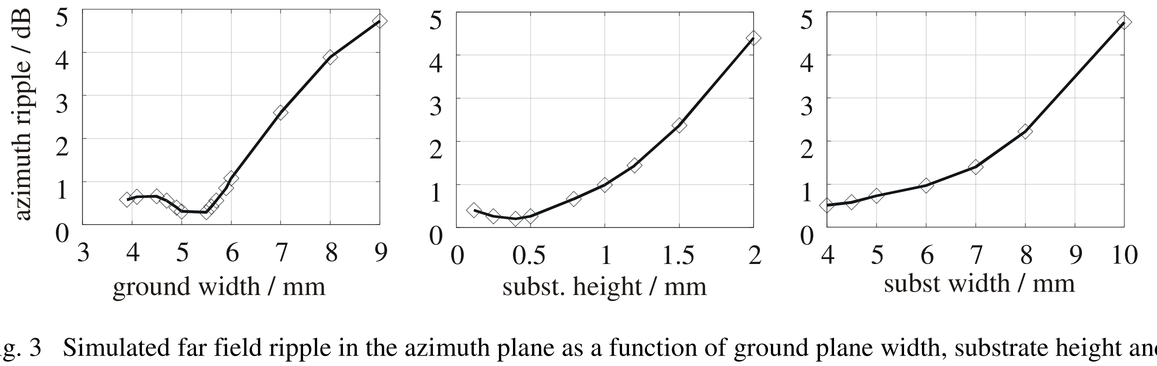

Fig. 3 Simulated far field ripple in the azimuth plane as a function of ground plane width, substrate height and substrate width at 24 GHz ($\varepsilon_r = 2.33$, $h_s = 0.79$mm, $w_n = 0.5$mm, slot width 3.7 mm, slot length 3 mm).

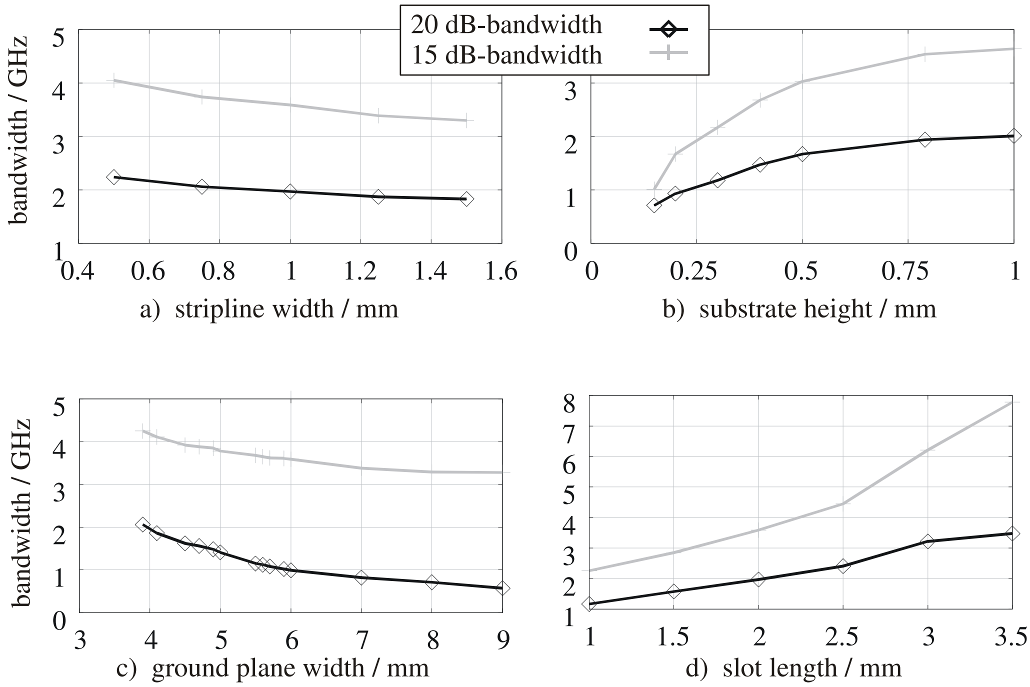

Fig. 4 Return loss: bandwidth of a single slot pair as a function of geometrical dimensions.

III. Antenna-Array

The multilayer antenna was fabricated by printing the ground metallization with the slots on one side and the center conductor on the other side of a substrate (RT/duroid 5870). A second substrate with only the ground metallization including the slots printed on it is bonded together with the first one. The thickness of the bonding film (35 µm) is very small compared to the substrate height, so that the setup can still be assumed to be symmetric in both, the x-y-plane and the y-z-plane. This assures that no parallel plate modes are excited and a low far field ripples in the azimuthal plane results.

Based on the results above a six element array was designed at 24 GHz (fig. 5 and 6). Each slot having different scattering parameters, the distance between the array elements is adjusted for equal phase of the electric fields in the slots, to have maximum gain in the x-z-plane. Special attention has to be paid to the coupling between slots. With a coupling coefficient between two neighboring slots slightly less than -10 dB the influence has to be included in the design process.

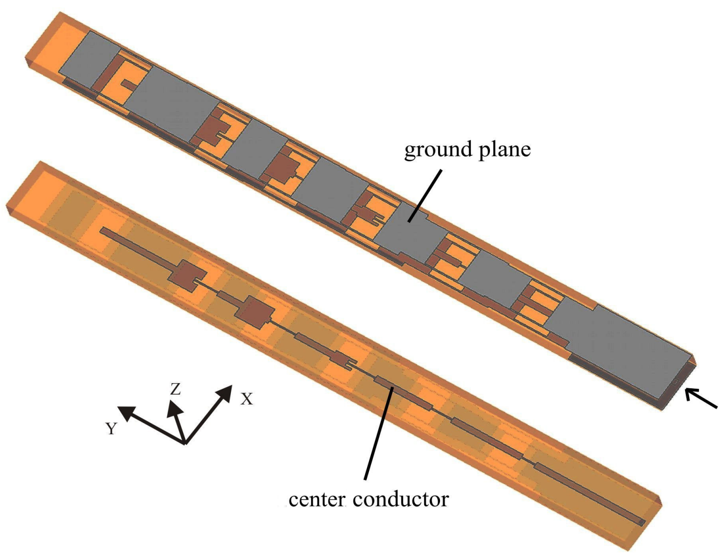

Fig. 5 Outer and inner metallization of the triplate structure

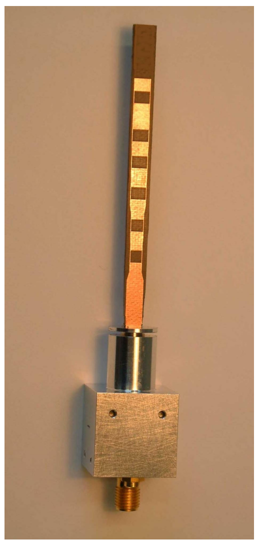

Fig. 6 Photograph of the antenna

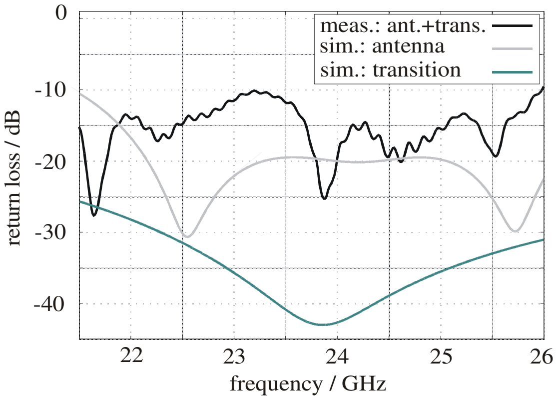

Fig. 7 Return loss of the antenna and transition

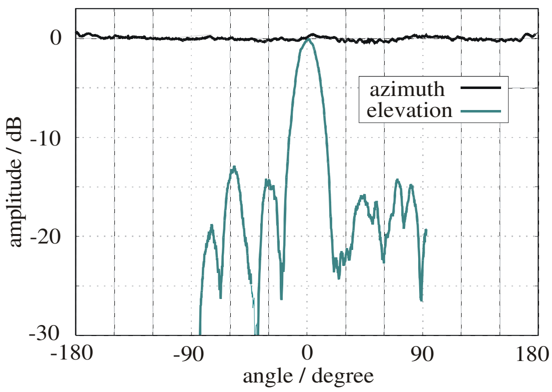

Fig. 8 Farfield radiation pattern at 24 GHz

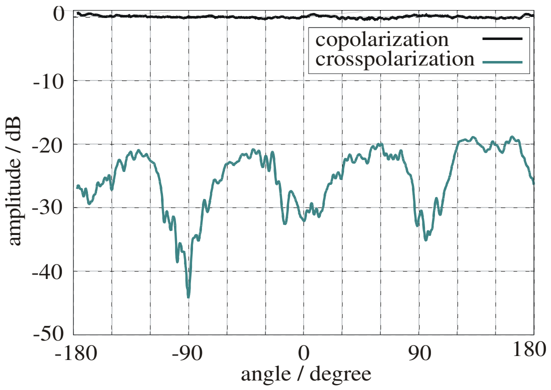

Fig. 9 Cross-polarization in x-z-plane

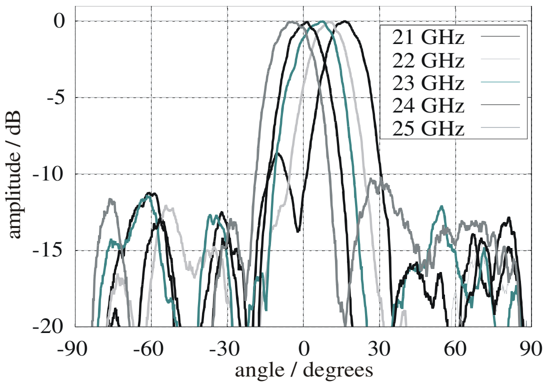

Fig. 10 Normalized farfield radiation pattern at different frequencies

The simulated return loss of the antenna shows a 20 dB-bandwidth of more than 4 GHz (fig. 7). The measured return loss of the antenna including a transition from coaxial-to-stripline is lower than 10 dB over the whole bandwidth. Differences between the simulated and measured values are mainly caused by contacting problems in the transition. Simulated results of the coaxial-to-triplate transition are shown in fig. 7. For frequencies in the mm-wave range, a transition from rectangular waveguide to stripline can be used.

The far field measurement shows very good omnidirectional radiation in the azimuth with less than 1 dB ripple and a 3 dB-beam-width of 16.5° in the elevation (fig. 8). Side lobe level is better than 13 dB. The cross-polarization level is beneath -20 dB (fig. 9). The beam panning is about ±6° at ±1 GHz offset from the center frequency (fig. 10).

IV. Conclusion

A linearly polarized array antenna has been presented in this paper. It is fed by a stripline and it shows a good omnidirectional radiation pattern. The influences of geometrical dimensions on the farfield pattern, the return loss and the bandwidth performance have been investigated. The antenna has been fabricated and simulated results have been verified by measurements. A circular polarized version of the planar array is currently under evaluation.

References

[1] Kin-Lu Wong, Fu-Ren, Tzung-Wern Chiou: "Omnidirectional Planar Dipole Array Antenna", Trans. A&P, Vol. 52, No. 2, pp. 624-628, Feb. 2004

[2] Naftali Herscovici, Zvonimir Sipus, Per-Simon Kidal: "The Cylindrical Omnidirectional Patch Antenna", IEEE Trans. A&P, Vol. 49, pp. 1746-1753, Dec. 2001

[3] Robert E. Plummer: "Surface-Wave Beacon Antennas", IRE Trans. A&P, Vol. 06, pp. 105 - 114, Jan. 1958

[4] Ralf Leberer, Wolfgang Menzel: "A Novel MM-Wave Dual Reflector Antenna with Omnidirectional Radiation Pattern", JINA 2002, Int. Symposium on Antennas, Nice, Session 3, Nov. 2002