A LOW-PROFILE, NARROW-BEAM ANTENNA WITH A PRINTED PERIODIC STRUCTURE

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Abstract: In analogy to dielectric superstrate structures, a periodic array of patches printed on a single substrate is used to achieve the necessary resonance condition to considerably improve the gain of a small radiating element. An antenna of this kind was designed for the 38 GHz frequency range, built and tested. The substrate has a diameter of 100 mm and is placed 4 mm or 8 mm in front of a simple waveguide feed, resulting in a beamwidth of 7.5°, i.e. an effective aperture of about 65 mm, a bandwidth of 300 MHz and a gain of 26.3 dB.

1. Introduction

The gain of single antenna elements like microstrip patch antennas, slot antennas, or waveguide feeds can be greatly enhanced placing a (multilayer) superstrate above them, resulting in resonances and a lateral extension of the antenna aperture, however at the expense of bandwidth. This has been demonstrated some time ago for microstrip patch antennas [1 - 4] . In [4] and [5 - 7] a single dielectric layer with a high dielectric constant is used, partly with a simple slot in the ground plane as original radiating element. Design of these antennas typically is done based on Green's functions and the method of moments, including leaky wave phenomena [5, 6, 8].

In [9] an interesting alternative point of view of this type of antennas is given, based on a periodic band gap structure with a defect. The superstrate layer structure, together with its mirror (with respect to a conducting ground plane, Fig. 1, left), but without the ground plane, is treated as a transmission resonator. Best gain improvement is achieved at the spurious transmission band or resonance slightly above 5 GHz as shown in Fig.1, right side.

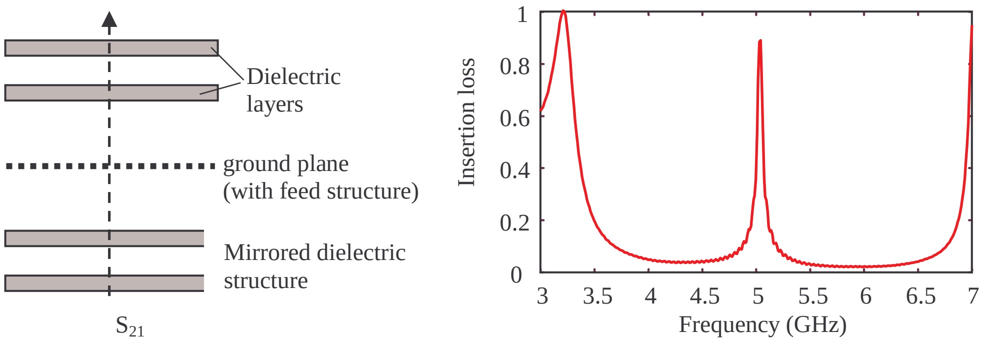


Fig. 1: Layer structure and transmission behavior of the antenna arrangement according to [9].

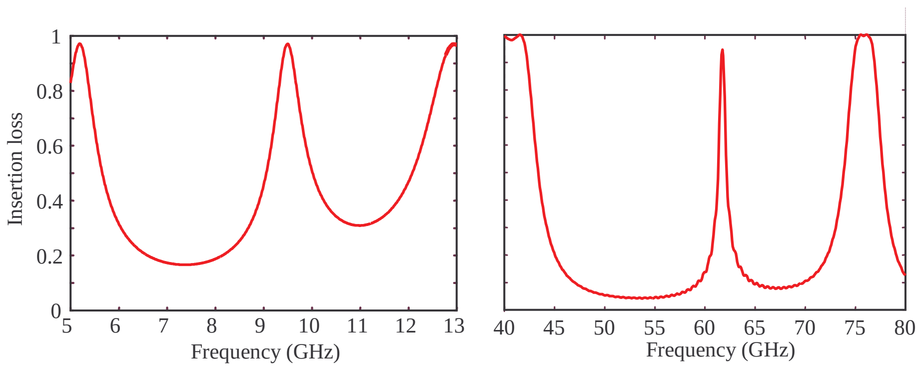


Fig. 2: Equivalent transmission resonance computation of the layer structures in [3], left side, and [7], right side, according to the principle of [9]. To this extent, the respective structures are mirrored at the ground plane and handled as a transmission resonator.

A quick check (Fig. 2) demonstrates that this principle works, too, for example, for the antenna layer structures given in [3] or [7]. This once again confirms that a resonance is formed by the superstrate, and that this easily can be determined by a simple plane wave or even an equivalent transmission line calculation.

2. Description of the novel antenna

Based on the original explanations and the alternative design procedure, the superstrate structure, consisting of either multiple dielectric layers or a single layer with very high dielectric constant [7] to improve resonance may be replaced by a simply printed structure which gives an equivalent higher reflection and lower transmission coefficient, respectively, to allow a reasonably good resonance. To this end, a periodic array of square patches, arranged on a square grid with half wavelength distances, was selected and designed (Fig. 3) to give an insertion loss of approximately -12 dB, equivalent to the layer structures in [7] or [9]. In this structure, parallel plate TEM waves cannot propagate due to the discontinuous metallization and the periodic nature of the printed elements, but the desired resonance with the electric field parallel to the substrate can be excited. The plane wave insertion loss of an infinitely extended single layer and of two of these layers placed face to face with a distance of 8 mm as well as of 16 mm is plotted in Fig. 4, showing resonances in the 38 GHz range – a full wavelength or a two wavelength resonance in the equivalent transmission structure and a half-wavelength or a full wavelength resonance for the final antenna for 8 mm and 16 mm distance, respectively.
For the antenna, a diameter of 100 mm was selected, and the substrate is placed 4 mm or 8 mm in front of a ground plane with a simple circular waveguide feed (Fig. 5). In this design, the resonant fields mainly are in air (no dielectric losses), and the dielectric substrate serves as radom. The substrate is held by a ring at the edge of the antenna.

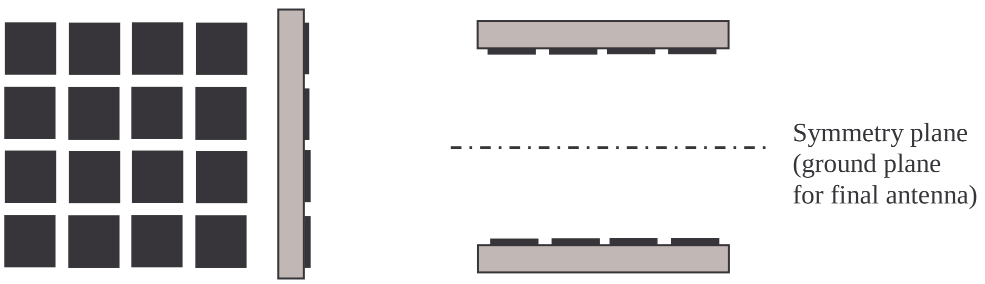
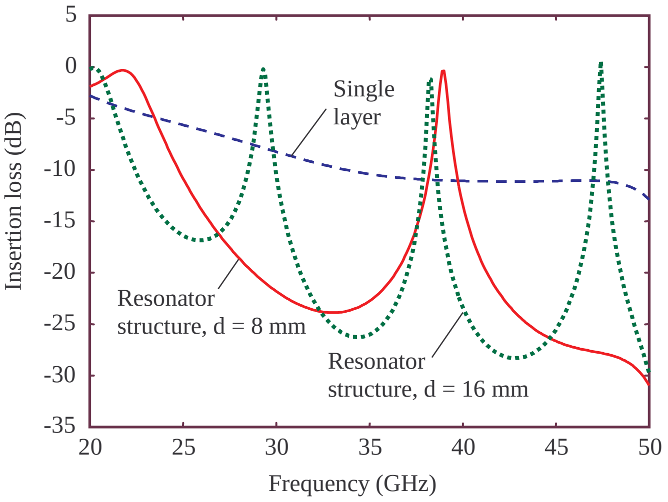


Fig. 3: Periodic patch array and arrangement for resonance calculation.



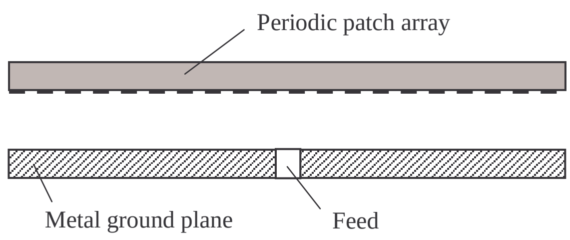


Fig. 4: Insertion loss of single layer and of resonator arrangement of two layers. Substrate thickness 3.18 mm, dielectric constant 2.2, patch size 3.4 mm × 3.4 mm, cell size 3.6 mm × 3.6 mm, distance of layers 8 mm and 16 mm.

Fig. 5: Cross section of the novel antenna. Periodic structure as in Fig. 4, distance of layer above ground 4 mm and 8 mm, antenna diameter 100 mm.

3. Results

The radiation diagrams of the antenna as described above were measured at different frequencies and for ground plane distances of the substrate of 4 mm and 8 mm. The E-plane and H-plane radiation diagrams for 4 mm distance at 36.1 GHz are plotted in Fig. 6. 3 dB beamwidths of 11.5° and 10° for E-plane and H-plane, respectively, can be found. Some asymmetry and a relatively high sidelobe level can be seen in the E-plane, this is probably due to an unequal width of the ring supporting the substrate.

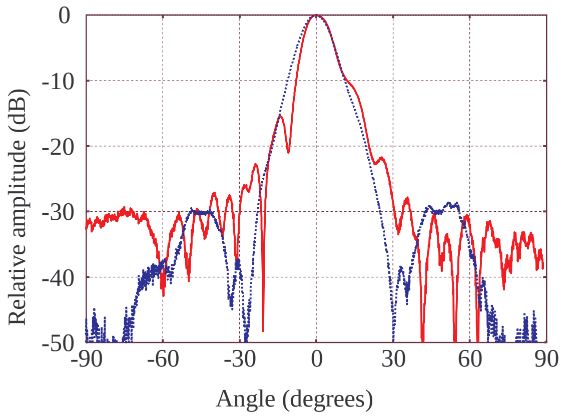


Fig. 6: E-plane (solid line) and H-plane (dotted line) radiation diagrams of an antenna with 4 mm substrate distance.

Better results could be achieved with a 8 mm distance between substrate and ground plane as shown in Fig. 7 with a reasonably good sidelobe level and 8° and 7° beamwidths in E-plane and H-plane, respectively, equivalent to an effective antenna aperture diameters of about 65 mm. Best results were found around 37 GHz, and comparable diagrams could be stated within a 300 MHz bandwidth. This is equivalent to earlier work, e.g. [3], stating that due to resonance bandwidth decreases with increasing gain. At frequencies further away from resonance, typical radiation diagrams with two separate main lobes occur, typical for leaky waves traveling in different directions. Impedance matching of the antenna was done with an iris in the feeding waveguide closely behind the feed aperture (Fig. 8).

To provide a some means of calculating this kind of antenna, a first brut-force calculation based on a commercial finite integration method [10] was performed. Theoretical radiation diagrams – at least in the E-plane – agree well with measurement (Fig. 7; a slight frequency shift, however, was found between theory and experiment). Maximum gain was calculated to 27.5 dB which compares well with a measured maximum value of 26.3 dB (Fig. 9) and a value of 26.8 dB calculated from the popular approximation $G \approx 27000/(\Delta\Theta\ \Delta\Phi)$.

As the transmission properties of the periodic structure printed on the antenna substrate change only moderately with frequency (Fig. 4), this antenna can be tuned over frequency by simply adjusting the distance of the substrate. Distances of 8.5 mm and 7.5 mm yield operating frequencies of 34.5 GHz and 39 GHz, respectively, partly with and adjustment of the input matching.

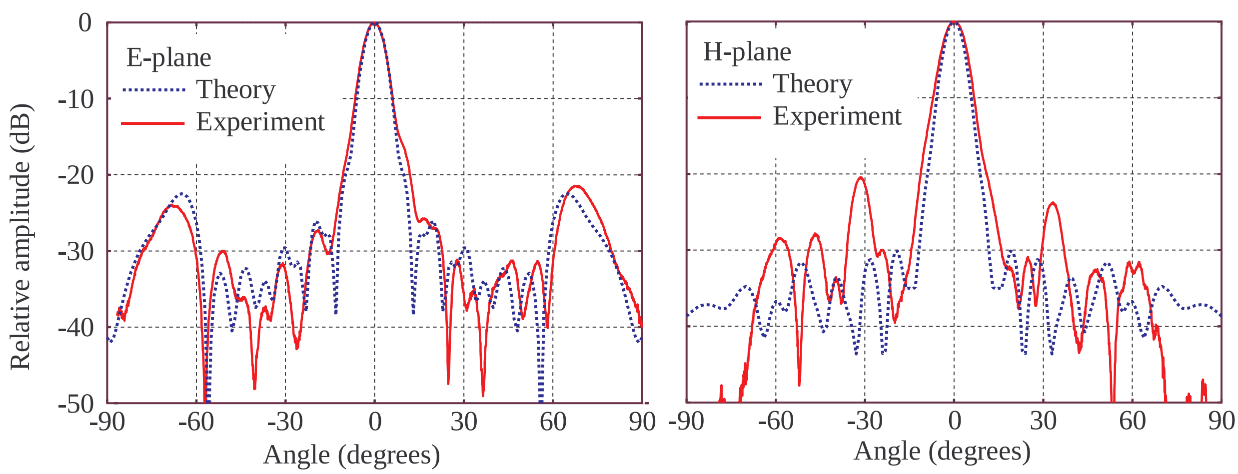


Fig. 7: E-plane and H-plane radiation diagrams of the PBG antenna according to Fig. 5 with 8 mm ground plane distance, frequency 37.1 GHz compared to a full-wave calculation (frequency of the full wave calculation was 37.5 GHz).

4. Conclusion

A first design and test is reported of a novel antenna based on a printed periodic structure placed 4 mm or 8 mm above a ground plane with a circular waveguide feed. Good radiation performance can be stated in a 300 MHz bandwidth. With the present design, a beamwidth of 7° to 8° or an effective radiating aperture of about 65 mm are found for the antenna of 8 mm depth. The described principle is being improved and extended to structures according to Fig. 10. These allow an automatic adjustment of the distance between periodic structure and ground plane. In addition, improved feeding arrangements for better return loss will be investigated.

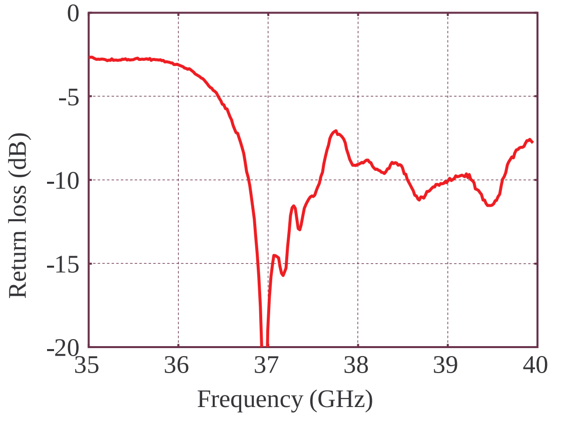


Fig. 8: Return loss of the antenna with 8 mm ground plane spacing (including matching).

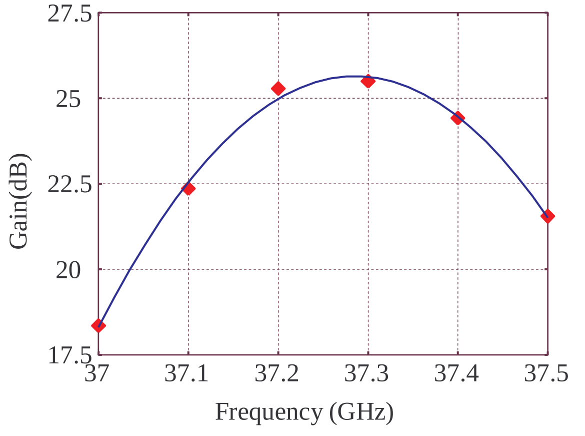


Fig. 9: Measured gain (dots) of the antenna with 8 mm ground plane spacing. (The solid line is a polynomial interpolation of the measured values).

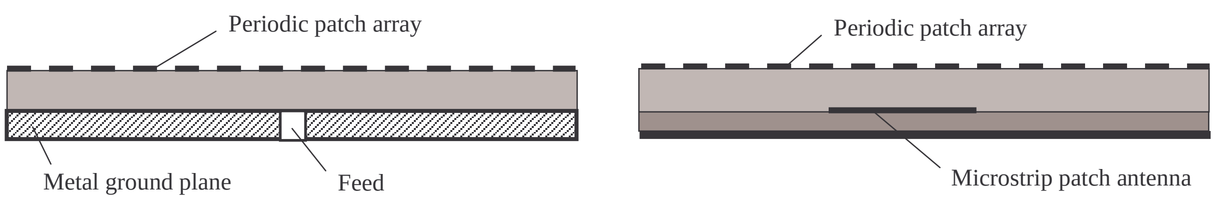


Fig. 10: Alternative antenna arrangements.

5. Acknowledgment

This work is funded by the German Research Association (DFG) under contract Me 1016/7.

6. References

[1] D. R. Jackson, N. G. Alexopoulos; Gain enhancement methods for printed circuit antennas, IEEE Trans. Antennas Propagat., vol. AP-33 (1985), pp. 976 – 987.

[2] H. Y. Yang, N. G. Alexopoulos; Gain enhancement methods for printed circuit antennas through multiple superstrates, IEEE Trans. on Antennas Propagat., Vol. AP-35 (1987), pp. 860 – 863.

[3] Xiao-Hai Shen, G. A. E. Vandenbosch, A. R. Van de Capelle: Study of gain enhancement method for microstrip antennas using moment method, IEEE Trans. Antennas Propagat., Vol. AP-43 (1995), pp. 227 – 231.

[4] Lei Zhu, I. Joishi, E. Yarnashita: Characterization of Microstrip Patch Antennas Suspended by a Dielectric Superstrate with High Permittivity. 1996 IEEE Int. Symp on Antennas and Propagation, pp. 704 – 707.

[5] H. Ostner, J. Detlefsen, and D. R. Jackson, "Radiation from one-dimensional dielectric leaky-wave antennas," IEEE Trans. Antennas Propagat., Vol. AP-43, pp. 331 – 339.

[6] H. Ostner, E. Schmidhammer, J. Detlefsen, D.R. Jackson: Radiation from Dielectric Leaky-Wave Antennas with Circular and Rectangular Apertures. Electromagnetics, Vol. 17, Number 5, September-October 1997, pp. 505-535.

[7] H. Ostner: The influence of leaky waves on the radiation properties of multilayer antenna structures (in German). MIOP 1995, Sindelfingen, Germany, pp. 479 - 483.

[8] D. R. Jackson, A. A. Oliner: A leaky-wave analysis of the high-gain printed antenna configuration, IEEE Trans. Antennas Propagat., Vol. AP-36 (1988), pp. 905 – 910.

[9] M. Thevenot, C. Cheype, A. Reineix and B. Jecko: Directive photonic-bandgap antennas. IEEE Transactions on Microwave Theory and Techniques Vol. MTT-47 (1999, Mini-Special Issue on Electromagnetic Crystal Structures, Design, Synthesis, and Applications), pp. 2115-2122.

[10] Microwave Studio, CST, Version 3.4.