Bi-Quad and Four-Quad WLAN Antennas with Magnetic Reflector

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***Abstract*—The gain of wire antennas can be increased by metal reflectors; such antennas, however, are no longer compact in size due to the required quarter-wave distance. As a way out of this problem, this contribution reports the integration of planar wire antennas with a synthesized planar magnetic reflector consisting of periodic mushroom-like structures. Sample antennas in the form of a bi- and a four-quad antenna with these reflectors have been designed for the 2.45 GHz frequency range; simulation and measurements are demonstrated for both antennas without and with integrated magnetic reflectors.**

Keywords—Wire antennas, planar antennas, magnetic reflector, wireless LAN

I. Introduction

Loop antennas including square or polynomial shapes are known since longtime [1-4]; the combination of two edge-fed square loops (quads) has found great interest in amateur internet forums for an easy design of wire antennas, partly with a metal reflector. Such “bi-quad” or “double-quad” antennas show a reasonable gain and can easily be built from some piece of wire for (digital) terrestrial TV (DVB-T) or WLAN applications, e.g. [5-8]; such antennas are even proposed for wireless networking in developing countries [9]. In [10], planar integrated versions of such antennas have been investigated, and work has been extended to the realization of a four-quad antenna (Fig. 1). The arm lengths of the antennas are approximately a quarter wavelength; slight differences are due to the feeding area. In its center, the four-quad antenna has four sections of symmetric transmission lines, basically used to match the overall structure.

A disadvantage of these antennas is that they radiate into two directions; this can be avoided by a metal reflector; with a quarter-wave distance of the reflector. In this way, however, the structures are no longer planar. Ref. [11] and recent publications, e.g. [12-14], have shown the possibility to design a periodic structure behaving, in a certain frequency band, like a magnetic reflector, i.e. exhibiting a reflection coefficient of +1, and to integrate this directly with different types of antennas.

II. Antennas without Magnetic Reflector

The basis for this work are previously reported bi- and four-quad antennas without reflector [10]. The two antennas according to Fig. 1 have been designed for a center frequency of 2.45 GHz on a 0.5 mm thick RT-Duroid substrate ($\varepsilon_r = 2.22$). Line widths are 2 mm, arm lengths 30.3 mm and ca. 34 mm (slightly different values in the two directions due to the feeding structure) for the bi- and four-quad antenna, respectively. All simulations are done using the frequency domain solver of the CST Microwave Studio. The antennas are fed by a simple coaxial cable soldered to the connecting points indicated in Fig. 1 by the white spots in the metallization area; for simplicity, no baluns are used.

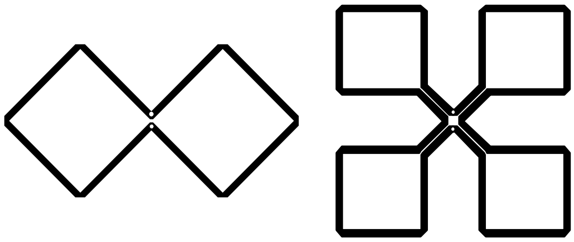

Fig. 1: Principle bi-quad and four-quad antenna layout. The antennas are fed symmetrically at the white dots (in the simplest way, a coaxial cable is soldered there without any balun).

Reflection coefficients and E-plane radiation diagrams are shown in Fig. 2 and 3. As can be clearly seen, both antennas exhibit radiation maxima at broadside (0°) as well as to the backside (±180°). A frame holding the antennas during measurement and the feeding cable placed on the backside led to some slight asymmetries of the radiation diagrams. As already has been demonstrated in [10], the four-quad antenna exhibits a much wider bandwidth compared to the bi-quad one. In general, simulated and measured results agree quite well.

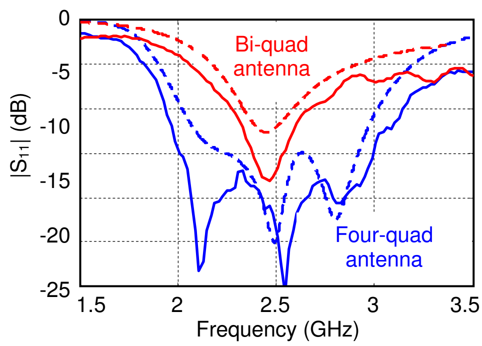

Fig. 2: Reflection coefficient of the two antennas according to Fig. 1. Dashed lines: simulation, solid lines: experiment.

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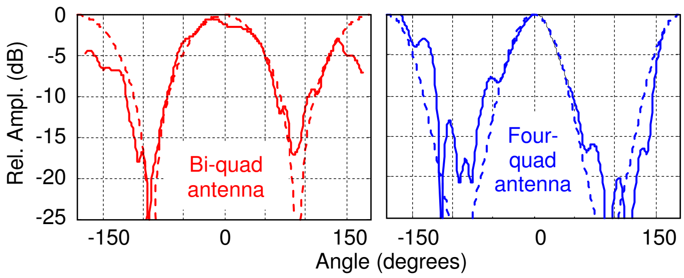

Fig. 3: E-plane radiation diagrams of the two antennas according to Fig. 1. Frequency: 2.45 GHz, dashed lines: simulation, solid lines: experiment.

III. MAGNETIC REFLECTOR

A radiation into one direction and an increase in gain can be achieved by a reflector placed on the backside of the antennas. To avoid a metallic reflector at a distance of approximately 30 mm and to maintain the planar structure of the antennas, a periodic structure with a reflection coefficient of +1 was integrated directly on the backside. The magnetic reflector as used in this approach consists of a periodic array of square mushroom-like structures [11]. The equivalent circuit of a single cell is given in Fig. 4. As frequency is rather low, and as an element cell should be small compared to wavelength, a dual layer substrate (RT-Duroid 5880, $\varepsilon_r = 2.22$) with thicknesses of 3.17 mm and 0.127 mm for the lower and upper substrate, respectively, was selected, providing additional capacitive elements in between the substrates (Fig. 5). Due to the overall large substrate thickness, the vias provide a reasonable inductance, finally leading to a relatively flat phase behavior depicted in Fig. 5 as well. Dimensions are 5.42 mm and 4.7 mm for top and intermediate level patches, respectively; cell size is 5.6 mm.

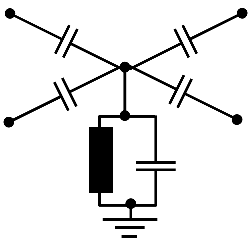

Fig. 4: Unit cell equivalent circuit of the mushroom structure.

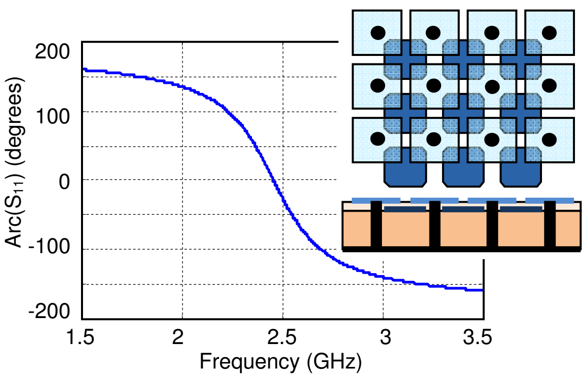

Fig. 5: Principle structure and phase behavior of the magnetic reflector (calculation of a unit cell with a plane wave incident from broadside).

IV. INTEGRATION OF ANTENNAS AND REFLECTOR

In the next step, the antennas were integrated directly on the reflector using a bonding foil. Due to this, some interactions of the antenna and the magnetic reflector are introduced, and the periodic structure of the reflector also provides some low-pass filtering performance for the currents on the antenna. Therefore, an optimization of both antenna and reflector had to be made using a full-wave calculation of the overall structure and to correct the dimensions of both structures. The overall size of the bi-quad antenna substrate including the reflector is 138 mm x 78 mm, that of the four-quad antenna 112.2 mm x 138.8 mm.

Once the overall design was completed, the antennas together with the reflectors were fabricated as integrated multilayer circuits. Some problems arose with the fabrication of the four-quad antenna as this exceeded the size of the in-house PCB fabrication (limited size of our small plasma oven for a pre-treatment of the holes for the vias), so the size of the magnetic reflector had to be reduced by four rows, influencing also the electromagnetic performance of the overall antenna structure. As a consequence, its main radiation regime was shifted down in frequency.

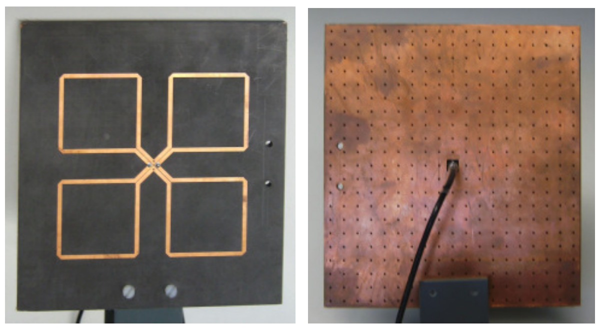

Fig. 6: Photograph of front (left) and back side (right) of the four-quad antenna with magnetic reflector.

Photographs of front and backside of the bi-quad antenna are given in Fig. 6. Simulated and measured reflection coefficients of the bi-quad antenna are depicted in Fig. 7, those of the four-quad antenna in Fig. 8. Due to the reason given above and some fabrication tolerances of the rather complex structures, experimental values show some deviation.

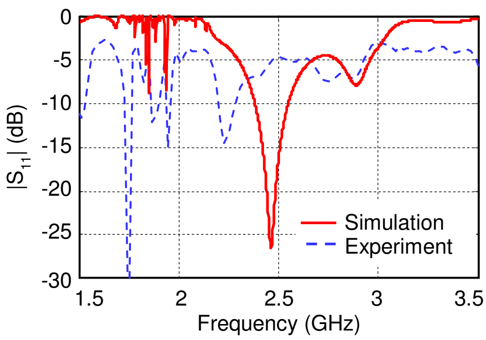

Fig. 7: Simulated and measured reflection coefficients of the bi-quad antenna with magnetic reflector.

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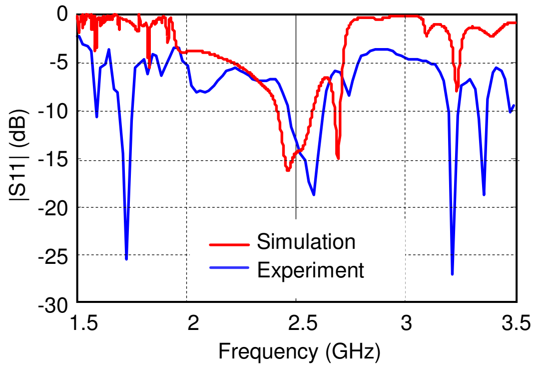

Fig. 8: Simulated and measured reflection coefficients of the four-quad antenna with magnetic reflector.

Fig. 9 shows simulated and experimental E- and H-plane radiation diagrams of the bi-quad antenna with integrated reflector. Simulation and experiment agree well, and backward radiation is suppressed by about 12 dB; higher values are possible with a larger reflector. In Fig. 10, measured E- and H-plane radiation diagrams of the four-quad antenna are plotted for a frequency of 2.1 GHz (as mentioned above, best performance of this antenna was shifted down in frequency). Reasonable diagrams are also found in the 2.0 to 2.3 GHz frequency range, although with a reduced gain (Fig. 11).

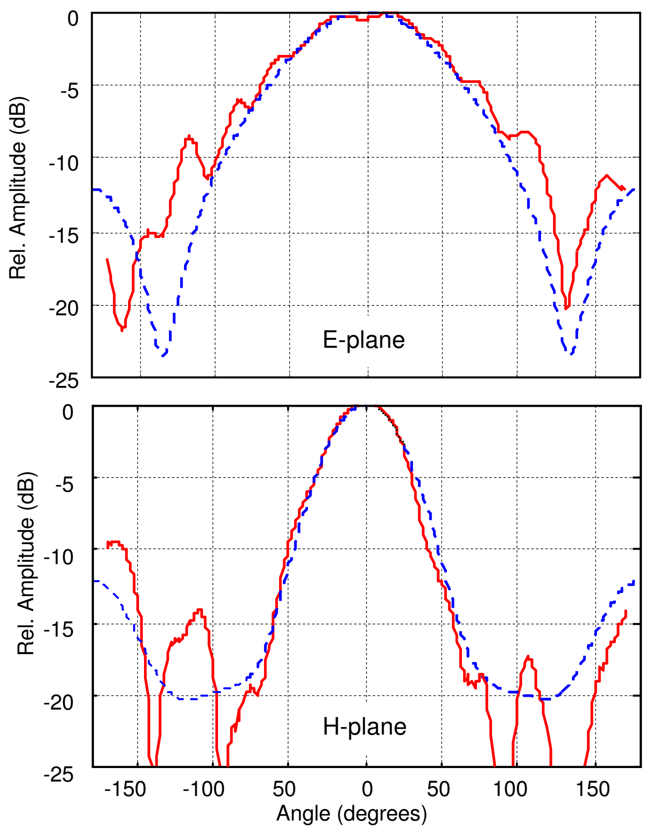

Fig. 9: E- and H-plane radiation diagrams of the bi-quad antenna integrated with a magnetic reflector. Frequency: 2.45 GHz, dashed line: simulation, solid line: experiment.

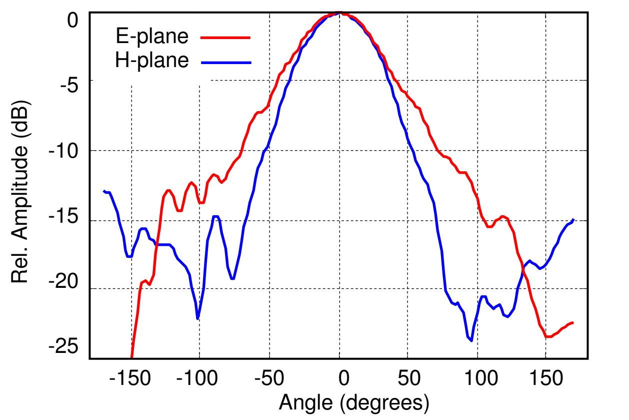

Fig. 10: Measured E- and H-plane radiation diagrams of the four-quad antenna at 2.1 GHz (Fig. 1, right) integrated with a magnetic reflector.

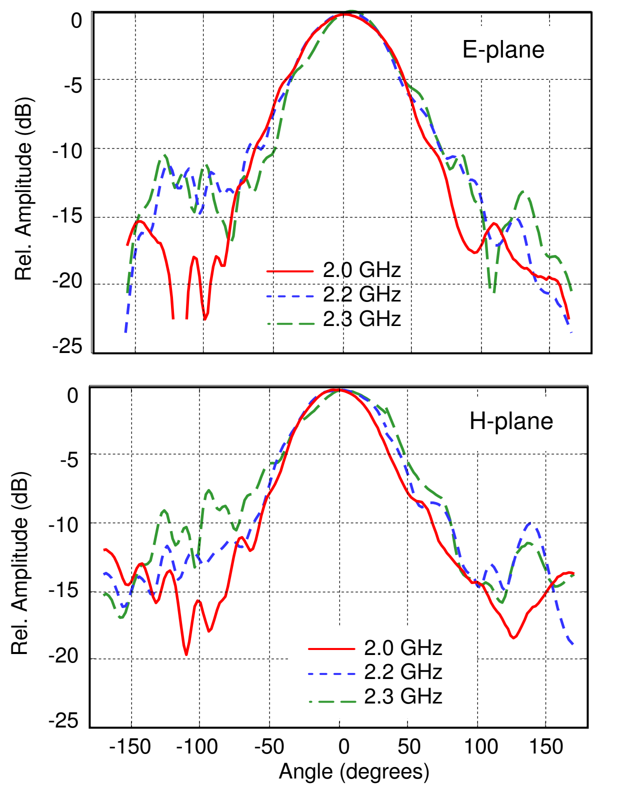

Fig. 11: Measured E- and H-plane radiation diagrams of the four-quad antenna integrated with a magnetic reflector measured at frequencies of 2.0, 2.2, and 2.3 GHz.

V. Conclusion

Based on previous work on planar realizations of bi- and four-quad antennas, these now have been extended with integrated reflectors consisting of artificial magnetic reflectors based on periodic mushroom structures. In this way very compact, low-profile and stable antennas are achieved. Both simulated and experimental results in general agree well and show promising performance.

For the bi-quad antenna, single beam characteristics with 120° and 54° in E- and H-plane, respectively, have been

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achieved; these values are 65° and 61° for the four-quad antenna. Even with reflectors not much larger than the original antenna structures, backside lobes are suppressed by about 12 dB.

References

[1] R.W.P. King, “Theory of the Corner-Driven Square Loop Antenna. IRE Transactions Antennas Propagation“, Vol. 4 (1956), pp. 393–407,.

[2] T. Tsukiji, S. Tou, “On Polygonal Loop Antennas”, IEEE Transactions on Antennas and Propagation, Vol. 28 (1980), pp. 571–575.

[3] H. Morishita, T. Iizuka, K. Himsawa, T. Nagao, T., “Wideband circularly polarized rhombic loop antennas with different feed models”, IEEE Antennas and Propagation Society International Symposium, 1995, Vol. 1, pp. 194 - 197.

[4] C.A. Balanis, “Antenna Theory: Analysis and Design”, John Wiley, 3 edition, 2005.

[5] T. Marshall, ”BiQuad 802.11b Antenna”, http://www.trevormarshall.com/biquad.htm.

[6] M. Pot, “Biquad Antenna Construction”, http://www.martybugs.net/wireless/biquad/, 2002.

[7] M. Raninen, “WLAN 802.11b/g Bi-quad Antenna: Building and Testing”, http://www.koti.mbnet.fi/zakifani/biquad/, 2006.

[8] The Flight Refuelling Amateur Radio Society (FRARS), “2.4GHz Double Quad Antenna: An Easy to Build, Compact Antenna for Wireless LAN Applications that Offers a Reasonable Amount Gain”, http://www.frars.org.uk/cgi-bin/render.pl?pageid=1064, 2002.

[9] R. Flickenger, C.E. Aichele, “Wireless Networking in the Developing World”, Limehouse Book Sprint Team, 2006.

[10] S. Ahmed, W. Menzel, “A Novel Planar Four-Quad Antenna”, Europ. Conf. on Antennas and Propagation (EuCAP 2012), Prague, pp. 1946 – 1949.

[11] D. Sievenpiper, “High-impedance electromagnetic surfaces”, PhD thesis, University of California, Los Angeles, 1999.

[12] Ying Zhang, J. von Hagen, M. Younis, C. Fischer, W. Wiesbeck, “Planar artificial magnetic conductors and patch antennas”, IEEE Transactions on Antennas and Propagation, Vol. 51 (2003), pp. 2704 – 2712.

[13] G. Niyomjan, Y. Huang, “A suspended microstrip fed slot antenna on high impedance surface structure”, Europ. Conf. on Antennas and Propagation (EuCAP 2006), pp. 1 - 4.

[14] Y. Murakami, T. Hori, M. Fujimoto, “Optimum reflector configuration for dipole antenna by using artificial magnetic conductor”, 2013 International Workshop on Antenna Technology (iWAT 2013), pp. 277 – 280.

ISBN 978-3-8007-3585-3