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Research Article

Low-Profile Array of Wire Patch Antennas

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A low-profile antenna over a ground plane that radiates a directive lobe in the end fire direction is described in this paper. An array of 16 wire patch antenna (WPA) fed by an integrated 16 ways power divider has been designed. Owing to its low height, low cost, high robustness, and monopolar radiation pattern, the WPA has been chosen as unit cell of the array that must be placed on the vehicle roof. A gain higher than 18.9 dB was achieved in the end fire direction over a 4.5% bandwidth. However, the antenna has been tilted in order to compensate the beam deviation caused by the edge diffraction. Moreover, a vertical metallic plane has been inserted to eliminate the back fire radiation. Its position and the disposition of the WPAs are explained in this paper. A prototype with four elements has been manufactured in order to validate the antenna principle. A gain difference lower than 0.5 dB is achieved between the measurements and the simulations.

1. Introduction

The context concerns a communication system between a vehicular and some base stations that are located on the trajectory. This paper deals with the design of the vehicular antenna that is must satisfy some particular requirements. At first, this antenna has to be integrated on the roof that induces a low-profile antenna working over a ground plane. Secondly, the antenna gain must be important in order to reduce the number of base stations. Finally, an end fire antenna which radiates toward the horizon must be used to communicate with the base stations. The design of an antenna that satisfies all these specifications is very difficult to perform. Indeed, the Yagi antenna [1–3] or the log periodic dipole array antennas [4, 5] that radiate in the array plane agree with the profile constraint. But, this kind of antennas cannot be placed close to a ground plane due to the tangential E field annulation. One solution could be to use an EBG ground plane, but it increases strongly the complexity of the antenna [6–8]. The usual arrays located near to a ground plane like patches or slots which provide a directive main lobe in the bore sight direction are not convenient with this application. Indeed, the array plane which is perpendicular to the radiating direction induces a height which is too high. A good candidate could be an array of quarter wavelength monopoles which radiates azimuthally toward the horizon [9–11]. In order to reduce the height, these last can be folded [12]. Another low-profile antenna which has an omnidirectionnal radiation pattern in the azimuthal plane is the "wire patch antenna" (WPA) [13–15]. Owing to its low height, low cost, high robustness, and monopolar radiation pattern, this kind of antenna is very suitable for practical wireless communications applications. In this paper we will describe a high-gain array of WPA which provides a directive lobe in one direction in the azimuthal plane. The beam scanning will be ensured by using a mechanically rotating support. In the first part, the wire patch antenna will be explained. Then, the principle, the design, and the performances of a linear array of 4 WPAs will be given. Finally, an array of 16 WPAs fed by an integrated microstrip power divider will be described.

2. Unit Cell of the Array: The Wire Patch Antennas (WPAs)

2.1. Principle. The Wire Patch Antenna [13, 14] presents the structure of a classical microstrip antenna with a roof of arbitrary shape (Figure 1). It is fed by a coaxial probe, which is connected to the patch through the ground plane. The

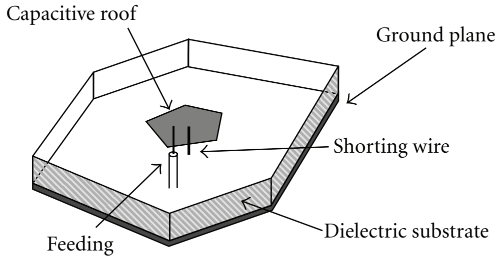

Figure 1: WPA configuration.

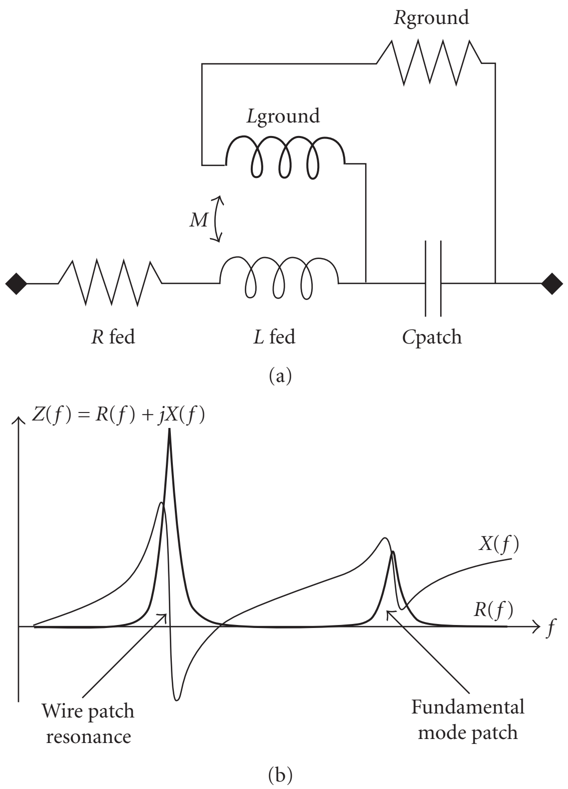

Figure 2: Equivalent circuit of the WPA and input impedance.

particularity of this antenna is that it has at least one shorting wire connected between the patch and the ground plane. Adding a shorting wire introduces a parallel inductance (*L*ground) on the capacitance constituted by the upper patch and the ground plane (*C*patch) (Figure 2). This creates a new parallel resonance at a lower frequency than the classical fundamental mode of the patch. This particular working mode is characterised by a high concentration of currents on the wire. The resulting radiation pattern reveals a monopole like radiation pattern (Figure 3). When the shorting wire is located at the edge of the roof, the wire patch antenna looks like a PIFA [15, 16]. In this case, the principle of the PIFA could also be used to design the " wire patch antenna."

Consequently the WPA is a low-profile antenna ($\approx \lambda/10$) with an omnidirectionnal radiation pattern in the azimuthal plane like monopole.

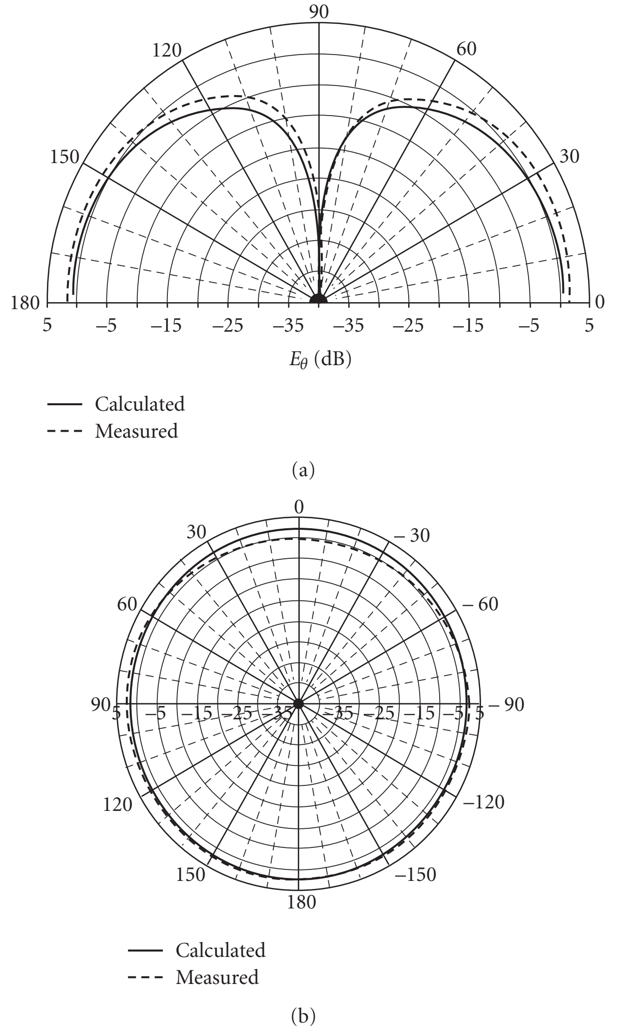

Figure 3: Radiation pattern. (a) Elevation. (b) Azimuthal.

2.2. Design of the WPA for the Application. As explained in the introduction, the application is a communication system that uses the WIMAX protocol between vehicle and base stations. The objective is to establish a high-gain WPA array that radiates a directional beam in the azimuthal plane within the frequency band 5.5 GHz–5.75 GHz. The unit cell antenna is shown in Figure 4. It consists of a rectangular capacitive roof and a wide shorting plate. The WPA feeding is provided by the coaxial probe of an SMA connector. The shorting plate is positioned at the edge of the roof in order to simply fold it and to facilitate the antenna manufacture. Thus, the antenna cost is reduced and its robustness is increased. A screw comes to set the WPA through a metallic plate on the ground plane. In this case, the antenna with an infinite ground plane provides a quasimonopolar radiation at 5.6 GHz (Figure 5).

The screw head is chosen to be the widest possible in order to avoid a perfect omnidirectional radiation and then concentrate the energy in such direction in the azimuthal plane. Maximum gain of 5.3 dB was obtained in the *E* plane on the feed side while the value is 3 dB lower in the opposite direction (shorting plate side). Moreover, using

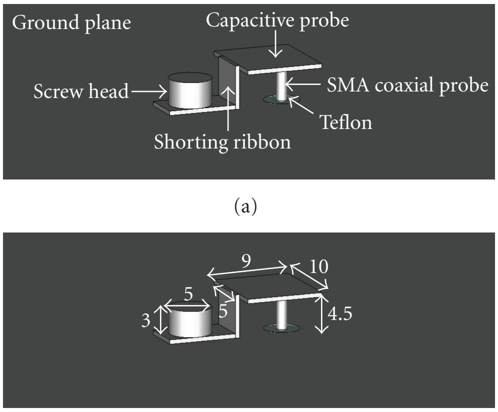

Figure 4: WPA configuration.

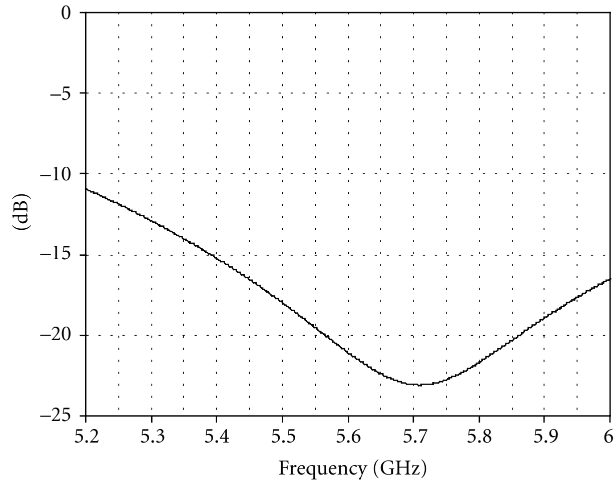

Figure 6: Modulus of S11.

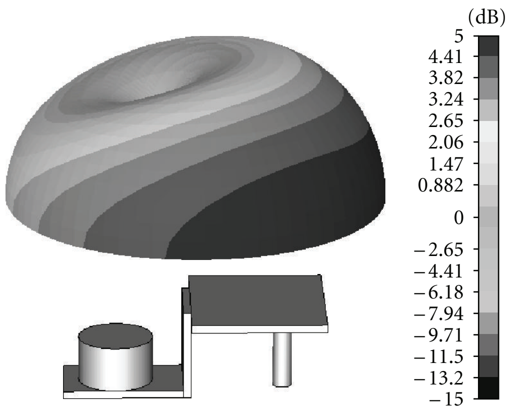

Figure 5: 3D radiation pattern with an infinite ground plane.

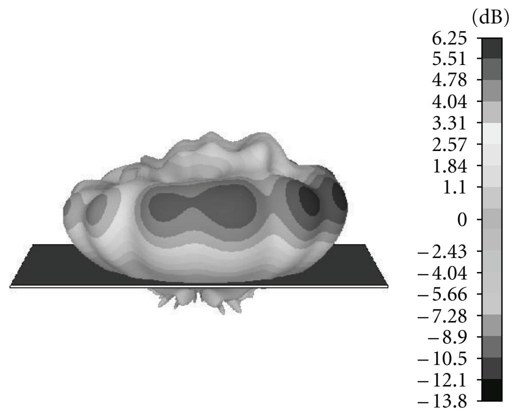

Figure 7: 3D radiation pattern with a finite ground plane.

a shorting plate instead of a shorting wire permits to increase the matching bandwidth. Indeed, the concentration of currents on the plate is less important that induces a lower-quality factor of the input impedance peak [14]. The WPA dimensions were optimized by a set of simulation to get the minimum reflection coefficient at the central frequency of the operating 5.6 GHz band (Figure 6). The WPA is positioned on a limited ground plane whose dimensions are $2\lambda_0$ by $2\lambda_0$. These values correspond to the size of support which will be positioned under the final WPA array. In the limited ground plane size case, the well-known scattering effects on the ground plane edges alter the radiation pattern [10, 11, 17] (Figure 7).

First of all, the interferences induce maxima and minima field on the radiation pattern. Their angular position is obviously related to the ground plane size. Then, we can observe the classic beam deviation in the elevation plane, which is caused by the scattering on the edges of the limited ground plane. Since the main beam direction does not coincide with the horizon, it will be necessary to compensate this deviation by an inclination of the whole antenna. Indeed, it is essential for our application that the maximum gain is radiated in the base stations direction.

3. Linear Array of 4 WPAs

3.1. Principle. The 4 WPAs linear structure must satisfy certain requirements in order to produce a directive lobe in the horizon plane. These are described below and are illustrated in Figure 8.

(i) The 4 WPAs must be λ_0 spaced out in order to have constructive interferences in the direction where WPAs are aligned. In this case, and according to the array theory, the antenna gain should be 6 dB increased at the endfire and the backfire directions.

(ii) Since our application requires only one high-gain radiation direction, it is proceeded to prohibit the radiation in the half space behind the antenna. The backfire radiation can be avoided with some no excited elements named “reflectors” in the Yagi antenna case or with a vertical metallic plane. Intended for cost and simplicity constraints, the second solution is selected. So, each WPA must spaced out of a multiple of $n^*\lambda_0/4$ distance (n is odd integer) from the reflector plane. This separation allows a constructive interference between the

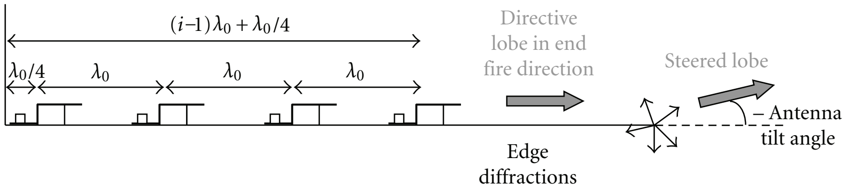

Figure 8: Principle of the linear arry.

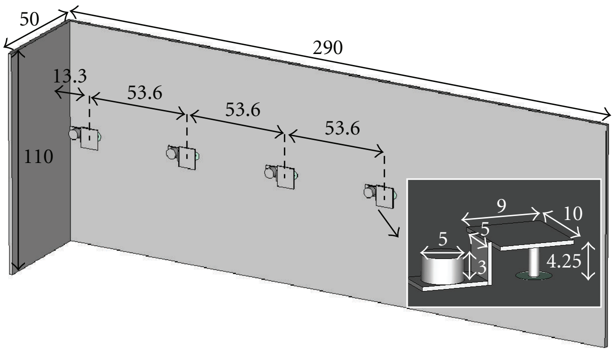

Figure 9: Configuration of the linear WPAs array.

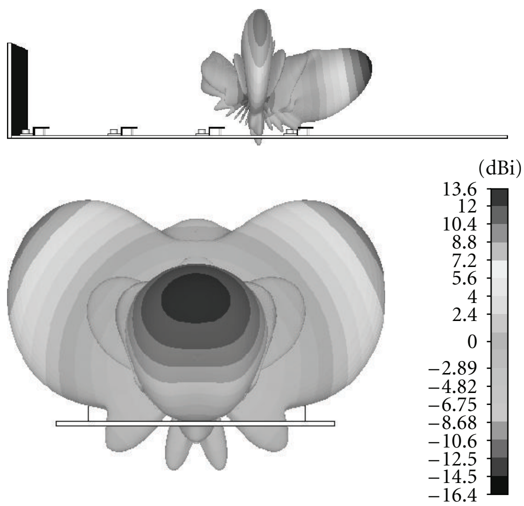

Figure 10: 3D simulated radiation pattern at 5.625 GHz.

Figure 11: Linear WPAs array prototype.

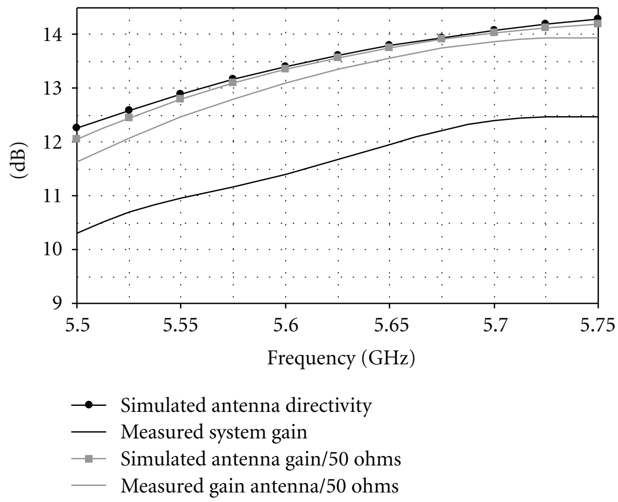

Figure 12: Simulated and measured gain.

reflected fields and the direct waves. Therefore, by adding the previous condition, the distance between WPA number. i and the vertical plane should be $(i-1)\lambda_0 + \lambda_0/4$. In this case and according to the images theory, the antenna gain should be 3 dB increased at the endfire direction.

(iii) The structure must be tilted to give back the main beam deviation caused by scattering at the ground plane edges [10, 11, 17]. The tilt angle that depends on the ground plane dimensions is adjusted a posteriori.

3.2. Design and Measure of the Linear WPAs Array for the Application. Linear array of WPAs was designed to operate at 5.5 GHz–5.75 GHz band where the dimensions are given in Figure 9. The ground plane, and the reflector plane dimensions were chosen arbitrary. The simulated radiation pattern antenna is shown at 5.625 GHz in Figure 10. The maximum directivity is 13.5 dB and is in accordance with the value provided by the theory (Section 3.1). Indeed, an increase of 8.5 dB, close to the theoretical value of 9 dB, has been obtained compared to the case with single WPA on a limited ground plane (Figure 7). The directivity value is acceptable but the diffraction on the ground plane edges creates an inevitable 14° lobe deviation. In addition, the perpendicular plane to the WPAs alignment contains very important side lobes. Indeed, the linear array has no

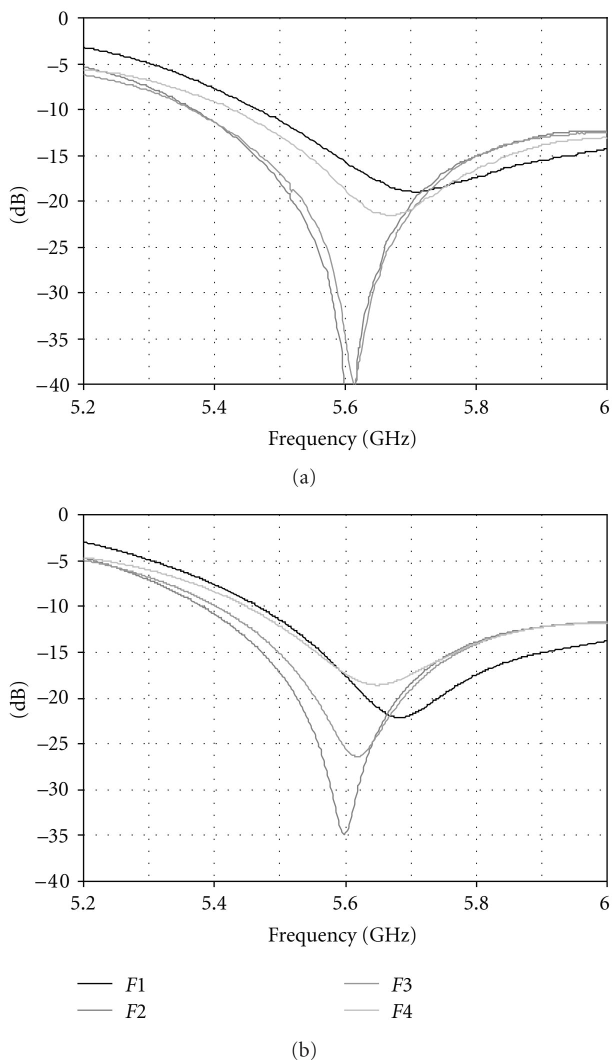

Figure 13: Parameters F. (a) Measurement. (b) Simulation.

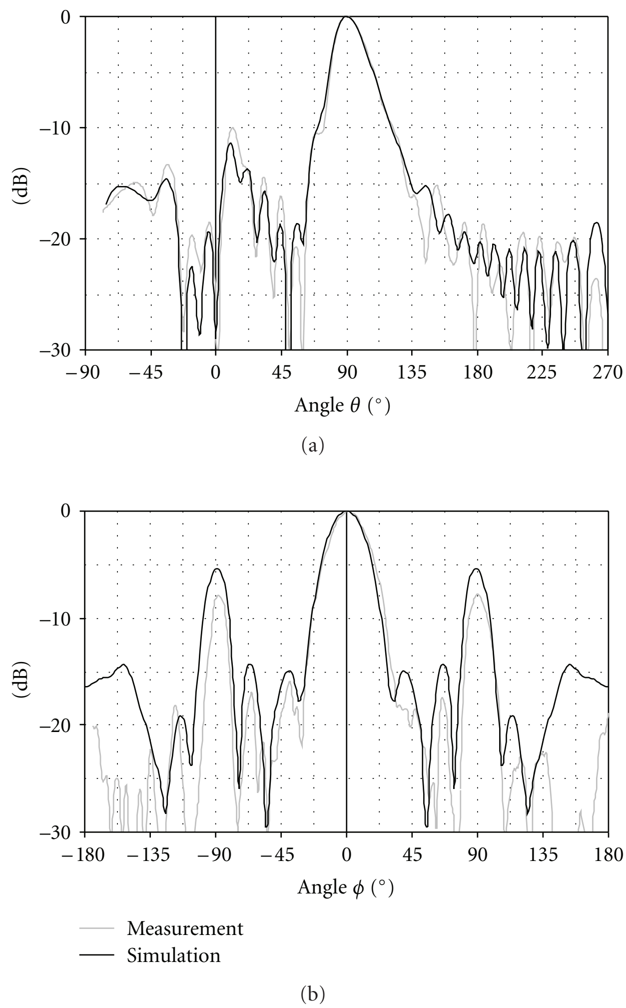

Figure 14: Measured and simulated radiation patterns at 5.625 GHz. (a) Elevation plane. (b) Azimuthal plane.

influence in this plane and the radiation pattern has the same shape as in a single WPA case (Figure 7). The antenna and a tilt system were manufactured to give back the lobe deviation (Figure 11).

A 4-way power splitter and 4 cables have been used to feed the antenna. The power splitter experimentation has shown a 0.2 dB ripple in magnitude and 4.5° phase dissimilarity between the 4 splitter outputs. The measured losses in this feeder circuit are between 1.45 dB and 1.85 dB over the 5.5 GHz–5.75 GHz band. These latter losses and the measured antenna-circuit system gain have been subtracted in order to get the measured gain of the 4 WPAs array normalized to 50 ohms (Figure 12). The difference between the simulated gain and measured gain is less than 1 dB over the frequency band. Indeed, the insertion losses are very low and almost identical in the 2 cases as shown by the reflected power on each input antenna port (Figure 13(a) for the measurement and Figure 13(b) for the simulation). In addition, the radiation patterns in the alignment WPAs plane (Figure 14(a)) and in the azimuthal plane (Figure 14(b)) correlate and show a good agreement between simulation and measurement at 5.625 GHz. To make this comparison, the antenna was tilted 14° in the elevation plane.

4. Array of 16 WPAs

The well-behaved experimental results validate the principle of the 4 WPAs linear array. In order to increase the gain, a 2D array of 16 WPAs was designed (Figure 15). Four subarrays, where each of them is described in Section 3.2, have been used to make the 16 WPAs array. Figure 10 shows that the radiation pattern of a subarray contains an important side lobes for $\theta = \pm 50^\circ$ in the perpendicular plane to the 4 WPAs plane alignment. Therefore, the 4 subarray are $0.75\lambda_0$ spaced out in order to avoid the interferences in these directions. Obviously, this WPAs alignment allows the constructive interference and so increases the gain in the end fire direction. A 16-way microstrip power splitter has been incorporated under the antenna ground plane, and then it feeds the 16 WPAs through a metallic vias

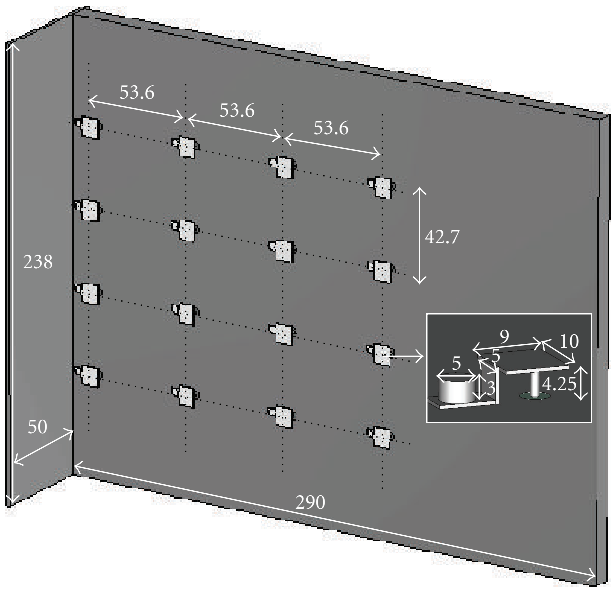

Figure 15: Configuration of the 16 WPAs array.

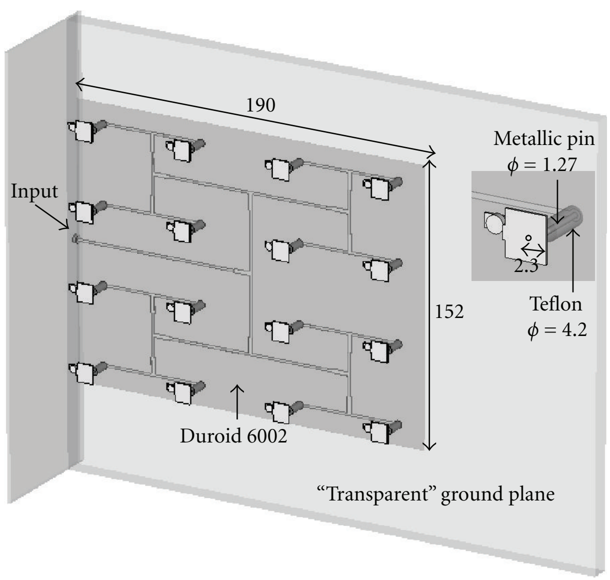

Figure 16: View with the transparent ground plane.

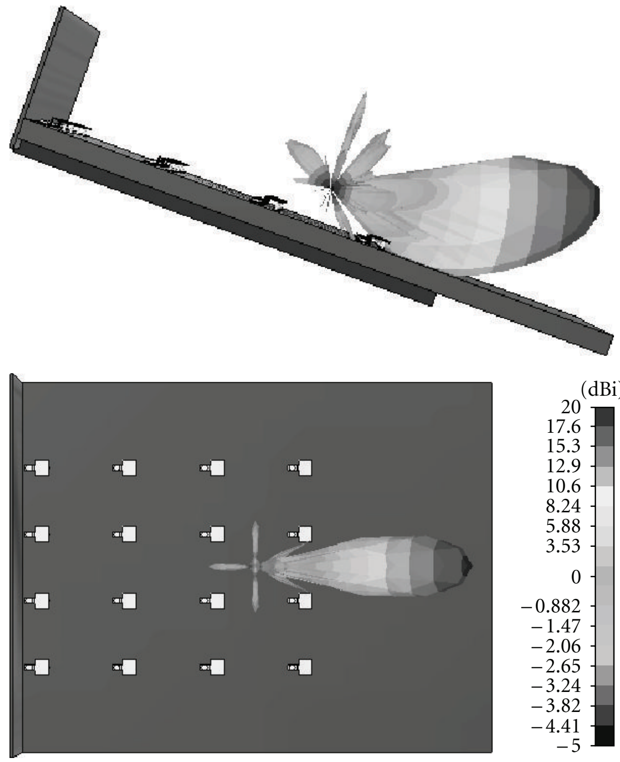

Figure 17: 3D simulated radiation patterns at 5.625 GHz.

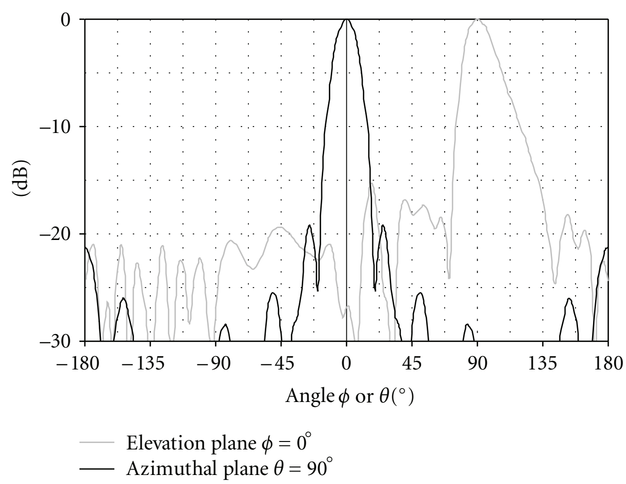

Figure 18: 2D simulated radiation patterns at 5.625 GHz.

(Figure 16). Those latter are composed of a metallic pin centred in a Teflon cylinder which allow the contact between the WPA roof and feed circuit outputs. The dimensions are given in Figure 16, and they were chosen to remain 50 ohms impedance in the transition. The feed circuit is printed on a 508 μm height of a Duroid 6002 layer. Lines width is 1.27 mm except for the T-junction branch which has set to 2.07 mm. The feed circuit simulation has been done with Momentum, and it goes to show a 0.3 dB magnitude ripple and 2° phase variation between the 16 outputs at 5.625 GHz. The losses are approximately 0.5 dB over the 5.5. GHz–5.75 GHz frequency band. The 3D (Figure 17) and 2D (Figure 18) radiation patterns show a very directive lobe while the side lobes remain below −15 dB.

The antenna was 17° tilted to give back the main beam deviation caused by scattering at the ground plane edges. A 19.5 dB maximum directivity is obtained at the endfire direction. The 6 dB directivity increase compared to one subarray is in accordance with the array theory. The antenna gain is 18.9 dB over the 5.5 GHz–5.75 GHz operating bandwidth (Figure 19). The directivity and the gain difference is mainly due to the power splitter loss. Indeed, the insertion losses are very low because the antenna

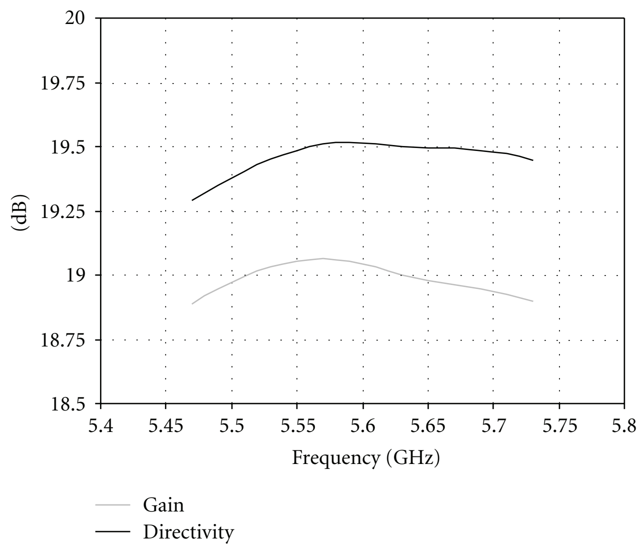

Figure 19: Directivity and gain versus the frequency.

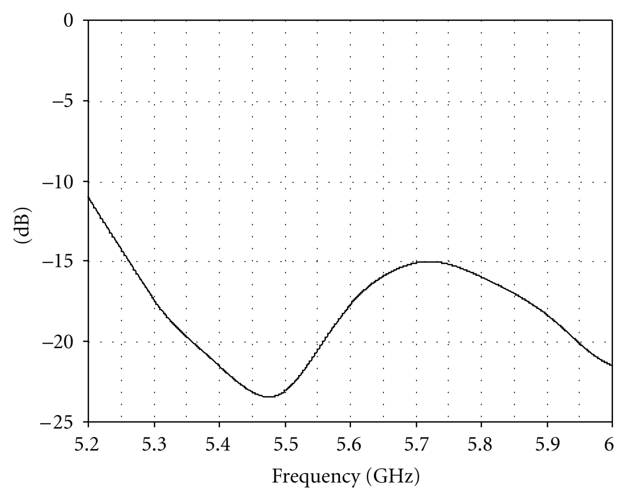

Figure 20: Modulus of S11.

reflection coefficient is lower than −15 dB over the 5.5 GHz–5.75 GHz band (Figure 20).

5. Conclusion

In this paper, a low-profile antenna with a ground plane has been presented. This high-gain antenna radiates in the azimuth plane through a single endfire beam. The purpose was to design a high-gain antenna which must be positioned on a vehicle roof in order to communicate with the far base stations. Owing to its low height, low cost, high robustness, and monopolar radiation pattern, the wire patch antenna has been used as unit cell of an array. As a first step, an array of 4 WPA element was designed. The WPA elements are λ_0 spaced out in order to constructively interfere in the direction where WPAs are aligned. In order to obtain a single endfire lobe, a vertical reflector was positioned at $(i-1)\lambda_0 + \lambda_0/4$ from the Number i WPA. Finally, the antenna was tilted to give back the main beam deviation caused by the scatterings on the ground plane edges. The 4 WPA elements antenna has been designed and realized whereas the measured gain is 13.5 dB. The measured results of this antenna are close to the simulation despite the 0.5 dB observed difference. Finally, an array of 16 WPAs fed by an integrated microstrip power splitter has been designed. A gain higher than 18.9 dB has been achieved over a 4.5% bandwidth. Actually, some studies are done to reduce the antenna height. The vertical metallic plane should be replaced by no fed WPA located at $\lambda_0/4$ behind the array.

References

[1] P. R. Grajek, B. Schoenlinner, and G. M. Rebeiz, "A 24-GHz high-gain Yagi-Uda antenna array," *IEEE Transactions on Antennas and Propagation*, vol. 52, no. 5, pp. 1257–1261, 2004.

[2] N. Kaneda, W. R. Deal, Y. Qian, R. Waterhouse, and T. Itoh, "A broad-band planar Quasi-Yagi antenna," *IEEE Transactions on Antennas and Propagation*, vol. 50, no. 8, pp. 1158–1160, 2002.

[3] Y. Qian, W. R. Deal, N. Kaneda, and T. Itoh, "Microstrip-fed quasi-Yagi antenna with broadband characteristics," *Electronics Letters*, vol. 34, no. 23, pp. 2194–2196, 1998.

[4] D. E. Isbell, "Log periodic dipole arrays," *IRE Transactions on Antennas and Propagation*, vol. 8, pp. 260–270, 1960.

[5] N. Barbano, "Log periodic dipole array with parasitic elements," *Microwave Journal*, vol. 8, pp. 41–69, 1965.

[6] J. Kim, S. Lim, M. F. Iskander, and J. M. Bell, "A low profile, multi-band Yagi antenna with high gain characteristic over an EBG ground plane," in *Proceedings of the URSI Symposium*, Chicago, Ill, USA, 2008.

[7] S. K. Padhi and M. E. Bialkowski, "A microstrip Yagi antenna using EBG structure," *Radio Science*, vol. 38, no. 3, article 1041, 2003.

[8] F. Yang and Y. Rahmat-Samii, "Reflection phase characterizations of the EBG ground plane for low profile wire antenna applications," *IEEE Transactions on Antennas and Propagation*, vol. 51, no. 10, pp. 2691–2703, 2003.

[9] H. Kawakami and T. Ohira, "Electrical steerable passive array radiator (ESPAR) antennas," *IEEE Antennas and Propagation Magazine*, vol. 47, no. 2, 2005.

[10] S. K. Sharma and L. Shafai, "Beam focusing properties of circular monopole array antenna on a finite ground plane," *IEEE Transactions on Antennas and Propagation*, vol. 53, no. 10, pp. 3406–3409, 2005.

[11] C. Phongcharoenpanich, S. Suriya, T. Lertwiriyaprapa, P. Ngamjanyaporn, and M. Krairiksh, "Analysis of circular array of monopole on the ground plane radiating linearly polarized conical beam for wireless LAN applications," in *Proceedings of the 5th International Symposium on Antennas, Propagation and EM Theory*, pp. 646–649, August 2000.

[12] J.-H. Jung, H. Choo, and I. Park, "Small broadband disc-loaded monopole antenna with probe feed and folded stripline," *Electronics Letters*, vol. 41, no. 14, pp. 788–789, 2005.

[13] C. Delaveaud, P. Leveque, and B. Jecko, "New kind of microstrip antenna: the monopolar wire-patch antenna," *Electronics Letters*, vol. 30, no. 1, pp. 1–2, 1994.

[14] F. Pasquet and B. Jecko, "New developments of the wire-patch antenna for ceramic technology and multifunction applications," in *Proceedings of IEEE International Symposium on Antennas and Propagation Society (AP-S '01)*, vol. 4, pp. 62–65, 2001.

[15] M.-C. Huynh and W. Stutzman, "Ground plane effects on planar inverted-F antenna (PIFA) performance," *IEE Proceedings: Microwaves, Antennas and Propagation*, vol. 150, no. 4, pp. 209–213, 2003.

[16] Y. Gao, C. C. Chiau, X. Chen, and C. G. Parini, "Modified PIFA and its array for MIMO terminals," *IEE Proceedings: Microwaves, Antennas and Propagation*, vol. 152, no. 4, pp. 255–259, 2005.

[17] V. Volski and G. A. E. Vandenbosch, "Modelling of microstrip antennas on a finite ground plane using the 2D physical optics model," *Microwave and Optical Technology Letters*, vol. 40, no. 1, pp. 26–29, 2004.