Triangular Patch Antennas for Mobile Radio-Communications Systems

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Abstract: - In this paper, the design procedure of triangular patch antennas is presented here. The antennas are compatible with the frequency interval of wireless communication systems. The design, simulation and experimental results are included for both antennas, where these antennas are based in one or two isosceles triangles. The first antenna has only one triangle in the patch, and the another one is a bowtie antenna, which involves two triangles with the same feeding point. The parameters employed in order to evaluate the two structures were the S_{11} parameter, the bandwidth, the radiation patterns and the antenna gain.

Key-Words: - Triangular antenna, bowtie antenna, antenna matching,

1 Introduction

Microstrip antennas have some advantages in order to be used in a lot of mobile communications systems [1-3]. The main advantages of this kind of antennas can be summarized as follows: they are compatible with mobile terminal equipment where a thin profile and a light weight might be necessary; they are relatively low-cost than other manufacturing techniques; their bandwidths are narrow; they have normally moderate quality factors; and, they have enough antenna gain, that is needed in the indoor radio-communications links [4-6].

Microstrip antennas can be made to emulate wire antennas; monopoles, dipoles, Yagi-Uda and logarithmic array antennas are widely configuration examples. Besides, triangular, rectangular and circular patches give a very narrow-band response approximately equal to 2%. Then, triangular and bowtie antennas offer a moderate bandwidth (5%) in comparison with rectangular and circular choices. Other approaches like fractal, slotted and defected structures have been developed intending to increase the bandwidth, but there are some tradeoffs to take into account, because this sort of antennas require a very high manufacturing accuracy, their electrical features are not stable and, its price is frequently more expensive [1-3, 7-9].

Triangular and Bowtie antennas have been studied analytically or experimentally, both points of views provide the radiation features, but with a smaller size in comparison with rectangular or circular patches. Besides, triangular and bowtie antennas can be smaller if they are loaded them using shorts or slots.

Triangular antennas can be implemented by equilateral or isosceles triangles. These triangles are normally modified with the aim of changing the impedance and electrical size, or in order to use cross-polarization diversity [11].

Bowtie antenna can be divided into two categories, sheet and microstrip patch antennas. Bowtie sheet antennas have omnidirectional radiation patterns and as a consequence of this, they have a lower antenna gain [1]. Thu use of ground planes in microstrip bowtie antennas changes the omnidirectional antenna pattern into a directional one.

In this paper, a Microstrip Bowtie Patch Antenna (MBPA) is presented and it is proposed for indoor communications systems. According to the considerations mentioned before, the MBPA is chosen in order to achieve a low-cost microstrip antenna with a 5% bandwidth and a moderate antenna gain in a wide beamwidth. The antenna will be used in educational and low-cost mobile handsets or other terminal equipment for transportation vehicles; but, it will be almost used in low power radio applications.

The article is divided into five sections: the section one is an introduction to microstrip antennas that are currently used in mobile radio-communications systems; the section two is dedicated to describe the design methodology of the triangular antenna, which is the base of the bowtie structure; the third section is dedicated to describe the design of the MBPA; in the fourth section of the paper, the main simulated and measured results are presented and discussed; and, the conclusions of this work are described in the section number five.

2 The triangular antenna

The simplest triangular antenna is illustrated in Fig 1, where an equilateral triangular patch is located on the front size of the board with a dielectric substrate and it is located according the coordinated system. I the back side there is a ground plane, which reflects the electromagnetic waves in the positive direction of the *z* axis, with the intention to narrow down the back lobes of the antenna pattern [10].

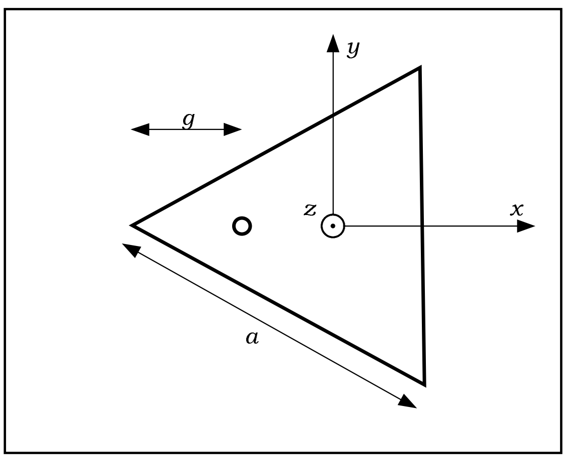

Fig. 1. Triangular antenna.

The thickness and the relative dielectric permittivity of the board are quit important in the resonant frequency of the patch. Despite the fact that this kind of antennas can be used in both Transverse-Electric (TE) or Transverse-Magnetic (TM) modes; it is necessary to solve only TM modes, because the duality principle assures the same performance in the radiation patterns. The feeding of the structured is determined by de distance *g*, this parameter is quite important in the matching procedure, because the impedance of the structure can be modified using this distance. In the following section, the feeding point is presented and modeled.

3 The design of the bow-tie antennas

The MBPA design is based on the triangular patch antenna theory presented in the section two. Uni-planar bowtie antennas like MBPA usually combine the use of two triangular antennas, but it is possible to use circular magnetic walls. This antenna can be built in a single side or in both sides of the Printed Circuit Board (PCB). In this work, a MBPA is designed and probed, this antenna uses a ground plane with the aim of achieving a directional radiation pattern with a very low back lobes, see the Figure 2.

Each triangle has a non-perfect magnetic wall, where the effect of this wall can be estimated using empirical methods. The design procedure of the MBPA presented here is based on the assumption that the triangles have perfect magnetic walls.

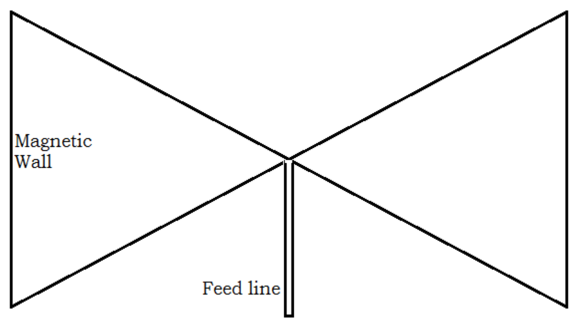

Fig. 2. Biconical antenna.

The resonant frequency corresponding to the many different modes in the MBPA can be calculated by equation (1) [8-9].

$$f_{m,n} = \frac{2c}{3a\sqrt{\varepsilon_r}} \sqrt{m^2 + mn + n^2} \quad (1)$$

Where *m*, *n* determine the $TM_{m,n}$ dominant mode; *c* is the light speed, m/s; ε_r is the dielectric constant of the substrate; and, *a* is the length of the antenna arm, m.

It is possible to increase the accuracy of the resonant frequency if the dielectric constant and the length of the arm are replaced by their effective values. The effect of the dielectric constant of the substrate is the major cause of this consideration, but it is necessary to consider, that the feeding points of the triangles is located in the same position at the *g* distance, which is excited by the microstrip transmission line.

It is possible to determine theoretically the distance of the feeding according to the cavity model. This mathematical procedure has been plotted for some important input impedance values [1].

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2} \frac{1}{\sqrt{1 + \frac{12d}{a}}} \quad (2)$$

$$a_{eff} = a + \frac{d}{\sqrt{\varepsilon_r}} \quad (3)$$

Where ε_{eff} is the effective dielectric constant of the substrate; a_{eff} is the effective length of the arm, m; and, d is the thickness of the substrate, m.

The geometry of the MBPA is illustrated in the Figure 3, where the antenna has been matched by a microstrip transformer to a coaxial line with a impedance equal to 50Ω and the triangles are folded in the patch, this point determines the impedance of the triangles. Another approach for the antenna tunning is to modify the triangles to cuasi-equilateral.

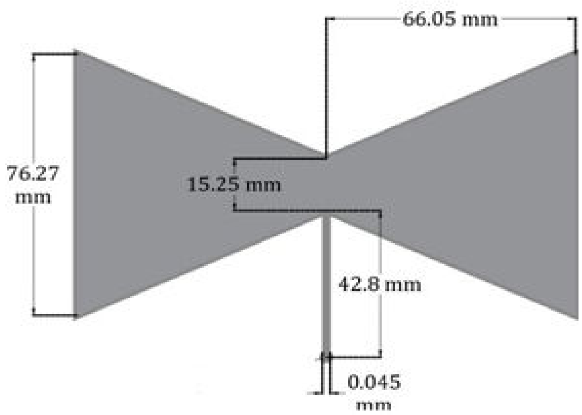

Fig. 3. Layout of the bowtie antenna.

This design and simulations were carried out for a resonant frequency nearly equal to 2.5 GHz considering the use of a FR-4 substrate. In the results section, the antenna was performed with a different substrate, which dielectric constant is approximately equal to 6.1. The final resonant frequency was 2.11 GHz approximately, as has been mentioned above.

The dimensions of the proposed antenna are shown in the Table 1, where the resonant frequency is included in both: with the ideal and the effective dielectric constants and the effective length of the antenna arms.

Table 1. Parameters obtained in the antenna design.

Parameter	Value
a	76.27 mm
u	66.05 mm
c	15.25 mm
f_r	2.5 GHz
ε_{eff}	4.22
a_{eff}	77 mm
f_r	2.52 GHz

The microstrip transmission line is necessary to match the antenna [1-3], where the thickness of the substrate is approximately 1.544 mm and the length of this strip line is equal to a quarter of the wavelength, see Figure 4. The coaxial connector is located at the end of the microstrip line on the ground plane.

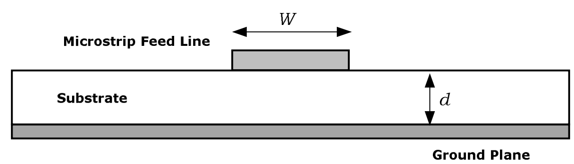

Fig. 4. Profile of the microstrip antenna.

4 Results

In this section, the most important electrical and radiation features of the antenna are presented. In the first stage, the antenna was modeled and simulated using High Frequency Simulation Structure (HFSS).

The Figure 5 illustrates the resonant frequency for a triangle antenna designed for wireless radio-communication systems operating at a carrier frequency equal to 2.4 GHz. The feeding point of the triangular patch was optimized in the simulation stage. The best matching distance was 12 mm to the left side, in the Figure 5, the dashed lines described the performance for 11 mm and 13 mm distances,

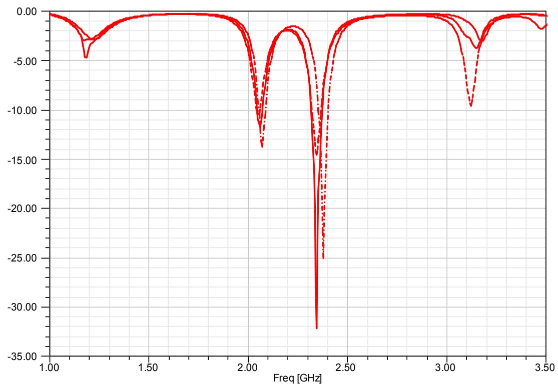

Fig. 5. S_{11} Parameter of the triangle antenna.

The tridimensional radiation pattern of the triangle at 2.4 GHz is shown in the Figure 6, where the antenna directivity is nearly equal to 4.54 dB.

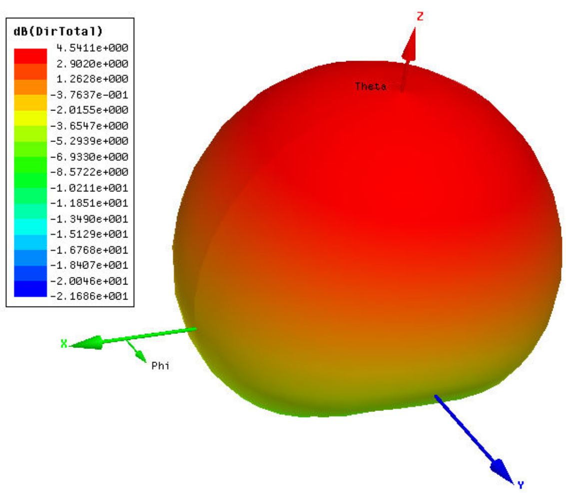

Fig. 6. 3-D radiation pattern of the triangle antenna at 2.4 GHz.

The small electrical size of the triangle antenna gives a low antenna gain. In the bowtie antenna the electrical size is significantly increased. Then this structure can improve this performance.

The model used in the computational tool is illustrated in the Figure 7, where the feeding point is located in the small circle on the patch. In this case the returning losses were optimized changing the distance of the feeding point, but it is possible to modify the structure to a cuasi-equilateral triangle.

Using the analysis and results of the triangle antenna, the simulation and experimental results for the bow-tie antenna are presented in the following plots.

The Figure 7 illustrates the field pattern on the patch surface of the Bow-tie antenna, wich is operating in the dominant TM01 mode.

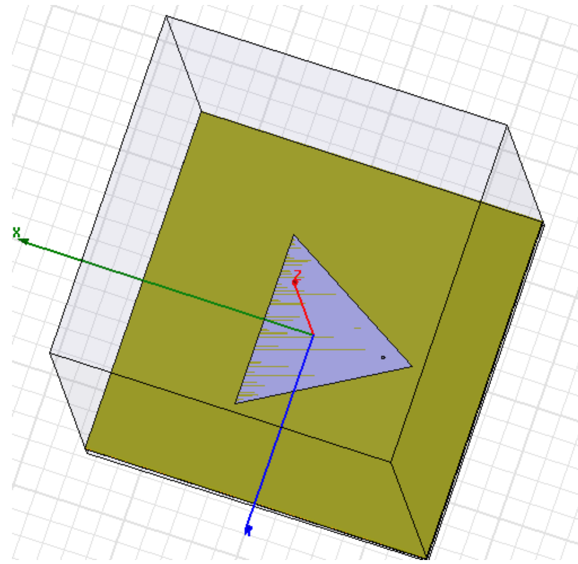

Fig. 6. Simulation model of the triangle antenna for an operating frequency at 2.4 GHz.

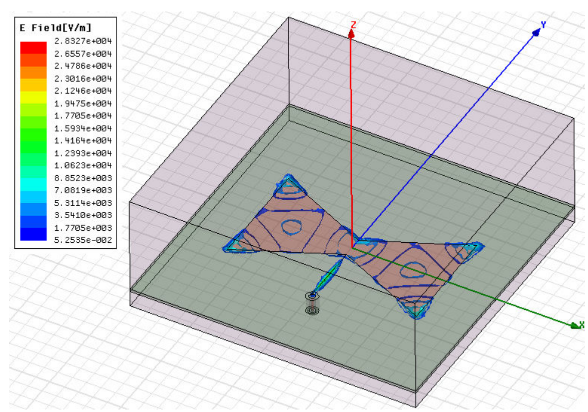

Fig. 7. Simulated model of the bow-tie antenna.

The simulation process includes the optimization of the structure. In this stage, the antenna patterns and S_{11} parameter are the most important results. The Figure 8 shows the matching interval of the antenna (from 2.05 GHz to 2.1 GHz).

The simulated 3-D antenna pattern at the far field zone is shown in the Figure 9, where the corresponding antenna gain is closed to 8.7 dB. The electrical size of the bowtie antenna generates a higher antenna gain in comparison with the triangle antenna (4.54 dB approximately).

Hector Fraga-Rosales, Mario Reyes-Ayala, Genaro Hernandez-Valdez, Edgar Alejandro Andrade-Gonzalez, Jose Raul Miranda-Tello, Felipe Alejandro Cruz-Perez, Sandra Lirio Castellanos-Lopez

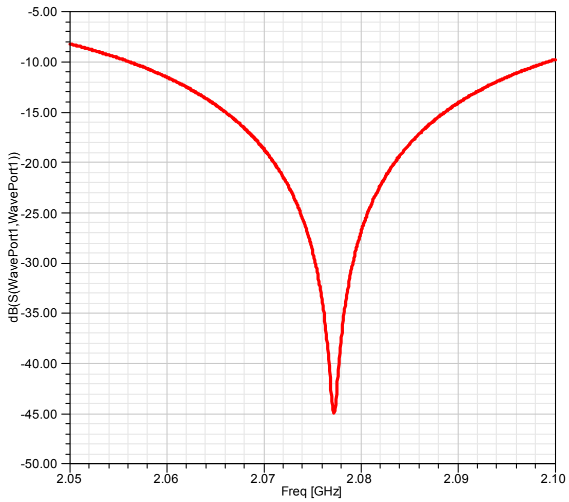

Fig. 8. S_{11} Parameter in the matching frequency interval of the antenna.

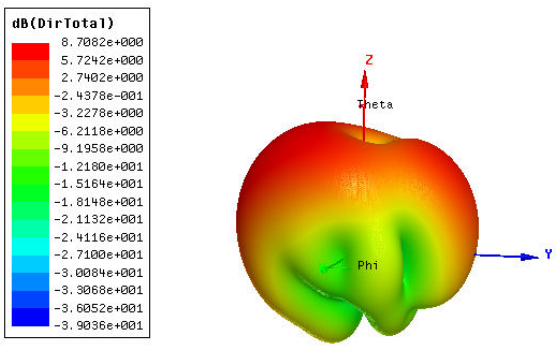

Fig. 9. Simulated 3-D antenna pattern at the far-field zone.

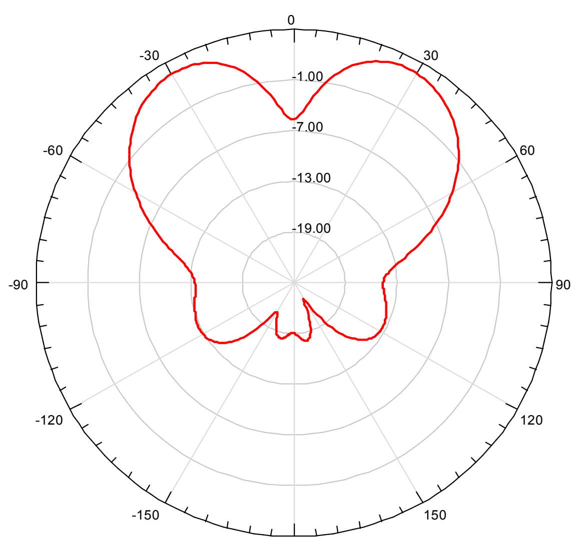

Fig. 10. Simulated radiation pattern in the E-Plane, for $\phi = 0^{\circ}$.

The 3-D antenna pattern can be divided in two radiation patterns. These patterns could be seen from Figure 10, for $\phi = 0^{\circ}$. The simulated radiation pattern in the E-Plane for $\phi = 90^{\circ}$ is plotted in the Figure 11. In both antenna patterns, it is clear that the beamwidth is greater than 100˚, this characteristic is desirable in almost all the mobile radio-communication systems.

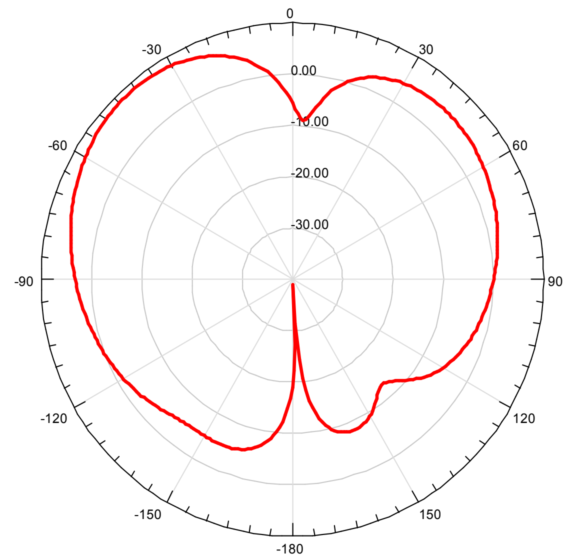

Fig. 11. Simulated antenna pattern in the E-Plane for $\phi = 90^{\circ}$.

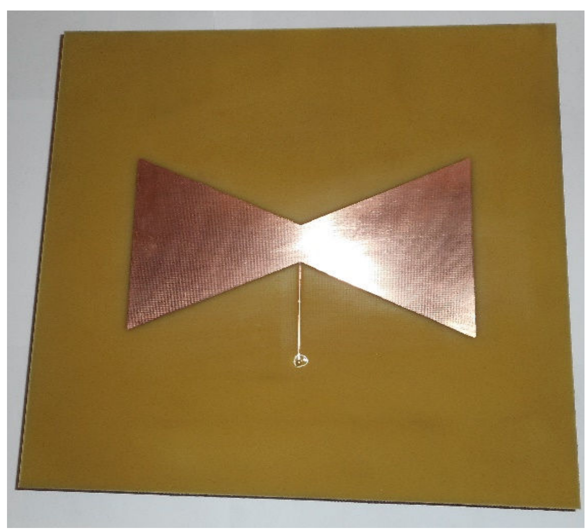

Fig. 12. MBPA printed in a PCB with a dielectric constant nearly equal to 6.

Based on the simulation results, the MBPA was built using a PCB with a dielectric constant $\varepsilon_r \approx 6$, as it is shown in Figure 12. The computational tool (HFSS) employs a finite-element numerical method, which offers a better agreement between simulated and experimental results. Other software choices in simulation of electromagnetic structures like Numerical Electromagnetic Code (NEC) or ENSAMBLE use the method of moments, where the antenna is modeled with surfaces instead of volumetric objects.

The return loss of the proposed antenna is shown in Figure 13. The measured frequency interval where the antenna matching is less than -10 dB is almost the same in comparison with the corresponding in the simulation results.

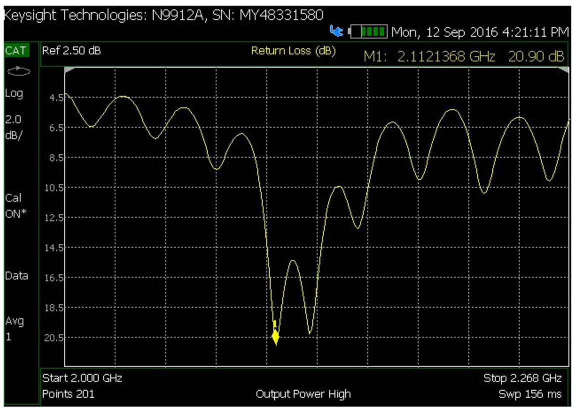

Fig. 13. Measured return loss for MBPA.

The measured far-field 3-D radiation pattern of the MBPA is shown in Figure 14. This result was obtained by interpolation using near-field evaluation equipment. It is obvious that simulation and measured antenna patterns look similar.

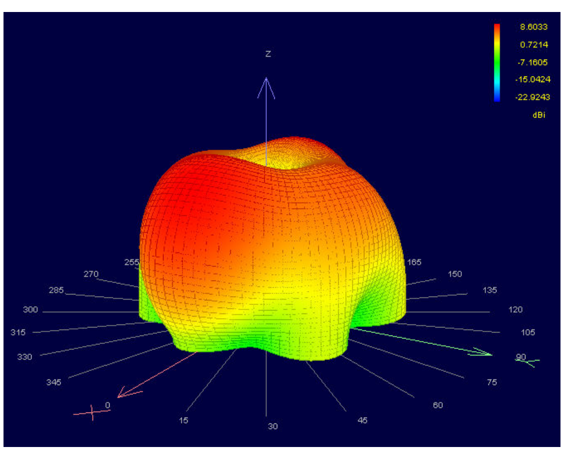

Fig. 14. Measured 3-D antenna pattern for MBPA.

The size of the antenna shown in the Figure 12 is compatible with the near-field equipment, which is a good choice in comparison with anechoic chambers.

The antenna has also a second resonant frequency at one half of the main resonant frequency (1.09 GHz instead of 2.11 GHz). This feature can be used in applications for a lower carrier frequency with the aim of reducing the electrical size of the structure, see Figure 15.

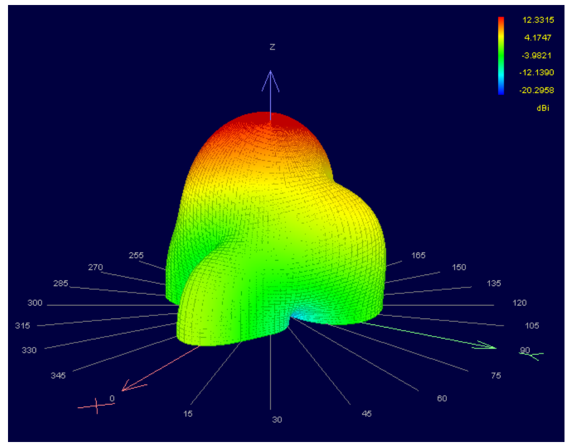

Fig. 15. Measured 3-D antenna pattern for MBPA (1.09 GHz).

5 Conclusion

A microstrip bowtie patch antenna was designed and implemented for indoor radio-communications. The bowtie antenna is based on the cuasi-equilateral triangular structure, which radiation principle is the same, but with a smaller electrical size. The feeding point of the triangle antenna is strongly related to the returning loses.

The proposed antenna has been simulated and measured in order to compare the results, where both numerical results are closed. The antenna gain (≈ 8.6dBi) is enough to make feasible the link budget in indoor radio-communications systems. In addition to this, the beamwidth is also compatible with this kind of applications.

The measured S_{11} parameter shows a good agreement with the simulation results and it is clear that the MBPA has a higher bandwidth in comparison with rectangular and circular microstrip patch antennas.

Finally, it is important to emphasize that the MBPA could be used at 1.09 GHz, as a consequence of the total length of the structure. In this case, the beamwidth is narrowed down to 60° approximately.

References:

[1] C. A. Balanis, *Antenna Theory*, 3rd Edition, John Wiley & Sons, 2005.

[2] D. M. Pozar, *Microwave Engineering*, 2nd Edition, New York, John Wiley & Sons, 1995.
[3] J. Volakis, *Antenna Engineering Handbook*, McGraw-Hill, 2007.
[4] K. R. Mahmoud, *Progress in Electromagnetic Research PIER*, Vol. 100, 2010, pp. 105-117.
[5] C. N. Ng, S. Uysal, M. S. Leong, *Proceedings of the RAWCON'98*, 1998, pp. 205-207.
[6] B. Harchandra, R. Singh, *International Journal of Engineering Trends and Technology IJETT*, Vol. 18, 2014, pp. 171-175.
[7] K. W. Loi, S. Uysal, M. S. Leong, Design of a Wideband Microstrip Bowtie Patch Antenna, *IEEE Proceedings Microwave Antennas and Propagation*, Vol. 145, No. 2, April 1998, pp. 137-140.
[8] M. Roslee, K. S. Subari, I. S. Shahdan, *Proceedings of the International RF and Microwave Conference RFM'2011*, 2011, pp. 430-433.
[9] C. Guo, R. C. Liu, *Proceedings of the International Conference Ground Penetrating Radar GPR'2010*, 2010, pp. 1-5.
[10] T. A. Milligan, *Modern Antenna Design*, 2nd Edition, , John Wiley & Sons, 2005.
[11] W. L. Stutzman, G. A. Thiele, *Antenna Theory and Design*, John Wiley & Sons, 1998.