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# Advanced Antenna Prototypes for Indoor and Outdoor Wi-Fi Communication

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**Abstract.** The design and fabrication of an individual patch antenna were realized in order to obtain an efficient and economical antenna replacement to routers, which operate at 2.4 GHz. This rectangular microstrip antenna was corner truncated rectangular due to its bigger gain compared with the rectangular one, because of losses reduction. With this antenna the indoor communication was possible, but it was not enough to supply the outdoor one. In order to provide also the outdoor service, antenna arrays were developed, on the base of the corner truncated rectangular antenna, considering traditional configurations such as, a driven patch antenna gap coupled to four patches along the edges as a first approximation. As second one, a driven patch antenna directly coupled to four patches along the edges was analyzed, and finally, a driven patch antenna was coupled considering both types of coupling. The last case constitutes a novel structure, which showed the biggest gain, but, experimentally, also showed a little displacement of the central frequency. The indoor and outdoor Wi-Fi communication was possible with the last two arrays. Their main limitations are their sizes, but they have competitive costs.

**Keywords:** Antenna prototypes, indoor and outdoor Wi-Fi communication.

## 1 Problem Description

The great demand of Wi-Fi networks has led to the constant search of connectivity improvements; among them has appeared the use of antennas to replace to the original routers antennas, in order to increase substantially the performance, the coverage and the data rate [1].

The gain is another characteristic to improve. The original antennas of low cost routers, provide gains from 1.5 up to 2 dBi, in special cases. In fact, in order toincrease the coverage some manufacturers of routers sell replacement antennas of high gain [2], for indoors and outdoors [3-4].

The aim of this work is to provide alternatives of replacement patch antenna. It is proposed the design and fabrication of an individual and antenna arrays for 2.4 GHz. The direct coupled arrays have provided a major robustness of the signal for indoor and outdoor communication and with lower cost compared to commercial alternatives.

## 2 Introduction

At the present time, there are several types of printed antennas in the wireless communications. The most common today is the microstrip or patch antenna, which is fabricated by recording the element pattern of the antenna in a metal piece, commonly cooper, connected to a dielectric substrate with a continuous metal layer connected along the opposed side of the substrate, which forms a ground plane. This kind of antennas is relatively inexpensive.

An arrangement patch provides much more than a simple patch gain for a small additional cost, and a bigger broadband.

In this work, we presented the design and fabrication of prototypes of individual and antenna arrays for 2.4 GHz. The tests for sending-receiving signals are realized in order to know their performance

## 3 Individual antenna prototype

The patch width is calculated using [5-7]:

$$W = \frac{c}{2 f_o \sqrt{\frac{\varepsilon_r + 1}{2}}} \tag{1}$$

where: *c* is the constant speed of light in vacuum, $\varepsilon_r$ is thedielectric constant substrate, $f_0$ is the operating frequency.

The patch length is given by: $L = L_{eff} - 2\Delta L$ Where $L_{eff}$ is the effective length and $2\Delta L$ represents the two increments in the length, which are generated by the fringing fields, make electrical length lightly larger than the physical length of the patch. The length and width of ground plane are [5]:

$$L_g = 6h + L \text{ and } W_g = 6h + W , \tag{2}$$

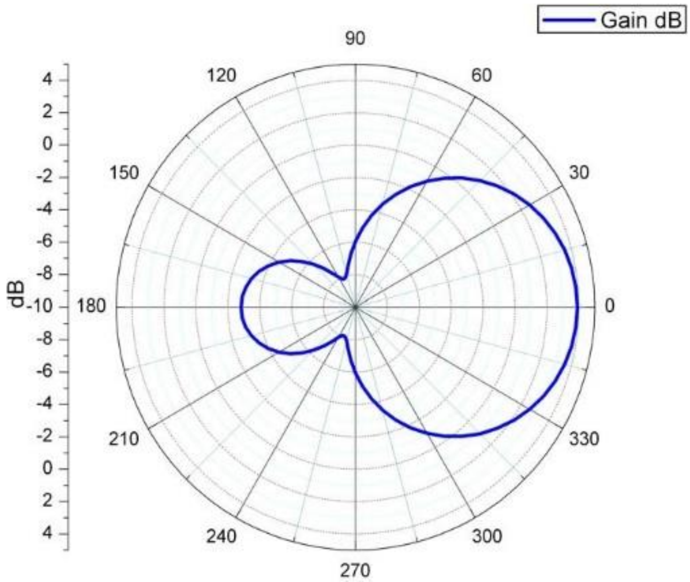


**Fig. 1.** Beam width of patch antenna.

Using 2.4 GHz as the operation frequency, and 1.6 mm asthe width of FR-4 PCBs plates, the values of W and *L*, are 3.95 cm and 3.08 cm, respectively. The feed point location since the antenna center is (-0.005 m, 0).

For simulation of the antenna performance, we use FEKO, which offers several tools for the patch antenna simulation, and has very friendly environments.

### 3.1 Modified Antenna

Rectangular patch antenna designs were realizedconsidering some variations, such as cuts and grooves.The rectangular geometry with cuts showed biggest simulated gain and was used as individual prototype.

The gain ratio between the rectangular and rectangular with cuts is 0.78 dB. The cuts depth has 1/8 of group wavelength. The polarization is linear.

The simulations results show a gain from 3.91 up to 4.04 dB for the frequency range from 2.4 up to 2.45 GHz; anda beam width of approximately 90 degrees (Figure 1).

The peak of the electric field was located at 2.41 GHz.The simulated results fit the design requirements. Theimpedance of the antenna considering a 50 Ω load at 2.41 GHz was of 60.51 Ω.

### 3.2 Individual Antenna Prototype

The fabrication of the individual prototype (figure 2a)was realized on PCBs templates. Coaxial cable of 50 ohms was used for feeding. The final prototype includes a female BNC connector because of its compatibility withthe laboratory equipment.

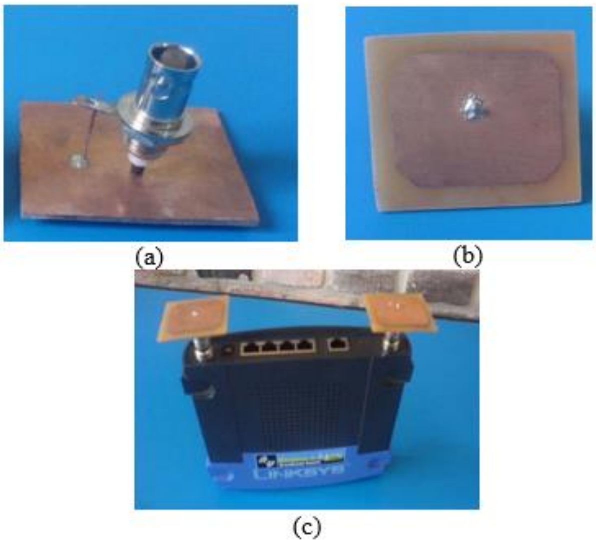


**Fig. 2.** (a) Individual patch antenna prototype.Frontal view. (b) Back view. (c) Router antenas replacement.

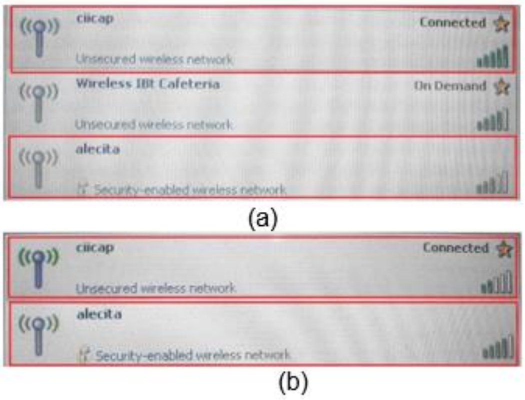


**Fig. 3.** The received power (a) outside and (b) insideof the CIICAp building.

### 3.3 Results

The transmission-reception testing was realized inside and outside of CIICAp building. The testing was realized by using a signal generator and a spectrum analyzer, with antenna prototypes coupled by means of coaxial cables. The distance between the antennas was of 6 cm. The peak frequency corresponded to the range from 2,4 to 2,45 GHz, as it was expected.

A comparison with a commercial antenna performance was also realized using two Wi-Fi similar routers. In one of them (“alesita”), we replaced its antennas with our

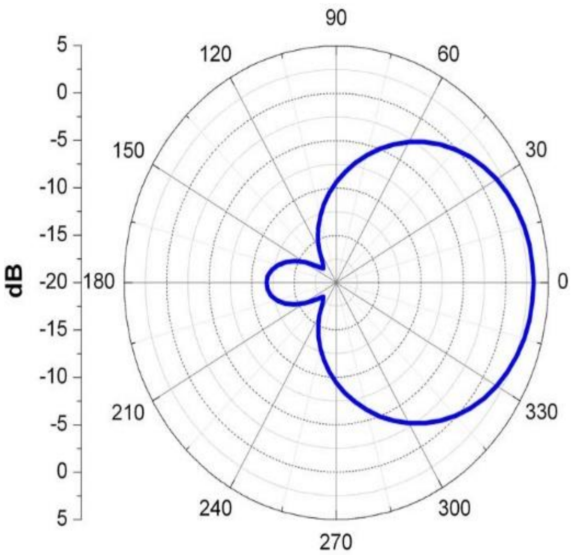


**Fig. 4.** Gain of the gap-coupled antenna array.

prototypes (figure 2b), while the other one remains with its original antennas ("ciicap"). Figure 3 shows the received power inside and outside of the CIICAp building, using a laptop as reference. As can be seen, outside the CIICAp building, the transmission/reception is better using "ciicap", but inside, the signal is stronger with "alecita". The individual prototype achieves the objective only for indoors.

# 4 Antenna Arrays Prototypes

## 4.1 Gap-coupled Array

In order to improve the reception outside of the building, we proposed at first the design of gap-coupled arrays. For the case of a spacing equal to approx. 8 mm, the gain was approximately 3.2 dB (figure 4).

The back radiation is fewer, in this case (-12 dB), than forthe individual antenna (-3dB), but this characteristic is notenough to provide a better response.

The transmission-reception testing was realized inside and outside of CIICAp building.

## 4.2 Direct-coupled Array

For the case of the antenna array connected by microstrip lines, the length of the microstrip lines corresponds to $\lambda g/8$, that is, 8 mm and a width of 2 mm. The impedance of the microstrip, obtained from tables [6] is approximately 60 $\Omega$. The maximum gain is 4.4 dB (figure 5), lightly bigger than the individual prototype. The directivity increased from 3.44, for the case of individual antenna, to 4.47 for the array. The beam

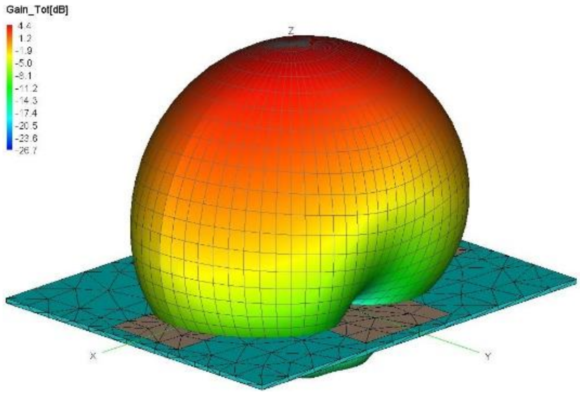


**Fig. 5.** Gain of the direct coupled antenna array.

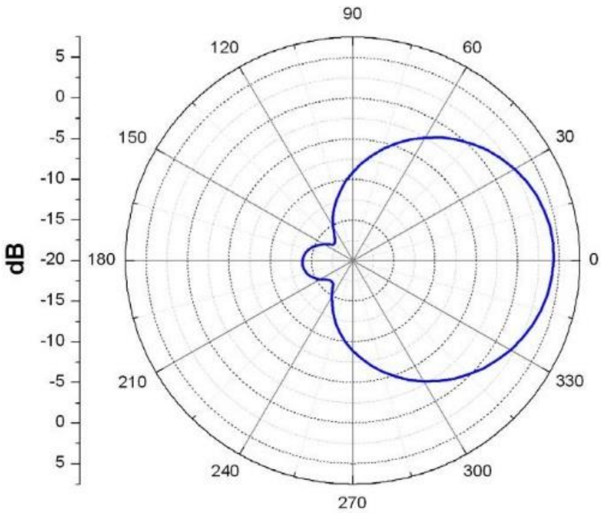


**Fig. 6.** Beamwidth of the direct-coupled antenna array.

width is similar to the other cases (figure 6). The corresponding prototype is shown in figure 7.

It must be mention that the simulated gain, considering arranges of rectangular with small cuts shape of the antenna components was of 5 dB, lightly bigger than for the case of the rectangular ones, but for simplicity only the rectangular case was fabricated.

The simulated electric field showed a peak in 2.44 GHz. experimentally, the frequency range, where there is a good response, is from 2.445 up to 2.65 GHz. The more representative measurements of the received signal, using a laptop, are shown in figure 8. As can be seen, with the direct coupled antenna array shows a very good response not only inside, but also an acceptable robustness outside of the CIICAp building, which was the aim of this design.We also compared the performance of the router with our antennas, against its performance considering its original antennas, see figure 9.

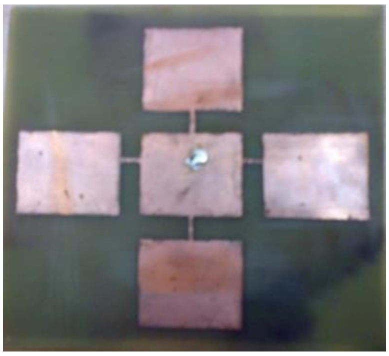

**Fig. 7.** Prototype of direct coupled antenna array.

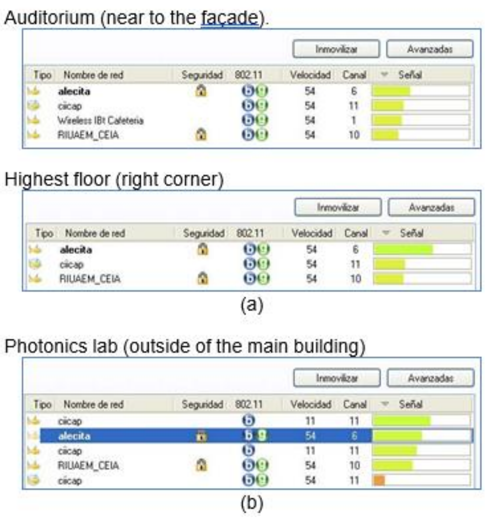


**Fig. 8**. The received power (a) outside and (b) insideof the CIICAp building using antenna arrays.

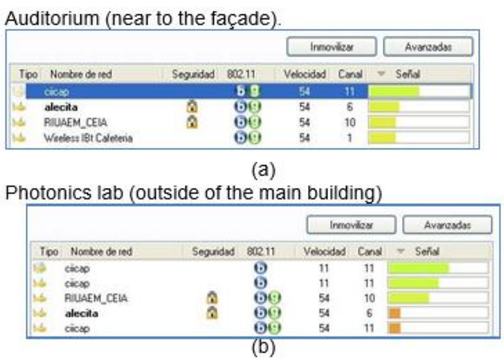


**Fig. 9**. Received power (a) outside and (b) inside ofthe CIICAp building, considering to the router with itsoriginal antennas.

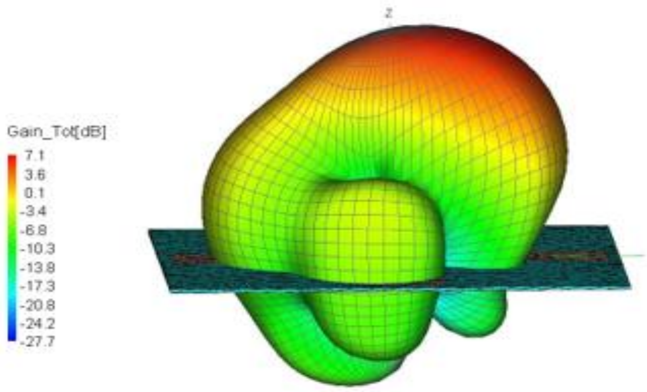


**Fig. 10.** Gain of mixed-coupled array.

From figures 9 and 10, it can be noted that the router with the antenna prototypes has better reception insideand outside of the building, compared with its performance using its commercial integrated antennas.

### 4.3 Mixed-coupled Array

Even though the last antenna array made possible to reachour initial objectives, we continue reviewing other configurations based on rectangular patch antennas. Anew proposal was realized considering a mixed-coupled array with a separation of $\lambda g/4$, combining gap and direct coupled antennas. The microstrip used to the direct coupling has a width of 1.45mm. The simulated gain was of 7.01 dB at 2.3 GHz and of 6.435 dB for 2.4 GHz (figures 10). The directivity and the prototype are shown in figures 11 and 12, respectively. The experimental results are satisfactory, but we need to improve the radiation pattern.

It is necessary to note that the gain value corresponds to the direct addition of the individual and the four direct- coupled array gains. But, this result cannot be generalized without to make more proofs.

## 5 Economic Profit

In this work, without considering the costs of the equipment, the devoted time, and the profit margin, the fabrication net cost of two individual antenna prototypes is approximately of $150 Mexican pesos, considering alsoan ABS cover. This cost is very competitive with the commercial antennas of similar performance. In the case of the antenna array the cost would be substantially increase due to the ABS cover. As it is known, the prices can be drastically reduced if a great scale fabrication is considered. In the case of the antenna arranges, the prices would be lightly increased, specially, due to the cover costs.

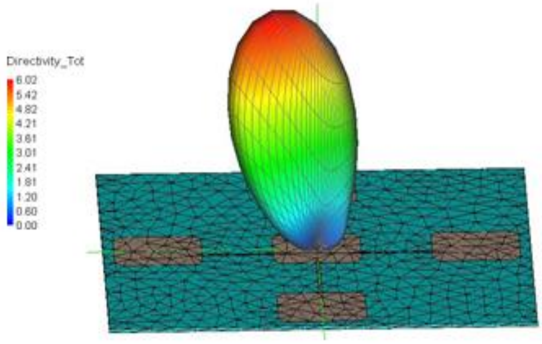


**Fig. 11.** Directivity of mixed-coupled array.

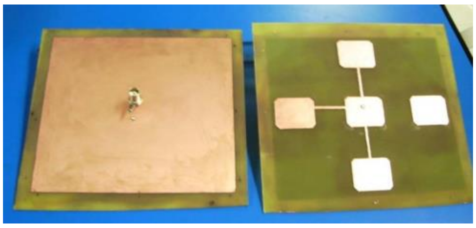

**Fig. 12.** Prototype of the mixed-coupled array with aseparation of $\square_g/4$.

## 6 Conclusions

The best response for the two cases (individual and antenna arrays) was obtained only using cuts, with approx. 8 mm deep length. For the antenna array, the length of the microstrip lines also corresponds to this value.

The receiving/sending tests showed lightly differences to the simulation results, considering to the corresponding loads. The possible sources of these deviations can be: the feed point has small dimensions in the prototype as well as the feed line. On the other hand, the coupling and the propagation medium also produce additional losses.

The prototype of individual patch antenna shows a good performance for indoor Wi-Fi communications, also in presence of obstacles like walls and in absence of line of sight, whereas the antenna array coupled by microstrip lines shows a better outdoor performance.

The fabrication of the individual prototypes has relatively a very low cost, which makes their use feasible for commercial applications.

For commercial purposes, in the case of direct coupled arrays, the analysis of other substrate materials in order to reduce the sizes must be realized.

The mixed coupling had the biggest gain, but the radiation pattern needs to be improved. Also, it is necessary to obtain more data in order to generalize the obtained result about its gain value.

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