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Application Article

Dual-Beam Antenna Design for Autonomous Sensor Network Applications

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This paper describes our contribution in the ANR project called CAPNET dedicated to the site security (autonomous sensor network). The network is autonomous in term of energy and it is very easy to deploy on the site (the time to deploy each node of the network is around 10 minutes). The first demonstrator was deployed in the fire base station of Brest, France with 10 nodes with a security perimeter around 1.5 km. Our contribution takes place in the field of antennas, with the development of two systems: a single-beam antenna reserved for the supervisor or the last node of the network, and a dual-beam antenna dedicated to the node in linear configuration. For the design and optimization of antennas, we use HFSS CAD software from ANSOFT. The antennas have been designed and successfully measured.

1. Introduction

In the wireless applications, directional antenna and dual-beam antenna play important roles [1].

In miniaturizing the wireless communication system, the antenna must be small enough to be placed inside the system. In a lot of point to point communication system and in sensor network applications, several-type antennas (dual-beam) such as array of patches [2], leaky wave antennas [3, 4], and EBG antennas [5] are usually not suitable due to their large size, complexity in the design to obtain a dual-beam, complexity in the matching feed network, and so forth.

The printed-circuit type antenna is the trend in antenna development, which is compact and relatively inexpensive. Various small size printed-circuit type antennas and several methods to reduce the size of the antenna exist such as use of high-permittivity substrates, printed dipole antennas [6], shorting pins, zig zag, fractal, slots and meander-line [7, 8], and printed Yagi antennas [9].

Among various types of printed-circuit antennas, planar Yagi structures are attractive for wireless applications due to their high gain and directive property in addition to the common qualities of printed antennas (simplicity design, low profile, small size, light weight, low cost, reduced losses, reduction of the connectors, as well as ease to fabrication and integration in the PCB). In addition, the dual-beam pattern can be easily implemented by Yagi antenna without complicated feeding networks as we show in this paper.

In this paper, the elementary structure is based on printed dipole antenna [10].

First, we have studied an elementary dipole antenna with reflector and director. The advantage of this is to increase the gain of the printed dipole and to decrease the backside radiation. Next, a printed Yagi antenna with 4 directors (reserved for the supervisor or the last node of the network) is studied in order to increase the gain of antenna. Finally, we have developed a special dual-beam antenna dedicated to the node in linear configuration. All the designed antennas were simulated, realized, and characterized by measuring their return loss, radiation patterns, and gain.

2. System Principle

This system is dedicated to site security or people security: jail, warehouse, and security during fire man intervention, for example (Figure 1). The principle of the sensor network is

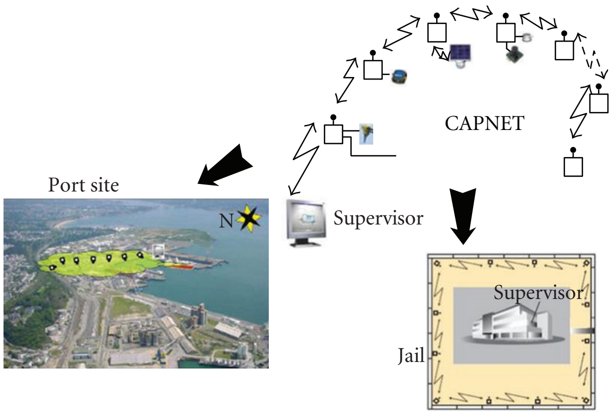


Figure 1: Examples of application.

to be autonomous in term of energy and to be easy to deploy on the sites. The time to deploy each node of the network is around 10 minutes.

The sensor network has two different channels, one for alarm information and the second one for image transmission. We can deploy different types of sensor on each node like people detection intrusion, camera, temperature, pressure, gas detection, explosimeter, and so on.

The network is design to be linear with a first node used by the supervisor. Each node is distant from each other at around 100 m. With 10 node it is possible to secure a perimeter around 1 km.

In the system, we anticipate the failure of 2 nodes with only a low degradation of the time response of the network. The time response for alarms is less than 1 s and around 10 s for image (depending on the weight of the image). For autonomous operation, each node is equipped with solar panel and wind turbine. The Figure 2 presents the first prototype of a node.

In order to estimate the performances of the system, two simulator were designed, one for the simulation of the energy consumption and harvesting and the other one for simulation of the communication system.

The communication simulator is to estimate the time delay in alarm and image transmission. It is also to determine the performance defaults when several nodes are not in operation.

A first demonstrator of ten nodes with a perimeter security of more than 1 Km was deployed in December 2011 in the fire station of Brest in Brittany (Figure 3). We obtained very good results.

Since this date, all the system is experimented in the ERYMA facilities in Lorient in order to obtain an industrial product. This company plans to commercialize the system in June 2012.

Figure 2: Photo of nodes of the sensor network.

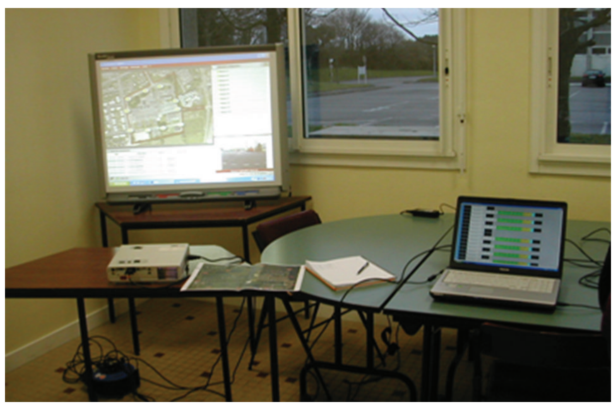


Figure 3: Photo of the supervisor of the sensor network deployed in Brest.

3. Antenna Design

3.1. Printed Yagi Antenna with 4 Directors. The geometry of the elementary dipole antenna with reflector and director is given in Figure 4. The two arms of the dipole are printed on each side of a CuClad substrate of thickness 0.8 mm and permittivity of 2.17 (to overcome the complicated feeding technique).

The reflector has to be longer than the length of the two arms of the dipole in order to reflect the radiated power in the front direction ($\theta = 0^\circ$). In the case of a shorter reflector, the radiation is concentrated in back direction, it performs as a director ($\theta = 180^\circ$).

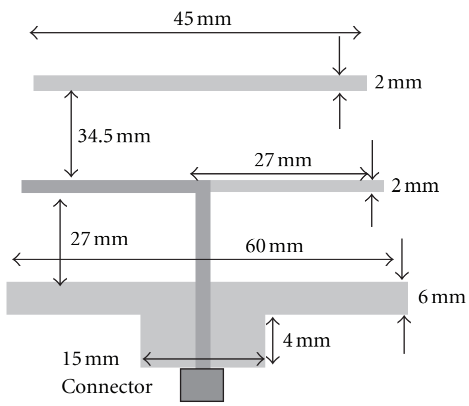
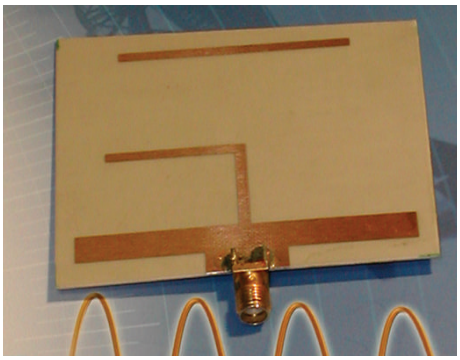
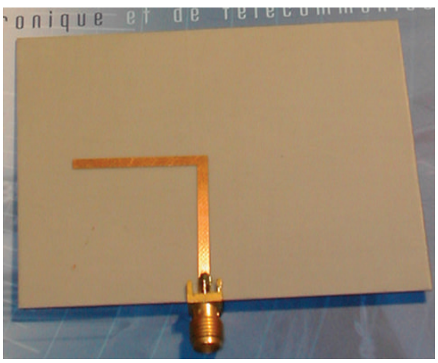


Figure 4: Geometry of the printed dipole antenna with reflector and director.



(a)



(b)

Figure 5: Photo of the printed dipole antenna with reflector and director.

In order to increase more gain in $\theta = 0^\circ$ direction, we put a metallic director. This director has to be shorter than the length of the two arms of dipole in order to concentrate the radiation.

The advantage of this structure is to increase the gain of the printed dipole and to decrease the backside radiation.

Figure 5 shows the realized printed dipole antenna with reflector and director.

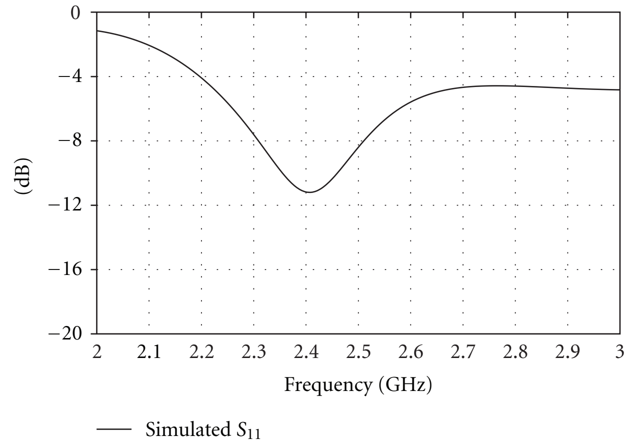


Figure 6: Simulated return loss of the dipole antenna with reflector and director.

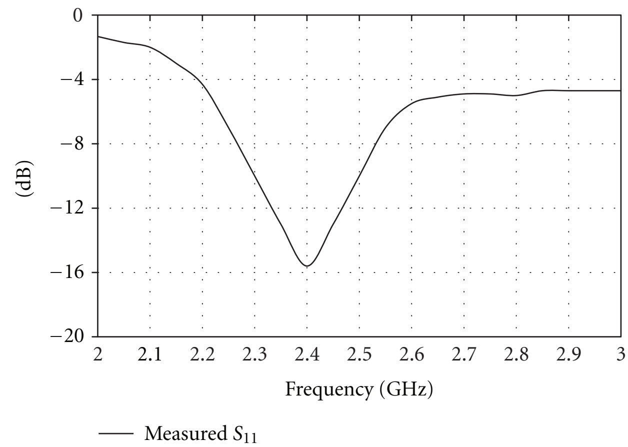


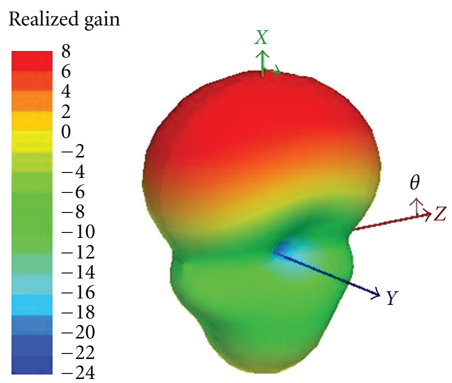
Figure 7: Measured return loss of the dipole antenna with reflector and director.

The simulated S_{11} of this antenna is plotted in Figure 6. The level is lower than −11 dB around the operating frequency (2.45 GHz).

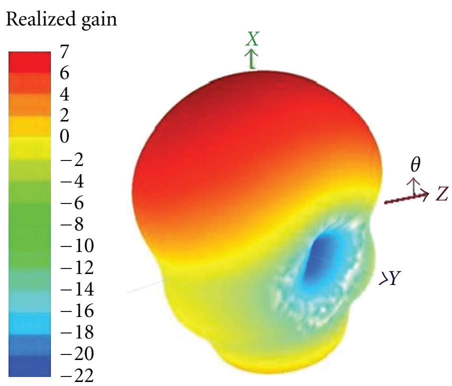
The measurements were achieved in the laboratory anechoic chamber and have been compared to simulation. The S_{11} depicted in Figure 7 shows that a value is approximately −15 dB at 2.4 GHZ and less than −10 dB between 2.31 GHz and 2.5 GHz.

We present the radiation pattern in 3D at 2.45 GHz obtained in simulation and measurement (Figure 8). We note a good comparison between simulation and measurement. The maximum value of measured realized gain of the single beam antenna is 7 dB in $\theta = 0^\circ$ (x direction). The difference between the simulated realized gain and the measured realized gain is around 1 dB. The measurement accuracy of the anechoic chamber (±1 dB) can be responsible for this variation.

In order to increase the gain in $\theta = 0^\circ$ direction, a printed Yagi antenna with 4 directors (reserved for the supervisor or the last node of the network) is studied (Figure 9). Four directors are sufficient to obtain the required gain (10 dB).



(a)



(b)

Figure 8: Simulated (a) and measured (b) 3D radiation pattern of the dipole antenna with reflector and director.

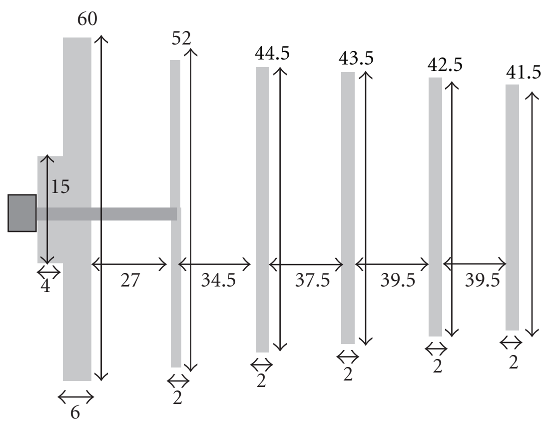
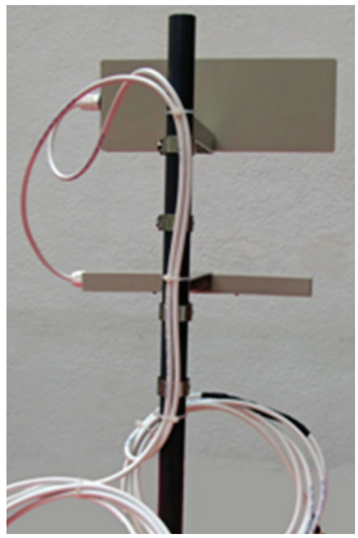


Figure 9: Geometry (in mm) of the printed dipole antenna with reflector and 4 directors.

A picture of the fabricated antenna is shown in Figure 10. The antenna is designed using the same size of the prototype described before.

The printed Yagi antenna is matched to −16 dB in simulation around the operating frequency (Figure 11). The return loss of the tested antenna is presented in Figure 12.

(a)



(b)

Figure 10: Photo of the printed dipole antenna with reflector and 4 directors.

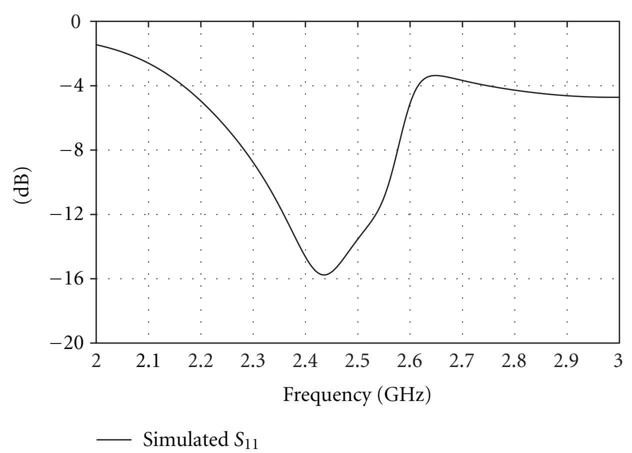


Figure 11: Simulated return loss of the dipole antenna with reflector and 4 directors.

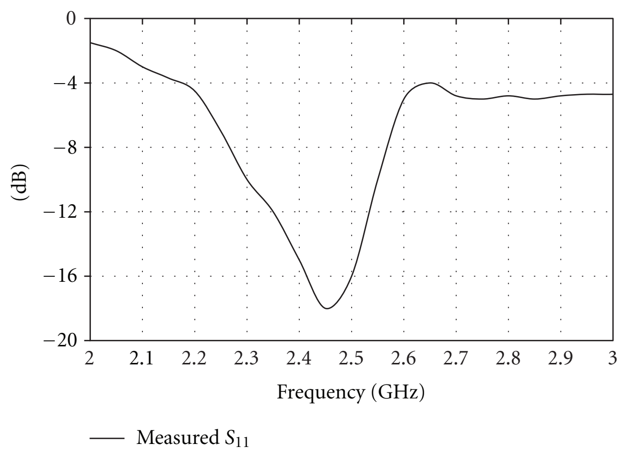


FIGURE 12: Measured return loss of the dipole antenna with reflector and 4 directors.

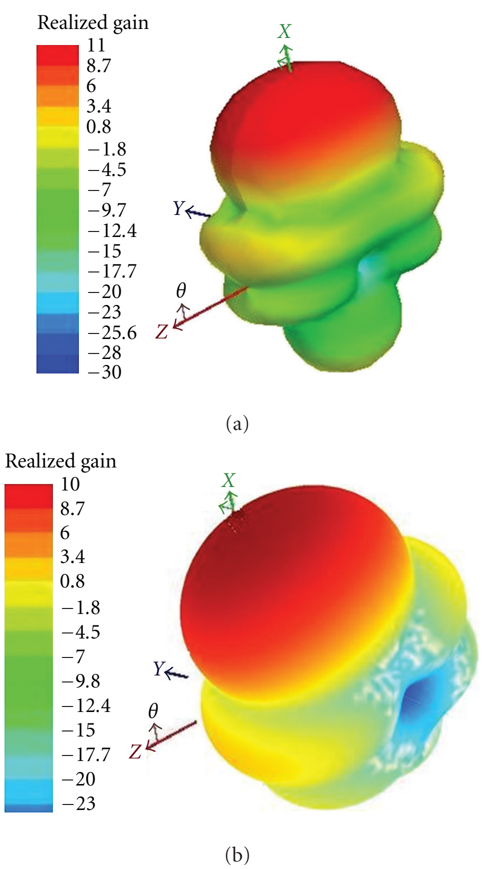


FIGURE 13: Simulated (a) and measured (b) 3D radiation pattern of the dipole antenna with reflector and 4 directors.

The level of measured S_{11} is lower than -10 dB over the operating frequency bandwidth (2.4 GHz–2.5 GHz).

Figure 13 compares the measured radiation pattern with the simulation in 3D at 2.45 GHz. The measured gain agrees very well with the prediction. We obtain 10 dB at 2.45 GHz in $\theta = 0°$ direction. We can conclude that the design is reliable.

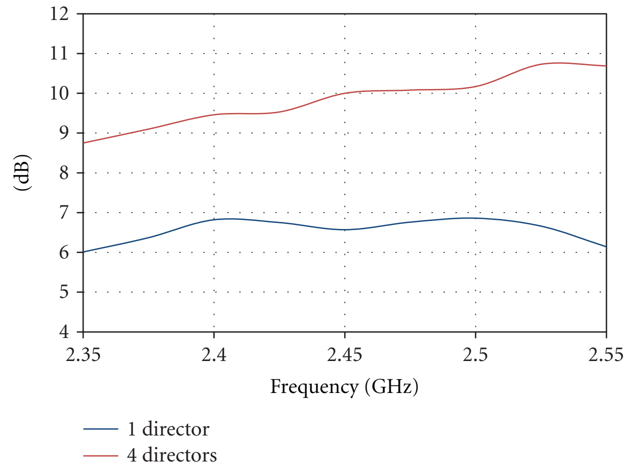


FIGURE 14: Measured radiation results (realized gain) versus frequency (red: antenna with 4 directors, blue: antenna with 1 director).

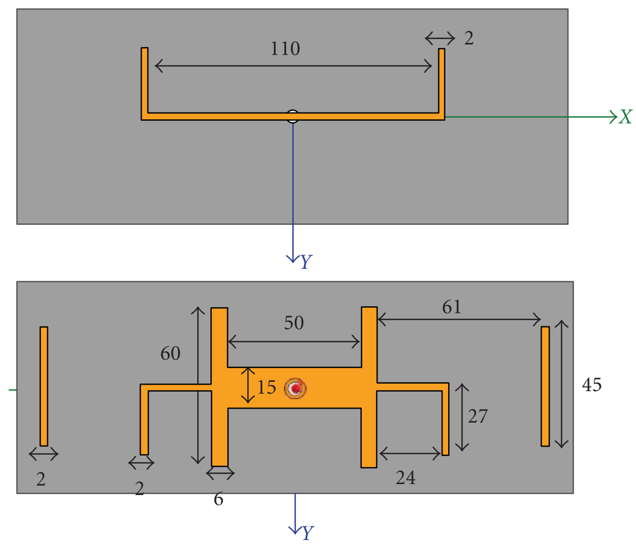


FIGURE 15: Geometry (in mm) of the dual-beam printed dipole antenna.

The difference of measured realized gain in $\theta = 0°$ between printed dipole antenna with one director and four directors is evaluated in Figure 14 over the frequency range. The maximum value obtained by Yagi antenna with four directors (red curve) is greater than the maximum value obtained by Yagi antenna with one director (blue curve) of around 3 dB in operating frequency bandwidth.

3.2. Dual-Beam Printed Dipole Antenna. For the node in linear configuration, we have developed a special dual-beam antenna. In order to realise a dual-beam antenna, we have combined the elementary structure antenna (presented in Section 3.1) back to back (Figure 15). We have optimized the distance between dipole and reflector, the distance between the two reflectors, and the size of the reflectors. The

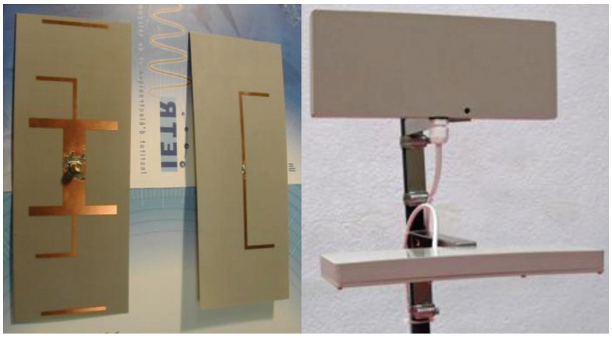


Figure 16: Photo of the dual-beam printed dipole antenna.

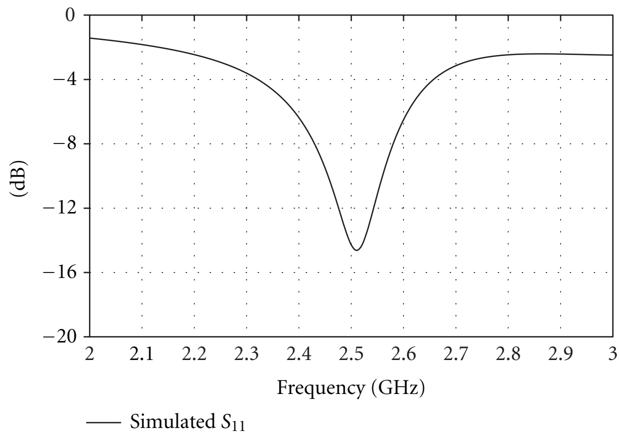


Figure 17: Simulated return loss of the dual-beam printed dipole antenna.

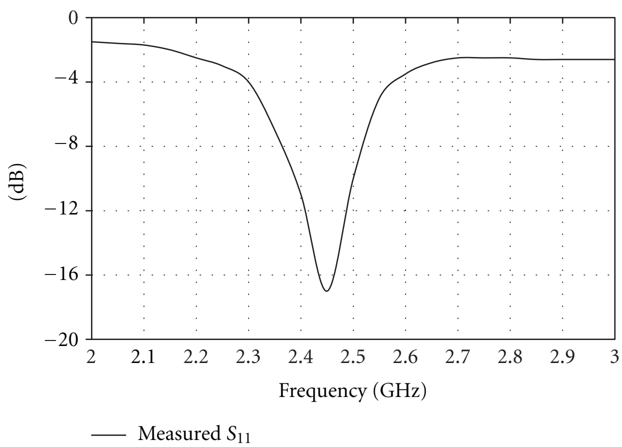


Figure 18: Measured return loss of the dual-beam printed dipole antenna.

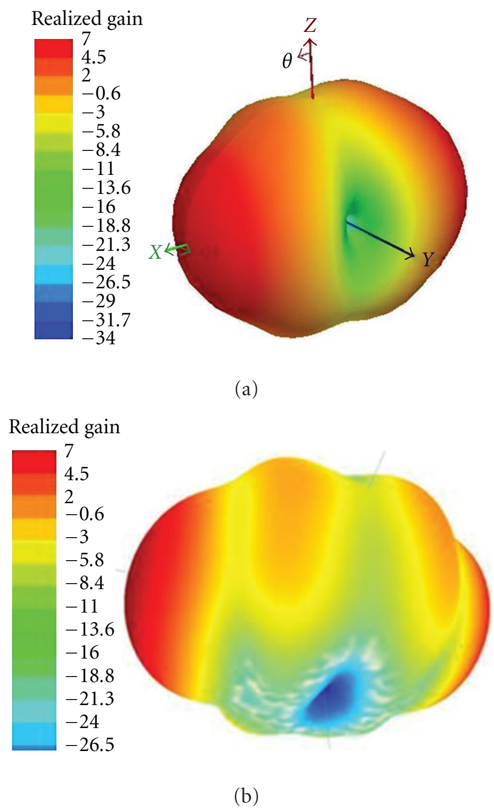


Figure 19: Simulated (a) and measured (b) 3D radiation pattern of the dual-beam printed dipole antenna.

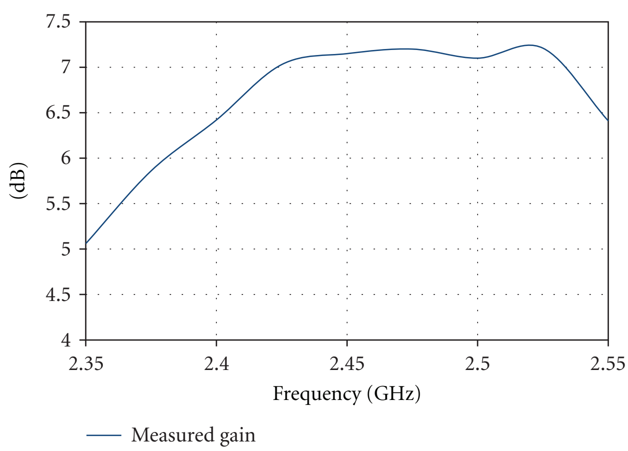


Figure 20: Measured radiation results (realized gain) versus frequency of the dual-beam printed dipole antenna.

originality of this paper consists in the design of this antenna. The realized antenna is respectively shown on Figure 16.

We present in the Figures 17 and 18, a comparison between simulation and measurement of the coefficients reflection. We obtain very good results. The dual beam-antenna is matched in simulation and measurement over the operating frequency bandwidth.

A comparison between the simulation and the measurement radiation pattern obtained at 2.45 GHz is shown in Figure 19. It can be noticed that the results of simulation agree very well with the measurement. Indeed, the maximum gain is obtained in $\theta = 0°$ and $\theta = 180°$ directions. In terms of levels (Figure 20), the measured realized gain at $\theta = 0°$ higher than 6.5 dB over the band [2.4-2.5] GHz satisfies the specifications in this direction. The realized gain at $\theta = 180°$ is the same as in the direction $\theta = 0°$ due to the symmetry.

4. Conclusion

In this paper, we have presented the design and the results obtained with printed dipole antennas with single and dual beam capability.

As a first step, a printed dipole antenna with one director was designed.

As a second step, in order to increase the realized gain of antenna, we have studied a printed dipole antenna with four directors. A gain higher than 10 dB has been achieved over the bandwidth.

Finally, we have developed a special dual-beam antenna for the node in linear configuration.

In conclusion, all the designed antennas were simulated, realized, and characterized by measuring their return loss, radiation patterns, and gain. We note very good results in term of gain and we obtain good comparison between simulations and measurements. These antennas are very suitable for communication systems and linear sensor network. We present a real system of ten linear autonomous sensor networks ready to be commercialized.

Acknowledgment

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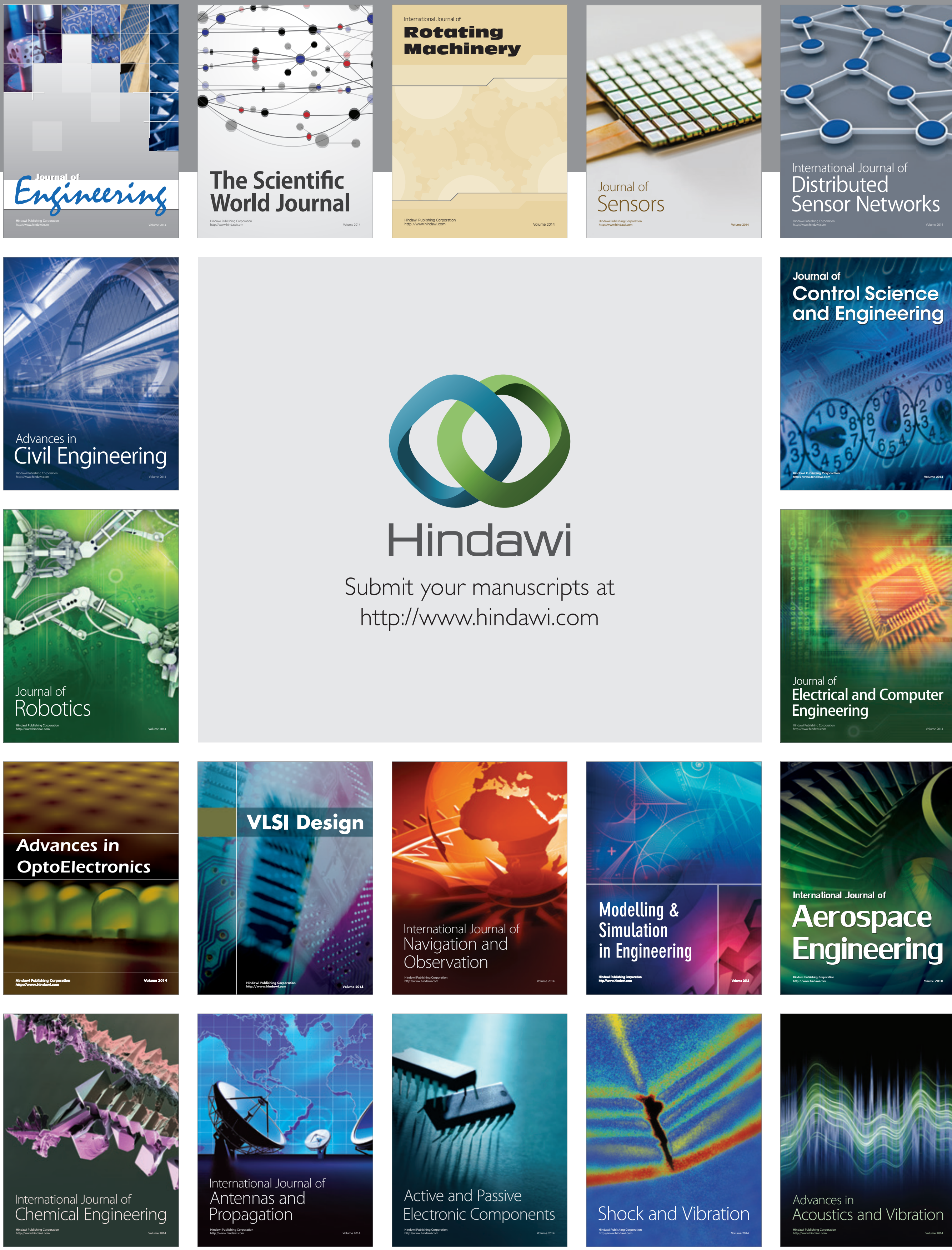

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