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Design of A New Hexagonal Patch Antenna Array

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Abstract
In satellite TV broadcasting, the general public's enthusiasm for this multimedia communication application is unprecedented, and demand is growing all the time. To meet this growing need for satellite reception, future generations of equipment will call for increasingly powerful yet discreet antennas. Our research focused on the design of a 2x1 planar antenna array with hexagonal-shaped patches operating in the Ku-band, basically at the frequency of 11.7 GHz. The original-shaped radiating element is designed using a methodical approach based on printed antenna theory and simulations.
Keywords: *Antenna Array; Hexagonal Patch; Ku Band.*

1. Introduction
The development of telecommunications technologies has created many challenges, particularly in recent years for the design of wireless communications equipment such as antennas. These challenges are all the more topical as market demand continues to grow [1]. They have become a major asset in the field of electromagnetism on the one hand, and an excellent comfort for various modern wireless applications (WiMax, satellite communications, etc.) and mobile standards (from 2G to 4G) on the other. Recent decades have seen considerable advances in the application of electronics to telecommunications. Satellite broadcasting, which is a very attractive field, is no exception as it is rather privileged [2-4]. All you need is a device capable of picking up a particular satellite to establish communications. Today, in satellite broadcasting, in the Congo and elsewhere, satellite dishes are generally installed and aimed at a specific satellite to pick up channels. Most often, the antenna is fixed, cumbersome in terms of weight, size and visibility [2-5]. It operates on the principle of wave reflection, concentrating the satellite wave we have LNB (Low Noise Block downconverter). A number of new approaches, each distinct from the others, are enabling the design of more efficient satellite reception antennas that escape the constraints mentioned above. And miniaturization is playing an increasingly important role in research and technical innovation. Worldwide, satellite links are a universal communications medium. More specifically, in the field of television broadcasting, the importance of satellite reception is demonstrated by the large number of households that receive television channels directly into their homes via satellite. Satellite services are competing with cable networks (ADSL, cable, fiber optics). However, the deployment costs associated with these networks are high, and may prove prohibitive to cover certain rural areas where the market potential is not sufficient to ensure their profitability. Satellite reception, on the other hand, offers incomparable possibilities and, above all, is free. A simple installation comprising an antenna and a satellite receiver provides access to hundreds, if not thousands, of free-to-air channels [2-6]. Currently, antennas placed on rooftops or in the gardens of detached houses, or on the balconies of apartment buildings, have invaded our urban

landscape to the point of being considered a public nuisance, also known as visual pollution. They are also vulnerable to the weather. In recent years, research activity has focused enormously on the study of planar structures. Planar circuits, which have recently undergone significant technological development, are very attractive for their low realization costs [7-9]. The main objective of this work is to design a flat antenna that operates in the Ku band, more precisely [10.7-12.7 GHz] with 11.7 GHz taken as the operating frequency, and has a reflection coefficient lower than -20 dB at resonance.

2. Theory

One of the most common configurations is the circular patch or disk, as shown in figure 1. The modes supported by the circular antenna can be determined by treating the patch, the ground plane and the material in between as a circular cavity. As with the rectangular patch, the modes supported primarily by a circular microstrip antenna with $h \ll \lambda$ are TMZ where z is taken perpendicular to the patch. For the circular patch, there is only one degree of freedom to control (patch radius). This does not change the order of the modes; but, it does alter the absolute value of their resonant frequency.

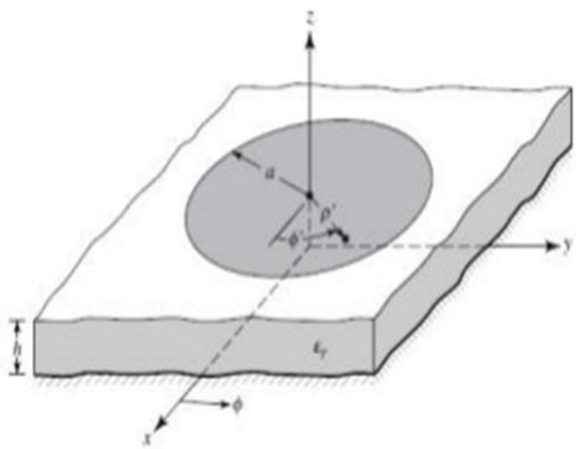

Figure 1 Circular Patch Antenna

To find the fields in the cavity, we use the vector potential approach. For TMz we must first find the magnetic vector potential Az, which must satisfy the homogeneous wave equation in cylindrical coordinates, such as [10]:

$$\nabla^2 A_z(\rho,\varphi,z) + k^2 A_z(\rho,\varphi,z) = 0 \quad (1)$$

3. Design

Our ambition is to explore the approach illustrated in figure (1) in order to eventually propose an antenna that meets the following specifications:

- **Shape:** flat antenna with reduced thickness;
- **Bandwidth:** 10.7 - 12.7 GHz;
- **Operating frequency:** 11.7 GHz.

In view of the multiplicity of geometric shapes of planar antennas, including those illustrated in figure (2), we have chosen the square hexagonal model. To design a hexagonal patch antenna, we must first design a circular patch antenna, as these two geometries are linked [11-12].

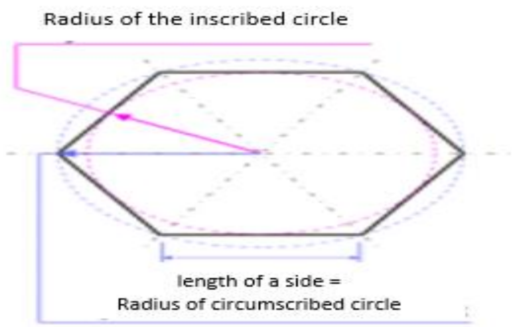

Figure 2 Correspondence Between Circle and Hexagon

$$\pi a^2 = \frac{3\sqrt{3}}{2} e^2 \quad (2)$$

a: Radius of Circular Patch
e: Hexagonal Patch Side

According to Balanis, the fundamental resonant frequency of a circular patch antenna is given by the formula 3:

$$f_r = \frac{1.8412c}{2\pi a_e \sqrt{\varepsilon_r}}$$

$$a_e = \frac{1.8412c}{2\pi f_r \sqrt{\varepsilon_r}} \quad (3)$$

With: fr: resonance frequency; C: celerity; εr: relative permittivity of the substrate; ae: effective radius of the circular patch, which is given by the formula

Or

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$$a = \frac{F}{[1 + \frac{2h}{\pi \varepsilon_r F}(ln\frac{\pi F}{2h} + 1.7726)]^{\frac{1}{2}}} \qquad (4)$$

$$F = \frac{8.79110^9}{f_r\sqrt{\varepsilon_r}}$$

Once all the calculations have been made and all the data fixed, we have listed the parameters of the circular prototype in the table 1 below:

Table 1 Antenna Parameter

Parameters	Symbols	Values
Permittivity of substrate	ε_r	3.27
Substrate thickness	h	1.58mm
Circular patch radius	a	3.75mm
Substrate length	L_S	65mm
substrate width	W_S	40mm
Feed line length	L_g	46mm
Feed line width	W_g	1.5mm
Cavity length	L_c	3.12mm
Cavity width	W_c	2mm
Excitation port length	L_p	1.58mm
Excitation port width	W_P	1.5mm
Distance between patches	L	27.88 mm

Using HFSS software, we modelled the shape shown in Figure 3:

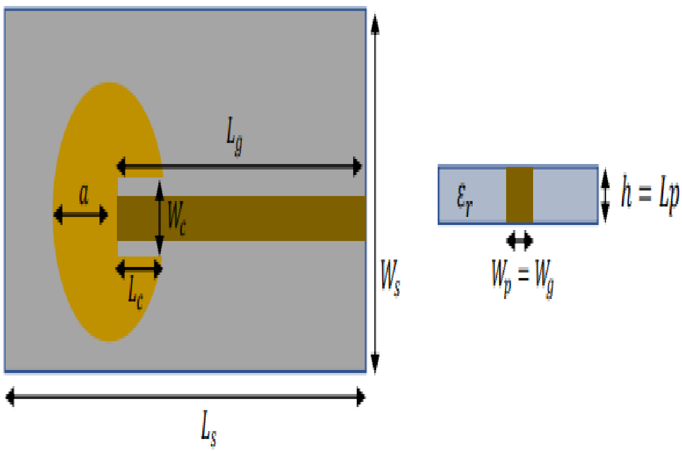

Figure 3 Illustration of A Circular Antenna

We simulated the variation of the reflection coefficient as a function of frequency for the circular patch antenna. The simulation revealed a resonance at 12.7 GHz corresponding to -26 dB. A shift in operating frequency is observed.

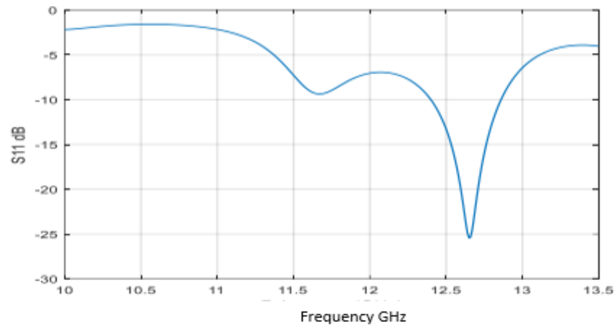

Figure 4 Variation of Reflection Coefficient as A Function of Frequency

To improve the value of the resonant frequency, we will design an antenna array with hexagonal-shaped patches. In this array, two hexagonal antennas with the same characteristics are arranged in the same direction and fed by a common microstrip line, as shown in figures 4 & 5.

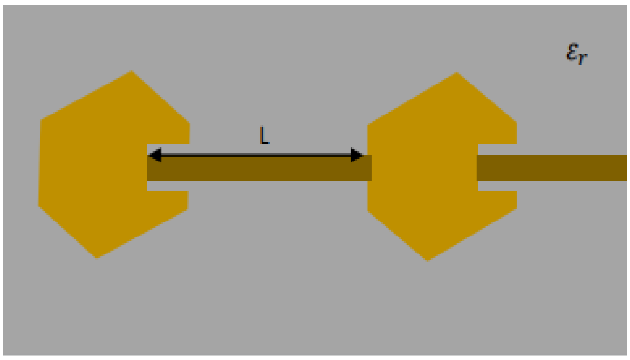

Figure 5 Hexagonal Antenna Array

4. Results and Discussion

In this section, we present simulation results of the proposed antenna.

4.1 Reflection Coefficient of Series Array Structure

Figure 6 shows the reflection coefficient versus frequency curve for a series-fed hexagonal antenna array. This antenna resonates at the desired frequency, i.e. 11.7 GHz, with a reflection coefficient of -36.9 dB.

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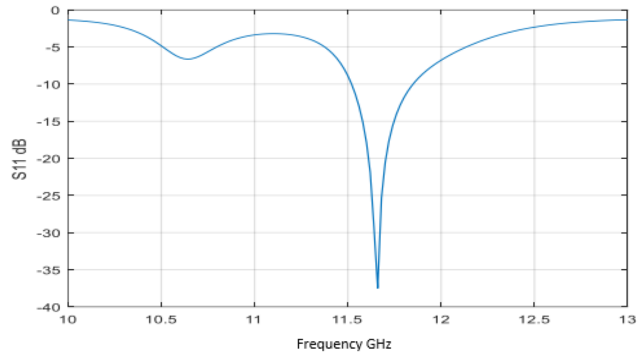

Figure 6 **Variation of Reflection Coefficient as A Function of Frequency (Series Network)**

4.2 Radiation efficiency

Figure 7 shows the antenna efficiency as a function of frequency. We note that at a frequency of 11.7Ghz, the antenna resulting from the series connection has a radiation efficiency of 89%.

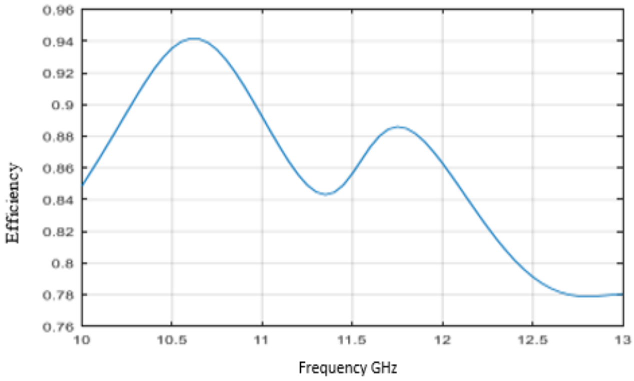

Figure 7 **Radiation Efficiency as A Function of Frequency (Series Network)**

4.3 Directivity

Figure 8 shows the variation of the directivity as a function of frequency. We note that directivity is maximal (value 4.4) at the operating frequency.

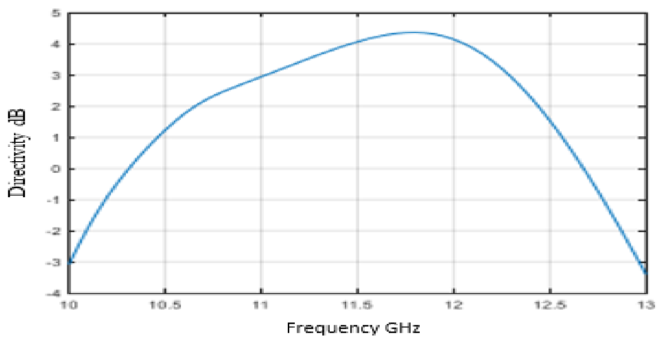

Figure 8 **Variation of Directivity as A Function of Frequency for The Series Network**

4.4 Influence of Permittivity on Reflection Coefficient

We set out to vary the permittivity of the substrate used to observe the behavior of the reflection coefficient. This step led us to conclude that for the series structure, decreasing the permittivity value allows for an increase in frequencies, as shown in figure 9.

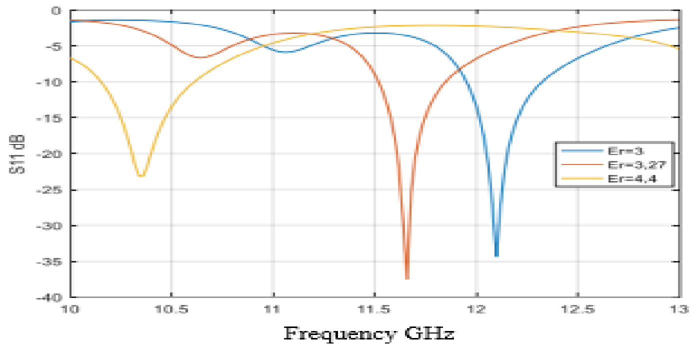

Figure 9 **Variation of The Reflection Coefficient as A Function of Frequency**

4.5 Influence of A Slot On Serial Network Behavior

To determine the influence of the slot radius on antenna performance, we will vary the slot radius while maintaining the antenna dimensions described in Table 1. We set out to place a circular slot of thickness r in the center of the patch in order to reduce the weight of the structure and maintain or improve antenna performance, as shown in figure 10.

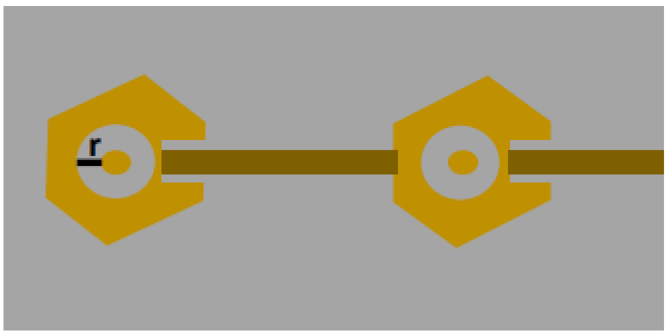

Figure 10 **Series Antenna Array with Circular Slots**

4.6 Reflection Coefficient of the Series Lattice Structure

Figure 11 shows the variation of the reflection coefficient as a function of frequency for different cavity thickness values. It can be seen that as the thickness increases, so does the reflection coefficient. There is a slight influence of the cavity radius on the bandwidth.

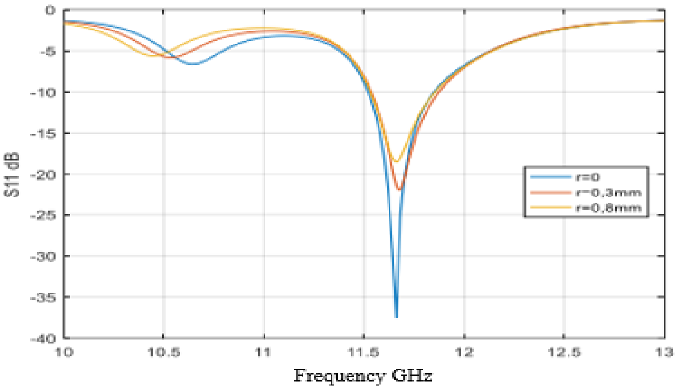

Figure 11 Variation of Reflection Coefficient as A Function of Frequency for Different Values of Slot Thickness

4.7 Impedance

Figure 12 shows the variation in impedance of the series network structure for different values of thickness r. The curve shows that thickness variation has no effect on impedance.

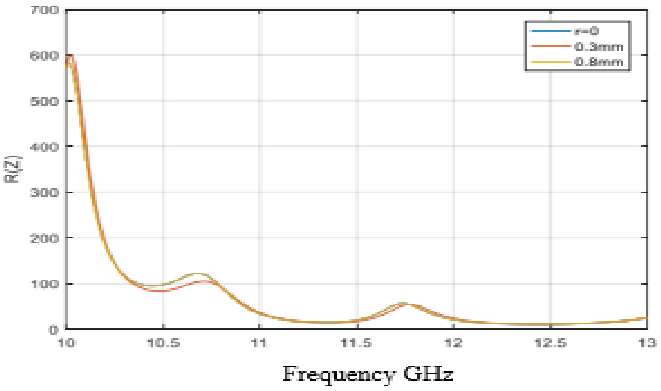

Figure 12 Variation of Impedance with Frequency for Different Cavity Thickness Values

Conclusion

With regard to the steps taken to design the final device, the simple circular model and the simple hexagonal model showed their limitations. Nevertheless, the hexagonal antenna array proved to be favorable. This was the best solution to meet our specifications. The series antenna array performs well at the operating frequency (11.7Ghz). The addition of slots on the antenna array enabled us to reduce some of the constraints associated with the antenna's weight.

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