Study and Design of Ultra Wide Band Patch Antennas, Tunable at Several Frequencies in a Cognitive Environment: Case of the City of Lubumbashi

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Abstract: ***This article provides information on the study carried out on patch antennas in order to solve the problem of setting up a multitude of antennas on a shared site, this causing telecommunications operator to have high costs for the acquisition of equipment as well as their maintenance. the results obtained prove with certainty that it is possible to substantially reduce the number of antennas on a co-shared site by combining each time two or more frequency resources in an antenna.***

Keywords: Patch; ULB (Ultra Wide Band); Tunable; Cognitive; PIN Diode

1. Introduction

The current boom in communications requires major innovations in the design of systems and associated antennas, the forms of which today vary greatly depending on the uses: mobile telecommunications, satellites, television, radio, identification, communicating objects... Indeed, reconfigurable antennas (discretely tunable1 or switchable) in frequency offer the possibility of delegating to the antenna itself some of the functions generally reserved for the radio stage or for digital signal processing [4]. Beyond these innovative systems, reconfigurable antennas also have many advantages over conventional antennas, which are less spectacular but which could prove decisive in terms of service life, compactness and integration [3]. [6]. Thanks to the rare functionalities of such antennas which bring new possibilities of bringing together two or more frequency resources (functionalities) in a single antenna, we propose to set up a system which could respond to a problem encountered in our society and which would be beneficial. network operators. Thus after having observed for a long time, it turns out that the frequency resources are badly used in many of the radio sets in the city of Lubumbashi [2, p.2].

Problem

The solution to increase the capacity (traffic) of the areas covered and to avoid having a large number of sites (which is expensive); the man had recourse to the sectoring technique on the same site (bringing together several antennas on the same location, each covering a given sector), which led us to the co-shared site [8, p.54] Unfortunately with all these antennas gathered in a single location, each emitting at different frequencies in a direction given, we end up with a multiplicity of antennas in a Telecom site. It turns out that the cost of acquisition and maintenance of telecommunications equipment in a site is extremely high, at most for operators who own a large number of equipment.

Hypotheses

- To succeed in bringing together two distinct resonant frequencies in a single antenna, we propose the technique of frequency reconfiguration, which consists of incorporating active components into the antenna structure in order to modify its electrical and radiation characteristics.
- There are several antenna optimization processes, we have chosen optimization by genetic algorithm, which would allow us to expand the bandwidth of our microstrip patch antenna into an ultra-wideband patch antenna, according to the standards established by the FCC [5, pp.5-7] and to allow the coexistence of a narrowband system and a broadband one.

2. Logical Detailed design

2.1 Tunable 2-Frequency Patch Antenna System

Multi-frequency reconfigurable antennas are particularly useful in cases where multiple communications systems are converging, because the multiple antennas required can be replaced with a single reconfigurable antenna. In the following lines, the operation of the tunable patch antenna at 2 frequencies is detailed.

2.1.1 How the 2-Frequency Tunable Patch Antenna System Works

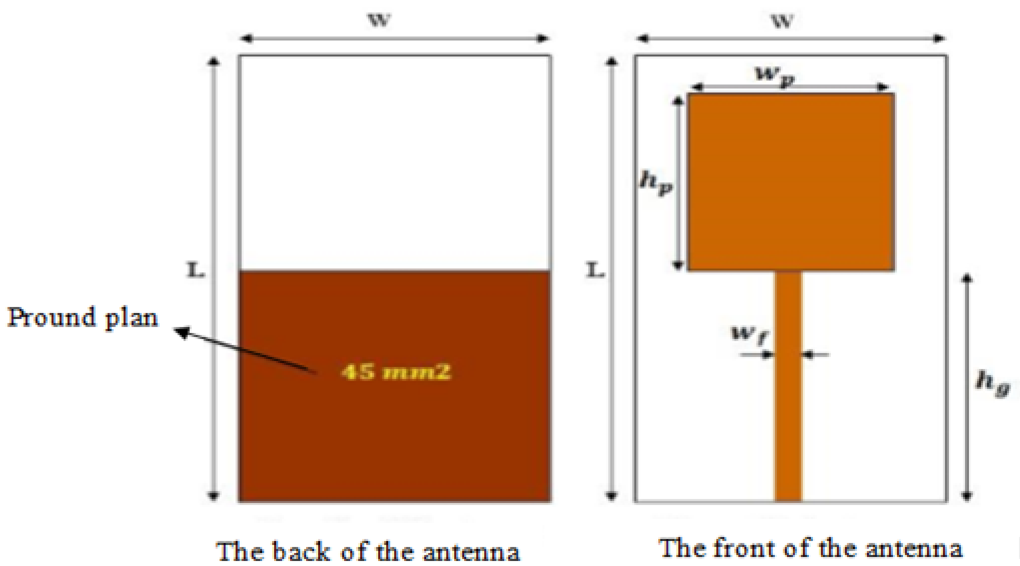

Figure 1: Patch 1 Antenna Nomenclature

It is a rectangular optimized patch antenna with dimensions hp = 29 mm and wp = 29 mm. Its radiating structure (the patch) is printed on an FR4 type dielectric substrate whose characteristics are as follows: thickness T = 1.59 mm; width W=45mm; length L=80mm. The ground plane is placed on the other side, and has an area equal to 45 mm^2 optimized so as to obtain maximum bandwidth. The width of the microstrip feed line is wf = 2.5 mm, and is driven by an SMA type connector.

Table 1. below, presents the geometric dimensions of the optimized patch antenna (the bandwidth is 3 to 7.5 GHz), on which we will perform the frequency switching by incorporating two PIN diodes on the radiating structure of the antenna, in order to have four resonance frequencies, included in the band from 2.2 to 7.5 GHz for the first resonance frequency and from 3 to 7.5 GHz for the second resonance frequency.

Table 1: Geometric dimensions of patch 1 antenna

Dimensions of the Rectangular Patch Antenna	Values in (mm)
Hp	29
Wp	29
T	1,5
W	45
L	80
Wf	2,5

A PIN diode (Positive Intrinsic Negative diode) is a semiconductor device consisting of an undoped region (known as the intrinsic region interposed between two other doped regions of the N and P type. The insertion of the PIN diode in the center of the slot, allows us to influence the current distribution on the surface of the antenna, which makes it possible to control and vary the resonant frequency of the antenna. The new resonances then make it possible to make the patch multiband [5], [6].

In our work, it is a question of short-circuiting the radiating structure of the antenna using two PIN diodes (a diode corresponds to two states, the on state "ON" and the blocked state "OFF"), in order to have a distinct resonance frequency for each state, which would give us four resonance frequencies.

The insertion of the PIN diodes, in the radiating structure of the antenna (the patch) allows us to have a resonant frequency of 6.5 GHz, included in the band from 3 to 7.5 GHz and is adapted according to the reflection coefficient (S11) at -10 dB. The 2.2 to 2.6 GHz band is not suitable. It will be necessary to use truncation techniques (Figure 2) on the radiating structure of the antenna. All these modifications aim to improve the performances of the studied antenna.

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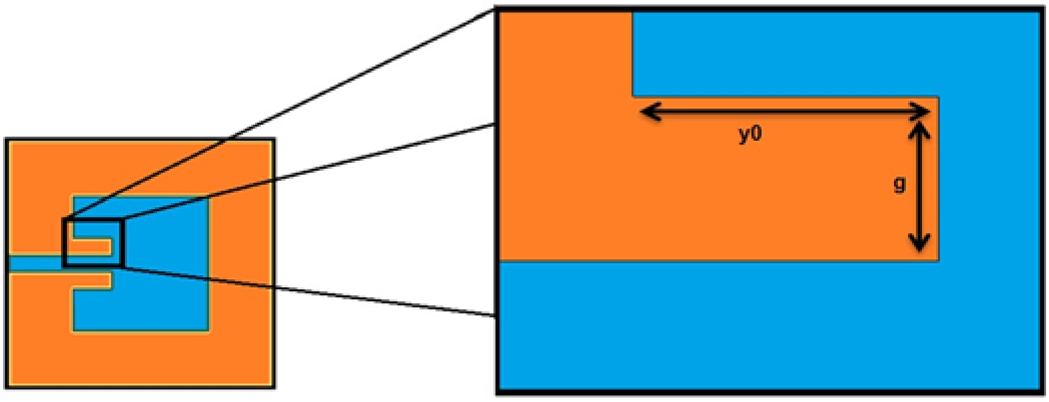

Figure 2: Insertion of truncations on either side of the feed line on the radiating structure of the antenna.1

Figure 3. presents the reflection coefficient (S11) adapted to -10 dB for the resonance frequencies included in the band from 2 to 7.5 GHz, after adding the truncations.

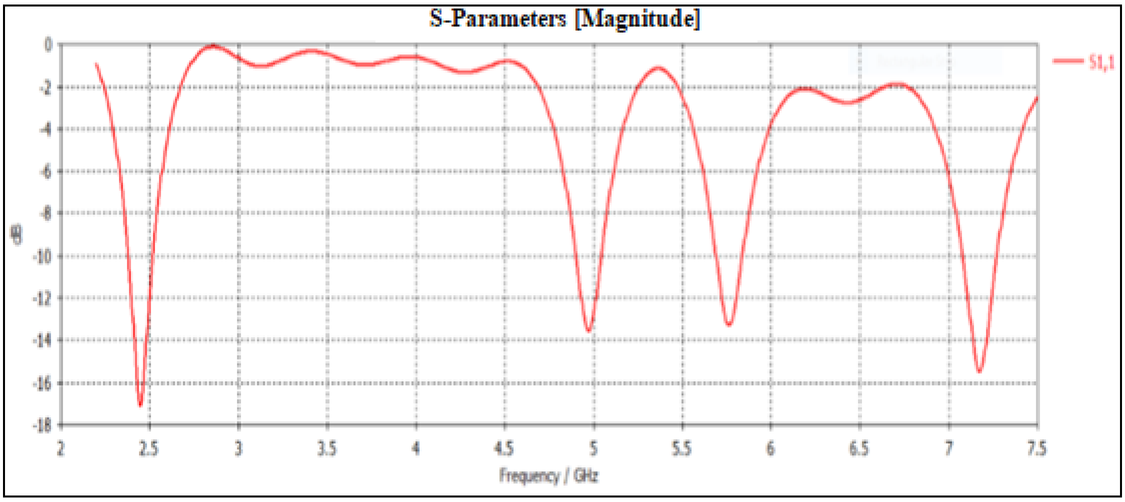

Figure 3: Resonance frequencies after adding truncations 1

Since we used the PIN diodes for the frequency reconfiguration, here are the resonance frequencies adapted according to the reflection coefficient less than or equal to –10 dB. Each state of the diode corresponds to a resonant frequency.

Table 2 : Fréquences de résonances 1

PIN diode status	Resonance frequencies in GHz
ON-ON	5,8
ON-OFF	2,4
OFF-ON	4,9
OFF-OFF	7,2

Our system gives us four resonance frequencies (the frequency of 2.4 GHz for 2.2 to 2.6 GHz) and (the frequencies of 4.9; 5.8 and 7.2 GHz for the band from 3 to 7.5 GHz) and can easily switch between them without affecting the signal quality.

3. Ultra Wide Band Patch Antenna System

3.1 Operation of the Patch U.L.B antenna system

Figure 4. below shows the retained topology of the original antenna (on which we will perform frequency switching and bandwidth optimization), it supports the band from 3 to 7.5 GHz.

3.1.1 Ground plan

There are two types of ground plane, the full ground plane and the partial ground plane. The total ground plane is that which completely covers the surface of the dielectric substrate and the ground plane, of partial type, partially covers the dielectric substrate. The ground plane is made of conductive nature of electric current.

3.1.2 Dielectricsubstrate

The substrate is dielectric in nature and is placed on the ground plane, it is between the radiating structure of the antenna and the ground plane. There is a wide variety of substrates, and the most desirable substrates are those that are thick with a lower dielectric constant, as they offer [19]:

- Better Efficiency;
- Greater bandwidth;
- Fields that are weakly bound for radiation in space At the expense of a larger antenna size;

Substrates that are thin, with higher dielectric constants are desirable for microwave circuits, as they require fields that are tightly bound to minimize unwanted radiation and coupling and lead to smaller sizes [19].

3.1.3 Radiatingelement(Patch)

It is the radiating structure of the antenna, and is made of current-conducting nature. It is commonly called a "patch". The geometry of the radiating element can take several different forms, depending on the intended application [19]. In ourwork, the antennageometryisrectangular.

3.1.4 Patch antenna power supply via microstrip line

A patch antenna can be excited by several techniques which are categorized into two types; Power supply with contact and without contact. In the first type, the antenna is fed directly using a connection like microstrip line and coaxial cable. Figure 5. shows a patch antenna by feeding a microstrip line commonly called “microstrip patch antenna” [6].

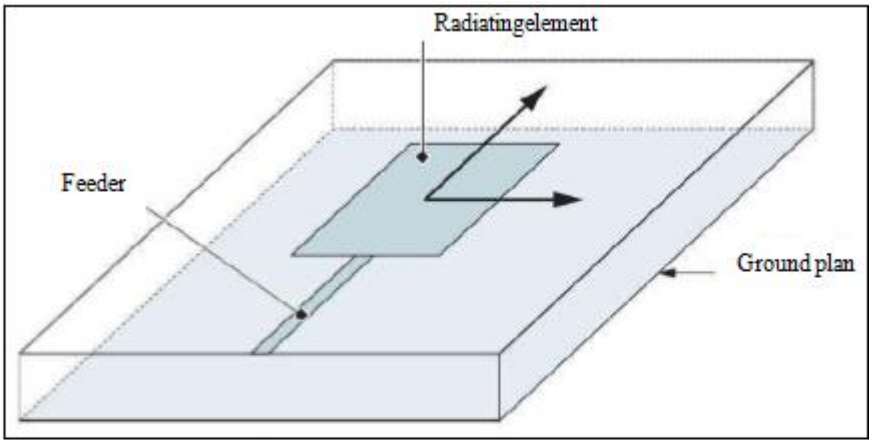

Figure 5: Topology of a patch antenna by feeding a microstrip line [6].1

3.2 Choice of technologies

Choice of components for frequency reconfiguration

3.2.1 Pin diodes

A reconfigurable antenna is one in which at least one or more of its characteristics are modifiable after manufacture (frequency, polarization and radiation pattern). There are various techniques for adopting reconfiguration.

Frequency reconfigurable (discretely tunable or switchable) antennas have attracted much attention due to their ability to span multiple frequency bands to greatly reduce the number of antennas needed for multimode communication and PIN diodes allow obtain an ideal short circuit in the on state (ON) and also a good open circuit in the off state (OFF).

3.2.2 Varicap diodes

A varicap diode is modeled by an ideal capacitance whose value is varied [5]. Their use also allows access to continuous reconfigurations by adjusting the value of their capacity. The two main criteria are of course the nominal value of the capacity, and the range of variation. The value of the capacity used must be in accordance with the frequency band(s) used; as for the dimming range, it must be as large as possible. In our work, we have opted for the use of PIN diodes, which offer the possibility of binary configurations (0 or 1), depending on the state of the diode (on or off state). Each state of the diode offers a distinct resonant frequency.

4. Simulation and test of the frequency-tunable ultra-wideband patch antenna system.

We had to implement the CST STUDIO SUITE 2021 software, for all the simulations that fit with the electromagnetic simulation. This software was developed by Computer Simulation Technology AG, it specializes in electromagnetic analysis and simulation.
Apart from this software, we had to use the MATLAB numerical calculation software, combined with the ANSYS HFSS electromagnetic simulation software, to be able to program the radiating element of the antenna (Patch) by defining the cost function of the optimization of bandwidth by genetic algorithm.

5. Simulation of the solution

5.1 Result of reconfiguration (switching) of frequencies

5.1.1 Reflection coefficient for switching (discrete tuning) of two frequency bands

The reflection coefficient indicates the quality of adaptation of the antenna [7]. Figure 5.1 presents the reflection coefficient of the reconfigurable patch antenna, adapted to –10 dB, at resonance frequencies of 2.4, 4.9, 5.8 and 7.2 GHz

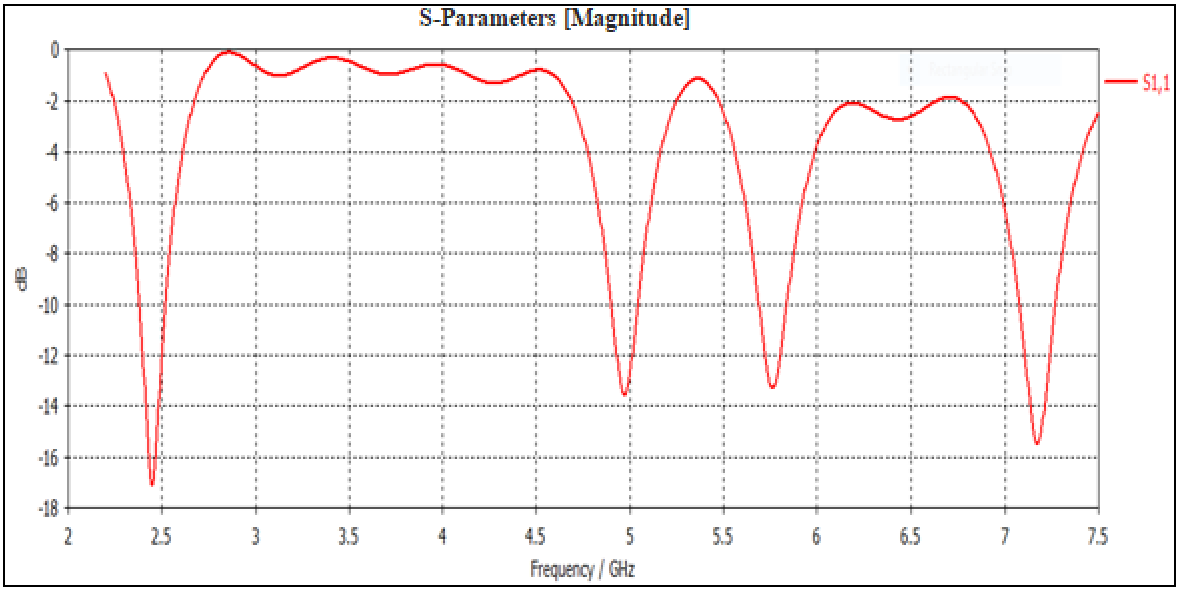

Figure 5.1: Reflection coefficient of reconfigurable patch antenna 1

5.2 Radiation pattern of the reconfigured patch antenna

It describes the variations of the power radiated by the antenna in the different directions of space. The axis for which the radiated power is maximum is called the radiation axis of the antenna and is identified by the angular coordinates.

Figure 5.2 shows the radiation pattern of the patch antenna at the frequency of 2.2 GHz.

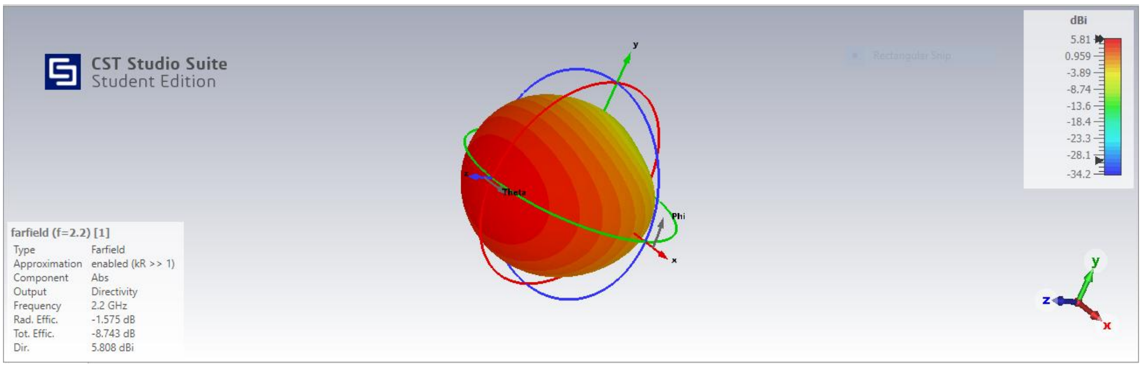

Figure 5.2: Shows the radiation pattern of the patch antenna at the frequency of 2.2 GHz.

Figure 5.3 shows the radiation pattern of the patch antenna at the 2.4 GHz resonant frequency.

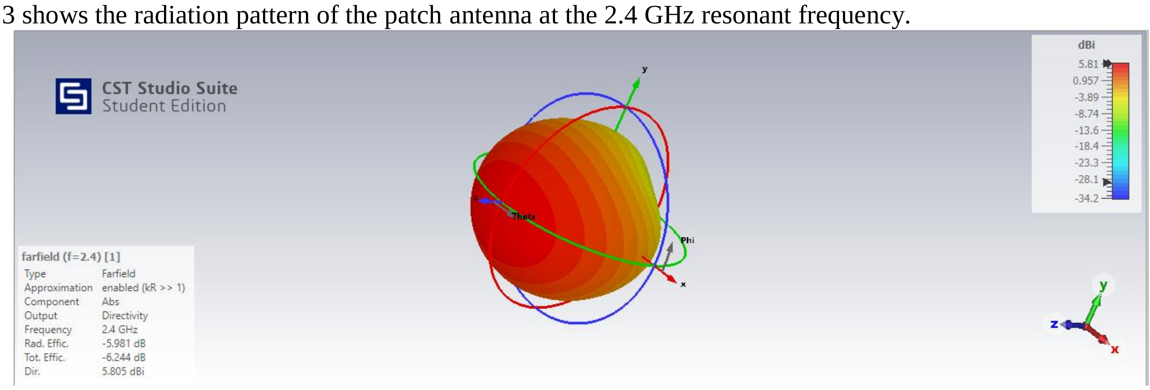

Figure 5.3: Radiation pattern at 2.4 GHz resonant frequency 1

Figure 5.4 shows the radiation pattern of the patch antenna at the 5.8 GHz resonant frequency.

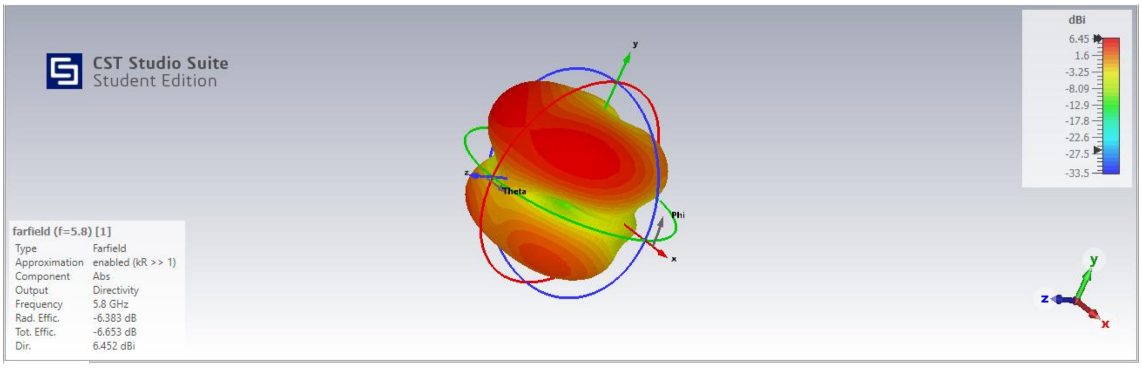

Figure 5.4: Patch antenna radiation pattern at 5.8 GHz resonant frequency.

Figure 5.5 shows the radiation pattern of the patch antenna at the 7.5 GHz frequency.

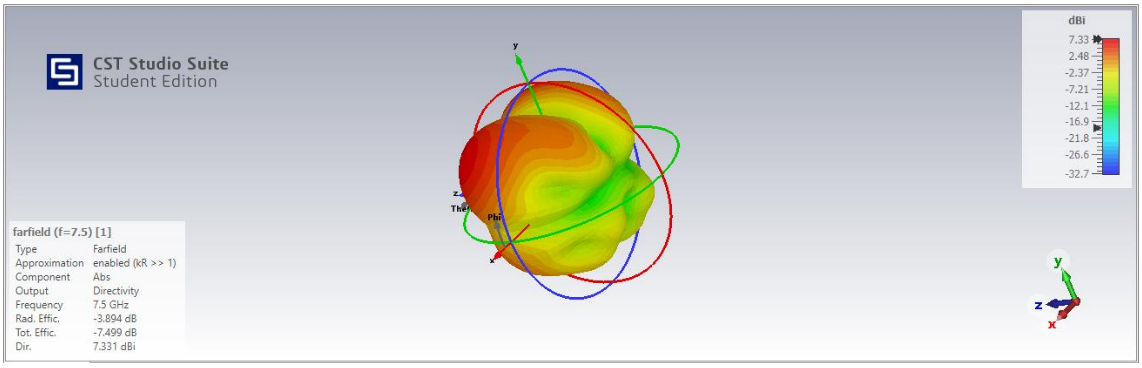

Figure 5.5: Radiation pattern at the frequency of 7.5 GHz 1

5.1.3 Directivity diagram of the reconfigured patch antenna

The directivity (dBi) of an antenna characterizes the way the antenna concentrates its radiation in certain dimensions of space [7], it indicates in which direction the power density is better.

Figure 5.6 presents the directivity diagram of the reconfigured patch antenna at the frequency of 2.2 GHz (Phi = 0).

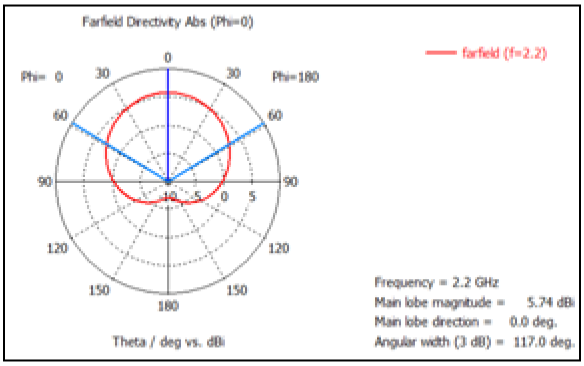

Figure 5.6: Directivity pattern at 2.2 GHz frequency

Figure 5.7 presents the directivity diagram of the reconfigured patch antenna at the resonant frequency of 2.4 GHz (Phi = 0).

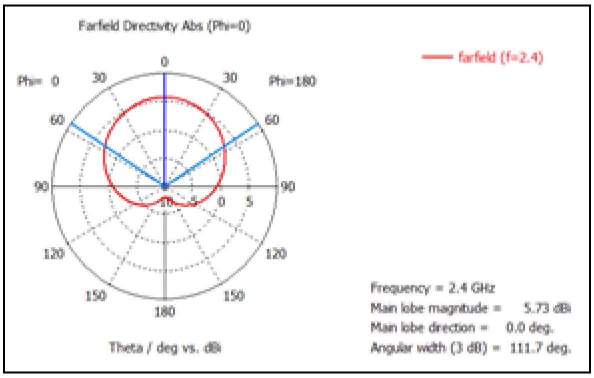

Figure 5.7: Directivity pattern at 2.4 GHz resonant frequency 1

Figure 5.8 presents the directivity diagram of the reconfigured patch antenna at the resonant frequency of 5.8 GHz (Phi = 0).

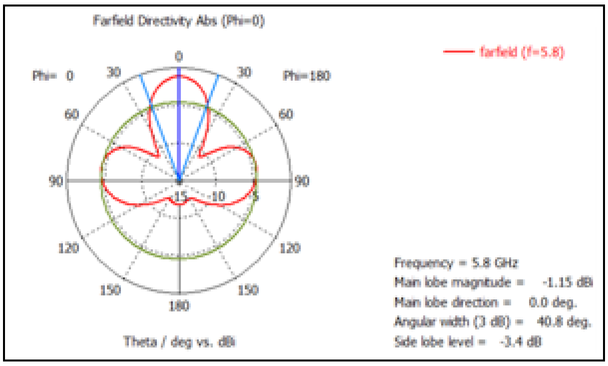

Figure 5.8: Directivity pattern at 5.8 GHz resonant frequency 1

Figure 5.9 presents the directivity diagram of the reconfigured patch antenna at the frequency of 7.5 GHz (Phi = 0).

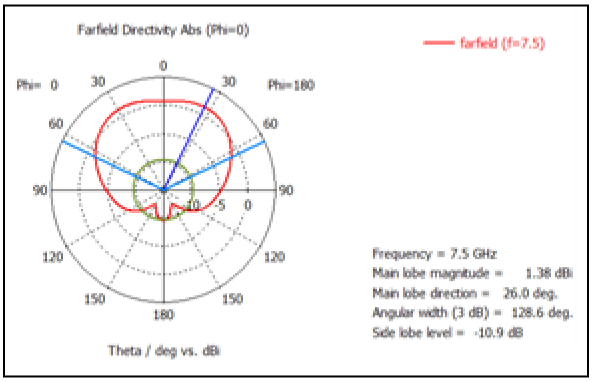

Figure 5.9: Directivity pattern at 7.5 GHz frequency 1

5.2 Result of the patch antenna command

PIN diodes are active components that influence the surface current distribution of the patch antenna. They make it possible to establish the frequency switching automatically and can only be controlled by a microcontroller.

5.3 Patch Antenna Power Result

The antenna power supply is essential since it allows the radiating element of the Patch antenna to transmit or receive radio signals.

Figure 5.10 presents the power radiated by the patch antenna1

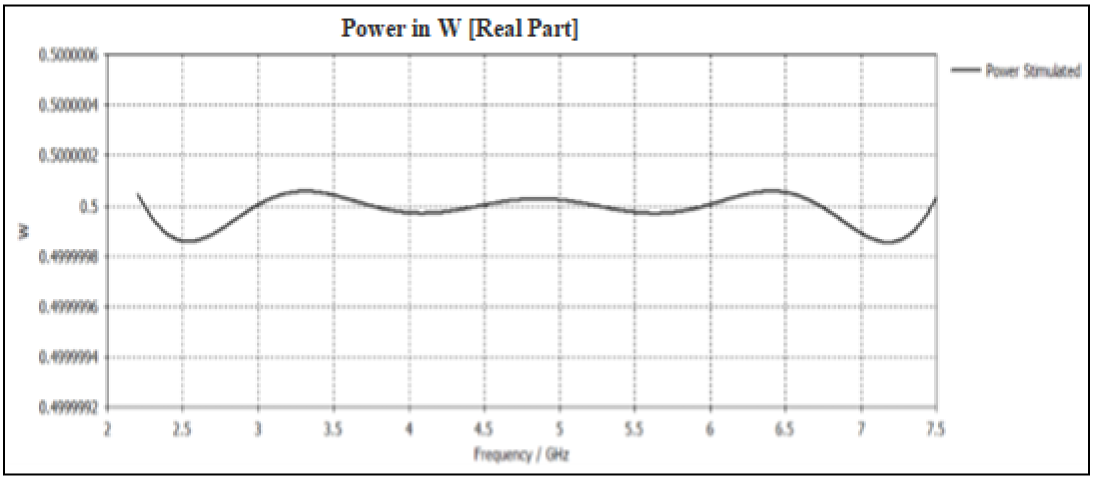

Figure 5.10: Power radiated by antenna 1

Figure 5.11 presents the power lost in the dielectric

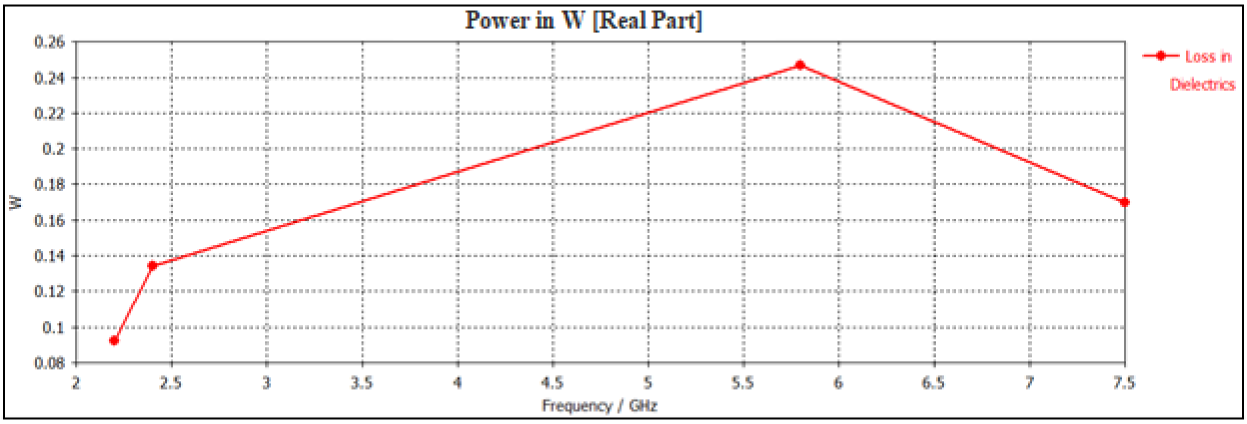

Figure 5.11: Power Loss in Dielectric 1

6. General Conclusion

Starting from a brief observation, we noticed a multitude of antennas in co-shared sites (location belonging to an operator which has its own equipment and allows other operators to install their equipment in order to cover the area) telecommunications, which led us to put forward the hypothesis of bringing together two frequency bands in a single antenna.

The simulation results show that the new reconfigured band has 2 switchable frequency bands using PIN diodes and truncations made on either side of power line. The two resonance frequencies switch instantaneously and are adapted to the reflection coefficient at – 10 dB and are on the one hand 2,4 GHz for the band from 2,4 GHz to 2,6 GHz and the other hand 5,8 GHz for the 3 GHz to 7,5 GHz band.

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