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Analysis and Design of a reconfigurable antenna for Wi-Fi and WLAN Applications

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Abstract—*In this paper we describe the analysis and design of a reconfigurable planar antenna that can operate in the Wifi band of 2.4 GHz and WLAN of 6.53 GHz, that is also in accordance to required parameters to be used for Cognitive Radio applications. The antenna was designed as a plane square spiral using microstrip technology and the re configurability was made with an inductor.*

Keywords—*Reconfigurable antenna; cognitive radio; patch microstrip antenna; ABCD parameters*

1. INTRODUCTION

Today, communications systems requires new ways to get faster data transmission and better use of spectrum in accordance to users priorities. A promising alternative that accomplishes these characteristics is cognitive-radio systems [1]. According to FCC [2], cognitive radio (CR) means "real-time monitoring of a radio channel or spectrum band and limiting transmissions in terms of frequency, power, or timing in order to avoid harmful interference to other spectrum users". Tawk *et al* [3] mention that, for a CR device to function properly, it is necessary to follow a cycle composed by:

1) Observing the channel activity
2) Deciding which part of the spectrum is suitable for communication
3) Acting appropriately to achieve the required mode of communication
4) Learning from previous channel activity

In CR [4], the unoccupied parts of the spectrum are inspected and, once identified, the primary and secondary users are dynamically allocated to the different parts of the spectrum. In most of the cases, secondary users are assigned to the white spaces of the channel. An important part of CR communication systems is the antennas, which must be reconfigurable in parameters like gain, frequency response or radiation pattern, according to the system needs.

In [5], Nalarwar *et al*. propose that "The possibilities for antenna to play an active role in system level performance are lost amid all these conceptions of CR. However, an antenna is the most important section of a CR system. Designing an antenna which carries out spectrum sensing as well as transmission is extremely difficult. Some research has been done related to the design of antennas for cognitive radio systems"

In [6], Balanis *et al*. mention that "Reconfiguration of an antenna is achieved through an intentional redistribution of the currents or, equivalently, the electromagnetic fields of the antenna's effective aperture, resulting in reversible changes in the antenna impedance and/or radiation properties. These changes are enabled through various mechanisms such as switching, material tuning, and structural modifications. System control can then be applied to result in desired antenna performance.” With this re configurability capacity, using different antennas are not necessary to cover different bands. There are different alternatives to obtain a reconfigurable antenna.

For example, in [7], a re configurability spiral monopole Microstrip antenna for DMB applications is described by Abou Shahine *et al.* The main structure of the antenna proposed in [7] was taken from the working of Lee *et al*. [8], where the re configurability was made by putting parasitic elements into the surface of the resonator. In both [7] and [8] did not present any analysis about how to get the dimensions or values of the elements that makes the re configurability. Another similar antenna is proposed by AbuTarboush *et al* in [9], which consists of an H-shape structure with coplanar wave guide (CPW), a varactor diode was put to get the re configurability. The CPW increases the size of the antenna. A more complex design is described as loop inverted F antenna by Li *et al* in [10]. This antenna can operate in different bands and is reconfigured by a PIN diode that modifies the electrical longitude of the antenna. Another model which operates according to CR is proposed in [5], as a pair of antennas, composed by an UWP circular monopole antenna and a narrowband rectangular microstrip antenna. In this paper we present an analysis and design of a spiral monopole microstrip antenna, which is reconfigured with an inductor in order to be used in application GSM and ISM for CR. This papers consists in three sections. In the design section, the steps and the mathematical model of the antenna are shown. The using of the component models in terms of the ABCD parameters let us determinate a reconfiguration method. In the results and analysis section, the results of the simulations and a comparison with the results obtained in the building of the antenna are described. Finally, in the results section is shown that the designed antenna has an acceptable response with low dimensions can be easily- translated in to mobile devices.

2. DESIGN

The proposed antenna is a spiral monopole microstrip. This antenna consists of a *$\lambda/4$* feed line and a *$\lambda/2$* microstrip resonator, as proposed in [7] and [8]. In [7], it is mentioned that the current in the spiral must be in the same direction of the current in neighboring wire to increase the radiation efficiency and to improve the antenna gain. The Figure 1 shows the geometry of this antenna. The feed line impedance is 50 ohms and the resonant frequency is 2.4 GHz. The substrate used for the design is 0.702mm FR-4 material. Before the fabrication of the antenna, a computer simulation was made with the software ADS software. The dimensions of the microstrip feed line and the resonator were calculated using the analysis explained in [11], where (1), (2), (3), (4) and (5) are proposed:

$$\frac{W}{h} = \frac{8e^{A}}{e^{2A} - 2} \qquad (1)$$

Where

$$A = \frac{Z_0}{60}\sqrt{\frac{\varepsilon_r + 1}{2}} + \frac{\varepsilon_r - 1}{\varepsilon_r + 1}\left(0.23 + \frac{0.11}{\varepsilon_r}\right) \qquad (2)$$

(Rogers 3003 in this case). With this results, it is possible to calculate W. The effective dielectric permittivity is described with (3):

$$\varepsilon_e = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2} \cdot \frac{1}{\sqrt{1 + 12(d/W)}} \qquad (3)$$

The length of the microstrip line is given by (4):

Where is the phase shift line (180° for a λ/2 line and 90° for a λ/4 line), and k0 is:

$$k_0 = \frac{2\pi f}{c} \qquad (5)$$

The antenna dimensions for the design frequency are shown inTable I.

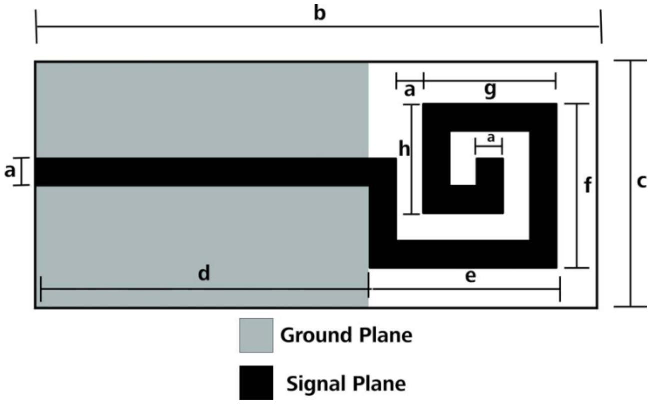

Fig. 1. Antenna design.

Dimension	a	b	c	d	e	f	g	h
Size (mm)	1.6	33.6	14.4	20	11.2	9.6	8	6.4

Table I. Antenna Dimensions

The re configurability was achieved, as in [7], with inserting an inductor, which was located in the limit between the feed line and the resonator. The inductor value was calculated according to the next ABCD parameters analysis. We prefer this analysis because the values of the ABCD parameters of the elements can be cascaded to get the system response. If the antenna is considered as a two-port web, composed by an array of a microstrip feed line and an open circuit microstrip resonator, the original response of the antenna, which operates at 2.4 GHz, is described with the next ABCD matrix equation:

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix}_{antenna2400} = \begin{bmatrix} A & B \\ C & D \end{bmatrix}_{feedline2400} \cdot \begin{bmatrix} A & B \\ C & D \end{bmatrix}_{resonator2400} \qquad (6)$$

Where,

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix}_{feedline2400} = \begin{bmatrix} \cos\beta_f\ell_f & jZ_0\sin\beta_f\ell_f \\ jY_0\sin\beta_f\ell_f & \cos\beta_f\ell_f \end{bmatrix} \quad (7)$$

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix}_{resonator2400} = \begin{bmatrix} \cos\beta_r\ell_r & jZ_0\sin\beta_r\ell_r \\ jY_0\sin\beta_r\ell_r & \cos\beta_r\ell_r \end{bmatrix} \quad (8)$$

In (7), ABCD feedline parameters ßf and lf were calculated using the ABCD model for λ/4 microstrip transmission line and, in (8), ABCD resonator parameters ßr and l r were found using the ABCD model for a λ/2 open-circuit microstrip resonator, according to the models shown in [11]. Analogously, the response of an antenna that operates at 1850 MHz was calculated.

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix}_{antenna1850} = \begin{bmatrix} A & B \\ C & D \end{bmatrix}_{feedline1850} \cdot \begin{bmatrix} A & B \\ C & D \end{bmatrix}_{resonator1850} \quad (9)$$

Now, combining (6) and (9), the discrete element was put between the border of the feed line and the edge of the resonator in a 2400 MHz antenna, with the finality of ABCD antenna2400 value is equal to ABCD value.

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix}_{antenna1850} = \begin{bmatrix} A & B \\ C & D \end{bmatrix}_{feedline2400} \cdot \begin{bmatrix} A & B \\ C & D \end{bmatrix}_{element} \cdot \begin{bmatrix} A & B \\ C & D \end{bmatrix}_{resonator2400} \quad (10)$$

With this matrix equation, we calculate the value of ABCD element

:

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix}_{element} = \begin{bmatrix} A & B \\ C & D \end{bmatrix}_{antenna1850} \begin{bmatrix} A & B \\ C & D \end{bmatrix}^{-1}_{feedline2400} \begin{bmatrix} A & B \\ C & D \end{bmatrix}^{-1}_{resonator2400} \quad (11)$$

The calculated value of ABCD: element has the form

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix}_{element} = \begin{bmatrix} 1 & Z_{element} \\ 0 & 1 \end{bmatrix} \quad (12)$$

Where Z element is the impedance of the element. This impedance is an imaginary positive value if an inductor is required. This indicates that an inductive charge is necessary to get the change of the ABCD antenna1850 value into ABCD antenna2400. According to this analysis, a 7 nH inductor is necessary to change the frequency response of the antenna from 2400 MHz to 1850 MHz. However, the effects of the square borders of the resonator were not considered in this analysis. According to [12], the discontinuity created by a bend in microstrip line is given by the model above:

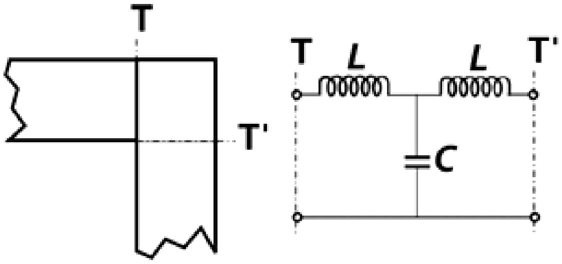

Figure. 2. Model of the mictostrip bends.

Where

$$C = 0.001h\left[(10.35\varepsilon_r + 2.5)\left(\frac{w}{h}\right)^2 + (2.6\varepsilon_r + 5.64)\left(\frac{w}{h}\right)\right] \quad (13)$$

$$L = 0.22h\left[1.0 - 1.35e^{-0.18\left(\frac{w}{h}\right)^{1.39}}\right] \quad (14)$$

3. RESULTS AND ANALYSIS

In this section we present the results of simulation and measurement of the antenna. The measurements were made with a Vector Network Analyzer (VNA). S parameters analysis points out that an antenna is radiating when the S parameter is lower than -10dB. To show the dependence of frequency response in terms of the inductor value, different simulations were made, in which the inductor value were changed. The results of these simulations are shown in the Figure 3:

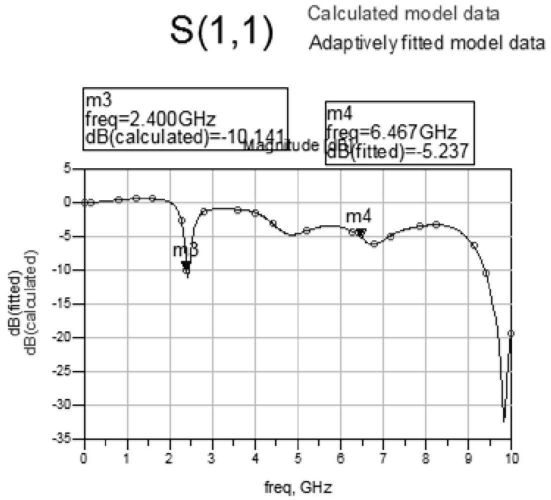

Figure 3: calculated model data vs adaptively fitted model data

In this graphic is demonstrated that that the resonance frequency of the antenna decreases when the inductor value is increased. But the inductor value we can choose has some limitations, for example, the dependence of the resonance frequency decreases when a great value inductor is chosen until it reaches a limit. Figure 4 shows the comparison of the frequency response for two different inductor values. This graphic shows that the reflection coefficient S of the antenna with a 7nH inductor changes the operation frequency of the antenna to 1775 MHz, which is lower than the expected. As we mentioned in the last chapter, in the analysis we did not consider the inductive effects due to the square borders of the spiral monopole [12]. To fix this problem, the value of the inductor was optimized to 6nH.

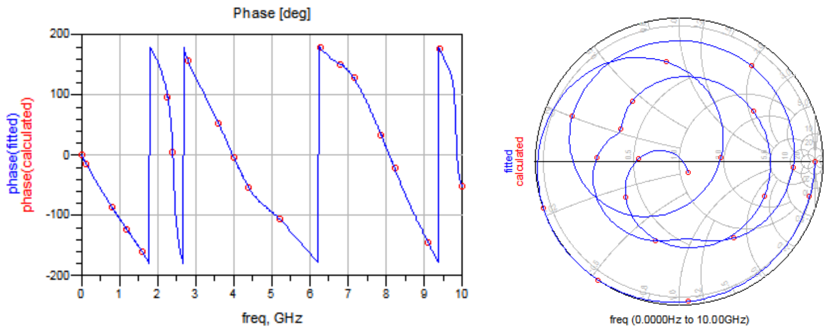

Figure 4: Frequency response Simulation

After having made the simulations, we selected the chip inductor Coilcraft 0603HP, with an inductance value of 6nH. The inductor was put between the end of the feed line and the beginning of the resonator, as shown in Figures 5 and 6. The dimensions of the antenna including the inductor are shown in Table 2.

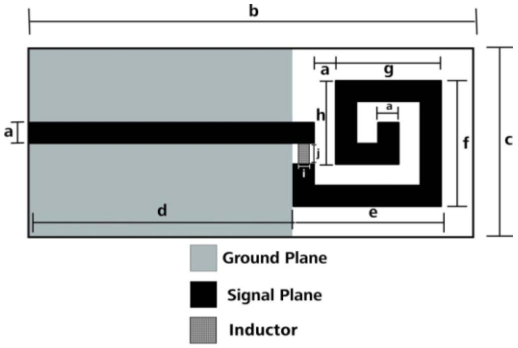

Figure 5: Antenna design with inductor

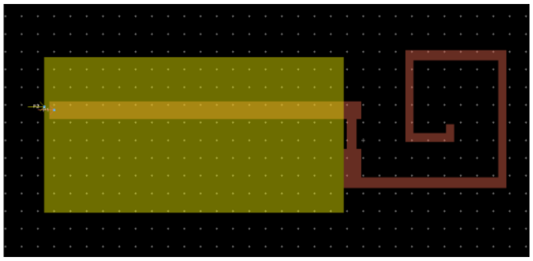

Figure 6: Reconfigurable antenna layout using slot

In the case for the antenna without inductor, we can appreciate that the both S parameter in simulation and measurement is better than the value required for an adequate working. Furthermore, the value S11 gotten in the measurement is lower than -35dB. Note that the lowest value of S11 for the antenna with a 6nH inductor is in 1820 MHz, but these results are acceptable because the value of the coefficient in 6.53 GhZ is lower than -10dB, which is the minimum value to ensure that the antenna is working.

4. CONCLUSION

In this work we demonstrate that it is possible to analyze and design a microstrip spiral monopole antenna that can be reconfigured with putting only a discrete element. This re configurability characteristic not only allows this antenna to be used in cognitive radio (CR) applications, but also the methodology can be applied in the designing of antennas for other bands and technologies. We show a way to get the value for the required element to reconfigure the antenna from calculating the ABCD parameters and also we show that our design can be designed and build easier than other models. This is important because let us translate the model into different systems or materials, in accordance to the requirements of the designers. Although the limitations of the component elements, the design let us reconfiguration an antenna into a lower frequency without increasing the electrical length, which cannot be possible in a multiband antenna, because this antennas are designed considering the wave length of the lower operation frequency.

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