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Reconfigurable Microstrip Patch Antenna Based on Liquid Crystals for Microwave Applications.

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Abstract— **In this project a novel design of a compact rectangular microstrip patch antenna using Liquid Crystals Substrates (LCs) for microwave applications is presented. To benefit from liquid crystal anisotropy and thus obtain frequency agility, a low bias voltage of about 10V is applied. This technique is used to reduce the cost and the overall volume of microwave subsystem especially in wireless communication systems. The proposed reconfigurable antenna based on LCs with DC voltage satisfies a minimal return loss of -52.47dB with a bandwidth of 60MHz for operating frequency of 2.53GHz. The variation of the simulation resonance frequency (ΔFr) obtained after applying a continuous voltage is 530MHz corresponding to an important frequency agility of 26.5%. This method based on LCs can be used to cover several frequency bands, overcome the problem of narrow bandwidth of antenna, increase the peak gain and achieved a good return loss. The design and simulation of antenna is done by using Ansoft HFSS.13. The simulated results are compared with experimental data, and good agreement is obtained.**
Keywords – Liquid Crystals, microstrip, patch Antenna, frequency agility, microwave application.

I. INTRODUCTION

With the rapid extension of wireless communication systems, reconfigurable antenna technologies have received substantial consideration in the communications world. The reconfigurable antenna commonly adapts its properties to achieve operation in several frequency bands or change frequency for several services while maintaining desired radiation characteristics.

For decades, to achieve this objective, enormous efforts [1-2-3] have been deployed for using new materials which have a better functionality. Among these materials, liquid crystals [4-5] are potentially useful. This material consists on a state of matter which has properties between those of a conventional liquid and those of solid crystals. LC has attracted considerable attention in commercial wireless applications. It's had anisotropic and intriguing properties, such as dielectric anisotropy as well as elastic constants and flexes electric coefficients. Those properties are essentially due to the orientation order of the LC phase depending on the direction of the applied electric field, and the knowledge of the orientation order is then important to get good agility [1-6].

Reconfigurable microstrip antenna has special significance in future smart and miniaturized wireless systems [3]. It has a control circuit to adjust their characteristics such as center frequency, bandwidth, and peak gain in a predetermined and controlled manner. It consists of replacing the need for multiple channels, improving overall system reliability, reducing size, weight, complexity, and cost.

In this paper, we present a new technique to reduce the cost, minimize the processing power required to analyze the signals acquired by reconfigurable microstrip antenna based on Liquid Crystal and enhance the performance of this structure. The proposed novel approach of accordable rectangular patch is fed by a microstrip line and is optimized to operate at 2GHz frequency. The optimization was carried out to achieve the best impedance bandwidth.
The compact microstrip patch antenna are simulated and compared with the measured results [7] to confirm the accuracy of the proposed analysis.

II. PROPERTIES OF LIQUID CRYSTALS

The substrate used in this work is Liquid Crystals Substrates (LCs). Some of the advantages of this organic substrate include low dielectric loss (tanδ ~ 0.002), constant dielectric permittivity at the frequencies of interest (εr ~ 2.9), low moisture absorption (<0.02%), light weight, mechanical stiffness, thermal stability (CTE = 0-30 ppm/°C) [5-9], chemical resistance, ease of mass fabrication and great flexibility which allows for the material to be rolled up, which is ideal for circuits and structures that need to be deployed in space.

Recent studies [2-5] have shown their dielectric anisotropy property. This property can be deduced from a permittivity tensor, depending on the direction of the applied electric field. The electrical parameters of the LC are defined as $\varepsilon_{\perp}$ and tan $\delta_{\perp}$ without DC voltage. The molecules can be rotated parallel to the RF field by applying a voltage between the conductors in order to create an electrostatic field in the LC, thus changing the value of the permittivity and loss tangent to $\varepsilon_{r//}$ and tan $\delta_{//}$ respectively. The orientation with electric field is schematically presented in Fig.1 and 2.

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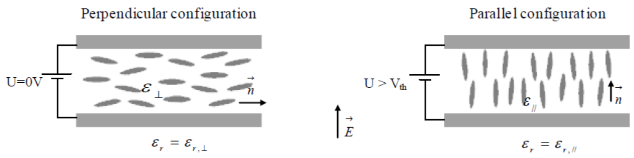

Fig.1: Configuration parallel and perpendicular permittivity ($\varepsilon_{r//}$, $\varepsilon_{r\perp}$)

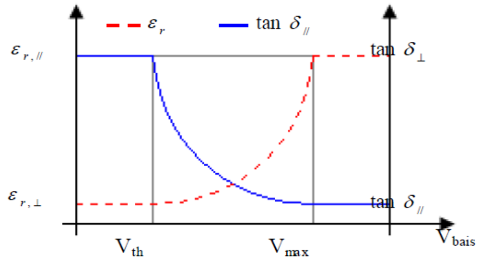

Fig.2: characteristics of the relative permittivity and then loss tangent of LC materials with DC

Anisotropy is then defined as the difference between parallel and perpendicular permittivity and ensues from the following relation:

$$\Delta\varepsilon = \varepsilon_{//} - \varepsilon_{\perp} \quad (1)$$

And, analogously for the relative permittivity:

$$\Delta\varepsilon = \varepsilon_{r//} - \varepsilon_{r\perp} \quad (2)$$

All of these advantages make it appealing for high frequency applications.

III. *DESIGN OF RECTANGULAR MICROSTRIP PATCH ANTENNA*

Compact microstrip antennas have received much attention in the present day communication systems at the RF front-end due to increasing application of small antennas for personal communication equipment's [10], simple and inexpensive to manufacture using modern printed-circuit technology. It consists of a radiating patch on one side of a dielectric which has a ground plane on the other side [9]. Patch antenna is also used in many applications to improve their performances such as aircraft, spacecraft, satellite, and missile applications etc.

In this design, a rectangular patch is fed by a microstrip line printed on a partial grounded substrate, which offers the advantage of ease of integration with active devices due to their uniplanar design and eliminating the need for vias.

To determine the dimension of rectangular microstrip patch antenna using transmission line model we have to first specify the operating resonant frequency 'f_c', the height of the dielectric substrate 'h' and the permittivity of the dielectric substrate material 'ε_r'. Then by using the equation given below [11-12-13], the width 'W' of the patch and length 'L' are calculated.

$$W = \frac{c}{2f_c}\sqrt{\frac{2}{\varepsilon_r+1}} \quad (3)$$

Because the electric field lines are moving into the air before entering the dielectric substrate the will be replaced by ε_{reff} which is slightly less than ε_r. The equation of ε_{reff} is given by:

$$\varepsilon_{reff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r+1}{2}\left[1+12\left(\frac{h}{W}\right)\right]^{-1/2} \quad (4)$$

The extended incremental length ΔL and efficient permittivity ε_{reff} of the patch can be calculated using the equations given below:

$$\frac{\Delta L}{h} = 0.412\frac{(\varepsilon_{reff}+0.3)\left(\frac{W}{h}+0.264\right)}{(\varepsilon_{reff}-0.258)\left(\frac{W}{h}+0.8\right)} \quad (5)$$

The effective length can be calculated by the following equation: (6)

$$L_{eff} = \frac{c}{2f_c\sqrt{\varepsilon_{reff}}}$$

The actual length of patch can be calculated by the following equation:

$$L = L_{eff} - 2\Delta L \quad (7)$$

Microstrip antenna design using above equations has attractive features such as light weight, conformability and low cost. However, major disadvantage of patch antenna is narrow bandwidth. But, there are many techniques to overcome this problem and convert the fixed-frequency antenna to a frequency agile antenna based on LC [3] for a cognitive radio environment.

The tunable rectangular microstrip antenna was to be designed and optimized through the simulation tool HFSS.13 (High frequency structure simulator) in order to evaluate the overall performance of the novel structure. Parametric study for different parameters of the reconfigurable microstrip antenna has been performed to find the most optimum values. The geometry and configuration of the proposed reconfigurable microstrip patch antenna based on LC is shown in Fig.3.

In this design, a radiating patch is printed on LC substrate which is inserted in the cavity only beneath the patch with a low dielectric constant permittivity of ε_r =2.9 and a loss tangent of 0.002. The bottom layer is a FR4 substrate with relative permittivity ε_r =4.4, loss tangent of 0.01 and thickness of 1.6mm. The thickness of copper coating on the top side of the substrate is approximately 0.07mm. The ground plane covers the back side of the substrate with a size of 45 x56mm^2.

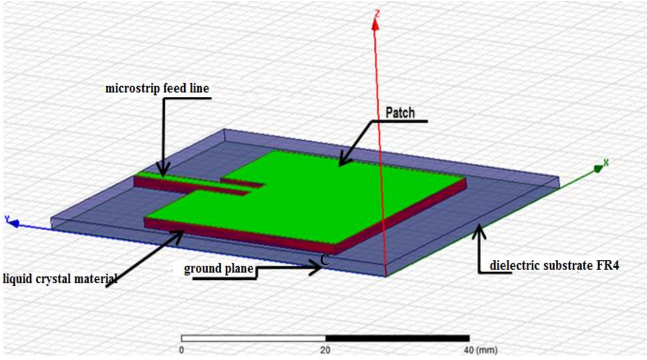

Fig.3: Design of microstrip patch antenna based on LC (HFSS)

As shown in the fig.3, a rectangular patch is excited by a microstrip line printed on a partial grounded substrate. The microstrip feed line is designed to match 50Ω characteristic impedance. The impedance matching of the proposed structure is enhanced by correctly adjusting the dimension of the feeding structure and the radiating patch size.

The design dimensions have been optimized in order to have a reconfigurable frequency antenna for wireless communication systems. By optimizing the length and width of the rectangular radiation patch and LC cavity, improved impedance bandwidth performance can be achieved for the proposed antenna.

The optimal microstrip patch antenna parameters are depicted in Fig.4.

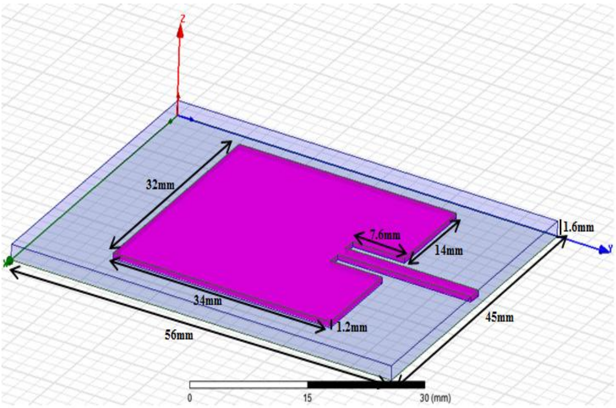

Fig.4: Dimensions of a microstrip patch antenna

Comparison of the simulated and measured return loss of the microstrip patch antenna without LC are presented in Fig.5, It is noted that a relatively good agreement is achieved between measurement and simulation results. there is nevertheless a noted frequency shift of 45MHz (2.25%) from the center frequency, which is due to the variations of permittivity in the substrate, i.e. 4.6 ± 0.15 (up to 3.26%) and the inconsistencies of dielectric thickness, i.e. 1.60.025 ± (up to 1.56%) , as well as manufacturing tolerance.

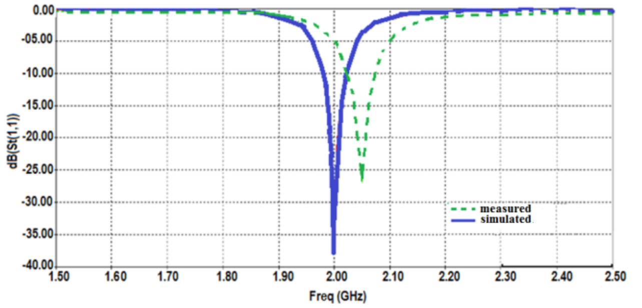

Fig.5: Comparison of simulated and measured response without LCs

In this section, a method to improve the performance and to replace the need for multiple antennas, thus reduce the overall volume of RF front-end subsystem especially in wireless communication systems is introduced. The proposed approach consists of placing LC material in the cavity of the microstrip antenna.

Fig.6 shows that agility was obtained by varying the LC Dielectric permittivity, established by dielectric characterization from 2.7 to 2.9.

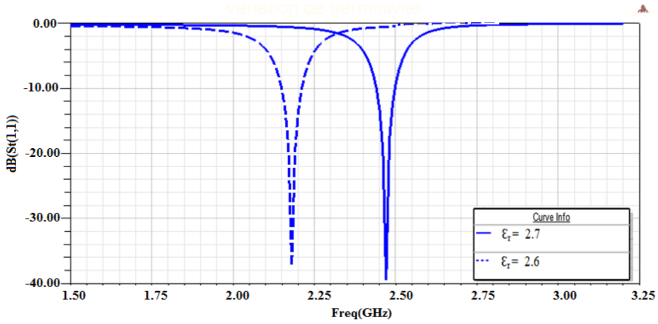

Fig.6: Simulated return loss for two different permittivities by (HFSS)

The simulated and measured return loss (S_{11}) with and without DC voltage of the rectangular microstrip antenna are presented to show the effects of the addition of this material to the operation of this antenna at high frequencies. In fact, from Fig.7, we can conclude that the addition of CL with dielectric permittivity of 2.7 to rectangular microstrip patch antenna without applying a DC voltage can be varied the resonance frequency of 180MHz corresponding to a frequency agility of 9%. , expanded the bandwidth to 60MHz and achieved a good return loss (S_{11}) exceeding -35dB.

To better explain the phenomenon of frequency agility, we applied a variable DC voltage varying from 0V to 15V in the CL cavity and examined the influence of this voltage on the performance of our antenna. And as we have seen in Fig.8, the variation value of the applied voltage allows moving the return loss of the antenna so as to cover adjacent frequency bands and therefore overcome the problem of the narrowness of the bandwidth. Indeed, if the instantaneous bandwidth of the antenna is fairly narrow (60MHz), the overall bandwidth obtained by switching is much higher (670MHz). A frequency agility of 32% is obtained with application of a bias voltage of 15V.

However, this increase of bias voltage caused a decreased in performance's antenna particularly in terms of return loss and gain. Indeed, to ensure compromise between bandwidth, frequency agility and efficiency of this device, we applied a maximum voltage of about 10V to our structure. With this value of voltage a return loss decreased of about 14.75dB (29.03%) and an antenna central frequency shifts from 2GHz to 2.53GHz which means a relative tuning range of 26.5%. Thus, an applied voltage of 10V is sufficient to obtain the desired orientation of the nematic LC molecules.

Fig.9 depicts the simulated far-field radiation patterns of the microstrip patch antenna based on LC for the plan φ=90°. It is clearly seen from the radiation pattern comparison that, the measured main lobe magnitude without LC achieved 5.1 dB at 1.0 degree direction from the origin point at center frequency 2 GHz and meanwhile for simulation with and without DC voltage give respectively the magnitude of 6.2dB and 7.1 at 0.0 degree direction from the origin point, therefore, the found gain with LC is improved.

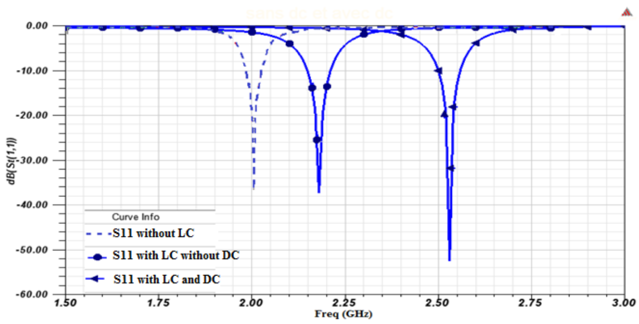

Fig.7: Simulated and measured return loss with and without DC voltage

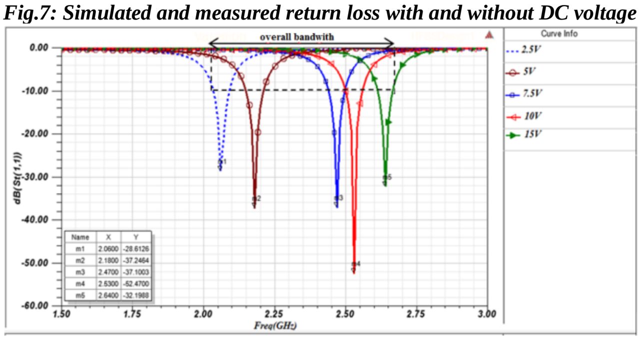

Fig.8: evolution of S_{11} as a function of DC voltage

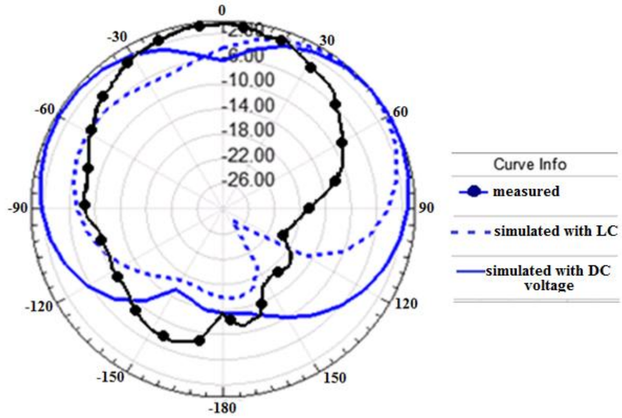

Fig.9: Simulated and measured radiation patterns with and without DC voltage

IV. CONCLUSION

This paper presents the fundamentals of LC material and its applications for reconfigurable microstrip patch antenna. This structure are designed and simulated with HFSS simulator. The observation of the results confirms the potential frequency agility by varying the LC dielectric permittivity with applied DC voltage, improved the radiation characteristics and increased the peak gain of the device. Thus, this new structure based on LC can be used in microwave systems where the reduction of overall physical volume and cost is very important.

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