International Journal of Electronics Communication and Computer Engineering
Volume 6, Issue 4, ISSN (Online): 2249–071X, ISSN (Print): 2278–4209

Compact CPW-Fed Ultra Wideband Antenna using Liquid Crystals Substrates

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***Abstract* – A novel design of a compact coplanar waveguide-fed (CPW) ultra wideband antenna (UWB) using Liquid Crystals Substrates (LCs) for microwave applications is presented. 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 the return loss requirement of less than -10dB with a voltage standing wave ratio (VSWR) less than 1.6 for entire operating frequency range of 3GHz to 11 GHz. The variation of the simulation resonance frequency before and after applying a continuous voltage is respectively 1.2GHz and 400MHz corresponding to a frequency agility of 26.08% and 8%. To enhance impedance bandwidth, notches and stubs at the rectangular radiation patch were used. This method based on LCs can be used to reduce the size of the antenna, increase the peak gain and achieved a good return loss. The simulated results are compared with experimental data, and good agreement is obtained.**

***Keywords* – Liquid Crystals, CPW-Fed, UWB Antenna, Agile Structure.**

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 have been deployed for using new materials which have a better functionality. Among these materials, liquid crystals are potentially useful [1]. This material consists on a state of matter which has properties between those of a conventional liquid and those of solid crystals. LCs 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 flex 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 theknowledge of the orientation order is then important to get good agility [2], [3].

For the reliable use of these communication services, the design of UWB devices such as antennas, filters, and LNAs is required. Various studies have been devoted to evaluating the performance of an UWB antenna [4], [5].

The UWB antenna requires an omni-directional, ultra-wideband, small size for mobility, gain flatness and phase linearity for no distortion of signal, and low-cost for manufacturing. Recently, many researchers have developed UWB antennas operating in the full UWB frequency band such as UWB patch antenna, planar diamond antenna, L-shaped metal-plate monopole antenna, bowtie antenna, fractal dipole, Vivaldi antenna, and monopole antenna [6], [7].

In this paper, we present a new technique to reduce the cost, minimize the processing power required to analyze the signals acquired by reconfigurable UWB antenna based on Liquid Crystal and enhance the performance of this structure. The proposed novel approachusing notches and stubs operating in a frequency range of 3.1-11GHz [8], [9], [11].To enhance impedance bandwidth, notches and stubs at the rectangular radiation patch were used. The compact CPW-fed UWB antenna aresimulated and compared with the existing data [10], [11] to confirm the accuracy of the proposed analysis.

II. Properties of Liquid Crystals

The substrate used in this work is LCP. 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) [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 [12], [13] have shown their dielectric anisotropy property. This property can bededuced from a permittivity tensor, depending on the direction of the applied electric field.The electrical parameters of the LCs 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 LCs, thus changing the value of the permittivity and loss tangent to εr// and tanδ// respectively. The orientation with electric field is schematically presented in Fig.1.

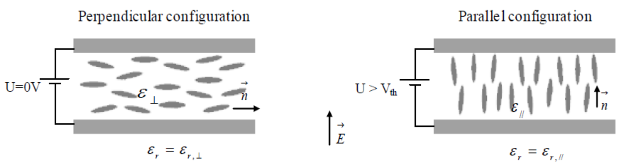

Fig.1. Configuration parallel and perpendicular permittivity ($\varepsilon_{r//}$, $\varepsilon_{r\perp}$)

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:

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

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

III. Coplanar Wave Guide Fed UWB Antenna Design and Analysis

The rectangular microstrip patch antennas have become attractive candidates in the present day communication systems due to their size that is smaller than the size of a conventional rectangular patch and to their low profile, conformable to planar and no planar surfaces, simple and inexpensive to manufacture using modern printed-circuit technology. In the designing process of rectangular microstrip patch antenna using CPW-fed model, which offers the advantage of ease of integration with active devices due to their uniplanar design and eliminating the need for vias, we have to first specify the operating resonant frequency 'f', the permittivity of the dielectric substrate material 'ε_r' and the thickness of the substrate 'h'. Thenthe width (W) of the microstrip patch antenna is calculated by [14].

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

Where fc is the centre frequency and $\varepsilon_r$is the relative permeabilityof the substrate material. ΔL and ε_{reff} is respectively extended incremental length and efficient permittivity of the patch can be calculated using the equations given below [15]:

$$\frac{\Delta L}{h} = 0.412\frac{(\varepsilon_{reff} + 0.3)(\frac{W}{h} + 0.264)}{(\varepsilon_{reff} - 0.258)(\frac{W}{h} + 0.8)} \qquad (4)$$

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r + 1}{2}[1 + 12(\frac{h}{W})]^{-1/2} \qquad (5)$$

The effective length can be calculated by the following equation:

$$L_{eff} = \frac{c}{2f_c\sqrt{\varepsilon_{reff}}} \qquad (6)$$

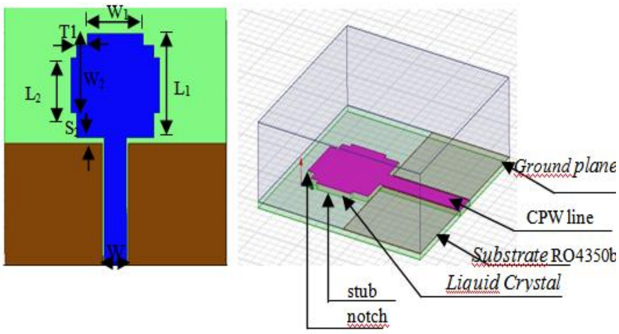
The actual length of patch can be calculated by the following equation:

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

Microstrip antenna design using above equations"3 to 7" 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 microstrip antenna into UWB such as increasing the height of the substrate,adding a step beneath the patch, using partial ground[15], using of tuning stub and notches[16], etc.

The proposed antenna model is simulated through the simulation tool HFSS13 (High frequency structure simulator) in order to evaluate the overall performance of the antenna. Parametric study for different parameters of the antenna has been performed to find the most optimum values. Fig. 2 (a) shows the physical layout of the CPW-fed UWB antenna.

Fig. 2 (b) shows the top side layout of a compact CPW-fed UWB antennabased on a Liquid Crystal Polymer (LCP) substrate. We have designed the proposed reconfigurable UWB antenna using rectangular radiation patch with notches and stubs at side corners of the patchand coplanar waveguide feeding [10]. The proposed UWB antenna is composed of two layer of dielectric. This antenna is printed on LC substrate with thickness of 0.751mm, the LC is inserted by capillarity with a low dielectric constant permittivity of ε_r =2.9and a loss tangent of 0.002. The bottom layer is a RO4350b substrate with thickness of 0.762mm and relative permittivity of 3.48. The thickness ofcopper coating on the top side of the substrate is approximately 0.0175 mm.



(a) (b)

Fig.2. Design of the CPW-fed UWB antenna based on Liquid Crystals by (HFSS)

The CPW feed line is designed to match 50Ω characteristic impedance. The impedance matching of the proposed antenna is enhanced by correctly adjusting the dimension of the feeding structure and the radiating patch size. The CPW line is printed on the rigid part of the substrate, where the central conductor width (W) is 4 mm and the slot gaps are G= 0.28mm wide. The ground plane covers the back side of the substrate with a size of 25 x40 mm2. The optimal UWB antenna parameters can bechosen as W1 = 10 mm,W2 = 1 mm, L1 = 16 mm, L2 = 8.5 mm, T1 = 2 mm, G = 0.32 mm, W = 4mm, and S2 = 1 mm.

The radiating patch and two ground planes are modified to improve the impedance matching over the UWB frequency range. It was found that the gap (G= 0.32 mm) between the radiating patch and CPW ground plane is the most critical parameter in order to achieve the good impedance matching within the UWB bandwidth.

The design dimensions have been optimized in order for the antenna to be matched over a frequency range of 3.1 GHz to 11GHz and have resonant frequency at 3.7 GHz. Byoptimizing the length and width of stub and notch attached to the rectangular radiation patch, improved impedance bandwidth performance can be achieved for the proposed antenna.

The Electric field (E-field) for the TE10 mode of the CPW-fed UWB antennais shown in Fig. 3. The simulations show the vector of E-field is typically concentrated in the cavity of this antenna.

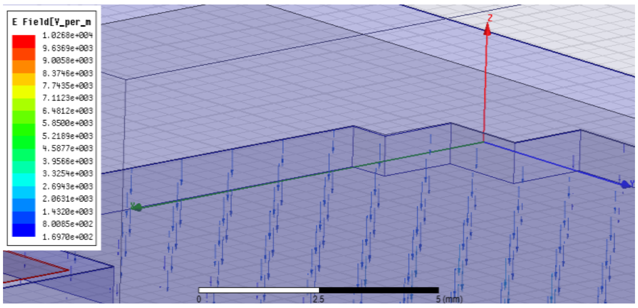


Fig.3. E-field distribution of rectangular SIW filter at centre frequency of 3.7GHz

Fig. 4 shows that agility was obtained by varying the LCsDielectric permittivity, established by dielectric characterization from 2.31 to 2.6.

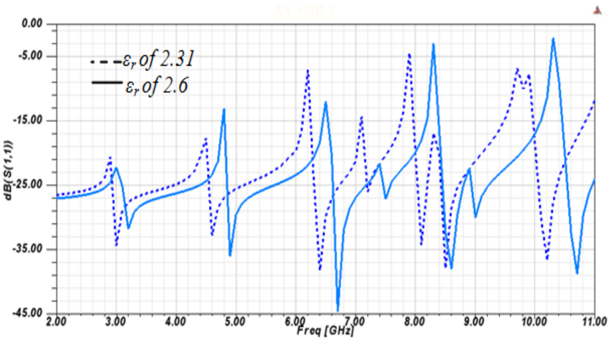


Fig.4. Simulated return losses for two different permittivity by (HFSS)

Fig.5 depicts the results of simulated and measured return loss with and without LC and the dielectric permittivity is 2.9, it can be observed that simulated return loss with LCs without DC voltage achieved -40dB from 4 to 5GHz and the measured without LCs achieved -27dB. The resonance frequency variation (ΔFr) between with and without LC is 1.2 GHz corresponding to a frequency agility of 26.08%. The bandwidths simulated with LCs without DC and measured without LCs of the CPW-fed UWB antenna are respectively 8.6GHz and 7.4 GHz for the return loss less than -10dB. So, this structure of antenna with LCs enabled to significantly expand the band frequencies.

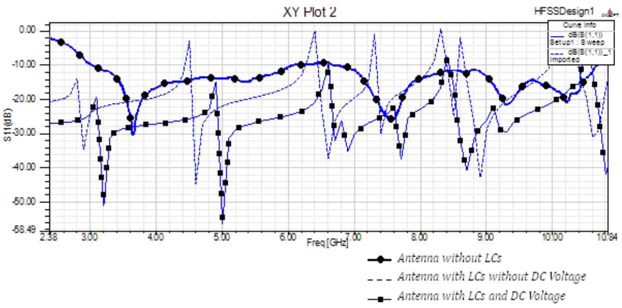


Fig.5. Simulated and measured return losses with and without DC voltage

The simulated return loss with DC voltage is less than -10dB, which is enough to cover the entire UWB system; and the simulated resonance frequency variation (ΔFr) between with and without applied DC voltage is 400MHz correspond to à frequency agility of 8% .The simulated impedance bandwidths with DC voltage, is increased to 9GHz for the return loss less than -10 dB.

A suitable control voltage of about 15 V is applied in order to obtain the desired tilt of the nematic LCs molecules.

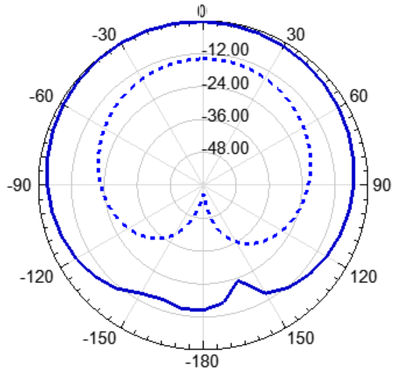


Fig.6. Simulated radiation patterns with and without DC voltage for plan (φ=90°) at 5GHz

Fig. 6 depicts the simulated far-field radiation patterns of the CPW-fed UWB antenna based on LCs for the plan φ=90°. It is clearly seen from the radiation pattern comparison that, the peak gains with and without applied DC Voltage is increased from4.27 dB to 4.75dB, therefore, the found gain with LC is improved.

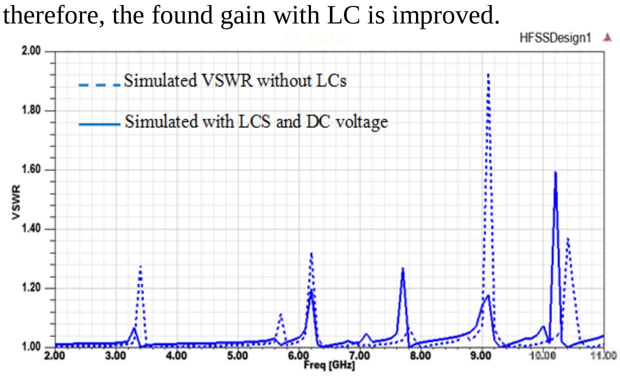


Fig.7. Simulated VSWR with and without LCs voltage

From the Fig. 7, it is clearly seen that the simulated VSWR of UWB antenna with and without LCs is respectively less than 1.6 and 2, therefore the found VSWR with LC is improved.

IV. Conclusion

This paper presents the fundamentals of LCs material and its applications for reconfigurable CPW-fedUWB 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 increases the peak gain of the device that uses LCs. Thus, this new approach of the reconfigurable antenna using notches and slots based on LCscan be used in microwave systems where the reduction of overall physical volume and cost is very important.

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