Integrated of a compact band-selective filter with ultra wideband antenna using Liquid Crystals

Sihem Missaoui, Sayed Missaoui, Mohsen Kaddour

Abstract— **A novel design of integrated compact band-selective filter with coplanar waveguide-fed CPW ultra wideband antenna (UWB) using Liquid Crystals Substrates for microwave applications is presented. This combined system based on cascaded technique is used to reduce the cost and the overall volume of RF front-end subsystem especially in wireless communication systems. The proposed reconfigurable antenna based on LCs without filter satisfies the return loss requirement of less than -20dB over the frequency range of 3.1 GHz to 11 GHz with variation of the simulation resonance frequency of 1.2 GHz corresponding to a frequency agility of 26.08%. The reflection return loss of the proposed reconfigurable antenna with filter has been greatly improved by about 105 dB, along with the variation of the simulation resonance frequency of 800 MHz (18.18%), both before and after applying a continuous voltage. The combined filter-antenna has the frequency band of 3 GHz to 11 GHz for VSWR less than 1.3. The simulated and measured results indicate that the proposed design can be used to reduce the size, achieved a good return loss and maintain good radiation gain.**

Index Terms—**Liquid crystals, CPW UWB antenna, band-selective filter, agile structure, cascaded Technique.**

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 the knowledge of the orientation order is then important to get good agility [2]-[3].

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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 ultra wideband antennas and enhance the performance of the combined filter-antenna. The proposed approach consists of integrating and matching a CPW ultra-wideband (UWB) reconfigurable antenna based on Liquid Crystal (LCs) with a compact band-selective filter.

The design procedure is as follows. First, we have designed a novel compact CPW ultra-wideband (UWB) antenna using notches and stubs operating in a frequency range of 3.0-11GHz [8]-[9]-[11]. To enhance impedance bandwidth, notches and stubs at the rectangular radiation patch were used. Second, we have designed a compact band-selective filter. To realize band- selective characteristic within UWB frequency band, two filters are integrated on both sides of the 50-ohm microstrip line. The filter consists of a cascade of three shunt short-circuited stubs, separated by connecting lines. To miniaturize the total filter size, the shape of resonators was modified to have small dimension. Finally, we have integrated CPW ultra-wideband (UWB) reconfigurable antenna based on Liquid Crystal (LCs) with a compact band-selective filter on the single dielectric substrate to be used in the frequency range of 3.0 to 11GHz. Three kinds of prototypes (the CPW ultra wideband antenna, the UWB band-selective filter, and the compact filter-combined ultra wideband antenna) are simulated 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 ($\tan\delta \sim 0.002$), constant dielectric permittivity at the frequencies of interest ($\varepsilon r \sim 2.9$), low moisture absorption (<0.02%), light weight, mechanical stiffness, thermal stability (CTE = 0-30 ppm/°C) [10], 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 be deduced 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 $\varepsilon_{r//}$ and tan $\delta_{//}$ respectively. The orientation with electric field is schematically presented in Fig. 1 and Fig. 2.

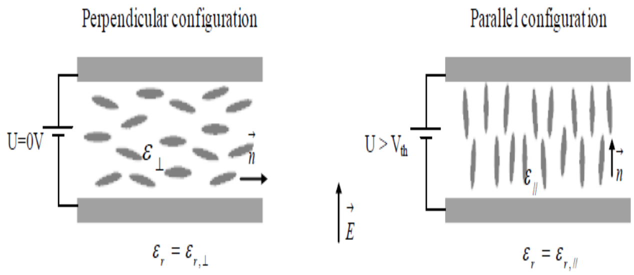

Fig. 1. Configuration parallel and perpendicular permittivity ($\varepsilon_{r//}$, $\varepsilon_{r\perp}$)

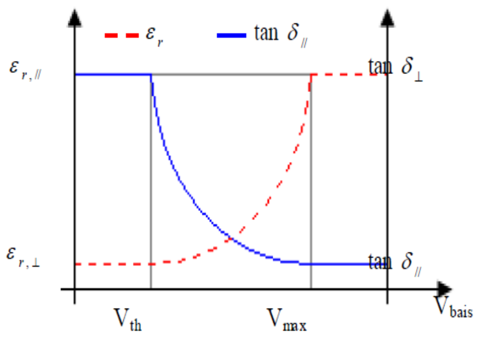

Fig. 2. Characteristics of the relative permittivity and then loss tangent of LCs materials with DC

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

$$\Delta\varepsilon = \varepsilon_{//} - \varepsilon_{\perp} \tag{1}$$

And, analogously for the relative permittivity:

$$\Delta\varepsilon = \varepsilon_{r//} - \varepsilon_{r\perp} \tag{2}$$

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

III. COPLANAR WAVEGUIDE-FED UWB ANTENNA DESIGN AND ANALYSIS.

Fig. 3(a), shows the top side layout of a compact Coplanar Waveguide (CPW)-fed UWB antenna on a Liquid Crystal substrate. We have designed the proposed reconfigurable UWB antenna using rectangular radiation patch with notches and stubs at side corners of the patch and coplanar waveguide feeding. The proposed UWB antenna is composed of two layer of dielectric. This antenna is printed on LC substrate with thickness of 0.751mm, the LCs is inserted in 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 RO4350b substrate with thickness of 0.762mm and relative permittivity of 3.48. The thickness of copper coating on the top side of the substrate is approximately 0.0175 mm.

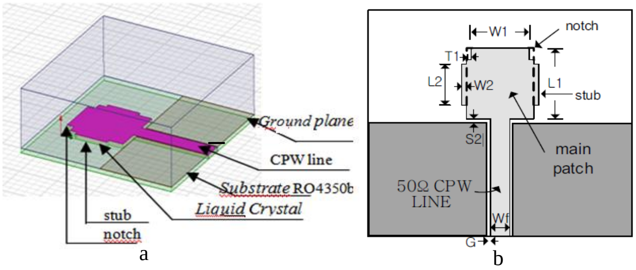

Fig. 3. Design of the CPW-fed UWB antenna based on Liquid Crystals by (HFSS)

As shown in the Fig. 3(b), 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. The ground plane covers the back side of the substrate with a size of 25mm x40 mm. The optimal UWB antenna parameters can be chosen as W1 = 10 mm, W2 = 1 mm, L1 = 16 mm, L2 = 8.5 mm, T1 = 2 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= 0.35 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 GHz to 11GHz and have resonant frequency at 3.7 GHz. By optimizing 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 proposed antenna model is simulated through the simulation tool HFSS13 (High frequency structure simulator) in order to evaluate the overall performance of the antenna. Fig. 4 shows that agility was obtained by varying the LC dielectric permittivity, established by dielectric characterization, from 2.31 to 2.6.

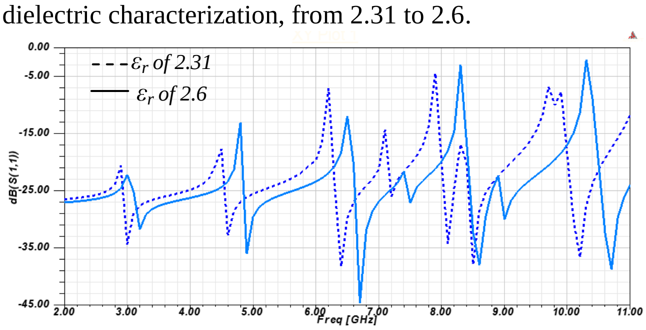

Fig. 4. Simulated return losses for two different permittivity by (HFSS)

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 -40 dB 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 and measured of the CPW-fed UWB antenna are respectively 8.6GHz and 6.6 GHz for the return loss less than -10dB. So, this structure of antenna with LCs enabled to significantly expand the band frequencies.

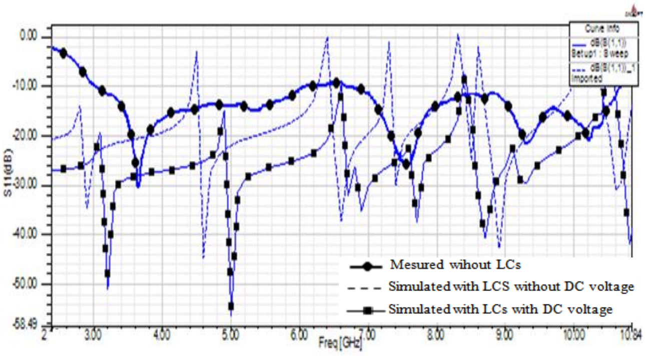

Fig. 5. Simulated and measured return losses with and without DC voltage

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.

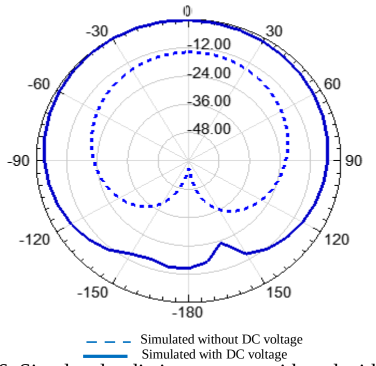

Fig. 6. Simulated radiation patterns with and without DC voltage for plan (φ=90°) at 5GHz

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 from 4.27 dB to 4.75dB, therefore, the found gain with LC is improved.

IV. FILTER DESIGN AND ANALYSIS

The band-selective filter structure can be divided into a conventional high pass and a band stop filter. The two filters are integrated on both sides of the 50-ohm microstrip line and design parameters are adjusted to obtain superior frequency response throughout the operating frequency band. Fig. 7 shows the geometry and equivalent models of the proposed filter. This filter is printed on 30-mil Rogers RO4350 substrate with dielectric constant (ε_r) of 3.48.

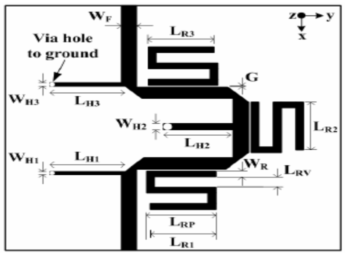

Fig. 7. Design of the band-selective filter

The designed filter has the maximum attenuation of 49.2 dB at 5.65 GHz with three resonators and the 3-dB rejection bandwidth from 5.29 GHz to 5.85 GHz. Design parameters of the final filter are summarized in Table 1.

Table 1: Parameters of the designed band-selective filter [Unit: mm].

Parameters	Values	Parameters	Values
W_{H1}	0.2	L_{R1}	5.26
W_{H2}	0.4	L_{R2}	5.46
W_{H2}	0.2	L_{R3}	5.36
L_{H1}	7.5	L_{RV}	1
L_{H2}	7	L_{RP}	5.76
L_{H3}	7.5	G	0.1
W_R	0.5	W_F	1.7

V. INTEGRATED COMPACT BAND-SELECTIVE FILTER AND RECONFIGURLE UWB ANTENNA USING CASCADE STRUCTURE

Many researchers have taken this into account to invent an alternative solution for the better communication device that able to reduce the overall size and cost of the end user [14]-[15]. However, most of the wireless communication applications require better performance in term of reliability, simple and small in size of the filter and antenna that can be implemented in a single device. Basically, filters and antennas are designed separately which have been connected using an external impedance as connection in between of it. In order to obtain better performance, both filter and antenna need perfectly matched by using a suitable impedance matching for both devices.

There are some methods have been proposed in [16]-[17] to realize the integration technique for filter and antenna. However, the method applied for the integration in [18], [19] using slots are difficult to realize due to its meandered slots structure and thus the design become more complex.

In this case, the compact band -selective filter is cascaded with the ultra wideband antenna port and the reconfigurable antenna port is terminated via a load of 50 Ω as shown in Fig. 8.

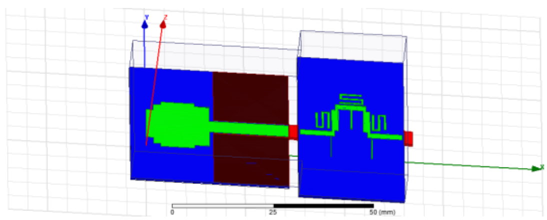

Fig. 8. The proposed antenna combined with a compact band-selective filter.

Simulated and measured return losses with and without LCs of the combination of the reconfigurable ultra wideband antenna and the band- selective filter is shown in Fig. 9.

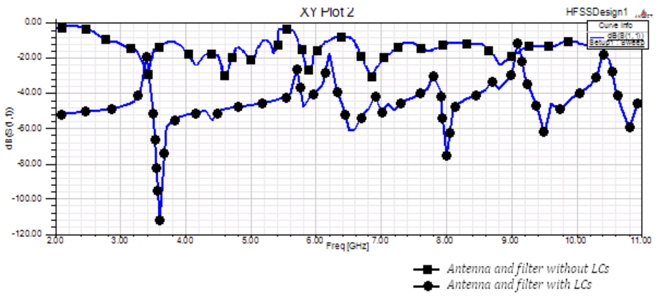

Fig. 9. Simulated and measured return losses with and without LCs

It can be seen that the simulated return loss with LCs achieved -110 dB and the measured return loss without LCs achieved −25dB from 3 to 4 GHz. the resonance frequency variation (ΔFr) between with and without LCs is 200 MHz correspond to à frequency agility of 5.55%. The simulated impedance bandwidths with LCs and measured without LCs are respectively 7.5GHz and 6GHz for the return loss less than -10dB. So, the integration of the LCs in the combined antenna and filter enabled to significantly expand the band frequencies.

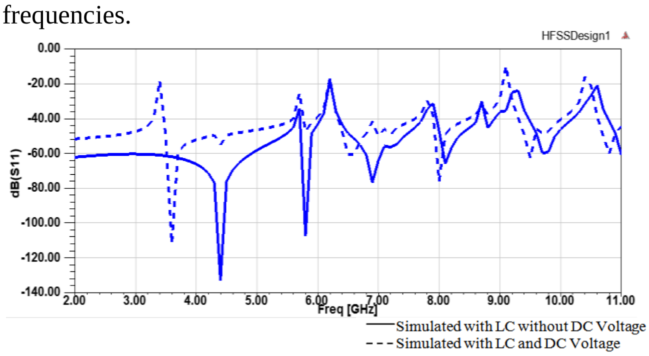

Fig. 10. Simulated return losses with and without DC voltage

Fig. 10 depicts the results of simulated return loss with and without DC voltage of the filter-combined ultra wideband antenna based on liquid crystal; it can be observed that simulated return loss (S11) with DC voltage achieved -135 dB from 4 to 5GHz with increased of bandwidth to 9dB The resonance frequency variation (ΔFr) between with and without DC voltage is 800MHz corresponding to a frequency agility of 18.18%, which is due to the variations of the permittivity in the LCs substrate and the inconsistencies Of dielectric thickness.

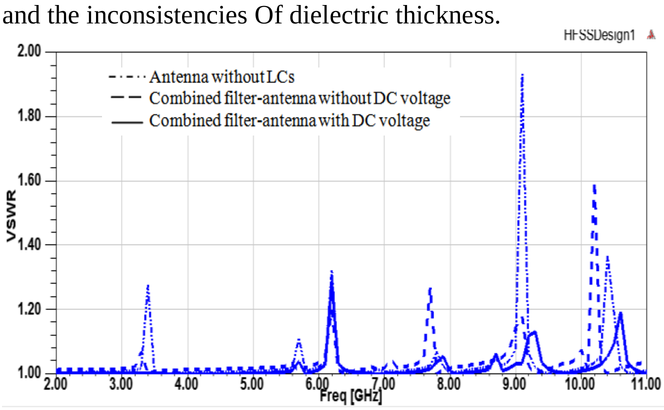

Fig. 11. Simulated VSWR of the combined filter-antenna with and without DC voltage

From the Fig. 11, it is clearly seen from the simulated VSWR comparison that, the VSWR of UWB antenna only and filter-combined ultra wideband antenna with and without applied DC Voltage is respectively less than 2, 1.3 and 1.6, therefore the found VSWR with LC is improved.

Radiation pattern simulations and measurements were taken in two different planes: the E and H planes. In all two cases, simulated and measured co- and cross- polarization is presented. Only measurements at 3.5 GHz, 5GHz and 9 GHz are presented.

The radiation pattern of the combined antenna and filter for the different modes in E-plane (y-z plane) and H-plane (x-z plane) is shown respectively in Fig. 12 (a, b and c) and Fig. 13 (a, b and c). An almost Omni-directional radiation pattern is obtained with the cross-polarization level. In all cases simulations and measurements are in very good agreement with the use of a combined structure for UWB application based on liquid crystal.

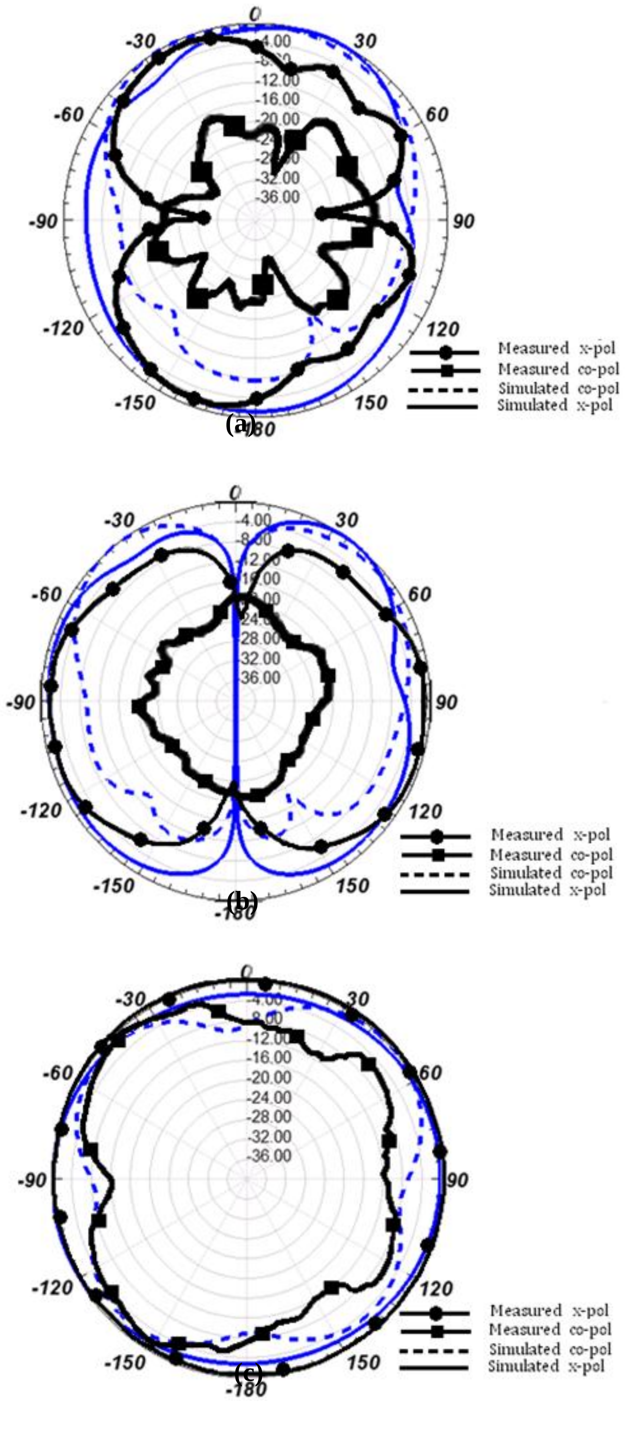

Fig. 12. Simulated and measured E-plane radiation pattern of the combined filter-antenna with DC Voltage for (a) 3.5GHz, (b) 5GHz and (c) 9 GHz

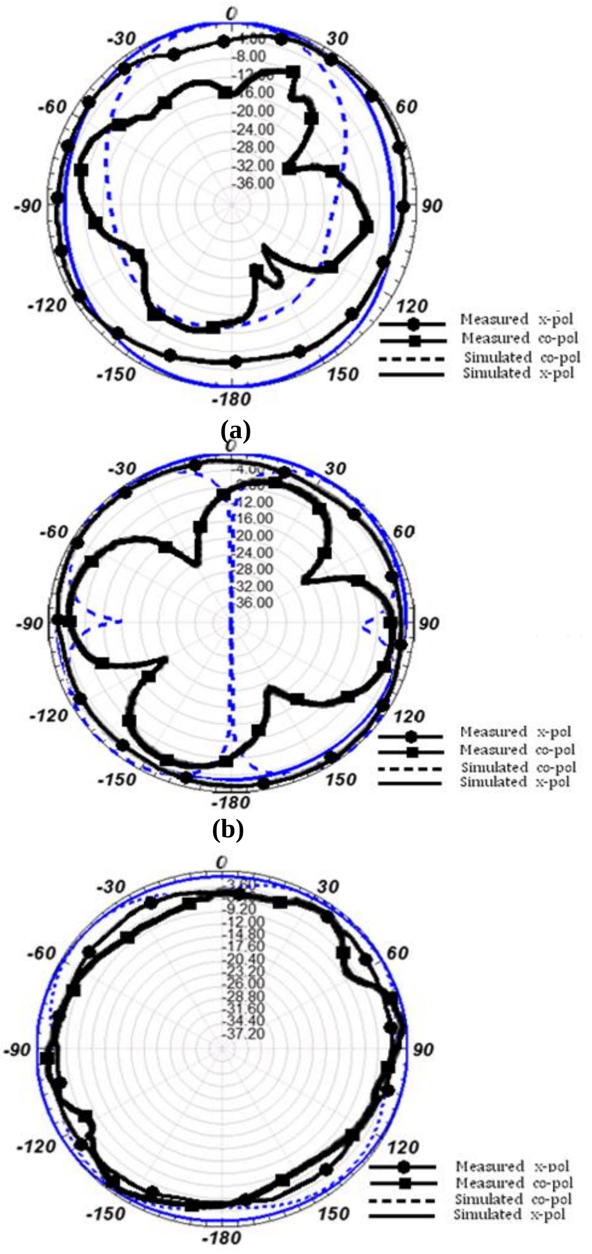

Fig. 13. Simulated and measured H-plane radiation pattern of the combined filter-antenna with DC Voltage for (a) 3.5GHz, (b) 5GHz and (c) 9 GHz

VI. Conclusion

This paper presents the fundamentals of LC material and its applications for reconfigurable combined CPW ultra wideband (UWB) antenna and band-selective filter. The two structures (antenna only and combined filter-antenna) were designed and simulated. 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 class of integrated filter and reconfigurable antenna based on LCs to produce filtering and radiating element in a single module would be useful in microwave RF front-end subsystems where the reduction of overall physical volume and cost is very important.

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