5ème Conférence Internationale des Energies Renouvelables (CIER– 2017)
Proceeding of Engineering and Technology –PET
Vol.28 pp.5-13

Co-design of an Antenna-Filter RF withAnisotropy of Liquid Crystalfor UWB Applications

SayedMISSAOUI[a], Mohsen KADDOUR[b]

[a]*Department of Physics, Faculty of Science of Tunisia, University of Tunis Elmanar 2092, Tunisia*
Department of Technology, Higher Institute of Applied Sciences and Technology of Kasrine, University of Kairouan, Tunisia
E-mail: sayed.elmissaoui@gmail.com

[b]*Department of Physics, Faculty of Science of sfax, University of Sfax, Tunisia*

Abstract

We propose and demonstrate novel reconfigurable combined design (Co-design) of an antenna-filter RF (Radio Frequency) with anisotropy of liquid crystal. The basic co-antenna-filter is designed usingmicrostrip interdigital coupled linesat the middle of the common ground plane.For these devices, reconfigurable UWB (Ultra-Wide Band) co-design has gained tremendous research interest for many different applications, cellular radio system, radar system and satellite communications. A reshaped structure with a liquid crystal cavity has been used in order to improve the device performance, miniaturization and defined as its capacity to change the fundamental properties. The simulated results of combined design are compared with measured data, and good agreement is obtained.

Keywords: Liquid Crystals, Optical Anisotropy, UWB-Antenna, Microwave Filter, Reconfigurable design.

1. Introduction

With the rapid extension of wireless communicationsystems, reconfigurable antenna and filter technologies havereceived substantial consideration in the communicationsworld. The reconfigurable antenna commonly adapts itsproperties to achieve operation in several frequency bandsor change frequency for several services while maintainingdesired radiation characteristics.The demand on tunable or reconfigurable components at micro- and millimeter waves increased during the last years.Today, these difficult problems are the subject of intensive studies in microwave planar filters [1–4]. For such applications,the use of combined antenna-filter appears as a quite convenient solution 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 agile microwaves devices [5–7] permit acompensation of the technological scatterings, the improvement of the instrumentation and the increase of the integrationfunctions[8-11]. An alternative method for frequency reconfiguration is provided by material variation. Generally in this technique, an applied static electric field is used to change the relative permittivity of a material embedded in the devices. These changes in relative permittivity can results in frequency shifting [12–13]. Reconfigurability with tuneable material is a very new research area and still facing challenges such as reliability, efficiency and proper modelling. However, in recent times many researches are carried out in this area and notable achievements have been reported [14-16]. Another approach which has recently gained some research interest is the liquid crystal (LC) tuneable antennas. The permittivity of a liquid crystal can be varied with DC bias voltage.LC state is known to vary withtemperature from solid to liquid. The nematic phase

ISSN 2356-5608

corresponds to the state where molecules have an orientationalorder, but no positional one. Application of an electric field to LC changes the direction of molecules and may createsignificant anisotropy, which explains why LC is currently chosen for microwave applications. This anisotropy varieswith frequency and temperature [17].

In this paper, a new technique to reduce the cost and the overall volume of RF front-end subsystem especially in wireless communication systems, to minimize the processing power required to analyze the signals acquired by reconfigurable UWB-antenna and enhance the performance of the combined filter-antenna, is proposed. The idea is based on producing radiating and filtering system in a single device by integrating and matching a reconfigurable microwave filter within the tunable UWB-antenna structure using multi-layer technology. The frequency tuning of the combined structure is ensured by the use of LC material.

2. Nematic LC Properties in the Microwave Range

In order to describe the operating mode of the agile tunableco-design, the microwave properties of the LCs are presented. The main property of the LC in the microwave range is the dielectric anisotropy due to the application of a static electric or magnetic field. All further explanations are related to nematic LCs, which have so far shown the best dielectric properties at microwave and mm-wave frequencies.The nematic phase is the most commonly used phase of LCs, especially at microwave and millimeter wave frequency. In this phase of liquid, through applying an external bias voltage, the electric field in the LC affects the orientation of the molecules [18]. At low voltage the effect is slight but it increases as the voltage increases. When the applied voltage reaches a certain level, all molecules are orientated stably along the direction of the electric field. LCs are specified by different phases depending on their temperature. These phases determine the state of the material, which can vary from a solid state to a liquid state. In this study, LCs are used in the nematic phase, where the molecules float around as in the liquid phase but are still ordered in their orientation. The nematic phase [19-22] is of great interest because of the dielectric anisotropy that permits the frequency agility [23].
Optical anisotropy is then defined as the difference between parallel and perpendicular permittivities and ensues from the following relation:

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

Where $\varepsilon_{//}$ and $\varepsilon_{\perp}$ are, respectively, the parallel andperpendicular relative dielectricpermittivitywhere the dielectric permittivity ε of a material is defined as the ratio of the capacitance C_{mat} of the parallel plate capacitor that contains the material to the capacitance C_{vac}, of the same capacitor that contains a vacuum:

$$\frac{C_{mat}}{C_{vac}} = \varepsilon$$

The dielectric constants are dependent on the temperature and the frequency of the applied field up to the transition to the isotropic liquid.

Figure 1(a) shows the orientation of the molecules, the least ordered phase is the nematic which has only long-range orientational order. In this case, the long axes of the molecules point on the average in the same direction, which is defined by a unit vector commonly known as "the director" (n). Figure 1(b) shows the optical micrograph of the characteristic Schlieren texture.

Figures 2 and 3 have shown the chemical structure and the molecular arrangements of 5CB liquid crystal in different phase states. The director vector $\vec{n}$ has the same direction as the nematic LC molecules. A parallel permittivity $\varepsilon_{//}$ of the molecules occurs for a microwave field parallel to the director $\vec{n}$, whereas a perpendicular permittivity $\varepsilon_{\perp}$ is effective for a microwave field perpendicular to the director $\vec{n}$. The result of applying a sufficiently large control voltage to LC is to align the LC along the electric field due to the control voltage. This LC alignment is nearly parallel to the microwave electric field because the transmission mode of the Microstrip line is quasi-TEM. On the other hand, if the control voltage is removed (changed to 0 V), the LC becomes aligned in the direction determined by the alignment layers, which is perpendicular to the microwave electric field.

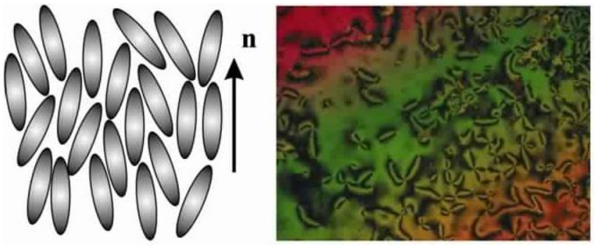


Fig. 1. nematic phase: (a) an illustration of the orientation of the molecules, and (b) an optical micrograph of the characteristic Schlieren texture.

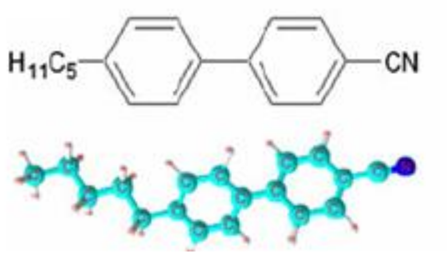


Fig. 2. Chemical structure of nematic liquid crystal 5CB

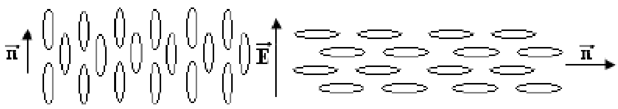


Fig. 3. Configuration matching the permittivity $\varepsilon_{//}$ and $\varepsilon_{\perp}$

3. UWB-antenna design and simulated results

The tuneableUWB-antennas have becomeattractive candidates in the present day communicationsystems due to their size that is smaller than the size of aconventional L-shaped stripand to their low profile,conformable to planar and no planar surfaces, simple andinexpensive to manufacture using modern printed-circuittechnology. In the designing process of UWB-antenna, whichoffers the advantage of ease of integration with activedevices due to their uniplanar design and eliminating theneed for vias, we have to first specify the operatingresonant frequency ‟f‟, the permittivity of the dielectricsubstrate material ‟ε_r‟ and the thickness of the substrateh‟. Thenthe width (W) of the microstrip patch antenna iscalculated by [9].

$$W = \frac{c}{2f_c}\sqrt{\frac{2}{\varepsilon_r + 1}}$$

Where fc is the centre frequency and ε_r is the relativepermeabilityof the substrate material. ΔL and ε_{reff} isrespectively extended incremental length and efficientpermittivity of the patch can be calculated using theequations given below [24]:

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

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

The effective length can be calculated by the following equation:

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

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

$$L = L_{eff} - 2\Delta L$$

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[24], using of tuning stub and notches[25], etc.

The UWB-antenna is modeled numerically by using a commercially available simulation tool (CST HFSSv13 software) based on Finite-Element-Method (FEM)in order to evaluate the electric overall performance. Parametric study for different parameters of the antenna has been performed to find the most optimum values.

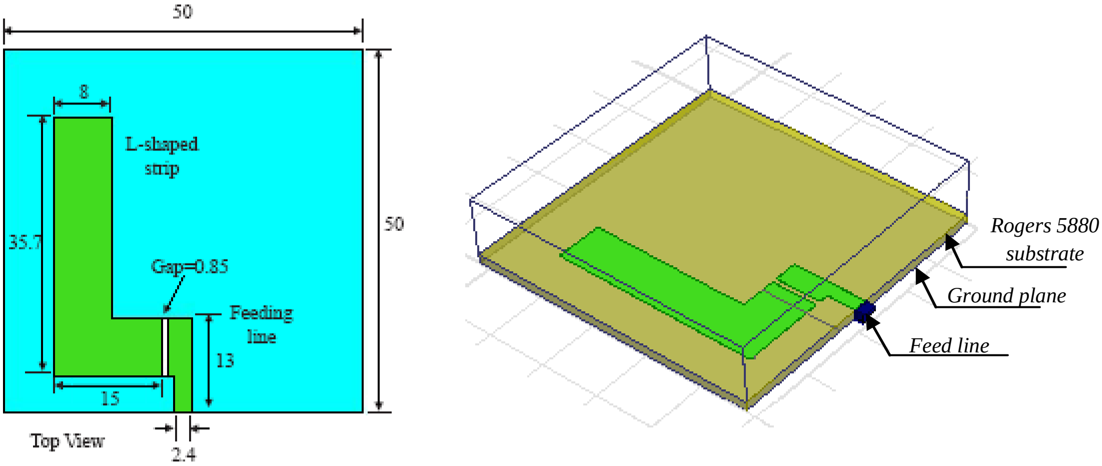
Figure 4 shows the top side design of a compact UWB-antenna. We have designed the proposedreconfigurable UWB-antenna using rectangular radiation patch with notches and composed of an L-shaped microstrip line which is capacitively coupled to a small feeding line. This antenna is printed on bottom layer of a Rogers 5880 substrate (permittivity $\varepsilon_r=2.2$, loss tangent $tan\delta =0.0009$), having a thickness of $h = 1.575$ *mm*.The length of the L-shaped stripis 35.7 mm and the slot gap is 0.85 mm wide. The length of the L-shaped strip determines the operating frequency (2.4 GHz) of the antenna.The ground planecovers the back side of the substrate with a size of $25x40\ mm^2$.Ground plane or metal cavity is often used to achieve directional radiation from anomni-directional antenna element. The effect of a ground plane can be seen as ashort circuited transmission line connected to the antenna.TheUWB-antenna is designed to match 50Ωcharacteristic impedance. The impedance matching of theproposed antenna is enhanced by correctly adjusting thedimension of the feeding structure and the radiating patchsize and the whole structure is backed by a conducting metal ground plane.

The design dimension has been optimized in order to match over a frequency range of 1GHz to 10 GHz and has resonant frequency at 2.4 GHz.Byoptimizing the L-shaped microstrip lineand notchattached to the rectangular radiation patch, improvedimpedance bandwidth performance can be achieved for theproposed antenna.

Figure 5 depicts the results of simulated return loss, it can be observed that simulated returnloss achieved – 16 dB at 2.4 GHz. The bandwidths of the antenna are100 MHz (4.16 %).

A two dimensional view of the far-field radiation patterns is presented in Figure6. Evidently, the UWB-antenna element possesses a wide beam width. The half powerbeam width at 2.4 GHz is more than 65°along E-plane (yz-plane) while the front-to-back ratio (FBR) is better than 16 dB. Theback radiation can be further reduced by increasing the ground plane size. We can conclude that while polarization is extremely pure in the E plane(phi=90°).From the Figure 7, it is clearly seen that the simulated VSWR of UWB-antenna achieved 2.5 at the 2.4 GHz.

A new integration technique of a reconfigurable filter and antenna is proposed which allows the antenna toconnect directly to the filter without any matching circuits.



(a) (b)

Figure 4. (a) Dimensions of the UWB-antenna with L-shaped microstrip line, (b) Design of the UWB-antenna by (HFSS)

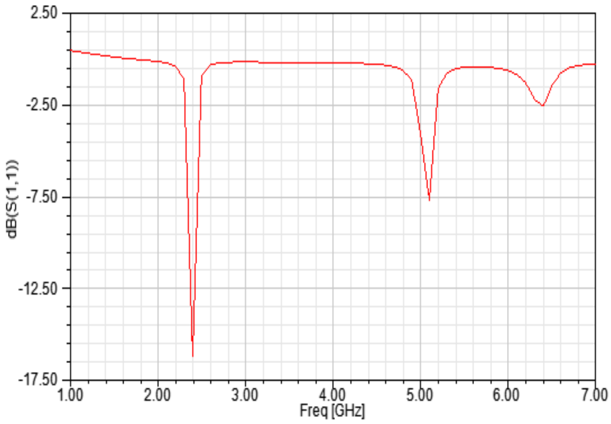


Figure5. Simulated return losses without LC

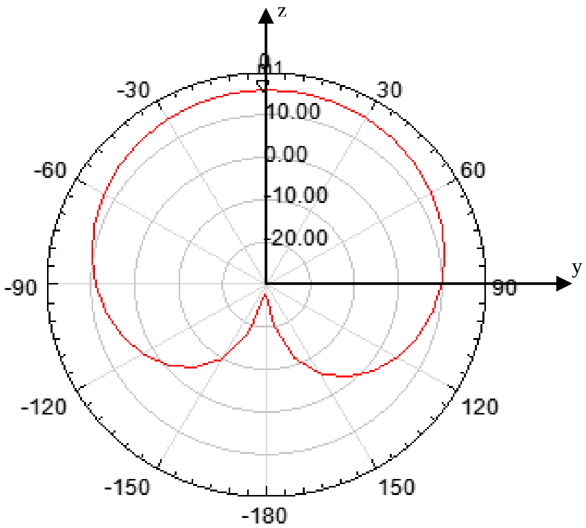


Figure 6. Simulated radiation patterns for E plane (φ=90°) at 2.4 GHz

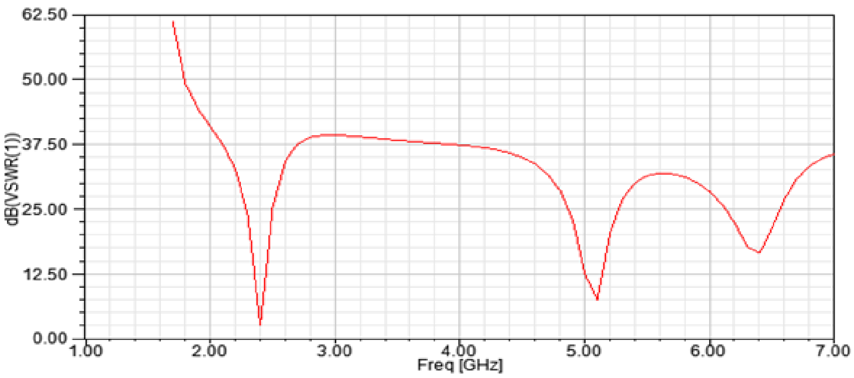


Figure 7. Simulated VSWR

4. Reconfigurable integrated filter and UWB-antenna design and results

A basic structure of an integrated microwave filter and UWB-antenna in a multilayer structure was chosen todemonstrate the concept, which designed using microstrip interdigital coupled lines. The design of the proposed novel integrated microwave filter and UWB-antenna with L-shaped microstrip line based on LCis showns in Figure8. From the simulation, it is found that the twomain factors determine the coupling between the filter andantenna are the position and the size of the L-shaped microstrip line at the Rogers 5880 substrate. Based on EM simulations and in order to achievea better response, the antenna has to be shiftedor off-set from the origin to critically couple between thefilter and antenna with the L-shaped has localized on Rogers 5880 substrate.

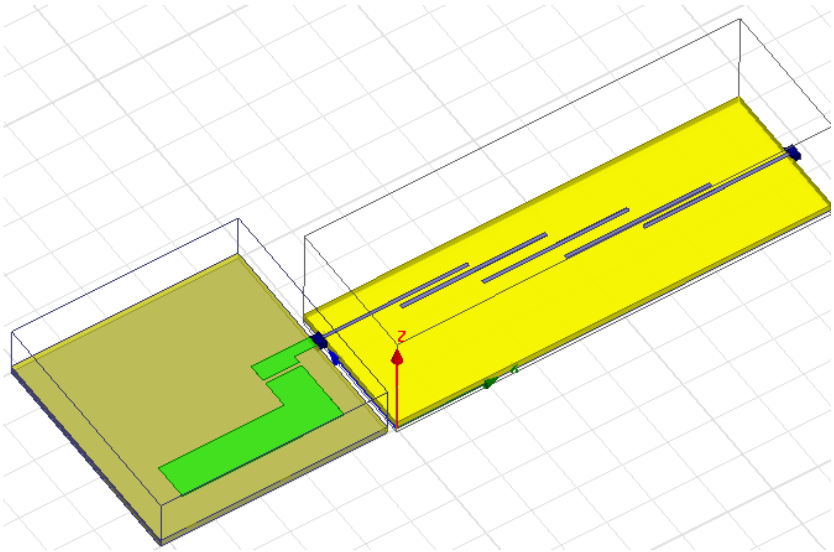


Figure 8. Novel integrated microwave filter and UWB-antenna with L-shaped microstrip line based on LC

It can be seen from Figure 9 that the return loss without LC simulatedachieved -100dB, -96dB and -82 dBrespectively, to 3.6 GHz, 6.7GHz and 9.2 GHz. The simulated return losswith LC achieved -107.5 dB, -100 dB and -102.5 dBrespectively, to 2.5 GHz, 6.2 GHz and 9.9 GHz. We noticedthat the use of the LC decrease the return loss of the co-design antenna-filter of a values of -7.5 dB, -4 dB and -20.5 dB. The resonance frequencyvariation (ΔFr) with and without LCs is 1100 MHzcorresponding to a frequency agility of 44%.

Figure 10 depictsthe VSWR results for the integrated filter and antennawithout LCs. It can be seen that the VSWR equal to 1.038, 1.013 and 1.037 respectively, to 1.6 GHz, 5.1 GHz and8.2 GHz. Figure 11 presents the VSWR results for the reconfigurable co-design UWB-antenna-filter with LCs.It can be seen that the VSWR equal to 1.004, 1.028 and 1.108 respectively, to 1.6 GHz, 5GHz and8.1 GHz. We noticedthat the use of the LC decrease the VSWR of the novel co-design antenna-filter of a values of 0.034, 0.015 and 0.029.

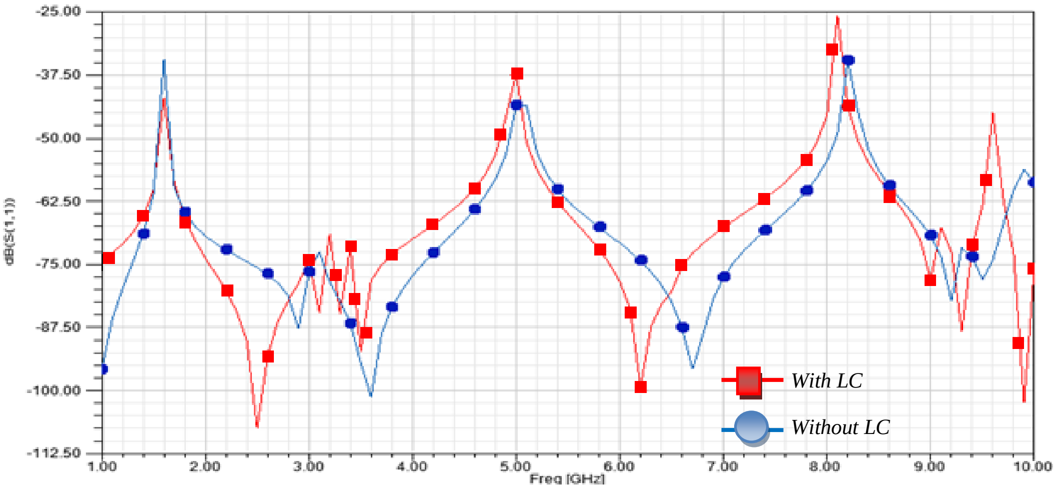


Figure 9. Simulated return lossfor co-design of an antenna-filter with and without Liquid Crystals

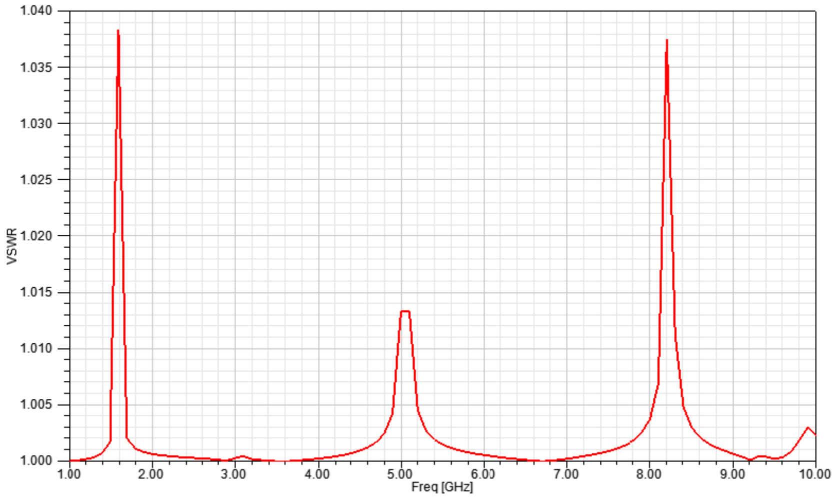


Figure 10. Simulated VSWR without LCs

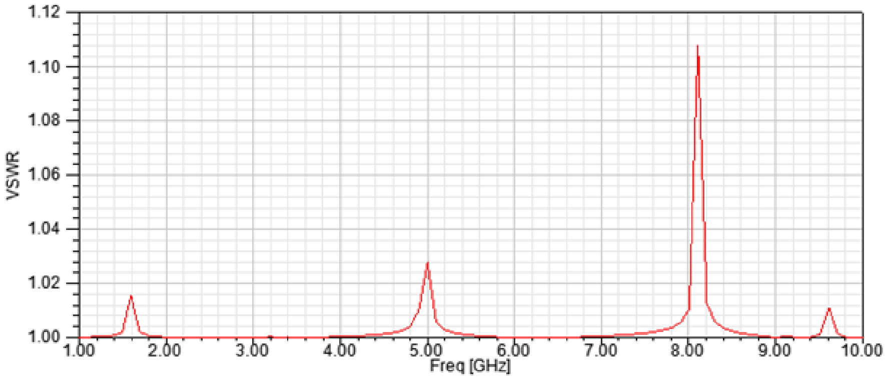


Figure 11. Simulated VSWR with LCs

4. Conclusion

A novel tunable co-design filter and UWB-antenna for microwave front-end subsystemsis proposed. The fundamentals of LCmaterial and it application for combined structure are noted.The resultsconfirmed the frequency agility by using LC dielectricpermittivity with applied a low DC voltage, improved theradiation characteristics and decreased the return loss and ten VSWR of thedevice. This novel design provides an alternative solution forcombining microwave filter and UWB-antenna to producefiltering and radiating element in a single reconfigurablemodule which can be useful in microwave RF front-endsubsystems where the reduction of overall physical volumeand cost and the improvement of the performances is anecessity.

References

[1] Zhu, H. and Q.-X. Chu, \Compact ultra-wideband (UWB) bandpass filter using dual-stub-loadedresonator (DSLR)," *IEEE Microw. Wireless Compon. Lett.*, Vol. 23, No. 10, 572{579, 2013.

[2] Fallahzadeh, S. and M. Tayarani, \A new microstrip UWB bandpass filter using defected Microstrip structures," Journal of Electromagnetic Waves and Applications, Vol. 4, No. 7, 893{902, 2010.

[3] Hao, Z.-C. and J.-S. Hong, \UWB bandpass filter using cascaded miniature high-pass and low-pass filters with multilayer liquid crystal polymer technology," IEEE Trans. Microw. Theory Tech.,Vol. 58, No. 4, 941{948, 2010.

[4] Xu, J., W. Wu, W. Kang, and C. Miao, \Compact UWB bandpass filter with a notched band usingradial stub loaded resonator," IEEE Microw. Wireless Compon. Lett., Vol. 22, No. 7, 351{353,2012.

[5] A. Petosa, “An overview of tuning techniques for frequency agileantennas,” IEEE Antennas and Propagation Magazine, vol.54, pp. 271–296, 2012.

[6] G. Perez-Palomino, P. Baine, R. Dickie et al., “Design andexperimental validation of liquid crystal-based reconfigurablereflectarray elements with improved bandwidth in F-band,”IEEE Transactions on Antennas and Propagation, vol. 61, pp.1704–1713, 2013.

[7] P. Yaghmaee, C. Fumeaux, B. Bates, A. Manabe,O.H. Karabey,and R. Jakoby, “Frequency tunable S-band resonator usingnematic liquid crystal,” Electronics Letters, vol. 48, no. 12, pp.798–7800, 2012.

[8] V. Palazzari, D. Thompson, N. Papageorgiou et al., “MultibandRF and mm-wave design solutions for integrated RF functionsin liquid crystal polymer system-on-package technology,”in Proceedings of the IEEE 54th Electronic Components andTechnology Conference Symposium (ECTC ’04), pp. 1658–1663,June 2004.

[9] Z. Zakaria, W.Y. Sam, M.Z.A. Abd Aziz, K. Jusoff, M.A.Othman, B.H. Ahmad, M.A. Mutalib, and S. Suhaimi. HybridTopology. of Substrate Integrated Waveguide (SIW) Filter andMicrostrip Patch Antenna for Wireless Communication System.Australian Journal of Basic and Applied Sciences, vol. 7, no. 3,pp. 24-34, 2013.

[10] Sayed. Missaoui, Sihem. Missaoui, Mohsen. Kaddour, “Integration of a Compact Circularly Polarized Antenna Arraywith a Reconfigurable Symmetric Stub Phase Shifterusing Liquid Crystals Substrates,”European Journal of Scientific Research, vol. 120, no. 2, pp. 153–161, 2014.

[11] Arpan Pal, Hengyi Zhou, Amit Mehta,"Co-design of an Antenna-Power Amplifier RF Front-end BlockWithout Matching Network for 2.4 GHz WiFi Application,"IEEE 2017

[12] S. Missaoui, M. Kaddour, and A. Gharbi, “Design and simulationof tunable phase shifters based on liquid crystals,” Electromagnetics,vol. 31, no. 4, pp. 285–293, 2011.

[13]N. Martin, G. Prigent, P. Laurent, P. H. Gelin, and F. Huret,"Technological evolution and performances improvements ofa tunable phase-shifter using liquid crystal,"Microwave andOptical Technology Letters, vol. 43, no. 4, pp. 338–341, 2004.
[14]Wang, K., S. W. Wong, and Q. X. Chu,"A compact UWB bandpass filter with short-ended H-shaped resonator and controllable notched band,"Microw. Opt. Technol. Lett., Vol. 55, No. 7,pp. 1577–1581, 2013.
[15]Nosrati, M. and M. Daneshmand,"Compact microstrip ultra-wideband double/single notch-bandband-pass filter based on wave's cancellation theory, "IET Microw. Antennas Propag., Vol. 8, No. 6,pp. 862–868, 2012.
[16]Zhao, J.-D., J.-P. Wang, G. Zhang, and J.-L. Lin,"Compact UWB bandpass filter with dualnotched bands using E-shaped resonator,"IEEE Microw. Wireless Compon. Lett., Vol. 23, No. 12,pp. 638–640, 2013.
[17] N. Tentillier, N. Martin, R. Douali, B. Splingart, and C.legrand,"Microwave dielectric properties of nematic liquidcrystals: applications to tunable phase shifters,"in Proceedingsof the 20`eme International LC Conference, Ljubljana, Slovenia,July 2004.
[18] Zakharov AV, Mirantsev LV. Dynamic and dielectricproperties of liquid crystals. Phys Solid State2003;45:183-8.
[19] Sheng-Hua Lu, Chien-Yell Wang, Cho-Yen Hsieh, Kuan-Yu Chiu, and Hui-Yu Chen, Applied optics Vol. 51, No. 9 (2012).
[20] Xiaoxi Qiao., Xiangjun Zhang., Yanbao Guo., Shikuan Yang., Yu Tian., Yonggang Meng, Rheol Acta, 52:939–947 (2013).
[21] Martin, N., P. Laurent, F. Huret, & Ph. Gelin, IEEE Trans. Microw. Theory Techniq., Long Beach (USA 2005).
[22] Spinglart, B, N. Tentillier, F. Huret, & C. Legrand, Mol. Crystals Liquid Crystals 368:183– 190 (2001).
[23] Sayed. Missaoui, Sihem Missaoui, Mohsen Kaddour, Advances in Microelectronic Engineering (AIME) Volume 1 Issue 3, (2013).
[24] Rajesh Kr. Raj, Sanjay Gurjar, Mayank Sharma. Design of Stairand Slotted UWB Antenna using Stepped-Feed with ModifiedSlotted Ground Plane. International Journal of ComputerApplications. 2014.
[25] R. Sangeetha, B.Rajalakshmi, M.E. Notch Band Antenna forWireless Applications. International Journal of ComputerApplications. Vol. 69, no.9, 2013.