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SIMULATION OF CO-PLANAR WAVEGUIDE LIQUID CRYSTAL BASED PHASE SHIFTER

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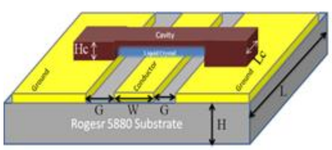
Graphical abstract



Abstract

This paper discussed the design and performances of a liquid crystal phase shifter that can be used in tuning devices. Tuning devices growth with the demand in the emerging in telecommunication system. Tuning devices with smooth continuous phase shifting at low cost and compact size would be an advantage. This paper proposed a phase shifter using 5CB liquid crystal material. The advantages of using the material is the smoothness and continuity of the transitions in the phase shift. It is done by having a structure with cavity filled with the liquid crystal and applied with certain voltage that can be changed. The changes in voltage would change the applied electric field, and thus would change the permittivity of the material. The changes would affect the wave propagation and thus contribute to the phase shifting. The performance of the phase shifter was tested by means of simulation using CST Suite 2014 software. The results show that the higher the frequency, the higher the phase shift would occur. The highest FoM achieved is 68 (deg/dB) at 8 GHz. A phase shifter with smooth and continuous phase shift can be used as the feeding network in an array scanning antennas systems.

Keywords: Phase shifter, liquid crystal, tunable materials, CPW, FoM

Abstrak

Kertas kerja ini membincangkan rekabentuk dan prestasi pengubah fasa bahan cecair kristal. Keperluan untuk peranti boleh ubah telah meningkat seiring dengan pembangunan system telekomunikasi. Adalah penting untuk merekabentuk pemboleh ubah yang berkesan dengan kos yang rendah dan saiz yang kecil . Kertas kerja ini membincangkan pengubah fasa menggunakan 5CB bahan kristal cecair. Kelebihan kaedah ini adalah kelancaran dan kesinambungan daripada peralihan dalam peralihan fasa. Pendekatan kaedah ini telah dicapai dengan menggunakan struktur dengan rongga kaviti yang diisi dengan cecair Kristal dan dikenakan voltan boleh ubah. Perubahan voltan akan mengubah medan electric dan dengan itu mengubah kebertelusan bahan berkenaan. Perubahan ini menyebabkan berlaku perubahan pada perambatan dan seterusnya mengubah fasa isyarat berkenaan. Rekabentuk berkenaan diuji melalui simulasi menggunakan perisian Suite CST 2014. Keputusan menunjukkan bahawa semakin tinggi frekuensi maka lebih tinggi anjakan fasa berlaku. FOM tertinggi dicapai ialah 68 (deg/dB) pada frekuensi 8GHz. Peralihan fasa yang lancar dan berterusan boleh digunakan sebagai rangkaian suapan pada sistem antena.

Kata kunci: Phase shifter, liquid crystal, tunable materials, CPW, FoM.

1.0 INTRODUCTION

Due to the increasing demand of frequency tunable devices in many applications (i.e. resonators, filters, antennas), tuning has been achieved by a method of using integrated electronic devices which involves the use of active components (i.e. PIN, Varactor, Schottky) [1, 2]. However, such a method has shown weakness in the transitions while tuning due to the discrete tuning ability where the tuning occurs at certain distinct frequencies. Beside the use of active elements, passive elements using tunable materials (i.e. ferrites, ferroelectrics, liquid crystal) provide continues frequency tuning [3, 4, 5]. Thus, introducing a phase shifter of which the shifting occurs due to the tunability of a material such as liquid crystal, would be able to produce a continuous and smooth phase shift. Hence, implying this result in a radar and communication systems would be beneficial as the existing mechanical system, which requires high power consumption, is not environment-friendly. Liquid Crystal (LC) is a dielectric material which occurs between the physical states of solid and liquid, hence the name. Moreover, LC has three common mesophases which are nematic, smetic and cholesteric. The nematic mesophase liquid crystal is the most commonly used in microwave and millimeter frequencies [6]. To exhibit the molecules of LC, a director $\vec{n}$ is used to point along the main direction of the molecule. The point of interest of LC is that, LC has the anisotropy property of dielectric where the permittivity of LC changes as the LC's molecules are polarized by electric or magnetic fields (i.e. in this case E-field is used). Furthermore, the permittivity of LC varies between perpendicular permittivity ($\varepsilon_\perp$) and parallel permittivity ($\varepsilon_\parallel$) whereas the permittivity increases as the applied E-field increases. The direction of the permittivity (parallel and perpendicular) is stated as the direction of the $\vec{n}$ director with respect to the direction of the applied of E-field [7, 8]. Figure 1 below the molecules orientation of dielectric anisotropy of LC by applying different E-field levels.

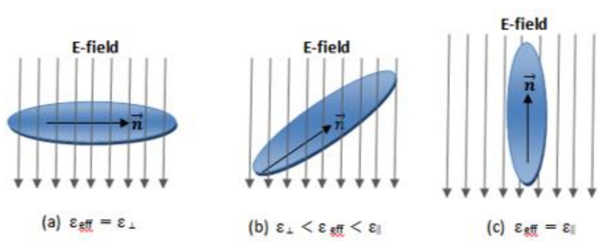


Figure 1: LC Molecules Polarization toward the applied E-field [4].

The Nematic Liquid Crystal (NLC) used in this paper is known as K15 (5CB) which has perpendicular permittivity of ($\varepsilon_\perp$= 2.72) and parallel permittivity of ($\varepsilon_\parallel$ = 2.9) [2]. Moreover, the impact of the dielectric anisotropy and the phase shift can be shown from the relationship as in equation (1) [5].

$$\boldsymbol{\theta} = \frac{2\pi.L.f.\sqrt{\varepsilon_{eff}}}{c} \quad (1)$$

Where θ is the insertion phase (S_{21}, deg°), L is the length of which liquid crystal is contained, f is the operating frequency, ε_{eff} is the effective permittivity and c is the speed of light in vacuum. Because the effective permittivity of the liquid crystal is varied between the minimum perpendicular permittivity and maximum parallel permittivity, the maximum phase shift that can be obtained using liquid crystal phase shifter, is found to be as differential phase between the obtained phase shift due to the perpendicular permittivity and the parallel permittivity. Equation (2) shows the differential phase shift of LC phase shifter.

$$\Delta\boldsymbol{\theta} = \frac{-2\pi.L.f.(\sqrt{\varepsilon_{(E)}} - \sqrt{\varepsilon_{(0)}}}{c} \quad (2)$$

2.0 LIQUID CRYSTAL FILLED CPW STRUCTURE

The concept of controlling the signal by controlling the molecule polarization is employed. The phase shifter in this work is realized by means of a CPW structure with a cavity. A CPW line in implemented with a bridge connecting the two ground planes as shown in figure 2. The bridge creates a cavity to be filled with liquid crystal.

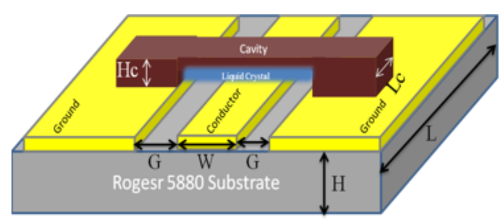


Figure 2: The CPW Structure with the Cavity and Liquid Crystal.

The structure is designed to have an impedance of 50 ohm and a substrate material of Rogers 5880 (ε = 2.2 which is less than LC permittivity, thus, allowing most of E-field to propagate through the LC. The dimensions and the descriptions as shown in Figure 2, are provided in Table 1.

Table 1: Dimensions of the Designed Structure.

Parameter	Value	Description
W	14 mm	Width of the conductor slot
G	0.35 mm	Gap between the conductor slot and a ground plane
L	26 mm	Length of the transmission line
H	0.79 mm	Height of the dielectric
Hc	5 mm	Height of the cavity
Lc	10 mm	Length of the cavity
T	0.0175 mm	Thickness of the copper
Wg	35 mm	Width of a ground plane

1

software which is object oriented software. The structure is drawn with the dimensions as shown in Table 1. Furthermore, the ports were of the type waveguide ports to allow the monitoring of the E-field through the structure. The liquid crystal was defined in the library of CST by means of using the dielectric dispersion of the material. Moreover, the simulation frequency was set as 1-70 GHz in order to investigate the performance of the phase shift for higher frequencies.

To verify the validity of the structure, monitoring the E-field in CST software was used. This feature of monitoring the E-field would help to show the propagation mode of the E-field. The structure is designed so that the E-field propagates through the liquid crystal. Figure 3b shows the propagation mode of the E-filed in the structure where it shows that the E-filed concentrates at the edges of the transmission line between the conductor slot and the ground planes.

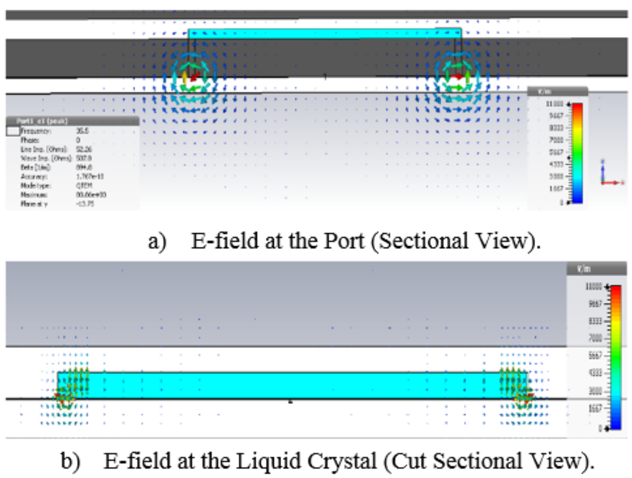


Figure 3 Propagation of the E-field though the structure (a) at the port, (b) in the cavity

3.0 RESULTS & DISCUSSION

The scattering parameters of the presented liquid crystal phase shifter were found by means of simulation using CST Studio Suite 2014. Figure 4 & 5, show the return and insertion losses (respectively) in decibel for the design versus the frequency range of 1 to 70 GHz. The losses figure show the responses of the phase shifter for different liquid crystal's permittivity (perpendicular and parallel). As shown from the losses results, it can be said that the phase shifter was able to pass the wave for every quarter wavelength and reject the rest.

Figure 6 shows the differential phase shift of the strcutre which is the difference between the phase shift obtained at the parallel permittivity and the phase shift obtained at the perpendicular permittivity as given by equation (2). Figure 6 shows that the maximum differential phase shift occurs at 55 GHz with phase shift range of 914 degrees. Such result would provide wide range of phase shifts when it is used for array beamforming antenna. In addtion, Figure 6 shows some peaks at different bands of frequnecies. These peaks could be of benefit when the frequency band is specified.

The phase shift response of some selected frequencies is shown in figure 7. In addition, figure 7 shows that the higher the frequency, the higher the phase shift is. Furthermore, the figure of merit of the structure is shown in figure 8. Figure of merit is known as the ratio of the phase shift of the structure over the insertion loss (deg / dB). Hence, for this structure the figure of merit is the ratio of the phase shift to the insertion loss for the maximum permittivty (i.e. parallel permittivty). The figure of merit response shows
some peaks at different bands of the range of frequency with the highest figure of merit of 68 (deg / dB) at frequency of 8 GHz.

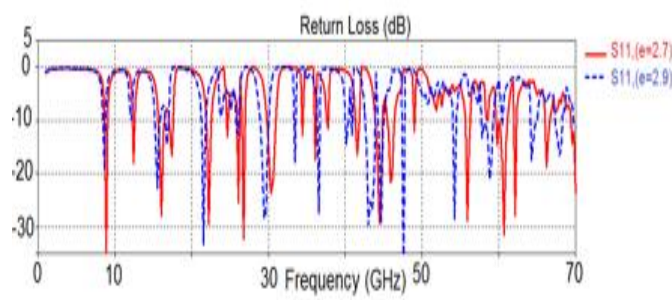


Figure 4 Simulated S_{11} at maximum and minimum permittivity

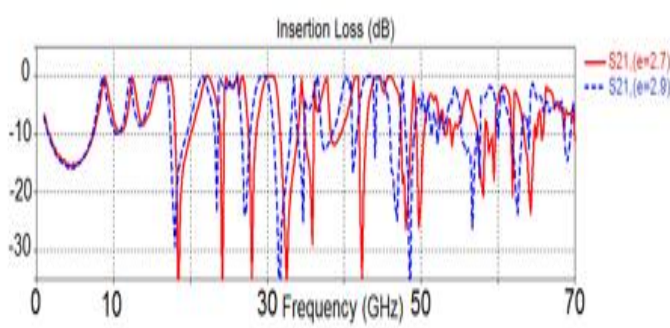


Figure 5 Simulated S_{21} at maximum and minimum permittivity

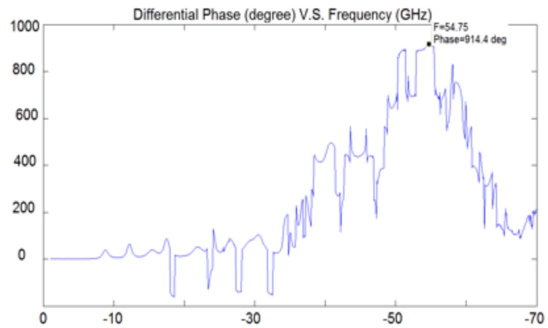


Figure 6 Differential Phase Shift between parallel and perpendicular permittivity

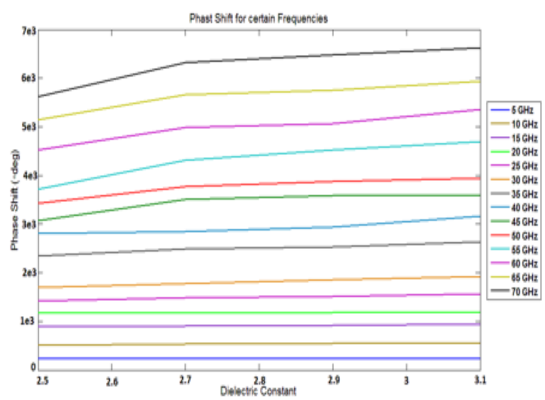


Figure 7 Phase shift at different frequencies

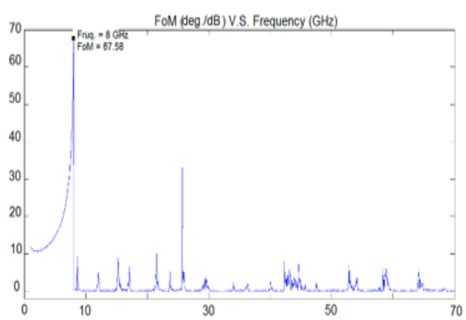


Figure 8 Figure of Merit (FoM)

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4.0 CONCLUSION

A passive phase shifter was introduced using anisotropy nematic liquid crystal. Modification upon coplanar waveguide transmission line was made in order to contain the liquid crystal in a cavity. The highest differential phase shift was obtained at 55 GHz as 914 degree. This wide range of the phase shift provides a preferable range for the phase shifter to be used in a feeding network of an array antenna system to perform scanning beamforming. In addition, the best ratio of FoM for this phase shifter was obtained as 68 deg/dB at 8 GHz, showing minimum loss for such design to be used in steerable antennas systems. All in all, the response showed that the higher the frequency is, the higher the phase shift would occur with some peaks at different frequency bands.

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