Jurnal Teknologi, 47(D) Dis. 2007: 131–138

PHASE AGILITY OF REFLECTARRAY PATCH ELEMENT USING NEMATIC LIQUID CRYSTAL

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Abstract. There has been much interest recently in developing reconfigurable reflectarray antenna for tunable microwave applications. Liquid crystal (LC) has been given much attention due to its dielectric anisotropy property which allows the change in the frequency and hence the reflection phase. In this paper, the phase agility of the periodic array using K15 nematic liquid crystal as the dielectric permittivity is presented. Numerical and experimental results at X-band are used to compare the plane wave scattering parameter from a two patch reflectarray cell of 500 μm. A tunable dynamic phase range of 221° is achieved over a broad band of 170 MHz which also gives a tunability of 0.39.

Keywords: Dielectric anisotropy, liquid crystal, phase range, tunability

Abstrak. Terdapat kajian yang cukup meluas darsa warsa ini dalam membangunkan teknologi antenna tatasusun terpantul yang boleh dimanfaatkan dalam kepelbagaian aplikasi kebolehtukaran gelombang mikro. Laporan kajian terkini menunjukkan bahawa kristal cecair telah diberikan tumpuan yang memberangsangkan oleh para pengkaji memandangkan ciri kebolehubahan dielektriknya yang membenarkan perubahan dalam frekuensi dan seterusnya fasa pantulan antena. Dalam kertas kerja ini, kebolehtukaran fasa untuk tatasusun antenna menggunakan bahan kristal cecair dalam fasa nematik K15 sebagai bahan dielektrik dibentangkan. Pengukuran bagi parameter taburan telah dijalankan menggunakan teknik simulator pandu gelombang dengan aplikasi voltan dc daripada 0 hingga 20 V. Keputusan-keputusan simulasi dan eksperimen dalam julat jalur frekuensi X digunakan untuk membandingkan parameter taburan gelombang sekata daripada sel tatasusun antena berkristal cecair yang berketinggian 500 μm. Keputusan eksperimen menunjukkan bahawa julat fasa dinamik setinggi 221° telah dicapai menerusi julat frekuensi berjalur lebar 170 MHz yang turut memberikan nilai kebolehtukaran sebanyak 0.39.

Kata kunci: Kebolehubahan dielektrik, kristal cecair, julat fasa, kebolehtukaran

1.0 INTRODUCTION

A reflectarray antenna consists of a planar array of radiating elements which are printed on a grounded substrate and illuminated by a primary feed horn [1]. The dimensions of the individual patches are designed to synthesize a progressive phase distribution across the aperture in order to create a plane wavefront. Although many aspects of the antenna performance are superior to microstrip arrays and conventional reflectors, the

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main disadvantage of the refletarray is the limitation that is imposed on the bandwidth of the radiating elements. For a number of applications and especially for radar systems, fast beam scanning is required [2]. Folded reflector antennas as described in [3] employ a simple mechanical scan mechanisme, however motors are slow, gravity sensitive and susceptible to shock. A better option is to use electronic beam scanning since this lends itself to faster beam steering and because no moving parts are required, it is a more robust and reliable method for obtaining the required coverage. Although electronic beam scanning can also be implemented by using tunable microwave devices such as ferroelectric phase shifters or varactor diodes [4], but they significantly increase the complexity and the cost of the scanning systems. In the past five years, there has been considerable interest in exploiting anisotropy property of nematic liquid crystals in order to produce tunable microwave components [3]. There have been many attempts reported [5-7] recently which have demonstrated the possibility of creating a phase agile reflectarray antenna using liquid crystal where the reflected signal is controlled by applying a dc voltage between the resonant element and the ground plane. Waveguide simulator measurements have been performed to validate the computer model predictions using a two patch array LC cell of 200 μm.

2.0 LIQUID CRYSTALS PROPERTIES

Nematic phase state liquid crystal is a non linear dielectric material in which the dielectric constant can be changed between two extreme states that are described by the orientation of the LC molecules, either parallel or perpendicular to the excited RF field. The effective dielectric anisotropy is defined as:

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

$\Delta\varepsilon$ = Dielectric anisotropy

$\varepsilon_{//}$ = LC permittiviy with DC voltage

$\varepsilon_{\perp}$ = LC permittiviy without DC voltage

The permittivity of the tunable layer and hence the electrical size of the patches can therefore be controlled by varying the voltage that is applied between each patch element and the ground plane.

Figure 1 depicts the change of the orientation of the liquid crystal molecules with and without the voltage applied. As shown in the above diagram, the molecules of nematic liquid crystals are aligned perpendicular to the electric field if there is no voltage applied because the effect of the rubbed thin polymer layer which is deposited on the surface of the two electrodes. The purpose of the applied field is to overcome the torque on the molecular dipoles that is exerted by the alignment layer.

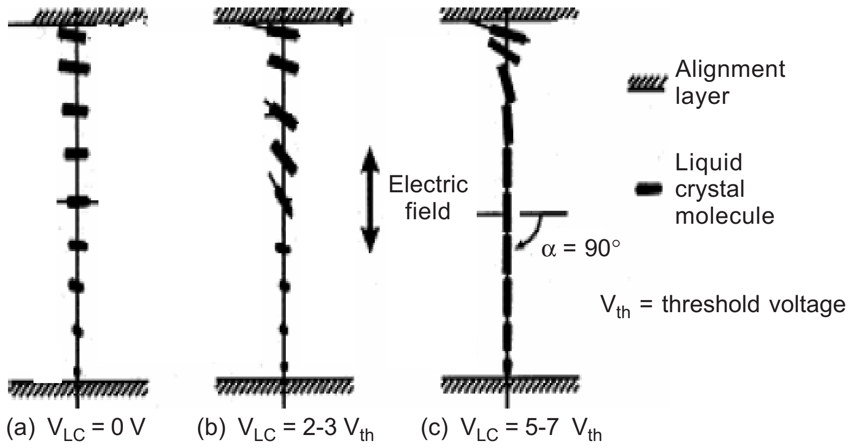

Figure 1 Change in the position of the LC molecules with increasing voltage [8]

3.0 SIMULATION RESULTS

Plane wave scattering from the reflectarray elements over the frequency range 9-11 GHz has been computed using Ansoft HFSS. The purpose of this study was to establish the effect of varying the LC permittivity material and anisotropy value on the phase range and the reflection loss. In this work, a cell geometry of 500 μm was modelled. Figure 2 shows the dimensions of the patch element which was separated from the ground plane by an LC cell (T_{LC}) of 500 μm in which the patch element was printed on a 125 μm glass reinforced PTFE substrate (T_s) with $\varepsilon = 2.8$, tan δ = 0.0028.

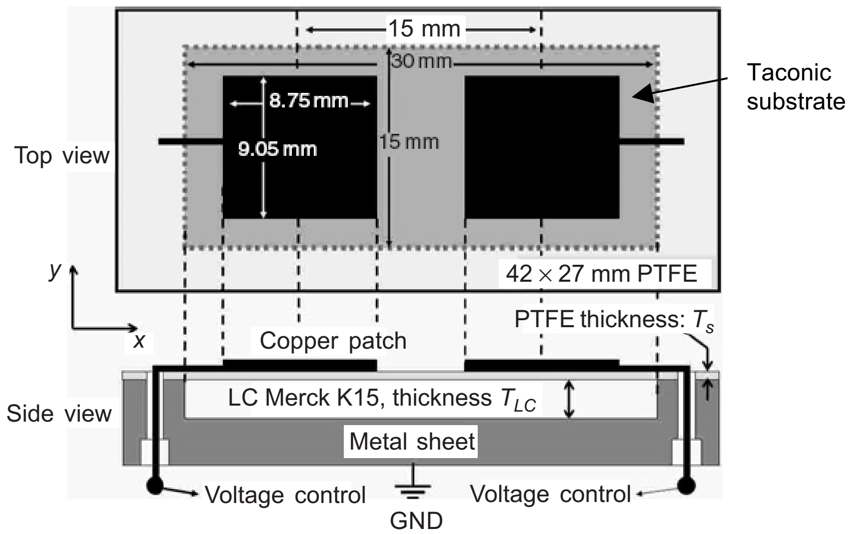

Figure 2 Reflectarray cell geometry

The ratio of the tunable layer and non tunable layer was selected to maximize the controlled phase range whilst reducing the reflection loss which is responsible for distortion in the phase plots when a small external voltage is applied. The electrical properties of the commercially available K15 LC were used in the computer model. A comparison between the measured and computed results (4.0) suggests that the anisotropy and loss tangent values of this material are ($\varepsilon_{\perp} = 2.10$ (0 V) and $\varepsilon_{//} = 2.27$ (20 V)) and 0.065 respectively. It should be noted that the anisotropy value is reduced because a rubbing layer was not used in the experimental devices [3]. Analysis of phase curves variation has also been done in Ansoft HFSS to investigate the phase curve trend using different values of dissipation factor. The objective of this computation was to demonstrate the trade-off between the phase variation and the reflection loss. As shown in Figure 3, it is clearly shown that the gradient of the phase curve becomes shallower as the dissipation factor (tan δ) decreases which results in the small phase variation.

For instance, the phase curve with dissipation factor of 0.065 has a rapid phase variation as compared to the phase curve with the lower dissipation factor of 0.03. This is due to the stronger dielectric absorption in the dielectric layer with higher dissipation factor which causes the rapid multiple bounces of the microwave energy to bounce back and forward in the LC layer. As a result, more energy is lost in the LC layer

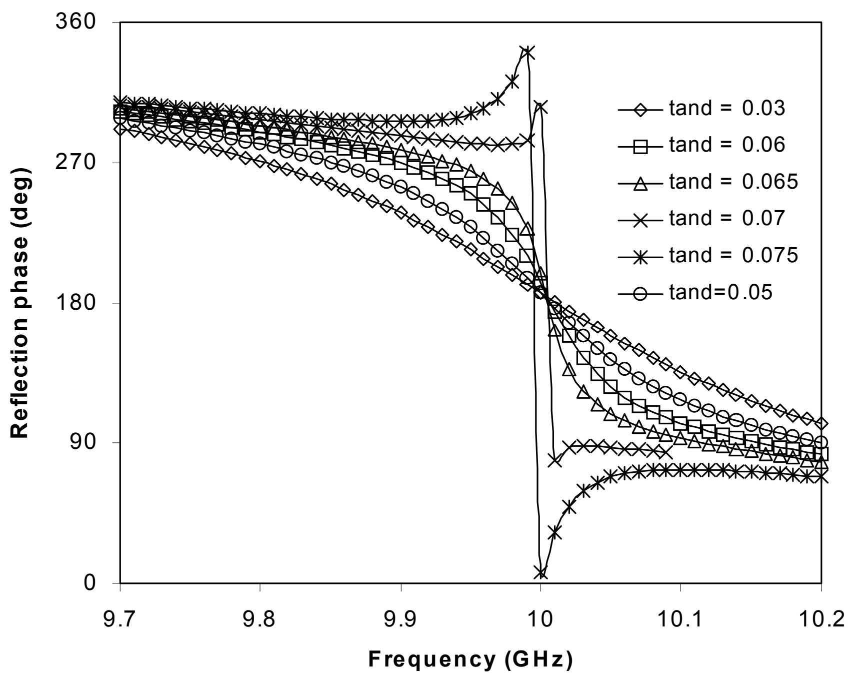

Figure 3 Phase curve variation of the periodic array with different dissipation factors

resulting in the sharper roll-off of the phase curve as shown in Figure 3. Additionally, the phase curve becomes distorted as the dissipation factor is increased to 0.07 which is the threshold value of dissipation factor for this antenna configuration.

4.0 EXPERIMENTAL RESULTS

Measurements have been performed using the waveguide simulator technique to validate the computer model. The patches were printed on 42 mm × 27 mm TACONIC glass reinforced PTFE substrate corresponding to the thickness and the electrical performance parameters that were modeled. The LC was inserted into a 30 × 15 mm × 0.5 mm milled cavity and the metal block was then bonded to the printed array using an epoxy gasket. An identical bias voltage was applied between the ground plane and the low impedance point positioned midway along the non radiating edge of the two patches as shown in Figure 2. These were energized by a 5 kHz sine wave with a maximum control voltage of 20 V peak to peak. The voltage was varied from 0 to 20 V as shown in Figure 4. Figure 5 shows the excellent agreement between the measured and predicted results using values of tan δ = 0.065, $\varepsilon_{\perp}$ = 2.10 (0 V) and $\varepsilon_{//}$ = 2.27 (20 V).

When the control voltage was increased from 4 V to 20 V the resonant frequency of the 500 μm thick LC reflectarray decreased from 10.2 to 9.98 GHz giving a maximum

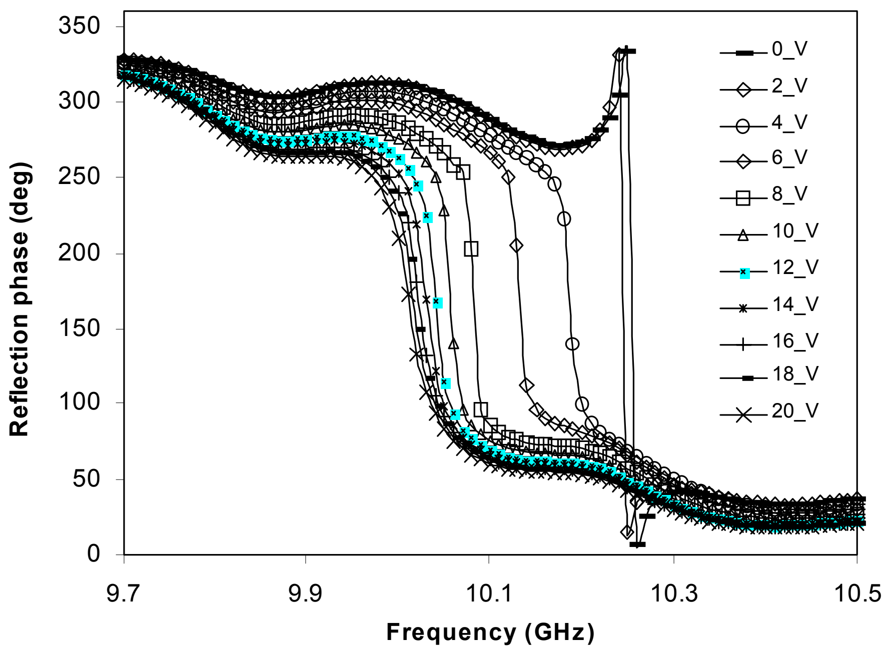

Figure 4 Measured phase response of the periodic array with applied dc voltage

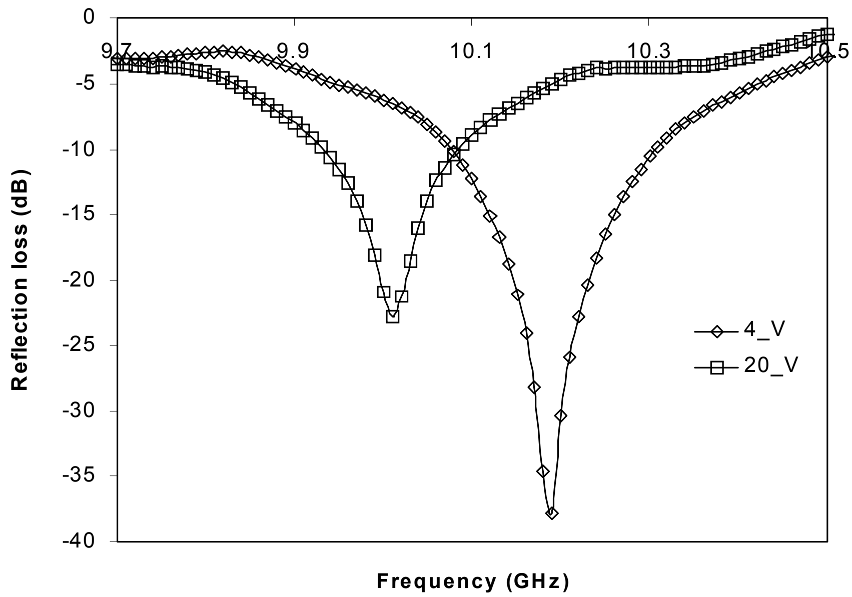

Figure 5 Measured reflection loss at two different voltage states

dynamic phase change of 221° at the band centre as depicted in Figure 7. As shown in Figure 5, the measured reflection loss was shown to vary between 22 dB and 38 dB in this range of phase states.

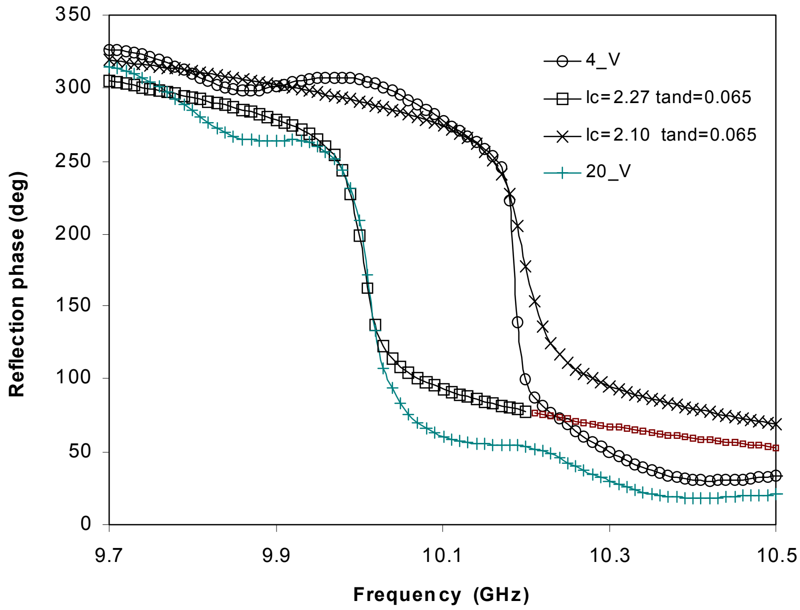

Figure 6 Measured and simulated phase response of the periodic array

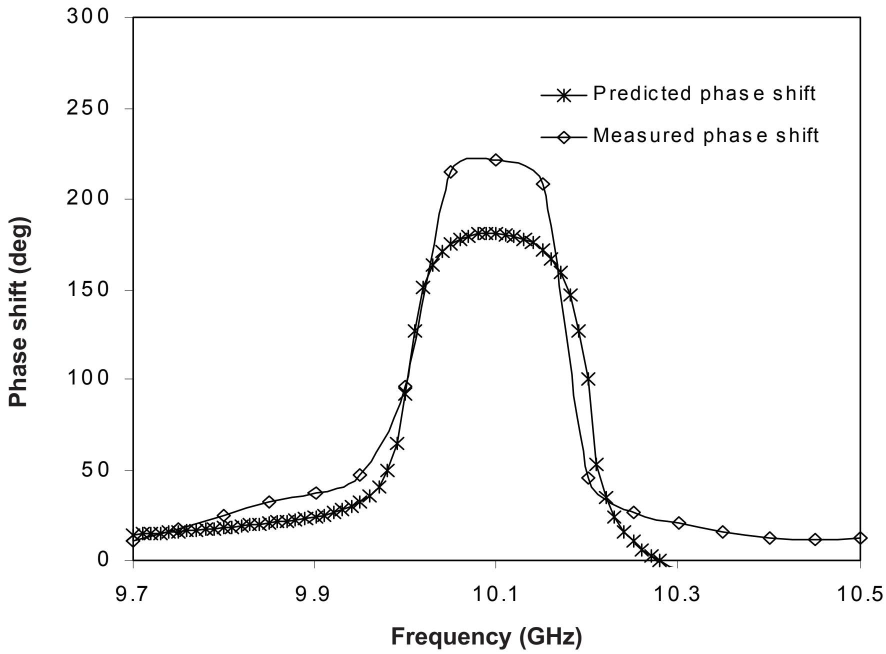

Figure 7 Measured and simulated phase shift curve of the periodic array

Data fitting was used to quantify the loss tangent and the permittivity values of the liquid crystal substrate, and these dielectric parameters were then used in the Ansoft HFSS MoM program. As shown in Figure 6, the results demonstrate that the dielectric constant changes from 2.10 to 2.27 which gives a tunability of 0.39 with a dynamic phase range of 221° over a broad band of 170 MHz as shown in Figure 7.

5.0 CONCLUSIONS

The results of this preliminary study demonstrates the feasibility of obtaining a tunability from the reflectarray elements by exploiting the anisotropy property of nematic liquid crystal of K15. Experimental implementation of this work involves the LC dielectric characterisation at microwave frequencies which has been investigated. Experimental evidence show that this type of phase shifter might be more suitable for milimeter wave applications to overcome the performance limitations with the existing phase shifters. Different techniques are still being developed to reduce the loss of the reflectarray antenna whilst obtaining a greater dynamic phase range.

ACKNOWLEDGEMENTS

M. Yusof Ismail is supported by a scholarship from the University of Tun Hussein Onn Malaysia.

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