Phase Tunability of Reflectarray Patch Elements Using Tunable Dielectric Substrate of 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 phase of reflection. In this paper, the phase tunability of the periodic array using K15 nematic liquid crystal as the dielectric permittivity is presented. Simulated 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 221o is achieved over a broad band of 220 MHz which also gives a tunability of 2.2%

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 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]. A progressive change in the phase is essential in order to scan the beam in a desired direction. 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],[6],[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 500 µm.

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 [8]. The effective dielectric anisotropy is defined as:

$$\Delta e = e_{//} - e_{\perp} \tag{1}$$

Δe = Dielectric anisotropy
$e_{//}$ = LC permittivity with DC voltage
$e_{\perp}$ = LC permittivity 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. An applied electric field is employed to overcome the torque on the molecular dipoles that is exerted by the alignment layer.

SIMULATED 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. Fig. 1 shows the dimensions of the patch element which was separated from the ground plane by an LC cell (TLC) of 500 μm in which the patch element was printed on a 125 μm glass reinforced PTFE substrate (Ts) with e = 2.8, tan d = 0.0028.

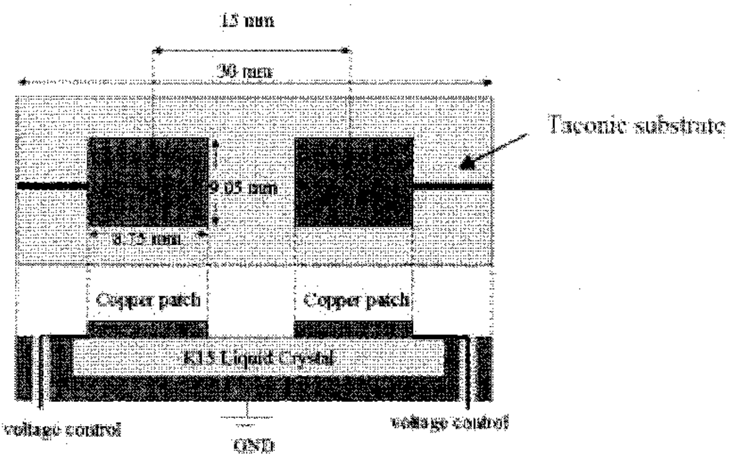

Fig. 1 Reflectarray cell geometry.

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.

EXPERIMENTAL RESULTS

Measurements have been performed using the waveguide simulator technique to validate the computer model. The patches were printed on 42 mm x 27 mm TACONIC glass reinforced PTFE substrate. The LC was inserted into a 30 x 15 mm x 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 Fig. 1. These were energized by a 5 kHz sine wave with a maximum control voltage of 20 V peak to peak. Fig. 2 shows measured phase curves of two patch element printed above a 500 μm grounded LC cavity generated within bias voltage range of 4V-20V.

As depicted in Fig. 2, 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 dynamic phase change of 221° at the band centre. Fig. 3 depicts measured scattering parameter results of the two patch element unit cell. As shown in Fig. 3, the measured reflection loss was shown to vary between 22 dB and 38 dB in this range of phase states. 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. Fig. 4 shows an excellent agreement in which a comparison between the measured and computed results suggests that the anisotropy and loss tangent values of this material are ($e_{\perp}$ = 2.10 (0 V) and $e_{//}$ = 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]. The results as depicted in Fig. 4 demonstrate that the dielectric constant changes from 2.10 to 2.27 which gives a tunability of 0.17 with a dynamic phase range of 221o over a broad band of 220 MHz.

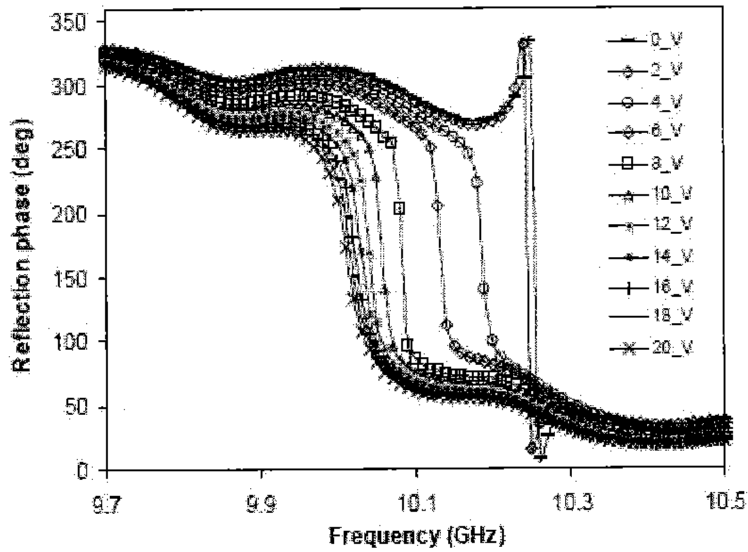

Fig. 2 Measured phase response of the periodic array with applied dc voltage.

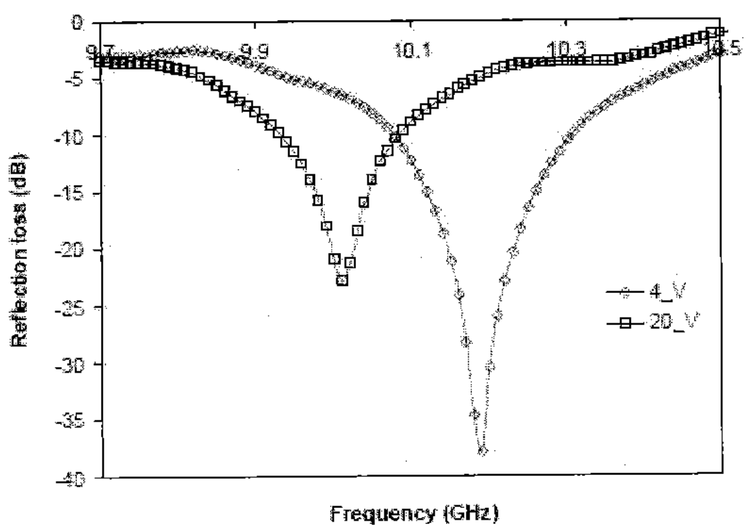

Fig. 3 Measured reflection loss at two different voltage states.

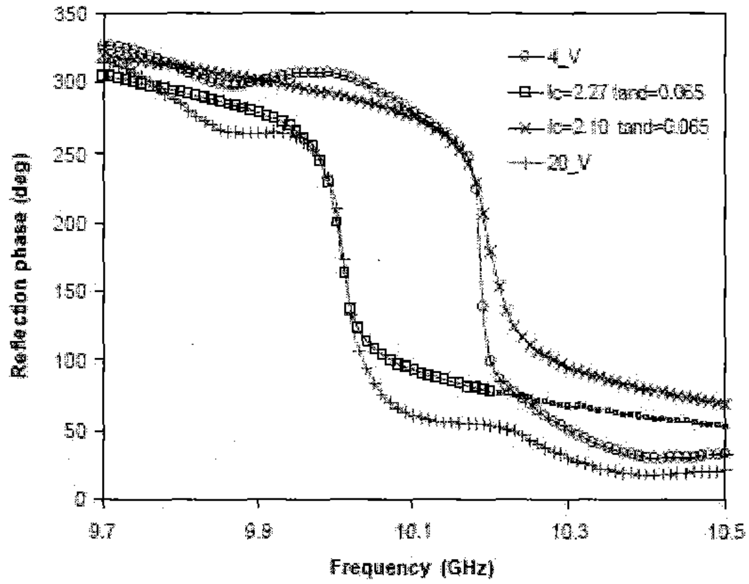

Fig. 4 Measured and simulated phase response of the periodic cell.

CONCLUSIONS

The results of this preliminary study demonstrate 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. Further work will be carried out to investigate the feasibility of realizing an electronically scanned reflectarray antenna. 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.

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