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Procedia Engineering 53 (2013) 203 – 207

Procedia Engineering

www.elsevier.com/locate/procedia

Malaysian Technical Universities Conference on Engineering & Technology 2012, MUCET 2012
Part 1 – Electronic and Electrical Engineering

Performance Analysis of Reflectarray Resonant Elements based on Dielectric Anisotropic Materials

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Abstract

This paper presents a thorough investigation of the relationship between reflection loss and dynamic phase distribution performance of three different reflectarray resonant elements. The tunability characteristics of rectangular, dipole and ring elements printed on grounded non-linear dielectric anisotropic substrates have been investigated at X-band frequency range using CST computer model. A detailed analysis of reflection loss and dynamic phase range, with respect to dielectric anisotropy is presented for different anisotropic liquid crystal substrate materials. Preliminary analysis results show that ring element offers the highest reflection loss and dynamic phase range of 56.54 dB and 248° respectively compared to rectangular element which offers 10.74 dB and 90° respectively. Furthermore the rectangular element attains a maximum frequency tunability of 796 MHz compared to ring element which attains 716 MHz. Moreover it has also been shown that an increase in dielectric anisotropy of non-linear materials affect dynamic phase ranges and frequency tunability of three resonant elements.

Selection and peer-review under responsibility of the Research Management & Innovation Centre, Universiti Malaysia Perlis

Keywords: reflectarrays; resonant elements; dynamic phase range; frequency tunability.

1. Introduction

Antennas have an important role in the field of communications to exchange the information at a distance. Parabolic antenna is the main consideration for communication purposes since last few decades but due to its curved surface and bulky structure, researchers are always in search of a better alternative solution. Therefore a flat surface reflectarray antenna is gaining importance because of its lower cost and smaller size. It consists of printed reflecting elements on a grounded flat dielectric surface, illuminated by a feed antenna [1]. It can be designed to have very high gain with relatively good efficiency, as well as to have its main beam scanned to large angles from its broadside direction [2]. But due to its loss performance and narrower bandwidth its applications are limited, especially in radar and satellite communications [3]. These limitations can be decreased by the selection of a suitable reflecting element with proper dielectric substrate [4], [5]. Liquid crystal materials can be realized as a dynamic phase control strategy in reflectarrays due to their non-linear dielectric properties [6, 7]. In this work various types of non-linear liquid crystal substrate materials, listed in Table I, are used to design different types of X-band reflectarray patch elements namely rectangular, dipole and ring, printed on 1mm thick anisotropic substrate resonating at 10 GHz.

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Selection and peer-review under responsibility of the Research Management & Innovation Centre, Universiti Malaysia Perlis
doi:10.1016/j.proeng.2013.02.027

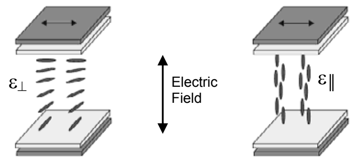

Fig. 1. Design configuration of unit cell reflectarray element with different resonant elements

TABLE 1 NON-LINEAR LIQUID CRYSTAL SUBSTRATE MATERIALS

Anisotropic LC Materials	$\varepsilon_\perp$	$\varepsilon_\parallel$	**Dielectric Anisotropy ($\Delta\varepsilon = \varepsilon_\parallel - \varepsilon_\perp$)**	**tanδ⊥**	**tanδ‖**
K15 Nematic	2.1	2.27	0.17	0.072	0.06
Merck BL037	2.25	2.45	0.2	0.048	0.025
Chisso JB-1017	2.5	2.9	0.4	0.015	0.005
LC-B1	2.6	3.05	0.45	0.022	0.007

The numerical Finite Integral Method (FIM) has been used to investigate the reflection loss and dynamic phase range characteristics by using commercially available CST computer model.

2. Dielectric Anisotropic Materials

Non-linear dielectric materials are also called dielectric anisotropic materials. Anisotropy means materials which have variation in values of a property in any direction. Dielectric anisotropic materials have a non-linear or variable dielectric permittivity "ε" [8]. It is possible to vary the dielectric permittivity of anisotropic materials simply by applying a dc voltage across the substrate [9], which allows the molecules of anisotropic material to be oriented parallel to the incident field and attain maximum dielectric permittivity value ($\varepsilon_\parallel$). Where as without a dc voltage molecules of anisotropic material are oriented perpendicular to the incident field and material attains a minimum dielectric permittivity value ($\varepsilon_\perp$) [10] as shown in Fig. 1. Table I summarizes the properties of non-linear dielectric materials that are used to design the reflectarray resonant elements. The tunability capability in dielectric permittivity is required in order to realize dynamic phase distribution of reflectarrays. The difference between maximum and minimum value of dielectric permittivity is called dielectric anisotropy of material and is given by equation (1).

$$\Delta\varepsilon = \varepsilon \parallel - \varepsilon \perp \qquad (1)$$

Where, $\Delta\varepsilon$ = Dielectric anisotropy

$\varepsilon_\parallel$ = Dielectric constant with applied DC voltage

$\varepsilon_\perp$ = Dielectric constant without DC voltage

3. Results and Discussion

The non-linear dielectric materials have a range of dielectric permittivity values. Therefore in this work, the minimum ($\varepsilon_\perp$) and maximum ($\varepsilon_\parallel$) dielectric permittivity values are considered for each material, so each material holds two different values for reflection loss and reflection phase, operating at 10 GHz.

3.1 Reflection Loss And Frequency Tunability

The reflectivity performance of reflectarray resonant elements based on a selected anisotropic material named LC-B1 is shown in Fig. 2. As depicted in Fig. 2, it has been observed that ring element is observed to offer a maximum reflection loss performance of 7.92 dB as compared to dipole and rectangular elements which offer 7.19 dB and 3.54 dB respectively. This is because the rectangular element has a wider reflecting area as compared to dipole and ring elements respectively.