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Microwave tunable split ring resonator bandpass filter using nematic liquid crystal materials

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ABSTRACT

In order to improve frequency selectivity of microwave devices and raise the frequency spectrum efficiency effectively, a new kind of microwave continuously tunable Split Ring Resonator (SRR) band-pass filter, using the field-induced nematic liquid crystal, is presented in this paper. Based on the fundamental theory of the electro-optic effect of liquid crystal, applying the bias voltage on liquid crystal can change its permittivity to mainly realize passband frequency shift at microwave band. The frequency characteristics of the filter are analysed. The proposed parameter extraction on the base of the frequency characteristics can easily analyze distributing parameter circuit about this liquid crystal filter. The simulation results shows that this liquid crystal tuning filter achieves 750 MHz offset obviously. Compared with the other tuning techniques, the liquid crystal tuning technology has many advantages, such as continuously tuning, miniaturization, low tuning voltage, etc. Thus, it shows great potentials for modern communication applications.

1. Introduction

In recent years, with the fast development of modern wireless communication, high spectrum efficiency has become increasingly prominent. The tunable devices are more requested to improve frequency selectivity and raise the frequency spectrum efficiency effectively. And the tunable filter is one of the key devices to meet demands. Miniaturization, low tuning voltage and wide tuning range become important design objectives for tunable filters.

Existing tunable techniques mainly include ferrite material tuning, ferroelectric materials tuning, variable diode tuning and radio frequency micro-electromechanical systems (RF MEMS) tuning [1–4]. But they have disadvantages of slow tuning speed, large volume, poor linearity, high density, high tuning voltage, low tuning ratio and high cost. Therefore it is inevitable to develop higher performance of tunable filter by new material and new technology.

For now, the liquid crystal materials have developed rapidly. Because of the advantages of light weight, low tuning voltage, good linearity, fast tuning speed and miniaturization, the liquid crystal tuning is becoming a novel tuning technology to overcome many shortages of existing tuning techniques.

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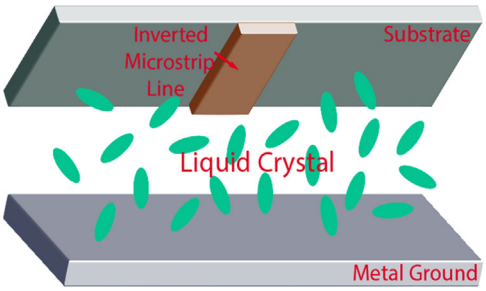

Fig. 1. The idea structure of the novel liquid crystal tunable circuit.

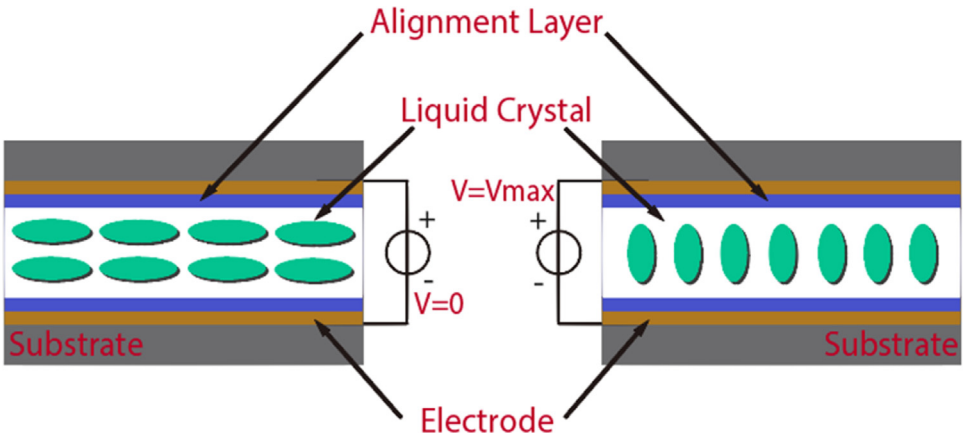

Fig. 2. Working principle of the field-induced nematic liquid crystal.

The liquid crystal belongs to organic compounds between liquid and crystalline under certain conditions (such as temperature), combining both the fluidity of liquid and the anisotropic of crystal. This kind of liquid crystal has a long cylindrical molecular structure, weak molecular bound and obvious fluidity. Because of the liquid crystal molecules are easy to slip between the layers, the liquid crystal is easily affected by the external environment, especially stresses, electromagnetic field and temperature. Therefore, the nematic liquid crystal presents special different electric-optical property from the ordinary crystal and the ordinary liquid. That is, The proposed nematic liquid crystal, as a high anisotropy electro-optic material, can realize the variations in dielectric permittivity, when applied various bias voltages [5]. This can be widely used in microwave and millimeter wave field and has offered an effective way to improve the performances of electronic systems.

The SRR is implemented by etching various forms of metal ring structures in the dielectric substrate. According to rational design and layout, the SRR is coupled to the main transmission line so that the flat structure of SRR exhibits negative effective permeability in the vicinity of its resonance frequency [6]. By using this character, the SRR structure has been widely researched and applied in microwave planar circuits. One advantage of SRR is that the structural size is far smaller than the wavelength at the resonance frequency, so that SRR can be used to design miniaturized devices.

In conclusion, researches and applications of liquid crystal and metamaterial SRR are becoming a focus in the new interdisciplinary study. This novel microwave tunable split ring resonator band-pass filter using the field-induced nematic liquid crystal can be widely used in modern wireless communication system. Fig. 1 shows the ideal structure of this novel liquid crystal tunable circuit.

2. Design of the field-induced nematic liquid crystal tunable SRR filter

2.1. The field-induced nematic liquid crystal

The structure design of this nematic liquid crystal filter is mainly due to the basic principle of the electro-optics effect of liquid crystal. As a kind of electro-optic material, the refractive index n_{eff} of liquid crystal change with the external electric field generated by bias voltage V, which led to the effective permittivity ε_r of liquid crystal change. Therefore, the dielectric anisotropy of liquid crystal changes to realize the frequency shifting in the condition of biasing [7,8].

The interaction between induced electric dipole moment of liquid crystal molecular and this electric field produce a torque that square with liquid crystal director for electric field when exposed to a low frequency drive electric field, that is, the special distribution of liquid crystal director is essentially changed. And for linearly polarized incident electromagnetic