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Original research article

A compact tunable microwave band-pass filter using liquid crystal material

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ABSTRACT

This filter uses liquid crystal (LC) as the electro-optic material. It can realize frequency shift by changing the dielectric anisotropy, when the bias voltage is added. It is mainly used in microwave frequencies. According to the simulation results, it achieves the center frequency with 770 MHz offset. It has many advantages compared to conventional filter, such as low weight, ability of continuously tunable, miniaturization, low processing costs, low tuning voltage, convenient manufacture, etc. Therefore, it has shown great potential for modern engineering application.

1. Introduction

With the rapid development of modern wireless communication technology, frequency congestion has become increasingly prominent. It makes a higher request to the tuning, multiband and multifunction of current RF and microwave devices to raise the utilization rate of the spectrum resource. The tunable filter is the key device to implement these technologies. Also, it is the key device in spread spectrum, frequency hopping and dynamic frequency allocation technologies. Therefore, low weight, low tuning voltage, fast tuning and wide tuning range become design requirements for a tunable filter.

The current tunable techniques mainly include variable diode tuning, ferroelectric materials tuning and radio frequency (RF) micro electro mechanical systems (MEMS) tuning. First, Yttrium Iron Garnet (YIG) has many advantages, but slow tuning speed and large volume limit its application in engineering field [1]. Second, most indices of Barium Strontium Titanate (BST) are in the middle level, though it shows a poor linearity. The density of Ba0.45Sr0.55TiO_3 is 5.9 g/cm^3–6.0 g/cm^3, and the density of liquid crystals is 1.0096 g/cm3. Therefore, under the same conditions, the weight of BST ferroelectric thin film is greater than that of the liquid crystal. Therefore, liquid crystal material is far more favorable for light weight applications, such as mobile devices, aerospace equipment, etc. In addition, the tuning voltage (up to about 30 V) of the BST ferroelectric thin film technology is much larger than that of Liquid crystal technology (up to about 10 V) [2]. Third, the tuning speed of diode is fast. But it has large poor linearity as well. And its bias voltage circuit is more complex [3]. Fourth, RF MEMS has better performances, but it has lesser tuning ratio and higher cost [4]. In conclusion, it is clear that the traditional microwave continuous tunable fail to meet the developing requirements of modern technology. So it is the inevitable to develop high

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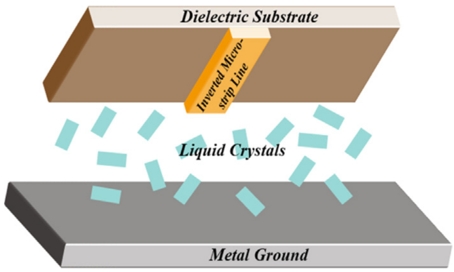

Fig. 1. The ideal structure of the novel liquid crystals circuit.

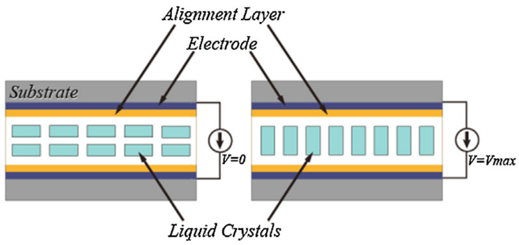

Fig. 2. Working principle diagram of the nematic liquid crystals.

performance microwave continuous tunable band-pass filter, which is designed by new material, new technology, new process and new method [5].

Recently, the nematic liquid crystals tuning technology becomes a new kind of tuning method in MICs. The nematic liquid crystals belongs to organic compounds. Its interior has long molecular structure. It is especially affected by the external environment. Especially in different concentration and temperature, it presents the orderly flow between liquid and solid. Thus, it has both the fluidity of liquid and the anisotropic of crystal. Liquid crystal is a fluid with its molecules directional distributed. Mainly, its optical properties, thermal properties, electrical properties, magnetic properties and mechanical properties all show the crystal anisotropy. And these properties are closely related to liquid crystal molecules alignment. Although liquid crystal merges the main properties of crystal and liquid, it presents special magnetic optical and electric optical properties which are different from the ordinary crystal and liquid. These properties of liquid crystal are widely used in different fields, particularly in the field of optical instruments. A lot of devices can be made of liquid crystal, such as liquid crystal light sensitive print head, electronic aperture, light modulator, phase diffraction grating, spatial modulator, optical switch, etc. Meanwhile, it has many advantages, such as low cost, miniaturization, low operating voltage and convenient manufacture, etc. The LC tunable filter can compensate the shortcomings of traditional structures with the feature of the variation of permittivity induced by electric field. With the advantage of low weight, low tuning voltage, fast tuning and wide tuning range, this filter is much applicable to modern wireless communication system. Therefore, the applicaion research of liquid crystal has become a research focus in the new interdisciplinary [6].

In this article, a novel microwave continuous tunable band-pass filter, based on nematic liquid crystals with better performance for microelectromechanical system application, has been presented. And an ideal structure of the novel liquid crystals circuit is shown in Fig. 1.

2. Design description

2.1. Nematic liquid crystals

As shown in Fig. 2, when the nematic liquid crystals work without bias voltage (V = 0), the long axis of the liquid crystal molecules are parallel to each other and parallel to the substrate (ROGERS 5880). At this point, the measured dielectric constant is $\varepsilon_\perp$. When applying an electric field E between the metallic ground plane and the inverted microstrip line with bias voltage (V = Vmax), the orientation of liquid crystal molecules will gradually turn to the direction of the electric field. When the bias voltage is high enough and achieves the saturation voltage of liquid crystals, the polarization of the nematic liquid crystals reaches saturation. At this point, the measured dielectric constant is maximum $\varepsilon_{//}$. And the dielectric constant stops changing over bias voltage Vmax. That is, ε has two different basic axis of eigenvalues $\varepsilon_{//}$ and $\varepsilon_\perp$ for its uniaxial symmetry structure. Meanwhile, the high frequency dielectric tensor corresponds to two kinds of different optical refractive index n_e and n_o. Liquid crystal molecules can interact with the externally loaded voltage for its low frequency dielectric anisotropic characteristics

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