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Tunable Microstrip Filters for Modern Wireless Communications

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***Abstract*— Microwave filters are essential components for a large variety of modern communication systems. Filters engage in many recreating roles in RF and microwave applications. Forthcoming technologies like wireless communications are racing with RF and microwave filters in performance, physical and cost parameters. Developing technologies in materials and fabrications are defining new paths in filter designs. Tunable filters that are able to cover a number of different frequency bands are always on demand by the progressing communications technology. In this paper, Electromagnetic Band Gap (EBG) structure is studied and the novel configurations of periodic filters on dielectric materials that dynamically change their electromagnetic properties under a DC voltage bias are obtained and analysed. A tunable filter is designed using a dielectric material which produces tuning in the filter frequency. The research is carried on a single resonance element and experimented for tunability variations. S-parameter responses are obtained and analysed for the developed model through simulations. The filter with EBG structure showed tunability replacing the Liquid Crystal (LC) dielectric material is presented.**

***Keywords*— Microstrip Filters, Tunable Filters, Electromagnetic Band Gap, Liquid Crystal Dielectric Materials, Wireless Communications.**

I. INTRODUCTION

Microwave filters are essential components for a large variety of modern communication systems. Filters engage in many recreating roles in RF and microwave applications. Futuristic applications like wireless communications are taxing Radio Frequency (RF) and microwave filters with stern requirements like higher performance, small size, light weight and low cost [1]. Modern technologies in materials, structures and fabrications like high-temperature superconductors (HTS), electromagnetic band gap (EBG), microelectromechanic system (MEMS) and miniaturization technologies have encouraged the advancement of microstrip filters in design and applications [1]. Superseding to it, development of computer aided design (CAD) software tools like Applied Wave Research (AWR) are uprising the design environments. These trends are continuing to grow by a greater pace with a demand of efficient signal transfer [2]. This research focuses on the tunable filters. Tunable filters are able to cover a number of different frequency bands. They provide greater functionality as the same hardware can be employed at multiple bands [3]. The design can bring supplementary operation in filters with either changing the patch size or dielectric substrate. These designs embrace advantages like compact size, simple circuit topology, good performances and miniaturizations, which can be easily tuned for the new applications. All above features are popular for the modern wireless communication systems [3].

This paper presents the research conducted on liquid crystal dielectric material to produce tunability in a microstrip filter. Initially to carry forward the experiment on dielectric material, miniaturized EBG structures based on complementary geometries is reviewed. Then simulation is carried on a structure with experimenting on path size and different dielectric material. With following experiments on the EBG structure S-parameters are produced using applied wave research – microwave office (AWR-MWO) simulation software thus expecting to gain tunability in the microstrip filter.

II. ELECTROMAGNETIC BAND GAP STRUCTURES

Developing interest in a miniaturizing microwave components (such as antennas, amplifiers, filters) and controlling harmonics via periodic structures etched on the ground plane i.e. EBG, photonic band gap (PBG) structures and defected ground structures (DGS) are the areas which are gaining extensive attention in current research. EBG structures are a class of artificial meta-materials which prohibits propagation of the electromagnetic waves within a certain frequency range [4]. EBG structure is selected as a base structure for this research as they are the periodic structures that prohibit the propagation of electromagnetic waves at microwave or millimetre wave frequencies. Based on the dimension of EBG unit cells, structures can be categorized into three-dimensional (3-D) and planar EBG structures. Because of their unique stop-band and slow-wave effect, planar EBG structures have been widely applied in designs of planar filters for the optimization of performance and miniaturization of the circuit. These properties favour the selection of structure for experimental process [4, 5].

EBG materials have a wide range of applications in RF and microwave engineering including microwave and optical cavities, filters, waveguides, and smart artificial surfaces, etc. [5]. Traditionally, band gap behaviour is achieved using a periodic dielectric or metallic structure with periodicity value comparable to the wavelength. Usually, 4–5 periods are needed to provide good band gap characteristics (high isolation). Considering above specifications the geometry seen in Figure 1 was selected for conducting this piece of research. The adopted geometry from Feresidis.et.al, (2006) establishes a strong base for this research work to develop confidence in expected research output.

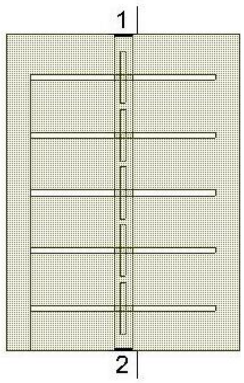

Fig 1: Schematic model Of EBG structure

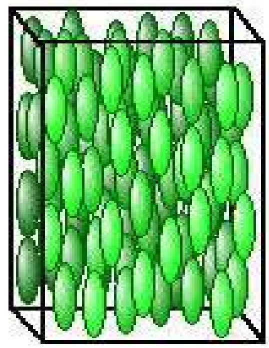

Fig 2: Nematic Phase in LC *adopted from* Dr. Mary Neubert, (1888)

III. Nematic Liquid Crystal MERK K15

An important property of a dielectric is its ability to support an electrostatic field while dissipating minimal energy in the form of heat. Another consideration is the dielectric constant. Lower the dielectric loss, the more effective is a dielectric material. Liquid Crystals (LC) exhibit dielectric properties within them due to their dielectric anisotropic and low loss. Liquid crystals are known for their widespread use in display devices. They have diverse properties like dielectric constant, dielectric anisotropy, optical transmittance and elastic constants which have commonly found multiple applications [6].

Nematic LC is a substance which has a high dielectric anisotropy and low loss property which makes it an ideal choice for preferring it to obtain tunability in the Microstrip filters. Anisotropy can be defined as, the variation amid the permittivity when the one dimensional molecules are orientated horizontal and vertical to the RF field [8]**.** Nematic phase is one of the phases of LC's. In this phase, the molecules are categorized with no positional order but they tend to point in the same direction. In the Figure 2, it can be noticed that the molecules point vertically but are arranged with no particular order. By applying external electrostatic field the nematic LC changes its dielectric constant between two tremendous states. Apart from this consideration of previous property, Nematic LC MERK K15 material used in this research study has an anisotropy value of 0.2 and it has electrically tunable dielectric constant (Є1 = 2.7, Є2 = 2.5) throughout the microwave frequency band (i.e., ΔЄeff = Є 1 – Є2) [7,8]. All these properties put together makes the LC MERK K15 most opt material for the research.

IV. Design and Simulation Results

Microstrip filter is modeled with a grounded periodic structure along with tunable LC substrate. Figure 3 shows a structure adopted from Feresidis.et.al. (2006) which has a microstrip line printed on a thin dielectric layer of polyester and is placed at the top of a grounded substrate of RT Duroid. At the bottom of the substrate the aperture array is etched. In very close immediacy another thin dielectric of polyester is placed where the dipole conductors are printed.

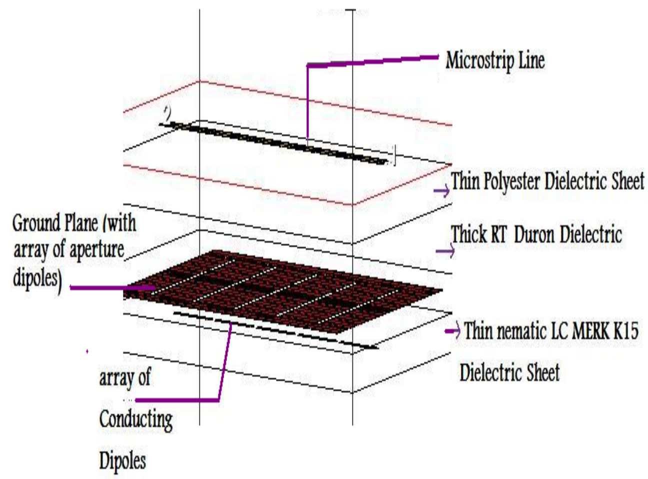

Fig 3: Sectioned Microstrip Layer

The apertures are rotated 90 degrees with respect to the conductor's as shown in Figure 4, so that both elements are polarized with the electric field and are therefore resonant. Significance of the rotation of the dipole aperture elements is that, they are perpendicular to the incident electric field [4] to achieve maximum element coupling.

The design of the microstrip filter starts with a simple computer model taken from Feresidis.et.al, (2006) in order to explore design options and gain an overall appreciation of the design problems and constraints. The approach adopted in this research is aimed to achieve same parameters and results obtained by Feresidis.et.al, (2006). The reason to use the same parameters is not to cross check the earlier results, but to gain the confidence on the process being followed by Authors. The parameters used for computer model are:50 Ω Microstrip line, aperture length L2, aperture width W2, conducting dipole length L1, conducting dipole width W1, thick dielectric substrate and thin dielectric substrate's thickness and dielectric constant.

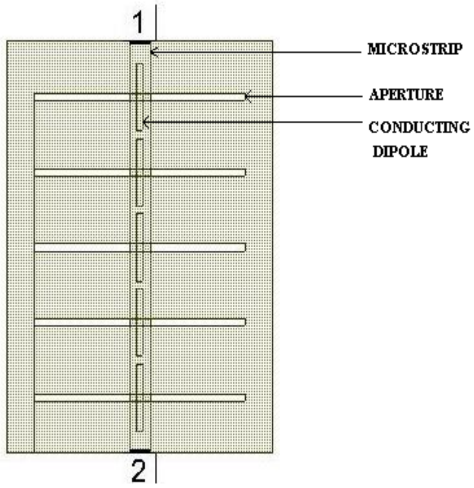

Fig 4: Schematic Microstrip structure with aperture and conducting dipoles

A. Modeling and Simulation

AWR MWO software package was chosen as platform to carry out the research work. This software includes advanced 3D design structure in its Axiem feature, which eases the design and simulation of the research model. A full wave analysis of a single basic section of the periodic structure and unit cell is carried out initially. With the design, simulation responses of S - parameters namely S11 and S21 of finite structures are obtained, for different parametric studies.

Aim of this work was to understand and improve the tunability of the microstrip filter in order to facilitate its tuning. Microstrip filter consists of grounded planar array of aperture elements [4]. Thin dielectric sheets with conducting dipoles are printed below the ground plane at 90 degree to the apertures to obtain maximum element coupling [4]. The shift in resonant frequency is observed by varying the physical size of conducting dipole as seen in simulation 1 with structures 1 and 2. Later in simulation 2 changing the thin layer of Polyester dielectric material above ground plane to LC MERK K15 dielectric material in the structure simulation experiment conducted. S-parameters responses obtained from simulation of microstrip filter with 0.035 mm thick LC substrate are analyzed and presented in next section.

B. Simulation 1: Analysis and Results

In this approach, the width of conducting dipoles is varied and their responses are noted. To prove them, two structures adopted from Feresidis.et.al, (2006) of 50 Ω Microstrip Line are considered with the specifications shown in Table I.

Figure 6 and 7 shows the simulation responses of structures 1 and 2 respectively obtained from AWR-MWO.

The conducting dipoles placed in close nearness with the apertures in structure 1 obtain the resonant frequency at lower frequency 4.7 GHz. The cut-off frequency emerges at 3.9 GHz and extends up to 7.1 GHz. In the structure 2 the width of the conducting dipoles are increased from 0.5mm to 2.5 mm. It is observed that the band-gap lowers to 3 GHz. The cut-off frequency emerges at 2.6 GHz and extends up to 4.5 GHz. Table IIIII shows the compared results

TABLE IV
STRUCTURE 1 AND 2 PARAMETER SPECIFICATIONS

PARAMETERS	SUB - PARAMETERS	STRUCTURE 1 (mm)	STRUCTURE 2 (mm)
Conducting Dipole	Length, L1	4.5	4.5
	Width, W1	0.5	2.5
Aperture	Length, L2	15.5	15.5
	Width, W2	0.5	0.5
Thick Dielectric Substrate	Thickness	1.125	1.125
	Dielectric Constant	2.2	2.2
Thin Dielectric Substrate	Thickness	0.055	0.055
	Dielectric Constant	3	3

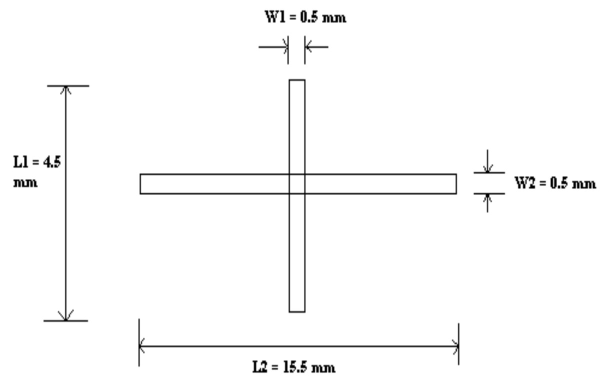

Fig 4: Schematic Microstrip structure with aperture and conducting dipoles sub-parameter's specifications

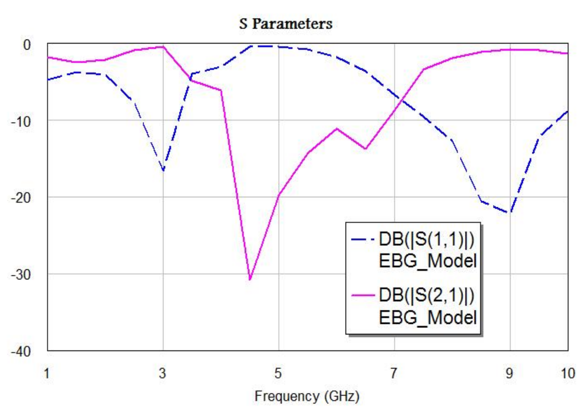

Fig. 5 Simulation response of structure 1

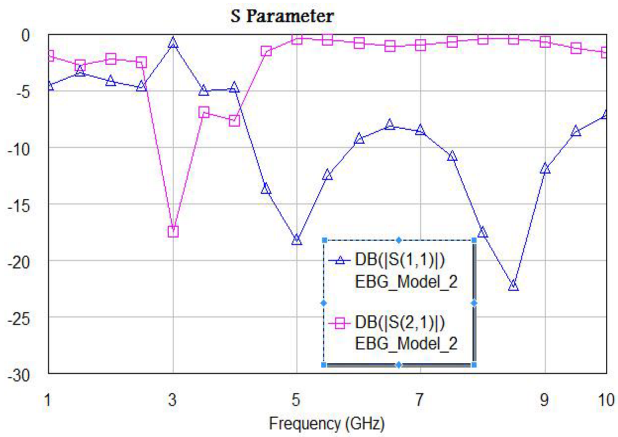

Fig. 7 Simulation response of structure 2

TABLE VVI

RESULTS FOR CONDUCTING DIPOLES

	Width W1 (mm)	Band-gap Frequency (GHz)	Bandwidth (BW) (GHz)
Conducting Dipole	0.5	3.9 – 7.1	3.2
Conducting Dipole	2.5	2.6 – 4.5	1.9

It can be observed from table VIIVIII that altering the width of conducting dipole 'W1', shifts the resonant frequency lower and also reduces the bandwidth. Hence, escalating the width of the conducting dipole results in variation in bandwidth of the filter thus tunability is observed.

C. Simulation 2 : Analysis and Results

Simulation 1 sets a base and develops the required confidence for proceeding forward with the research. Work carried out on the structures and the parameters in the AWR-MWO design environment with simulation 1 sets the background for the simulation 2 of the computer model. In this simulation, variation in the bandwidth is desired to be obtained by experimenting with different dielectric material. In this computer model structure, the thin polyester dielectric sheet above ground plane is replaced by nematic LC MERK K15 dielectric sheet. The dielectric constant of nematic state LC can be changed between two tremendous states by applying external electrostatic field. Nematic LC MERK K15 dielectric is used in the study as it is market-ably available material and has an anisotropy value of 0.2. It has electrically tunable dielectric constant (€ 0=3, €1 = 2.7 and €2 = 2.5) throughout the microwave frequency band [8].

The parameters of structures with 50 Ω Microstrip Line are considered with the specifications same as structure 1as stated in Table IX. The only parameter which varies is the dielectric value of thin nematic LC MERK K15 dielectric material. This change in the dielectric value between 3, 2.7 and 2.5 is observed due to the applied DC voltage across the filter.

Three different simulations are carried out with changing dielectric values € 0=3, €1 = 2.7 and €2 = 2.5. It can be observed in the comparing response as shown in Figure 8, that the resonant frequency with permittivity 2.5 is observed at 4.2 GHz and the Band Gap for the apertures emerges at 3.9 GHz and extends up to 6.2 GHz. Whereas in the resonant frequency with permittivity 2.7 is observed at 4.1 GHz and the Band Gap for the apertures emerges at 3.8 GHz and extends up to 6 GHz. And finally the resonant frequency with permittivity 3 is observed at 4 GHz and the Band Gap for the apertures emerges at 3.7 GHz and extends up to 5.8 GHz. Table XXIXII records the tunability of filter with changing resonant frequencies with the change in dielectric permittivity.

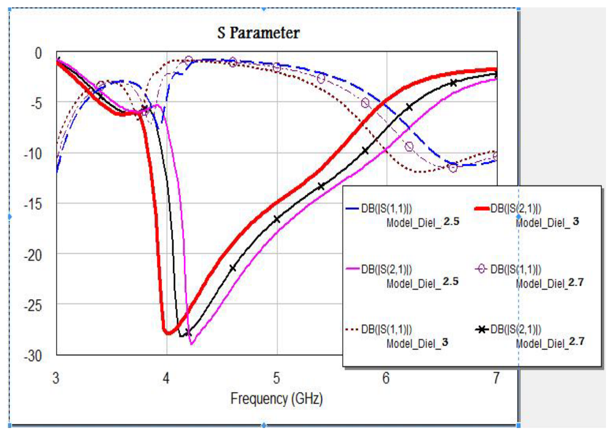

Fig. 8 Graph showing the comparing responses of the filter with dielectric permittivity 2.5, 2.7 and 3.0

It can be observed from Table XIIIXIVXV that, replacing the dielectric material shifts the resonant frequency lower and further lower the bandwidth. Hence, change in the dielectric material in the structure results in variation in the bandwidth of filter thus attaining the tunability.

As a result, two simulations are experimented which produces tunability in the microstrip filter. Simulation 1 worked with varying path size produced variation in the bandwidth i.e., tunability. Similarly, simulation 2 worked with replacing different dielectric material with applied DDC voltage across the filter also produced variation in the bandwidth in a controlled manner. Though both the simulations achieve tunability in the filter, simulation 2 finds more flexibility and efficiency as the voltage applied across the circuit brings the tunability in the filter which is easily achievable. Whereas in simulation 1, achieving frequent variation in the path size i.e., width of conducting dipole which are embedded in the design circuit is found to be tedious and time consuming process.

TABLE XVIXVIIXVIII
RESULTS COMPARISON OF CHANGING PERMITTIVITY OF LC DIELECTRIC MATERIAL

Dielectric Permittivity Єr	**Conducting Dipole Width W1 (mm)**	**Resonant Frequency (GHz)**	**Band-gap Frequency (GHz)**	**Bandwidth (BW) (GHz)**
Єr = 2.5	0.5	4.2	3.9 – 6.2	2.3
Єr = 2.7	0.5	4.1	3.8 – 6.0	2.2
Єr = 3.0	0.5	4.0	3.7 – 5.8	2.1

V. CONCLUSIONS

The research focuses on a new tuning approach by implementing nematic state liquid crystal to tune the microstrip filter.Plane wave scattering from a grounded periodic structure with a tunable liquid crystal substrate is modelled as an infinite array using appropriate boundary conditions in AWR MWO environment. The change in the resonant frequency from 4.2 GHz to 4 GHz i.e., 2% tunable range achieved is shown in Figure 8 for permittivity values 2.5, 2.7 and 3.0.

The scope of this research is limited to single EBG structure design and single LC dielectric material opted in the research work. This research could be extended by experimenting further with different structures of DGS, EBG and PBG and its results can be compared with existing structure for more visibility into tunability, etc. Experimenting with different DGS, PBG and EBG structures is expected to produce more efficient results with low cost and light weight features. Newly developed liquid crystal dielectric materials can be experimented in substitution with the existing liquid crystal dielectric material used in this research to achieve high tunability range in the microstrip filters. Future research can lead us to further full wave resonators for better signal transmission and similar other applications.

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