MMW 60 GHz Tunable Periodic Filter

Abdolreza Divsalar, Shahin Salarian, Dariush Mirshekar-Syahkal,

RF & Microwave Research Lab, School of Computer Science and Electronic Engineering
University of Essex, Colchester, United Kingdom
E-mail: adivsa@essex.ac.uk

Abstract

A novel mm-wave periodic filter structure has been proposed based on a new design approach. The filter performs at 60 GHz with 3.5 GHz bandwidth. The structure composed of periodic Microstrip stubs on BL037 Liquid Crystal substrate. Changing the bias voltage of LC provides a tunability from 58.5 to 62 GHz, while maintains the fractional bandwidth around 5%. The return loss of passband is better than 10dB with insertion loss variation from 3.8 to 5 dB. In addition, the effect of a different LC substrate (i.e. GT3-23001) has been investigated which provides similar behavior with a wider tuning distance.

1. Introduction

Broadband MMW 60 GHz transmission systems are the most promising technology to respond to the demanding requirements of increased data rate and wide bandwidth of future indoor fast data/audio/video distributions and communication systems [1].

However, due to the different allocated free licensed frequency bands around the world regions and because of required set-ups and internal functions, tunable filters and adaptive components would be required for future 60 GHz wireless systems. A filter with periodic structure at equal intervals, is a filter with a series of deep notches in its frequency response. Each notch acts as narrow band-stop filter, with a high-quality factor. These filters will be used to remove periodic noises and undesired frequencies. In microwave micro-strip filters, operation frequency and filter characteristics would be a function of both physical (i.e. dimensions and thickness of conducting strip and substrate layer) and electrical characteristics of the microstrip structure which consists of a conducting strip separated from a copper ground plane by a dielectric layer known as the substrate. For a tunable filter the physical characteristics cannot be changed for a built component, therefore the possible control would be on the electrical characteristic.
The electrical characteristic can be controlled by changing the effective permittivity (i.e. ε_{eff}) of the dielectric layer(s). Filter tuning in microwave components is possible using ferroelectric, piezoelectric and Liquid Crystal (LC) materials. The basics of these approaches are varying electrical properties of the above-mentioned materials with a bias voltage to tune the RF component. Among these materials, LCs have the advantages of lower cost, lower operating voltage, virtually no power consumption and benefits from having stable and continuous electrical tuning. Several reports of tunable filter experimental & simulation designs in frequencies up to 33 GHz band have been published in the recent years [2].

2. Theory of Periodic Structure

A Periodic Filter is a structure formed by cells of similar repeated components to provide filtering characteristics. Cascade structure of capacitive stubs periodically loaded to a transmission line can form a periodic filter. Each capacitive stub can be presented as a Susceptance *jb* to form the following structure of Fig.1:

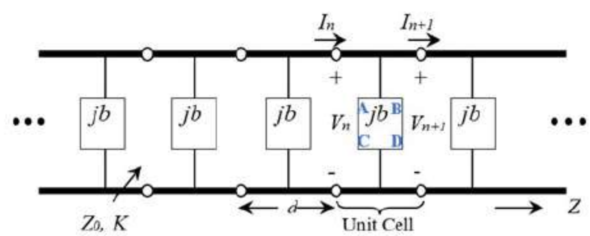

Fig. 1. Periodic Structure

3. Design Method

Traditional method of microstrip filter design starts determining the values of the lumped inductive and capacitive components from the available tables for the allowed ripples and the order of the filter, and then the dimensions of distributed elements of microstrip would be obtained step by step using Richard Transformation and Kuruda identities. Periodic Structures consist of cascade of a number of identical "Unit Cells" providing distributed inductance/capacitance to obtain the required filter performance. Therefore, design of periodic structure starts with the design of the Unit Cell.

The proposed design method for determining of the "unit cell" parameters and then periodic filter is shown in the flowchart of Fig 2. This novel method is obtained from the theoretical analysis of periodical structures.

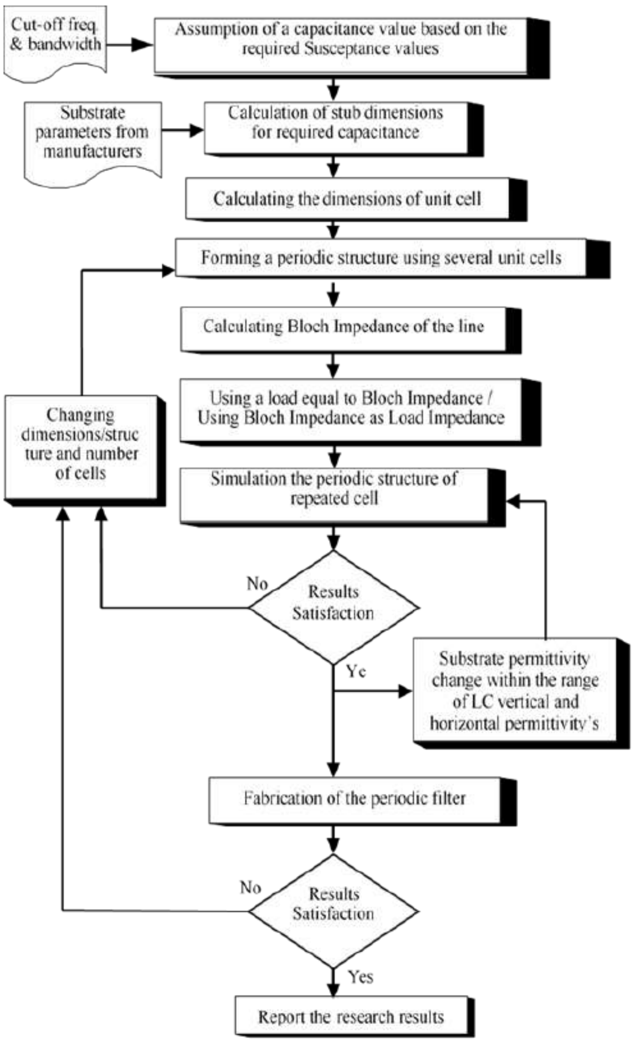

Fig. 2. Proposed design procedure for periodic filter

Unlike traditional filter design method, we do not have sets of formulas and tables for different filter models (i.e. Butterworth, Chebyshev, Elliptical). The proposed method for filter design is based on initial estimations for the key elements to meet the requirements of periodic structure kd-βd diagram and required operating frequency region. The required bandwidth and other filter specifications, would be the design parameters which defines the number of "unit cells".

4. Liquid Crystal Substrate

Different methods have been reported to provide tunebility in microwave components using Liquid Crystal (LC) materials. The basics of these approaches are varying electrical properties of the LC with a bias voltage to tune the RF component. LCs have the advantages of lower cost, lower operating voltage, virtually no power consumption and also benefits from having stable and continuous electrical tuning. LCs can flow like liquids, but still its molecules are oriented in a crystal-like way. Nematic LCs are anisotropic materials, and their physical properties change with the alignment and direction of rod-shaped molecules. The relative permittivity of a nematic LC varies between two values of $\varepsilon_{r-\parallel}$ and $\varepsilon_{r\perp}$ for when the molecular orientations are aligned (parallel) or perpendicular with the surface of LC. An external voltage that changes the LC director field can control the molecular orientation of LC. The difference between $\varepsilon_{r-\parallel}$ and $\varepsilon_{r\perp}$ is known as liquid crystal anisotropy. Because of the fluid nature of liquid crystal material, it should be confined in a cavity inside the device and then sealed. For this reason, the topology of inverted-microstrip in that the line substrate covers liquid crystal cavity, seems to be the most adequate to implement the filter [3].

Below table lists some of the most common nematic liquid crystals which are already used at microwave frequencies [4]. We have used two different types of BL037 and GT3-23001liquid crystal substrates for our design and simulations.

Table 1. The most common liquid crystal specifications at room temperature 20ºC

Liquid Crystal	Permittivity		Dielectric anisotropy
	$\varepsilon_{r\perp}$	$\varepsilon_{r-\parallel}$	$\Delta\varepsilon$
K15(5CB)	2.72	2.90	0.18
BL037	2.35	2.61	0.26
BL006	2.62–2.69	3.11–3.12	0.49–0.43
E7	2.72	3.17	0.45
GT3-23001	2.46–2.50	3.28–3.30	0.82–0.80
GT3-24002	2.50	3.30	0.80

5. Results and Discussion

Different periodic structures are designed and simulated with 3, 5, and 7 unit cells with the calculated parameters based on the proposed method, using the ADS software. The band-pass/band-stop behavior of the structure has been maintained in different number of cells, however, the frequency response and number of notches and width of pass-band (i.e. filter bandwidth) has changed for different number of unit cells. Fig. 3 shows the results for a filter with 5 stubs.

In another simulation, the permittivity of the substrate of the 5-cell periodic structure has been changed to demonstrate the changes in the electrical characteristic of Liquid Crystal substrate as the bias voltage changes. As shown in Fig. 4(a), for BL037 LC, the pass band shifts from 60.5-64 GHz to 57-60.5 GHz. This is an ideal tuning performance as there is no overlap between the pass-bands for such a small liquid crystal anisotropy.

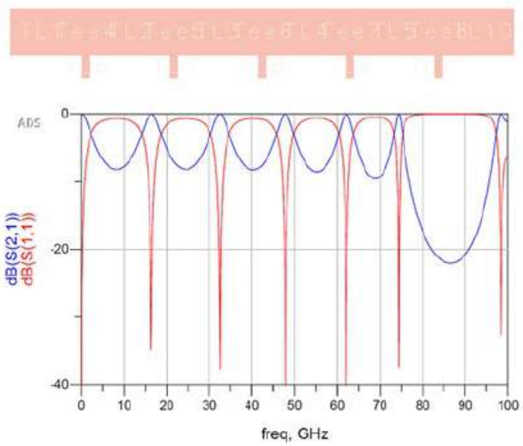

Fig. 3. Simulation results of 5-unit cells in a periodic structure

In simulation of Fig. 4(b), the substrate is GT3-23001 liquid crystal, the pass-band of a 5 sell periodic structure moves between band 58-61.5 GHz to 53-54.5 GHz, also the adjacent band 62-64 GHz which is narrower would be available if the bias voltage change the permittivity of the liquid crystal. For GT3-23001 the anisotropy is much more than BL037 and provides a much better isolation between pass-bands, therefore this LC can be used for the applications when a large separation is needed.

6. Conclusions

Various Periodic Filters based on LC have been designed modelled and investigated using capacitive open circuit stubs in 60GHs. A novel design method and procedure using kd-βd curve has been proposed for periodic structures. Different numbers of repeating cells for periodic structures have been simulated to analyses the effect of the number of repeating cells on filter performance.

References

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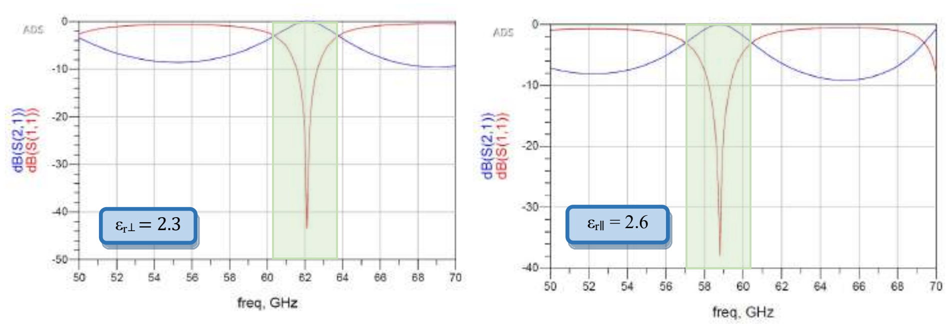
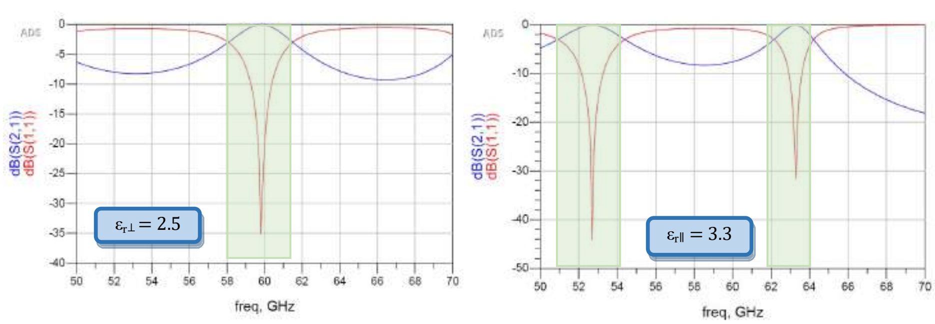


(a) Liquid Crystal BL037: $\varepsilon_{r\perp} = 2.3$, $\varepsilon_{r\parallel} = 2.61$



(b) Liquid Crystal GT3-23001: $\varepsilon_{r\perp} = 2.5$, $\varepsilon_{r\parallel} = 3.3$

Fig. 4. Frequency tuning with liquid crystal