Design Method for MMW LC Tunable Microstrip Periodic Filters

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Abstract— With the ever-increasing global pressure to develop higher data rate/wider bandwidth networks, most telecommunication service providers are considering MMW as the mainstream technology to provide mission-critical capabilities such as superior speeds and low latencies. The license free internationally assigned MMW spectrum are not utilized normally and indeed sections of the spectra are engaged in different countries around the world. Therefore, tunable filters performing frequency selection are essential elements of the MMW equipment. Microstrip periodic structures on Liquid Crystal (LC) substrate are the most cost-effective solution for the required MMW tunable filters. A novel method is proposed for LC MMW microstrip periodic filter using a new design approach. The designed filters perform at 60 GHz with 3.5–5 GHz bandwidth. The structure composed of periodic Microstrip stubs on BL037 LC 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 10 dB with insertion loss variation from 3.8 to 5 dB.

1. INTRODUCTION

This paper presents a method using the numerical analysis of the Finite Element method to model MMW microstrip periodic structures based on their unit elements, Fig. 1, and demonstrates designs of tunable filters with desired tunability, return loss in passband, and fractional bandwidth.

In this method the reflection coefficient of the filter input will be calculated as a function of reflection coefficients of periodic stubs of microstrip periodic structure [1] and [2]. This will be a similar approach as impedance matching between a source of electromagnetic signal and a load. A successful matching can be verified when return loss (RT) in operation frequency is less than $-60\,\text{dB}$ [3].

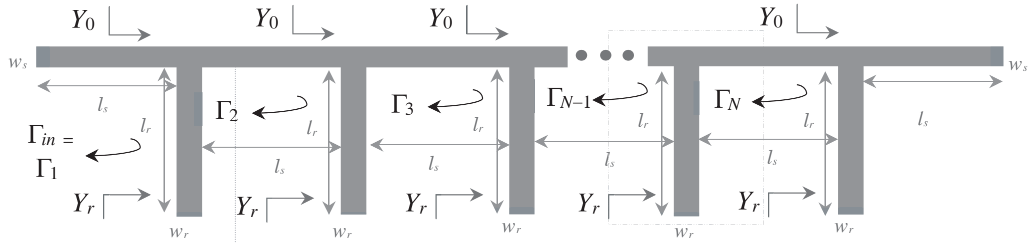

Figure 1: Reflection coefficient of periodic structure.

2. THEORICAL BASICS

The reflection coefficient of a periodic structure (i.e., Γ_{in}) shown in Fig. 1 can be calculated as follows [1]:

$$|\Gamma_{in}(f)| = \Sigma|\Gamma_n(f)|e^{\left(-j\frac{4\pi nl}{C}f\right)} \tag{1}$$

where f is the frequency.

This formula is used in [4] for design and calculate the frequency response of filters, with reasonable measure results, however for periodic structures of multiple stubs this method with limitation when the characteristic impedances between the neighbouring stubs has sharp changes. As a novel and modified method is used to design periodic filters, using numerical analysis method to optimise reflection coefficient.

To develop the calculation process of Γ_{in}, we start with a single stub structure which is a very simple structure as shown in Fig. 2.

In this figure equivalent admittance of the connected load is Y_L, where Θ_s and Θ_r, are equivalent electrical lengths of the source line (i.e., transmission line) and resonator (i.e., microstrip stub) and input reflection coefficient is Γ_{in}. For two conditions of short stub and open stub, we have:

- Short Stub: $Y_r = \infty \rightarrow Y_{in} = Y_0 - jY_0 \cot\theta_r$
- Open Stub: $Y_r = 0 \rightarrow Y_{in} = Y_0 - jY_0 \tan\theta_r$

We would be only interested to open stub as for final design of tuneable periodic filter, short stubs will not be practical to be built, due to the liquid nature of substrate (i.e., liquid crystal).

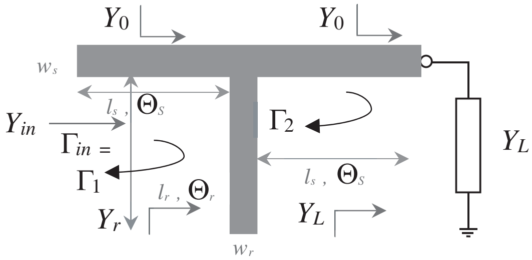

Figure 2: Reflection coefficient of single stub structure.

Assuming that the characteristic impedances of the periodic structure sections are equal, then for input reflection coefficient Γ_{in}, we have [6]:

$$\Gamma_{in} = \frac{-j}{j + 2\cot\theta_r} \quad \textit{(for open stub)} \tag{2}$$

For cascade transmission line circuits, reflection coefficient can be calculated using following formula:

$$\Gamma = \frac{|\Gamma_1| + |\Gamma_2| e^{(-2j\theta)}}{1 + |\Gamma_1||\Gamma_2| e^{(-2j\theta)}} \tag{3}$$

The value of $|\Gamma_1|\ |\Gamma_2|$ is much smaller than 1, therefore denominator will be 1 and ignored. Now the periodic structure of Fig. 1 is basically a repeat of the structure of Fig. 2. For N repeats, we assume that the N stubs are loaded to the main source line in N ports $1, 2, 3, \ldots, N$, and $\Gamma_{r,N}$ is the reflection coefficient of the loaded stub at port N. Considering that that connected load to the periodic structure is a match impedance, then for the Nth stub we can write: $\Gamma_N = \Gamma_{r,N}$ $(\Gamma_L = 0)$

$$\Gamma_{N-1} = \frac{|\Gamma_{r,N-1}| + |\Gamma_N| e^{(-2j\theta_s)}}{1 + |\Gamma_{r,N-1}||\Gamma_N| e^{(-2j\theta_s)}} \tag{4}$$

For the periodic structure the electrical lengths of the loaded resonator stubs will be same (i.e., Θ_r in Fig. 1), now If we expand the values of the stub reflection coefficients into the above formulas, then:

$$\begin{aligned} \Gamma_N &= \Gamma_{r,N} = \frac{-j}{1 + 2\cot\theta_r} \quad (\Gamma_L = 0) \\ \Gamma_{N-1} &= \frac{\left|\frac{-j}{1+2\cot\theta_r}\right| + |\Gamma_N| e^{(-2j\theta_s)}}{1 + \left|\frac{-j}{1+2\cot\theta_r}\right||\Gamma_N| e^{(-2j\theta_s)}} \end{aligned} \tag{5}$$

3. PERIODIC FILTER DESIGN

Using the above formulas, the dimensions of microstrip stubs can be calculated using numerical analytic methods to optimise the value of Γ_{in} to be close to -60 dB on centre frequency of the bandpass frequencies of periodic structure filter.

Because of the complexity of estimation calculations, MATLAB is used, the initial dimensions of the source line and microstrip stubs will be calculated using filter operation frequency and desired number of stubs. Then using Finite Element Method (FEM) the estimation is divided to smaller elements and then by regular changes of stubs and source line dimensions, in a both directions, different filter performance and reflection coefficient are calculated and compared with each other to find the best results, which represents the optimum dimensions.

MATLAB scripts are developed to determine periodic structures configurations and dimensions for periodic filter parameters. Design and performance of several filters are simulated to validate the accuracy of the design method.

4. LIQUID CRYSTAL CHARACTRISTICS

Liquid Crystal (LC) substrates are used to provide tunability for periodic filters. The basics of these approaches are varying electrical properties of the LC material with a bias voltage to tune the filter. LCs have the advantages of lower cost, lower operating voltage, virtually no power consumption and benefits from having stable and continuous electrical tuning. 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 $\varepsilon_{r||}$ and $\varepsilon_{r\perp}$ for when the molecular orientations are aligned with the surface of LC and $\varepsilon_{r||}$ varies between 2.6 to 3.5, or perpendicular with the surface of LC and $\varepsilon_{r\perp}$ varies between 2.2 to 2.8 [5] and [6]. Change of substrate permittivity is a periodic structure, shifts the pass band of filter and therefore filter can be tunned accordingly.

A few LC microstrips periodic structures with different unit cells for MMW applications are modeled and analyzed based on the algorithm of Fig. 3. The calculated parameters of periodic structures are then used to design periodic filters. Characteristic and performance of some of the designed filters are simulated using ADS results as shown in Fig. 4. 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 10 dB with insertion loss variation from 3.8 to 5 dB.

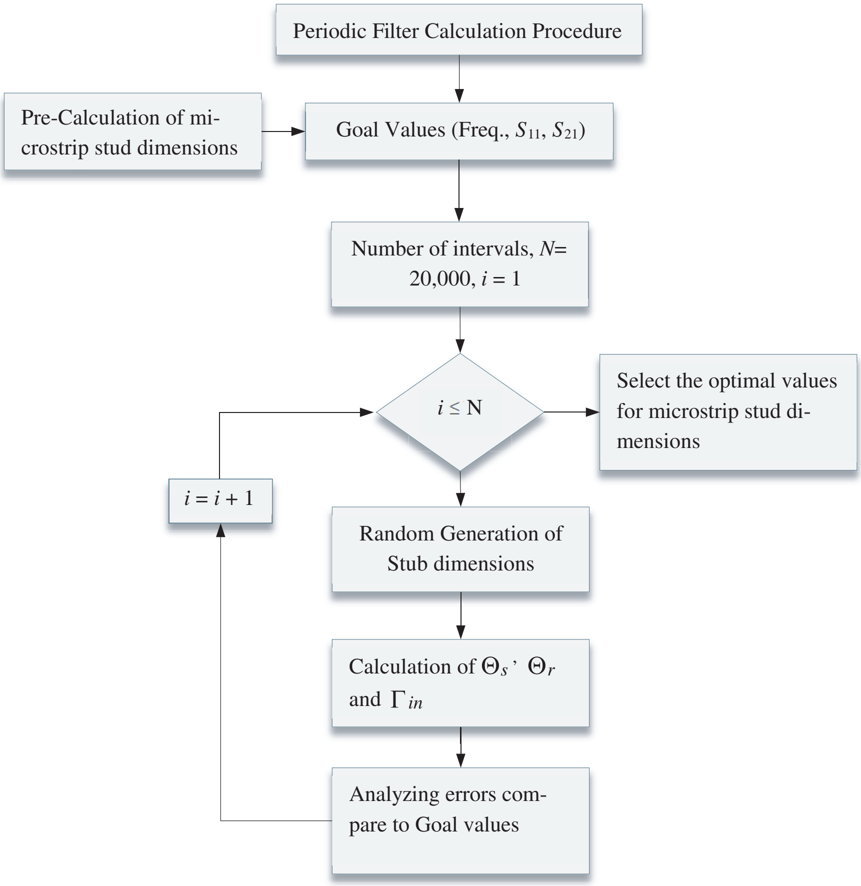

Figure 3: Algorithm of numerical analysis.

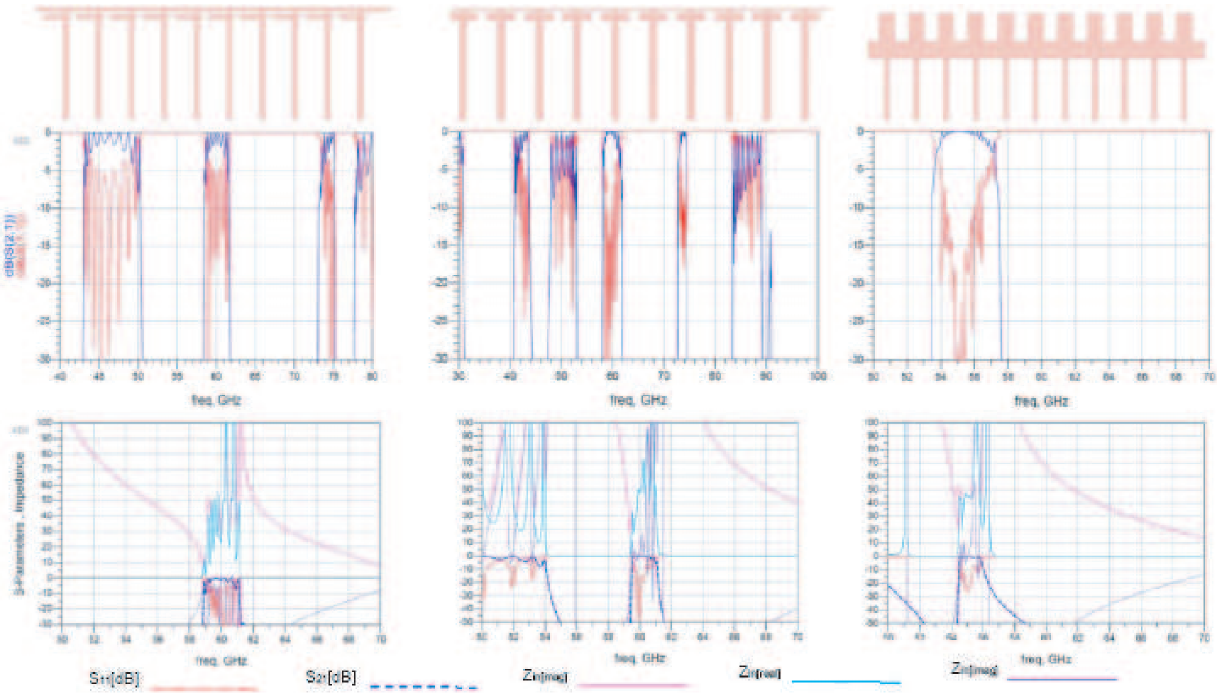

Figure 4: Designed microstrip periodic structure, S-parameters and input impedances.

5. CONCLUSION

A novel design method and procedure using reflection coefficient of microstrip filters has been proposed for periodic structures. Different number of repeating cells for periodic structure have been simulated and the effect of the number of repeating cells on filter performance has been analyzed.

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REFERENCES

1. Pozar, D. M., "Impedance matching and tuning," *Microwave Engineering*, 4th Edition, Chap. 5, Sec. 5, 250–252, John Wiley and Sons Inc., New Jersey, USA, 2012, ISBN:8126510498.
2. Hendijani, N., M. Khalaj-Amirhoseini, V. K. Sharghi, et al., "Design, simulation, and fabrication of tapered microstrip filters by applying the method of small reflections," *International Symposium on Telecommunications*, 133–137, Tehran, Iran, 2008, DOI: 10.1109/ISTEL.2008.4651287.
3. Olokede, S. S. and B. S. Paul, "A novel microstrip feed based on the theory of small reflection," *IEEE Radio and Antenna Days of the India Ocean*, St. Gilles-les-Bains, Reunion, 2016, DOI: 10.1109/RADIO.2016.7772018.
4. Yuan, Y., W. Wu, W. Yuan, et al., "A method based on the theory of small reflections to design arbitrary passband microstrip filters," *Radioengineering*, Vol. 27, No. 1, 214–220, 2018, DOI: 10.13164/re.2018.0214.
5. Yaghmae, P., O. H. karabey, B. Bates, C. Fumeaux, and R. Jakoby, "Electrically tuned microwave devices using liquid crystal technology," *International Journal of Antennas and propagation*, Vol. 2013, 2013.
6. Urruchi, V., C. Marcos, J. Tottcilla, J. M. Sanchez-Pena, and K. Garbat, "Tuneable notch filter based on liquid crystal technology for microwave applications,".