Engineering, Environment

Design bandpass filters using non-uniform transmission lines based on liquid crystal polymer substrate

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Abstract

In this paper, the liquid crystal polymer (LCP) is used to reduce the size of non-uniform transmission lines (NUTLs) filters and design suitable filters to operate in high frequency band. The LCP ($\varepsilon_r = 2.9$) substrate of 0.127 mm substrate thickness is used to improve the performance of filters. Two filters (NUTL) are designed using an optimization process to work in ultra-wideband (3.1GHz-10.6 GHz) and (22 GHz-29 GHz) band, respectively. The performance of the designed filters is tested by using high frequency structure simulator (HFSS) and computer simulation technology (CST) software packages.

Keywords

Non-uniform transmission lines; Micro strip line; Bandpass filter; Liquid crystal polymer

Introduction

Filters are the most common components used in microwave circuits. They usually made using micro strip technology, which are used in planar circuit board (PCB). Bandpass filters are badly needed in many applications. Liquid crystals are emerged recently as a promising technology to implement them [1].

Liquid crystal polymer (LCP) is one of the most popular materials used in high frequency applications. It could be used up to 110 GHz [1]. This is due to its electrical and mechanical characteristics which are suitable for high frequencies. Also, there are many advantages offered by liquid crystal polymer to make it preferable to be used in electric devices that works in high frequency range (microwave/ mm wave). Therefore, many authors used (LCP) substrate in their design. In [2], the authors used LCP substrate with thickness of 50μm in designing lowpass filter with 10 GHz cut frequency, and bandpass filter about 9.5 GHz, by using LCP, a good performance of the designed filters and the compact size was achieved. Additionally, the bandpass filter was not sensitive to bending which makes it suitable to be used in flexible devices. In [3], the authors used LCP substrate with 0.5mm thickness for designing wideband tapered step antenna with serrated ground. The radiating patch take a shape of intersection of two half circles connected back to back, the flexibility of antenna is tested by using different tubes with different diameters. The results show that the proposed model is providing excellent flexible characteristics. In [4], the authors designed UWB bandpass filters on multilayer LCP substrate that consist of three metal layers. The first layer contains broadside-coupled patches and high-impedance micro strip lines. The second layer contains stepped impedance resonators (SIRs) that were used to suppress a stopband harmonic response. The embedded open-circuited stubs into broadside-coupled SIRs used to investigate single, double, and triple notch-bands and the compact size was achieved. In [5], the authors designed slotted patch four-element antenna array using liquid crystal based phase shifter, the design contained phase shifter between micro strip on second layer that contains LC channel that changes its effective dielectric constant between two values ($\varepsilon_\perp$ and $\varepsilon_\parallel$) with a bias voltage, and the phase shifter steers the beam in the E-plane by a maximum of 14^0 (different between $\varepsilon_\perp$ and $\varepsilon_\parallel$ beam width).

In [6], the authors designed Single-Input-Single-Output (SISO) dual-band filters operating at (2.4-2.5) GHz and (5.15-5.85) GHz frequency bands, using the novel “dual behaviour resonators” technique. The very low cost and high performances integrated circuits for mm-wave and RF applications are obtained by using LCP and LTCC.

Getting a smaller circuits size is one of the most engineers demands, so many techniques have been used to satisfy this. Using non-uniform transmission line NUTL is one of these techniques that compact the microwave circuits. The non-uniform structure can be obtained by optimization process that aims to investigate the desired functionality such as matcher [7-11]. Additionally, NUTL is used to design filters to overcome problems that occur in other methods such as the discontinuity that causes amplitude and phase errors [12-16]. Many researchers used NUTL or LCP separately to design filters.

The objectives of this research are to improve the performance of bandpass filters by combined the non-uniform transmission line that obtained by optimization process and the liquid crystal polymer (LCP). This is enable us to benefit from the electrical properties of the LCP in the high frequency bands to design suitable filters for working within these ranges and to investigate the compactness of circuits at the same time.

Material and method

In this section, the non-uniform micro strip structure is shown to work as bandpass filter. The micro strip's structure is subdivided into many uniform short sections each of length Δz. Then the normalized characteristic impedance of each section is expanded as a truncated Fourier series as [8]

$$\ln\left(\frac{Z(z)}{Z_0}\right) = \sum_{n=0}^{N} C_n \cos(2\pi nz/d) \quad (1)$$

Where: Z(z) – the characteristic impedance of the short uniform transmission line; Z_0 the characteristic impedance of source and load impedance; N - the number of series coefficients; C_n – series coefficients; z –position of short uniform section; d- the total length of non-uniform transmission line.

In this work, the 10 coefficients are used related to another work [7]. The optimum values of the coefficients of the series are obtained through an optimization technology. This is achieved by using a built in MATLAB function called fmincon.m. The purpose of the used function is to find the minimum value of the main function that aim to investigate the optimum response of filters and find the suitable characteristic impedance. The main function used in bandpass filters design aims to minimize the reflection coefficient S_{11}in the pass band, and transmission coefficient S_{21} in the reject band. This function can be written as Eq. (2):

$$F= \frac{\sum_{f_{min}}^{f_{c1}} |S_{21}|^2+\sum_{f_{c1}}^{f_{c2}}|S_{11}|^2+\sum_{f_{c2}}^{f_{max}}|S_{21}|^2}{N_f} \quad (2)$$

Where: F – the main function; f_{c1} – lower cut-off frequency; f_{c2} – higher cut-off frequency; S_{11} – reflection coefficients; S_{21} – transmission coefficients; N_f- the number of frequencies in the range (f_{min}-f_{max}) which increment by Δf, (f_{c1}-f_{c2}) is the pass range.

The optimization process need to present the main function in term of series coefficients, so the s-parameters presented in term of *ABCD* parameters which depends on the characteristic impedance that is written in term of series coefficients as Eq. (3) and Eq. (4).

$$S_{11}=\frac{AZ_0+B-CZ_0{}^2-DZ_0}{AZ_0+B+CZ_0{}^2+DZ_0} \quad (3)$$

$$S_{21}=\frac{2Z_0}{AZ_0+B+CZ_0{}^2+DZ_0} \quad (4)$$

The total ABCD parameters are found by multiplying the ABCD parameters of each uniform section as Eq. (5).

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix}=\prod_{n=1}^{k}\begin{bmatrix} A_n & B_n \\ C_n & D_n \end{bmatrix} \quad (5)$$

$$A_n = D_n = cos(\Delta\theta)$$

$$B_n = jZ\big((n-0.5)\Delta z\big)\, sin(\Delta\theta)$$

$$C_n = jZ^{-1}\big((n-0.5)\Delta z\big)\, sin(\Delta\theta)$$

$$\Delta\theta = \frac{2\pi}{\lambda}\Delta z$$

Where: A, B, C, D – ABCD parameters of the whole of NUTL; Π - the product symbol; k - the number of subsections; A_n, B_n, C_n, D_n - ABCD parameters of the n-th segments ; j – imaginary unit; Z - is the characteristic impedance of the uniform short section; Δθ – electrical length of each segment; Δz – the length of each segment.

The substrate material that used in designed filter is liquid crystal polymer which is a material that combines some of the properties of solids and liquids. This material, takes a good place in the orientations of engineers and scientists because of many features. These include their low price, small size, matched coefficient of thermal expansion (CTE), excellent electrical properties, flexible, lightweight, high dielectric strength (breakdown voltage), and its ability to realign its molecules depending on magnetic or electric field, i.e., they are anisotropic materials [1].

The design methodology can be summarized as follows:

- The characteristic impedance of the filter is considered as truncated Fourier series expansion.
- Optimization process is done using MATLAB built-in function (fmincon.m) to solve the series coefficients of the characteristic impedance of the filter.
- The width of non-uniform structure is obtained from the solved characteristic impedance.
- The response of filters is tested by simulated software's (HFSS, CST).

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The scheme of designing filters is shown in Figure 1.

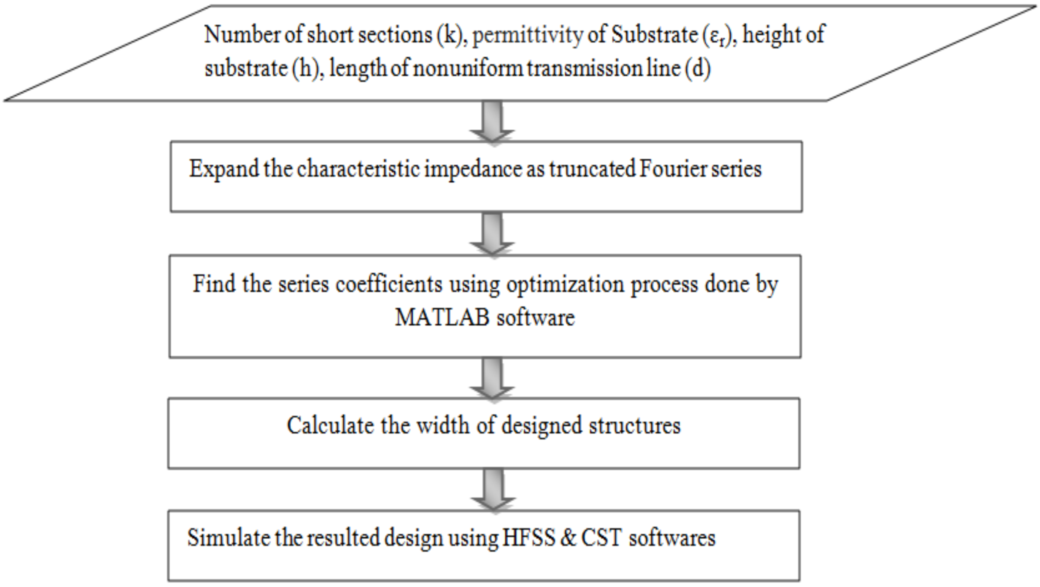

Figure 1. The scheme of designing filters.

Result and discussion

After the optimization process, the coefficients of filters $\{C_n\}$are obtained, and given in Table 1 and Table 2.

Table 1. Fourier coefficients and normalized characteristic impedance for (NUTL) as UWB

C0	C1	C2	C3	C4	C5		C6	C7	C8	C9	C10
-0.8974	0.5615	0.0238	-0.0377	-0.0476	-0.2961		0.2074	0.3075	-0.0356	0.0414	0.1728

Table 2. Fourier coefficients and normalized characteristic impedance for (NUTL) bandpass filter

C0	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
-0.6432	0.7745	-0.7102	0.2554	0.0125	-0.1035	0.2814	0.0077	0.0801	0.0689	-0.0236

The designed structures of filters are shown in Figure 2 and 3.

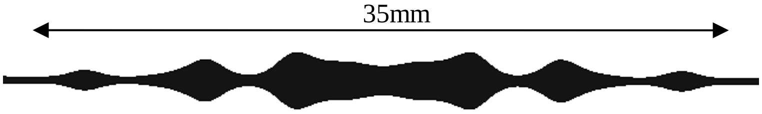

Figure 2. Non-uniform transmission line UWB bandpass filter

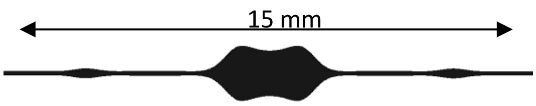

Figure 3. NUTL bandpass filter in high frequency range (22-29) GHz

The response of filters is presented by the simulation that is done by HFSS and CST software.

The simulated S-parameters for the UWB filter are shown in Figure 4, and the group delay of the filter is shown in Figure 5.

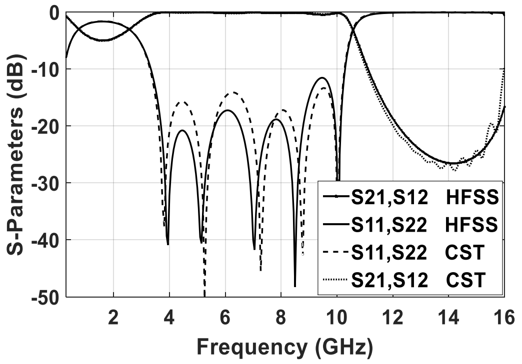

Figure 4. Simulated S-parameters of (NUTL) UWB bandpass filter

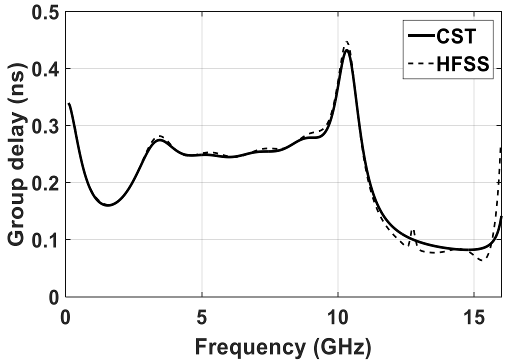

Figure 5. Simulated group delay of (NUTL) UWB bandpass filter

It is clear that the reflection coefficients values are less than -10 dB and the values of transmission coefficients are more than -1dB at the desired band, which present good matching and transmission in the desire band, and the constant delay is achieved at the desired band. Using non-uniform transmission line and LCP reduces the length of the designed filter and improve the performance of the filter.

Figure 6 shows the simulated S-parameters of the bandpass filters that work in high frequency range, and the group delay of filter is shown in Figure 7.

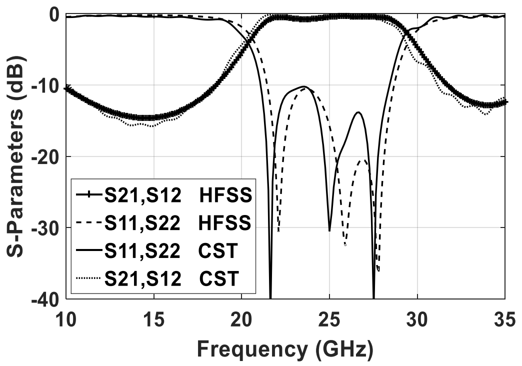

Figure 6. Simulated S-parameters of bandpass filter

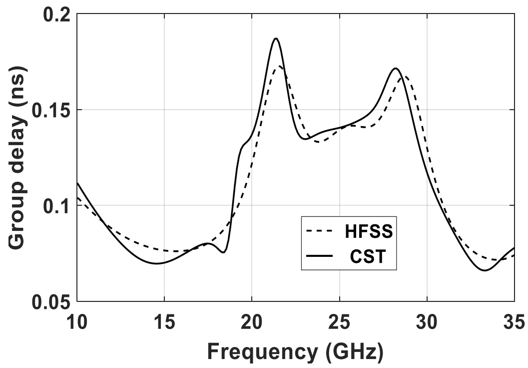

Figure 7. Simulated group delay of bandpass filter

The simulated transmission coefficients S_{21}, and S_{12} are more than -1 dB, the transmission is good over the UWB in high frequency range, and the matching is good where the reflection coefficients is less than -10 dB. Additionally, the very low distortion is obtained as shown in group delay.

The good performance of filter is obtained in the high range by using LCP which has excellent electrical properties such as low dielectric constant and dissipation that make signal faster and has a good quality. From the simulated results, the achievement of two software packages is obtained.

Conclusions

The non-uniform transmission line is used to reduce the length of microwave components and to overcome the discontinuity problem that caused by the sharp edge in the other type as stubes, stepes impedance,coupled transmition line.etc. Therefore, UWB bandpass filter and bandpass filter that work in high frequency range are designed using nonuniform transmission line in this work. The liquid crystal polymer substrate is used in filters design to satisfy the reduction on circuits size and to improve the filters functionality on different range especialy in the high range which is related to its excellent electric properties. The reflection and transmission coefficient of designed filters are shown an excellent response in the desire range. The group delay of filters show low distortion effect. Additionally, the agreement between HFSS and CST simulated results was excellent.

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