Design and Simulation of 2.4GHz Microstrip Parallel Coupled Line Low pass Filter for Wireless Communication System

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***Abstract*—A low pass filter only allows signals below its cut-off frequency to pass while attenuating other signals with frequencies higher than those of the filter. Several interesting techniques were proposed by researchers to design low pass filter. However, majority of those filters present difficulties of integration with other elements of electronics gadgets, high cost, high power consumption, large size and low-frequency application. Consequently, the current study focussed on design and simulation of a parallel coupled-line microstrip low pass filter. CST microwave software was used for the design and simulation of the filter. Results Analyses were made and the resulting frequency responses were plotted using a sigma plot. It was concluded that the proposed microstrip filter presents solutions to the issues observed in the former designs.**

***Index Terms*— Microstrip; Coupled line; Low pass filter; Insertion loss, Return loss.**

I. Introduction

A microwave low pass filter is a two-port, passive, reciprocal and linear device that shunts unwanted signal frequencies while allowing the desired frequency to pass. In general, the electrical performance of a filter is described in terms of its frequency selectivity, insertion loss, return loss and group delay variation in the passband. Filters are required to have small insertion loss, large return loss for good impedance matching with interconnecting components and high-frequency selectivity to prevent interference [1]. If a filter has frequency selectivity, and guard band between channels can be determined to be small which indicates that the frequency can be used efficiently. Also, a small group delay and amplitude variation of the filter in the passband is required for minimum signal degradation [2]. Microwave low-pass filters (LPFs) have been widely used as a key building block to suppress all the unwanted high-frequency harmonics and inter-modulation in various wireless communication systems [3]. Due to unexpected frequency-distributed behaviour, the conventional transmission-line based LPFs, such as stepped-impedance and open-stub filters, always suffer from gradual cut-off attenuation skirt and narrow upper-stop bandwidth [4]. To sharpen this roll-off skirt, it is a usual approach to raise the order of a low-pass filter to a great extent. Unfortunately, this enlarges the overall circuit size and accumulates in-band insertion loss. In [5], a microstrip line with extremely high impedance is formed by etching out an aperture on the ground plane underneath the strip conductor. This approach allows effectively widening the upper stopband of stepped-impedance low-pass filters due to an enlarged impedance ratio. But, it still suffers from poor rejection near the cut-off frequency [6].

In recent years, various types of miniaturised and performance-improved low-pass have been explored in [7]-[8] based on the original idea of [9]. These low-pass filters are basically constructed by a hairpin- or C-shaped folded unit in geometry. Because an additional coupling route is created between the two non-adjacent sections,

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attenuation poles are excited to improve the upper stopband performances. High impedance transmission lines and tightly-coupled twin lines are connected in parallel to generate three attenuation poles in the stopband [10]. A stepped impedance hairpin resonator is presented in [11] to make up a class of elliptic-function LPFs with a wide stopband. By allocating an attenuation pole close to the cut-off frequency, a sharp roll-off skirt was achieved in [12]. However, only one attenuation pole was excited in the stopband [13] all three attenuation poles are far away from the desired low passband, so the roll-off skirt near the cut-off frequency has not been increased so much [14].

In this letter, for the first time, a class of coupled-line hairpin filters is designed on a microstrip to have a low-pass frequency response with an expanded upper-stopband. It was designed by centrally tap-connecting the two coupled-line strip conductors and adjusting the coupling strength between them, three attenuation poles with controllable spacing can be excited in the first harmonic passband to widen and deepen the upper stopband. In analysis, a set of closed-form design equations are firstly established based on the well-known coupled-line theory [15] to explain the mechanism for exciting and reallocating these attenuation poles. Finally, two LPFs with a single and two asymmetrical units are optimally designed with the 3dB cut-off frequency at 2.5 GHz. Measured results are provided to confirm the predicted ones for the single-unit LPF and experimentally demonstrate a wide upper-stopband in the range 3.2–11.8 GHz with the insertion loss higher than 20 dB for the two-unit LPF [16].

II. Materials and Method

A. *Setting of Simulation Parameters*

The design specification of the filter is shown in Table I. The specification of the dielectric material was obtained from the Rogers Corporation [16].

TABLE I. FILTER SPECIFICATION

Filter specification	Value
Cut-off frequency	*2.4GHZ*
Load impedance	*50Ω*
Source impedance	*50Ω*
Insertion loss	*-30dB*
Return loss	*Greater than -0.5dB*
Order	*3*

Microstrip coupled line low pass filter is composed of three basic layers; the ground layer, the substrate and the patch which is the top layer. At each port of the low pass filter, there is a waveguide. As shown in Figure 1, the ground and the upper layers are made up of conducting material. While the middle layer is the substrate, an insulating material, between the parallel-coupled lines forming the capacitor; and vacuum was used as the dielectric material. The filter was designed by following various steps using CST microwave studio.

I. Ground layer: It is made up of a conducting material i.e. annealed copper which formed the base of the filter with a very thin thickness typically 0.035mm. The dimension of the ground plane is 90mm by 30mm. The ground layer is shown in Figure 2.

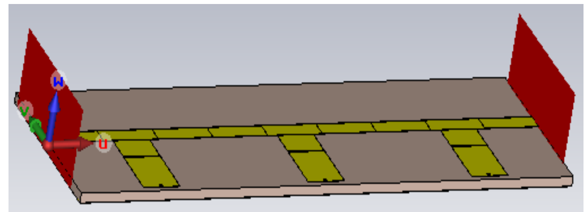

Fig. 1. Proposed microstrip low pass filter

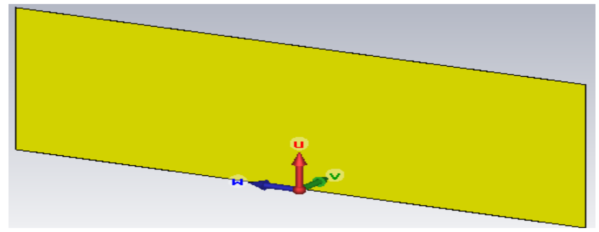

Fig. 2. Ground layer of the filter

II. Substrate layer:
The proposed structure is printed over a low-cost FR-4 material which is readily available. The substrate with a dielectric constant of 4.3, loss tangent of 0.016 and thickness of 1.52 mm is considered material forming the substrate. The substrate layer is quite thicker than the ground plane. It has the same dimension as that of the ground plane. The substrate layer is shown in Figure 3.

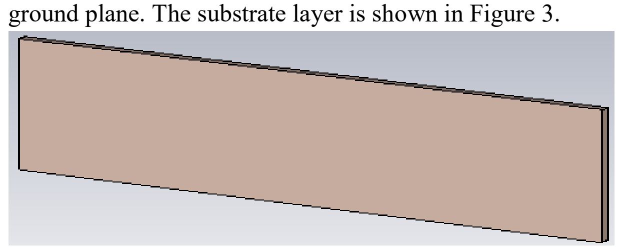

Fig. 3. Substrate layer of the filter

The specification of dielectric material used as a substrate is given in Table II.

TABLE II. SPECIFICATION OF DIELECTRIC MATERIAL USED AS A SUBSTRATE

Parameter	Value
Dielectric constant (ε_r)	*4.3*
Substrate height	*1.52mm*
loss tangent (δ)	*0.016*
Copper thickness	*0.035mm*

III. Transmission lines:
The transmission lines form the upper layer of the low pass filter. It is also made up of annealed copper of thickness 0.035mm. It consists of a rectangular bar laying horizontally and vertically on top of the substrate. The horizontal patch ensures the inductive or resistive effect, while the vertical layer which is space at one point ensures the capacitive effect and thus is responsible for rejecting other harmonics above the fundamental cut-off frequency. The horizontal transmission lines run throughout the length of the substrate (i.e. 90mm). They are located 12mm

to 15mm of the substrate width, hence they are 3mm width. The vertical ones which are attached with the horizontal ones are generally of equal length and width i.e. 14mm and 6.66mm respectively. But, to ensure the capacitive effect of the low pass filter the vertical annealed copper was spaced between 4.8mm to 5mm to provide a space of 0.2mm for the vacuum serving dielectric material.

The vertical bars were grounded at 13.5mm below the midpoint of the vertical patch with a cylindrical annealed copper material with inner and outer radius 0.15mm and 3mm respectively with a thickness that runs to ground layer of the filter. The transmission line layer is shown in Figure 4.

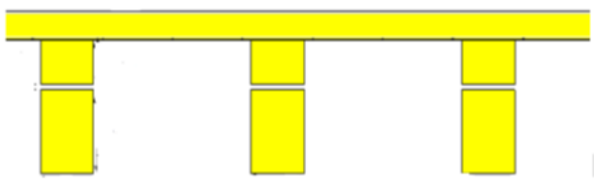

Fig. 4. Transmission line layer of the filter

B. Analytical relation for calculating characteristics impedance and effective dielectric constant

If thickness of the copper track '*t*' and the width '*W*' of the copper track is less than the height '*h*' of the insulating material, the effective dielectric constant 'ε_{ff}' is found to using eqn. 1. Whereas, if the width of the track is greater than the height of the insulator, 'ε_{ff}' is found using eqn. 2.

$$\varepsilon_{ff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left[\frac{1}{\sqrt{1+\frac{12h}{W}}} + 0.04\left(1-\frac{W}{h}\right)^2\right] \tag{1}$$

Where ε_r is the relative dielectric constant.

$$\varepsilon_{ff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left[\frac{1}{\sqrt{1+\frac{12h}{W}}}\right] \tag{2}$$

Thus, the characteristics impedance becomes:

$$Z_O = \frac{120\pi}{\sqrt{\varepsilon_{ff}}\left[\frac{W}{h}+1.393+0.667\ln\left(\frac{W}{h}1.444\right)\right]} \tag{3}$$

C. Impedance Matching

Impedance matching is necessary especially in communication to minimise loss of signal strength and ensure all the power generated is merely transmitted. The filter is no exception. CST microwave studio has the advantage of its built-in analytical calculator, which is used in determining various design parameters.

I. CST microwave studio calculator method:

The calculator performs several functions but, most important for this design is calculating the wavelength, effective dielectric constant and the input impedance to ensure impedance matching and other important design parameters given in Table III.

This calculator is easier to use in calculating the input and output impedance of the filter. The only parameters needed are the height of the substrate (h), the width of the transmission line (w) and lastly the dielectric constant of the substrate (ε_r). In some CST microwave calculator even the cut-off frequency may be of utmost importance. The values of Table III were inputted to the calculator in which the input and output impedance of the filter was found to be 49.80ohm. This is displayed in Figure 5.

TABLE III. PROPOSED LOW PASS FILTER DESIGN PARAMETERS

Parameter	Value
Height of the substrate (h)	*1.52mm*
Width of the transmission line (w)	*3.00mm*
Dielectric constant of the substrate (ε_r)	*4.30*
Cut-off frequency	*2.4GHz*

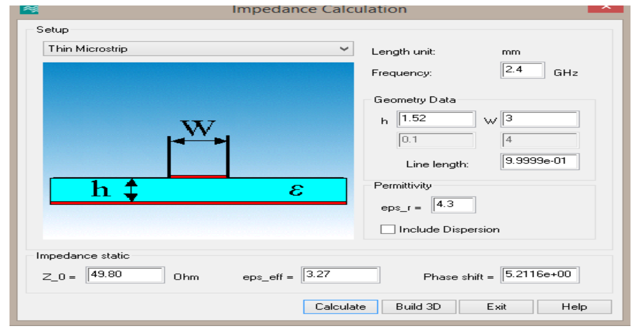

Fig. 5. CST Microwave studio impedance calculation

II. Analytical method for impedance calculation:

This is given by the relationship shown in eqn. 6. First, we determined the effective dielectric constant from the information given in Table II.

$$\varepsilon_{ff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left[\frac{1}{\sqrt{1+\frac{12h}{W}}}\right] \tag{4}$$

$$\varepsilon_{ff} = \frac{4.3+1}{2} + \frac{4.3-1}{2}\left[\frac{1}{\sqrt{1+\frac{12(1.52)}{3}}}\right] = 3.27 \tag{5}$$

The dielectric constant value obtained from eqn. (5) coincides with the value of effective permittivity calculated by the CST microwave calculator.

$$Z_O = \frac{120\pi}{\sqrt{\varepsilon_{ff}}\left[\frac{W}{h}+1.393+0.667\ln\left(\frac{W}{h}1.444\right)\right]} \tag{6}$$

$$Z_O = \frac{120\pi}{\sqrt{3.27}\left[\frac{3}{1.52}+1.393+0.667\ln\left(\frac{3}{1.52}1.444\right)\right]} = 49.80\Omega \tag{7}$$

It can be seen from Figure 5 and eqn. (7) that, the results were found to be almost equal if not exactly equal to the one obtained from the CST microwave studio calculator. Thus, the CST microwave studio calculator and the analytical method proved to be effective.

III. Simulation Results and Analyses

A. Insertion (S_{21}) and Return (S_{11}) Loss

The simulated low-pass filter response is shown in Figure 6. The gain (dB) is plotted on the y-axis against the frequency (GHz) on the x-axis. It is clear that the simulated cut-off frequency was found to be 2.4GHz. The value of the insertion loss (S_{21}) and return loss (S_{11}) at 2.4GHz were found to be -29.941dB and -0.505dB respectively.

B. Field Monitors

As expected, Figure 7 shows the surface current at different frequency. The field monitors applied at 0.4GHz, 0.8GHz and 1.2GHz show all the signal passing through the filter because, they are within the pass band frequency. The cut-off frequency of the filter as already known is 2.4GHz and this correspond to what happened in Figure 7 (d) in which the signal is attenuated.

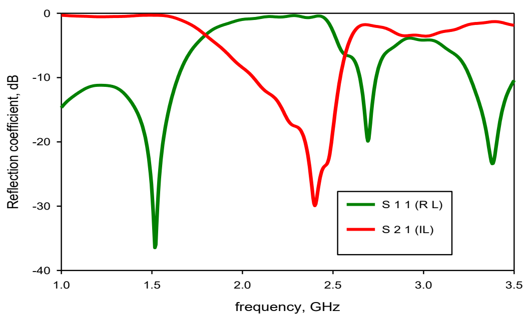

Fig. 6. Frequency response of the low-pass filter

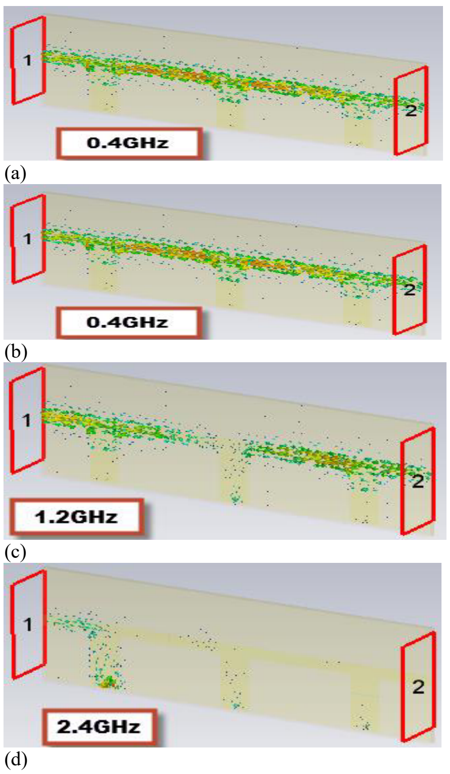

Fig. 7. Surface current at different field monitors

IV. Conclusions

Filters are one of the primary and essential parts of the microwave and communication systems. The microstrip low-pass filter was simulated using CST microwave studio software. In order to predict the performance of the filter, few parameters in the structure were analysed and found to have good relationship with the microwave theory. An optimisation process has been introduced along with the simulation procedure, focusing on the filter dimension in order to improve the response of the filter.

A. Suggestions for Future Studies

Validation of the proposed filter topology via prototype development is beyond the scope of this research study. It is suggested that this should be part of a future study's objectives.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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