A Reduced-Size Bandpass Filter Using Symmetrical Coplanar Structure

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Abstract: This paper proposes a new symmetrical bandpass filter based on capacitive loading with a coplanar waveguide (CPW) structure. The filter was numerically designed at the operating frequency around 2 GHz by using IE3D software package. The characteristics of the proposed filter were then measured which the results were in good agreement with simulation. The passband insertion loss was considerably low (~3 dB) and the return loss was high (greater than 10 dB). The size of the proposed filter was also decreased approximately 50% when comparing with the filters using conventional transmission lines.

1. Introduction

In present day, filters play important roles in several RF and microwave communication systems. The current trend in RF and microwave filter design points towards increased performance, integration and smaller, lighter weight, and lower cost. Unfortunately, smaller size can be crippling towards a microwave engineer, since it is often convenient to utilize the properties of structures which have dimensions comparable to the signal wavelength. When the design area becomes comparable to or smaller than the signal wavelength, such structures can be difficult or impossible to incorporate. The slow wave structures have been used to reduce the size of such structures by reducing the signal wavelength along the structure [1]-[2]. However, the proposed slow wave structures either introduce additional dissipation loss leading to reduced performance, or increase process complexity by utilizing non-planar structures, therefore such a strategy may not be acceptable for the filter design, especially when fabricating integrated circuits. Miniaturization of RF and microwave filters may be achieved by using very high dielectric constant substrate, but very often for specified substrate, a change in the geometry of filters is required and therefore numerous new filter configurations become possible. Another technique to reduce circuit size is to use capacitive loading to the filters, but this could further increase insertion loss in passband [3]-[8].

As we know, a variety of transmission line structures can be formed to be bandpass filters including coaxial, microstrip, and coplanar waveguide (CPW) lines. However, only microstrip and coplanar waveguide are extensively used when fabricating radio frequency and monolithic microwave integrated circuits (RFICs and MMICs) due to their planar natures and integrated circuit fabrication compatibility. Microstrip transmission lines are presently employed for commercial RF and microwave devices, partly because of the vast amount of design information available. Using microstrip suffers inevitably from high dispersion and high insertion loss. In addition, shunt elements must be mounted by drilling through the substrate [9]-[10]. This adds cost and discontinuities which make the design more difficult and degrade the performances of the devices. Moreover, the microstrip impedance and guide-wavelength are usually sensitive to substrate thickness, which further increase design problems at high frequency. To overcome these disadvantages, a CPW transmission line structure was proposed to design for several RF and microwave devices such as directional coupler [11] and mixer [12]. The coplanar waveguide structure can be also easily applied for RFICs and MMICs because of its fabrication process compatibility.

This paper, therefore, proposes the development and design of a reduced-size bandpass filter using CPW transmission line open circuits as capacitive loading at the operating frequency around 2 GHz. The study is expected to obtain a high performance reduced-size bandpass filter.

2. Theory

Theory related to this work including the analysis and design of a CPW transmission line and a size reduction technique using a capacitive loading will be described in the following subsections.

2.1 A CPW Transmission Line

Fig.1 shows a structure of coplanar waveguide consisting of a center conductor and the close proximity of the ground planes on each side of conductor strip. The characteristic impedance of a CPW line using the conformal mapping technique can be calculated as [10]

$$Z_0 = \frac{60}{\pi} \frac{1}{K(k_1)/K'(k_1) + K(k_3)/K'(k_3)} \tag{1}$$

The effective dielectric constant (ε_{re}) of the CPW transmission line can be obtained as

$$\varepsilon_{re} = 1 + q(\varepsilon_r - 1) \tag{2}$$

where the filling factor is

$$q = \frac{K(k_2)/K'(k_2)}{K(k_1)/K'(k_1) + K(k_3)/K'(k_3)} \tag{3}$$

$$k_1 = \frac{s}{2w + s} \tag{4}$$

$$k_2 = \frac{\sinh(\pi a/2h)}{\sinh(\pi b/2h)} \tag{5}$$

$$k_3 = \frac{\tanh(\pi a/2h_1)}{\tanh(\pi b/2h_1)} \tag{6}$$

when h_1 is height of cover shield, and $K(k)$ and $K'(k)$ are the complete elliptic integrals of the first and its complement, respectively

The ratio of K / K' can be determined as

$$\frac{K(k)}{K(k)} = \frac{\pi}{ln\left[2\left(1+\sqrt{k'}\right)/\left(1-\sqrt{k'}\right)\right]}$$

$$\text{for } 0 \le k_i \le 0.707 \tag{7}$$

$$\frac{K(k)}{K'(k)} = \frac{1}{\pi} \ln\left[2\left(1+\sqrt{k}\right)/\left(1-\sqrt{k}\right)\right]$$

$$\text{for } 0.707 \le k_i \le 1 \tag{8}$$

where $k' = \sqrt{1 - k^2}$.

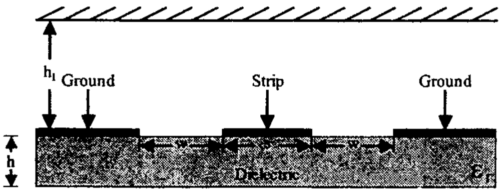


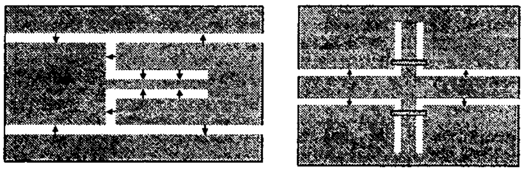
Fig. 1 A cross section of a CPW line

2.2 A Size Reducing Technique

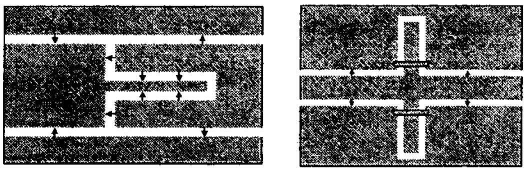
There have many types of size reducing techniques using additional lumped element or distributed element loading. As we know, the distributed capacitance and inductance of the transmission line determine the absolute value of the line's capacitance and inductance, and these in turn determine the phase of a signal traveling along the line. If the length of transmission line is now simply reduced without modifying, the total capacitance and inductance will also reduced and this will lead to altering of electrical phase of signal. In order to have the electrical phase equivalent to the original transmission line, its capacitance and inductance must be increased so that they are once again equal to that of the original line. This can be easily be done by adding lumped capacitors or inductors at the ends of transmission lines. This principle can be applied to substantially reduce the RF and microwave devices. However, the lumped capacitors and inductors may be replaced by shunt and series distributed elements, respectively. Fig. 2 (a) and (b) show the realization of CPW series and shunt circuits of short and open stubs. All arrows inside Fig.2 show directions of electric filed patterns. Through selection of the appropriate stub termination and its length, a series or shunt reactance can be form to realize size reduction.

In this work, CPW open stubs as shunt distributed elements were utilized to be capacitive loading due to its simple structure when fabricating the proposed bandpass filter. The capaitance can be formed by creating a gap, g, between the end of center strip and a ground plane as shown in Fig. 3. The electric field interaction between the open end and the ground plane produces a capacitive reactance resulting to size reduction. A CPW open end occurring in a bandpass filter for g/h ≥ 0.3 results to capacitance which can be approximated independent of g. For a/b = 0.5 the open stub capacitance can be calculated as [1]

$$C = 9.7179749 + \frac{0.34173829}{g/h} - \frac{0.004232911}{(g/h)^2} (fF) \tag{9}$$



Short stub　Short stub



Open stub　Open stub

(a)　(b)

Fig. 2 CPW stubs for size reduction (a) series circuit and (b) shunt circuits.

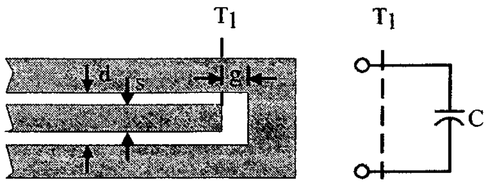


Fig. 3 A CPW open stub and its lumped element equivalent circuit

3. Design and Implementation

Fig.4 shows the proposed bandpass filter schematic consisting of seven transmission lines, eight short stubs and four open stubs. The characteristic impedances of all CPW transmission lines in the filter circuit were designed to be 50 Ω at the operating frequency around 2 GHz. The center conductor width of a CPW line was calculated to be 65.5 mil. The IE3D software package (EM simulation) from Zeland was employed to design and optimize the length of each CPW line of the filter circuit. In this research, a microwave substrate of RT/Duriod 3006 with relative permittivity, ε_r, of 6.5 and dielectric thickness, h, of 50 mil (1 mil = 1/1000 inch) from Roger Corp. was utilized to built up the proposed bandpass filter. The capacitive loading value was found to be 9.843 fF from each open stub to obtain optimized size reduction which corresponding the gap width (g) of 80 mil. Fig.5 (a) shows the circuit layout of the CPW bandpass filter with all optimized lengths listed in the following.

L_{T1} = 289 mil,
L_{T2} = 320 mil,
L_{T3} = 400 mil,
L_{T4} = 310 mil.
L_{S1} = 325 mil,
L_{S2} = 320 mil,
L_{S3} = 338 mil,

A microcomputer-controlled milling machine (LPKF-model) was employed to etch the circuit patterns. The circuit lines were connected with 50 Ω SMA connectors at input and output ports. Air bridge strips were then used to connect both sides of ground planes together. The picture of complete reduced-size bandpass filter is now shown in Fig.5 (b).

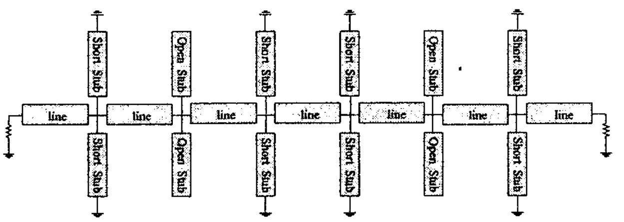


Fig. 4 The proposed bandpass filter schematic using short and open stubs.

4. Results

The constructed bandpass filters were finally tested using a calibrated vector network analyzer. Simulation and measurement of insertion loss and return loss of the proposed CPW bandpass filter were obtained as results plotted in Fig. 6 (a) and (b), respectively, which we can see good agreement. However, some small characteristic discrepancies are believed to be due to the coplanar transmission lines interconnections, discontinuities and also the effects of dimension errors.

5. Conclusions

The bandpass filters using a CPW symmetrical structure was proposed in this paper. The results exhibited high performances with ~80 MHz bandwidth, low insertion of ~3 dB and high return loss of ≥ 10 dB at operating frequency around 2 GHz. The size of the proposed filter was also decreased ~ 50% of the conventional filter structure. As results, the proposed bandpass filter circuit, therefore, could be potentially applied for RFICs and MMICs due to its planar structure and fabrication process compatibilities.

6. Acknowledgment

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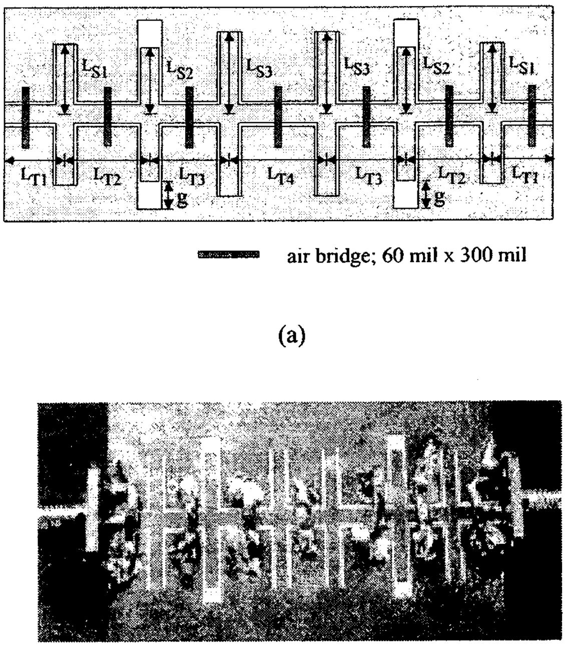
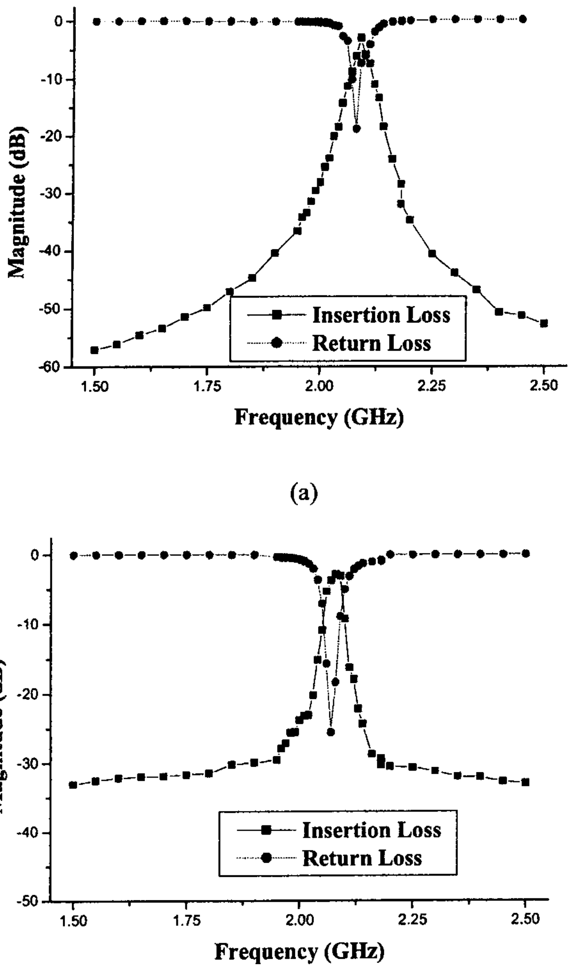


(a)

(b)

Fig. 5 The proposed bandpass filter (a) layout and (b) picture of the complete circuit.



(a)

(b)

Fig. 6 Performances of the bandpass filter using a CPW (a) simulation and (b) measurement.

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