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QUASI-LUMPED DESIGN OF BANDPASS FILTER USING COMBINED CPW AND MICROSTRIP

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Abstract—A bandpass filter (BPF) using CPW combined with microstrip is proposed. The target BPF is composed of two element filters built from combined CPW and microstrip structure. The design of element filter is based on the lumped elements approach with each circuit component built from a CPW or microstrip. In the circuit model, transmission zeros are created by the passband edges to enhance the signal selectivity. The element filter's characteristics are analyzed by the lumped *L*-*C* circuit model. Experiment is conducted, and a good agreement is observed between the measurement and simulation.

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1. INTRODUCTION

Recently, many circuits of planar structure, especially the CPW, have been presented and successfully implemented in wireless communication systems, e.g., the technologies of satellite systems, mobile communications, and monolithic microwave integrated circuits (MMICs) [1–3]. Among these systems, the filters, especially the BPFs, are essential elements with large quantity used in system's building blocks and play important roles in affecting system performance. They exhibit several characteristics such as compact size, high selectivity, and wide stopband to enhance the circuit performance in both the passband and the stopband. In particular, the CPW possesses a uniplanar feature and advantages such as ease in series and shunt connection without via hole, insensitive to substrate thickness, lower phase velocity variation with frequency or impedance, lower crosstalk and parasitic radiation, low dispersion effect, and simple fabrication process. Those advantages render the CPW a primary connection structure between circuit blocks of the MMICs circuit designs.

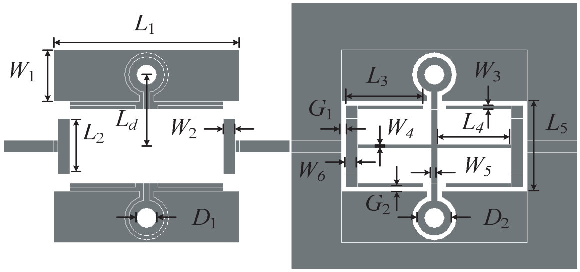
In the past few years, the designs of CPW [4–7] and microstrip filters [8–10] mainly follow the coupled line theory or resort to very complicated numerical analysis. Besides, the impedance (admittance) inverters, coupling coefficients, and numerical derivations of integral equations used in their designs might lack of circuit sense. Hence, an ordinary electronic circuit designer might not easily understand the circuit's functions, let alone predict circuit performance. In this paper, we propose a simple idea which uses the lumped-elements circuit model to design the BPF. The BPF is built from cascading two same-operating-frequency CPW-combined-microstrip BPFs. Each of the filters can implant a transmission zero either by the left or the right side of the passband to enhance the signal selectivity. A section of microstrip is used to connect the filters. It also implements the I/O ports. An equivalent L-C circuit model is developed to analyze the filter's frequency response. The lumped elements are realized by various discontinuity structures of CPW or microstrip. Furthermore, an effort is made to reduce the circuit size. A transmission zero is created by a shunt capacitance implemented by a pair of ground-coupling microstrip patches. And its frequency can be controlled by the capacitance's value. Initially, the HFSS [11] simulation is used to validate the S-parameter data derived from the equivalent circuit model. Then, an experiment is conducted to verify the circuit design. It is observed that the measured data agree well with simulated ones.

2. FILTER DESIGN

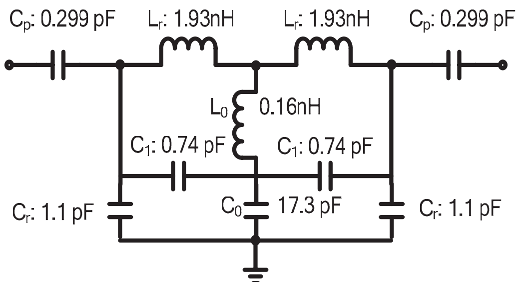
Shown in Fig. 1 is the CPW-combined-microstrip filter (termed the element filter) and its equivalent lumped-elements circuit model. Two distinct element filters with the same passband compose the proposed quasi-lumped designed BPF. The filters are built on both sides of the RT/Duroid 6010 substrate with thickness 0.635 mm, dielectric constant 10.2, and loss tangent 0.0023. The right of the Fig. 1(a) (CPW side) is the size-reduced CPW structure. It is originated from a dumbbell-shape CPW structure. To achieve the size reduction, the dumbbell's two large ends have the inner part depleted and remain the edges next to the surrounding ground metal. The saved edges preserve the couplings of the structure to the surrounding ground. The inner-depleted dumbbell ends transform to two hairpins. They are brought closer to each other, connected by a narrow strip in the center. As a consequence, the circuit's horizontal dimension is reduced from 14 mm to 9 mm, a 35.7% size reduction.

The connected-hairpins layout of the element filter is transformed from a dumbbell-shape CPW resonator, providing an extra microstrip shunt capacitance for creating a transmission zero. The equivalent circuit model is come up with the series and shunt paths of the signal traveling in the filter structure shown in Fig. 1(a). For example the elements C_p's and L_r's represent discontinuities resided at the series path from the left port to the right one. The elements L_0 and C_0 stand for the discontinuities existing on the shunt paths starting from the middle of the horizontal strip to the bilateral grounds via the vertical strips and the opposite-side patches. It should also be mentioned that the values of the lumped elements in Fig. 1(b) are evaluated by several technologies. The inductances and the shunt capacitances, e.g., L_0, L_r, C_0, and C_r, are initially evaluated by the quasi approach of the distributed inductor and capacitor from a transmission line model [12]. The coupling capacitances, C_1 and C_p, are extracted from the S-parameter data simulation of two coupled lines of the corresponding layouts. And these lumped elements' values are finely tuned to compare with the curves obtained from HFSS simulation.

On the opposite of the circuit shown in the left of Fig. 1(a) (microstrip side), it exhibits two microstrip patches and two T-shape microstrip. The formers are together with the ground on the opposite side form the shunt capacitance C_0 in Fig. 1(b) and the latter ones make the circuit's I/O ports. The structure's dimensions and its equivalent lumped elements values are given in the figure caption. In the circuit model, the L_0 represents the effect of the two vertically oriented narrow strips in the middle of the CPW side. The metallic via holes, neglecting



(a)



(b)

Figure 1. (a) Structure of the zero-implanted CPW-combined-microstrip element filter (with dimensions $W_1 = 2.6$, $W_2 = 0.6$, $W_3 = 0.2$, $W_4 = 0.3$, $W_5 = 0.4$, $W_6 = 0.6$, $L_1 = 9$, $L_2 = 2.6$, $L_3 = 2.8$, $L_4 = 3.5$, $L_5 = 4.4$, $L_d = 3.5$, $D_1 = 1$, and $D_2 = 1.8$, all in mm) and (b) the equivalent L-C circuit model.

their effect in circuit model, are used to connect the microstrip patches to the vertical narrow strips. Note that the capacitance, C_0, together with the inductance, L_0, creates a transmission zero. The effect of the horizontally directed narrow strips is equivalent to the inductances, L_r's, and the shunt capacitances, C_r's, denote the coupling effect between the hairpins and the bilateral grounds. The filter's operation frequency (also its resonant frequency) is mainly defined by the value of $1/2\pi\sqrt{L_r C_r}$. The capacitances, C_p's, stand for the couplings between the T-shape microstrip I/O and the hairpins. In the element filter structure, the couplings between the hairpins and the microstrip patches on the opposite side together provide a minor signal patch represented by the capacitances C_1's.

In Fig. 2, we compare the simulated frequency response of circuit model in Fig. 1(b) with the one obtained from the full-wave simulation (HFSS) for Fig. 1(a). The agreement between two curves evidently assures the validity of the equivalent L-C circuit model. The passband's central frequency is 2.45 GHz which is designed for the WLAN applications, and the created transmission zero is observed at 2.2 GHz (2.16 GHz) from the lumped-elements circuit model simulation (HFSS simulation). To enhance the BPF's performance, two element filters of distinct transmission zeros are cascaded to construct the proposed target filter. Therefore, a similar element filter is built next to the existing one on the same substrate. The lumped elements' values of the latter filter different from those in Fig. 1(b) are $L_r = 2.48\,\text{nH}$, $C_0 = 10.1\,\text{pF}$, and $C_1 = 0.387\,\text{pF}$. Shown in Fig. 3 is the frequency responses of the latter element filter which has a transmission zero by the high end of the passband edge at 2.76 GHz (2.71 GHz) from circuit model (HFSS). Ideally, the cascading filter should have two zeros, and each of them is located by either side of the passband edges to increase the signal selectivity.

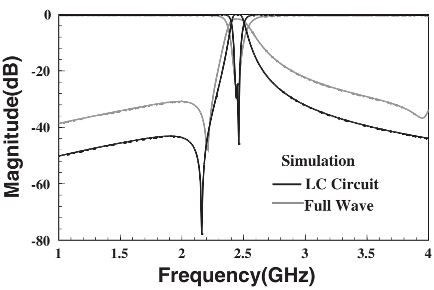


Figure 2. The simulated frequency responses for the element filter of Fig. 1.

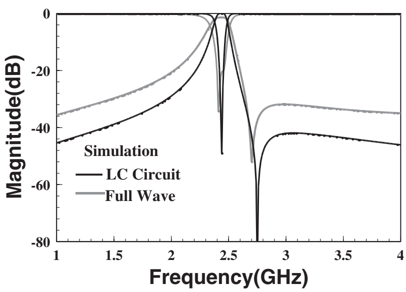


Figure 3. The simulated frequency responses for the element filter of Fig. 1.

In Fig. 4, we show the proposed quasi-lumped design of the BPF composing of two element filters in a cascading configuration. On the microstrip side, an I-shape microstrip is laid between two element filters for the connection. The distance between the element filters is 7.4 mm. Two T-shape microstrips form the I/O ports. The circuit only occupies an area of $22.9 \times 9.2\,\text{mm}^2$ (neglect the dimensions of microstrip I/O ports). The cascading filter expects to have much sharper band-edge slopes and two transmission zeros with each of them located by either side of the passband. In Fig. 5, we give the measured and simulated frequency responses for the proposed cascading BPF. The BPF has the measured passband central frequency, 2.44 GHz, and obtains a 7.75% of 3-dB fractional bandwidth with a measured minimum insertion loss of 3.9 dB. The discrepancy between the simulation and measurement around the second zero (3.45 GHz) is owing to the reason that the measurement equipment does not have enough dynamic range to

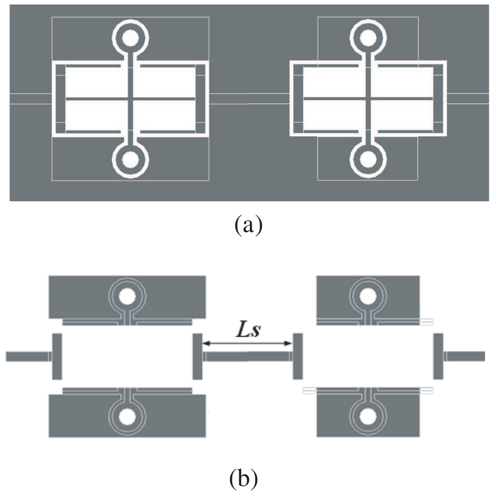


Figure 4. The layouts of the two element filters in the cascading configuration ($L_s = 7.4\,\mathrm{mm}$), (a) CPW side and (b) microstrip side.

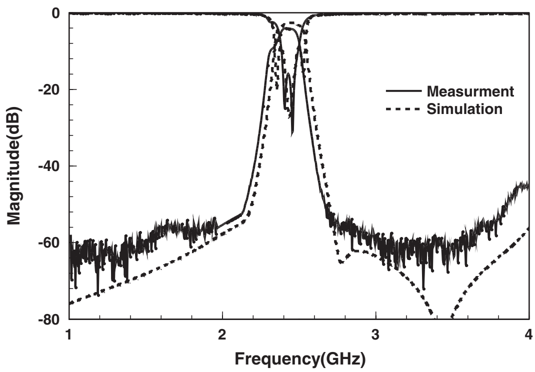


Figure 5. The measured and simulated frequency responses for the BPF in Fig. 4.

recover the signal response from the noise floor below $-60\,\mathrm{dB}$. The filter belongs to a 4th order circuitry, and the band edge's roll-off slopes in both the higher end and the lower end are around $250\,\mathrm{dB/GHz}$ ($102\,\mathrm{dB}/f_0$, f_0 in unit of GHz).

The sensitivity of the circuit should be rather comparable to those of CPW and microstrip structures since the field distribution is similar to those of CPW and microstrip. However, the circuit performance is quite sensitive to the length of the connection microstrip, L_s. It should be chosen carefully to minimize the mutually loading effect between the element filters. The length is empirically decided to be 7.4 mm from extensive simulations.

3. CONCLUSIONS

A quasi-lumped design of a CPW-combined-microstrip BPF is developed, and its performance is presented in this paper. The design of the filter is intuitive from using a lumped-elements circuit model. Two transmission zeros are deliberately created in the circuit design to improve the passband's signal selectivity. Effort of size reduction is exerted on the filter design, and a 35.7% size reduction is achieved. Experiment shows a good agreement with the simulation. It is believed that this filter design should find many applications in modern wireless communication systems.

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