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Parallel Coupled Microstrip Filters With Suppression of Harmonic Response

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***Abstract*—Corrugated coupled microstrip lines are proposed to design planar microwave filters with suppression of spurious response at twice the center frequency $(2f_o)$. The corrugated structure is designed to equalize the phase velocities of the two eigenmodes in the propagation direction. The designed bandpass filters have a wide upper stopband with satisfactory attenuation levels. In addition, the symmetry of the passband response is improved. Measured results of two fabricated circuits show that the idea works very well.**

***Index Terms*—Corrugated microstrip, microstrip filter, spurious response.**

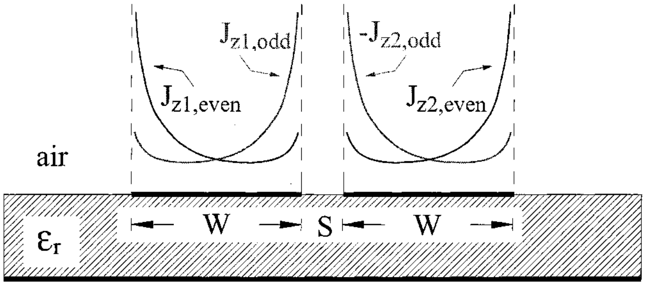

Fig. 1. Typical current distributions of the odd- and even-modes of a pair of symmetric coupled microstrips.

I. INTRODUCTION

FILTERS are essential in the RF front end of microwave wireless communication systems. In planar microstrip realization, one of the most common implementation methods is to use a cascade of parallel coupled sections, since the synthesis procedure [1] is easy and a wide range of filter fractional bandwidth is achievable [2].

The tradition design of parallel coupled microstrip filter suffers from the spurious response at twice the basic passband frequency $(2f_o)$ [2], [3], which causes response asymmetry in the upper and lower stopbands, and could greatly limit its applications; it is resulted from the inequality of the even and odd mode phase velocities of the coupled lines in each stage. This problem becomes more severe if inverted microstrip and suspended- substrate stripline are used, since these two media exhibit a considerably greater difference in mode velocities [3].

Many works [3]–[6] have been proposed to tackle this problem. They fall into two categories [4]: providing different lengths for the even and odd modes and equalizing the modal phase velocities. It is found in [3] that connecting a short uncoupled line section at either end of the coupled section can improve the filter characteristics, if the section lengths are chosen correctly. In [4], an overcoupled resonator is proposed to extend phase length for the odd mode to compensate difference in the phase velocities. Subsections with a coupled three-line microstrip are inevitable at both ends of each coupled section in the filter. The capacitively compensated structures [5], [6] are also effective in suppressing the spurious passband at $2f_o$. It should be noted that the values of the loading capacitors are subject to the electrical parameters of each coupled section.

Recently, [7] combines different stripline-stepped impedance resonators (SIR) with specified coupling angles to suppress the spurious responses. In [8], the gap size and the linewidth for the input/output coupled resonators are reduced to improve the rejection of the filter at $2f_o$. The coupled wiggly microstrip lines in [9] also show an effective suppression on the spurious passband. The strip-width perturbation does not require the filter parameters to be recalculated, and the classical design methodology for coupled-line microstrip filters can still be used.

Here, we introduce corrugated coupled microstrip lines as building blocks for constructing parallel coupled-line filters. Section II explains the technical background of the idea, and Section III compares the predicted and measured responses with the traditional design method using two fabricated bandpass filters. Section IV draws the conclusion.

II. THE IMPROVED DESIGN

Along a pair of symmetric coupled microstrip lines, the odd mode propagates faster than the even mode, i.e., $\beta_o < \beta_e$. Thus, if a coupled section with identical even and odd mode electrical lengths is required, the traveling path for the odd mode should be extended. It is known that, of symmetric coupled microstrips, typical current distributions of the odd and even modes are those shown in Fig. 1. It clearly indicates that electromagnetic energy for the odd mode gathers around the center gap, while for the even mode, it gathers around the outer metallic edges. Thus, a possible way to extend the path for the odd mode, and to increase that for the even mode to a minimal extent at the same time, is to alter the flat coupled lines to corrugated coupled lines, as shown in Fig. 2. The coupled lines, of course, are no longer symmetric with respect to the propagation direction. The even and odd modes of symmetric coupled lines are perturbed and

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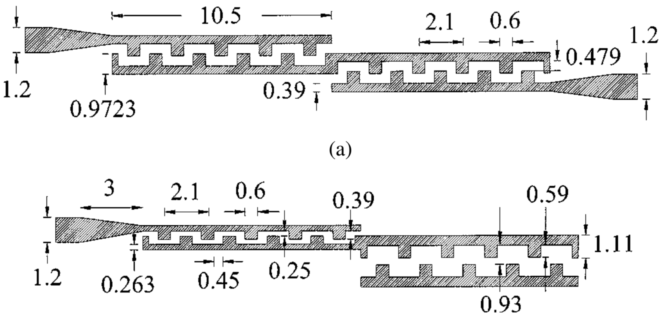


(a)

(b)

Fig. 2. Layouts for the fabricated microstrip filters. The dimensions are in mm. (a) Maximally flat filter of order $N = 1$. (b) Chebyshev filter of order $N = 3$; only half of the circuit is plotted.

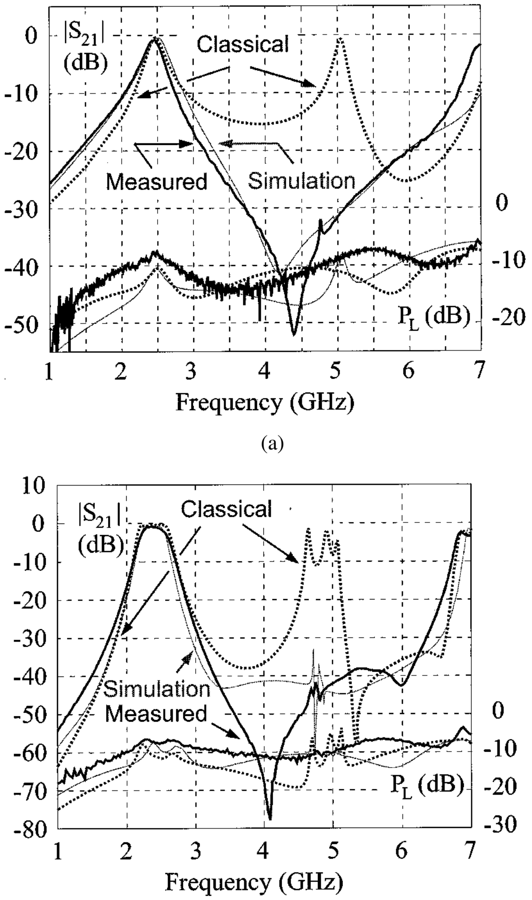
turn into c-mode and π-mode, respectively. Most of the energy of the π-mode will travel along the central wiggle coupling slot, while that of the c-mode along the straight outer metallic edges. Thus, the total electrical lengths of these two eigen-modes in a coupled section can be equalized, i.e., $\theta_c = \theta_\pi$, since the path length $l_\pi > l_c$ and phase constant $\beta_c > \beta_\pi$.

The design procedure for the circuit is as follows. First, the classical synthesis method, e.g., [1], is used to determine the linewidth and gap spacing for each coupled section. Then, for each section, the slot trace is indented. For an initial design, the width of the gap is kept the same all the way along the slot in a coupled section. A possible pattern for the indentation is to use a periodic rectangular-wave contour, as shown in Fig. 2. The purpose for choosing rectangular-wave shape is for the ease of simulation, as well as fabrication. The more indentation periods in a section, the more possible radiation loss is expected. The fewer periods in a section, on the other hand, the less effectiveness in phase velocity equalization can be achieved. In our case studies, five periods in a section are found to best meet these two requirements. Finally, the section length is adjusted to finely trim the center frequency. For a multistage filter, the above procedure is applied to every section before the whole circuit is constructed for simulation.

III. MEASURED RESULTS

We use the full-wave simulator IE3D [10] to do the CAD work before the circuits are fabricated. Fig. 2(a) shows the detailed layout of the first fabricated bandpass filters with maximally flat response of order $N = 1$, and Fig. 2(b) shows that of the second filter with Chebyshev response of $N = 3$ and ripple level 0.01 dB, respectively. All dimensions are in millimeters. The filters are made on substrate with $\varepsilon_r = 10.2$ (RT/duroid 6010) and thickness $h = 1.27$ mm. Their fractional bandwidth $\Delta = 10\%$, and the center frequency $f_o = 2.45$ GHz. The filter of $N = 3$ has four coupled sections; only the first two coupled sections are shown for saving the plot area. It is found that the length for a coupled section with indented slot is about 10% shorter than that with straight slot.

There are three $|S_{21}|$ (in dB) curves in Fig. 3(a) and (b). The response labeled "classical" is the simulation for filter designed with ordinary coupled lines, of which the spurious passband at $2f_o$ seriously deteriorates the filter rejection at upper stopband.



(a)

(b)

Fig. 3. Simulation and measured responses for the fabricated filters. Structural parameters are in Fig. 2. (a) Maximally flat filter of order $N = 1$. (b) Chebyshev filter of order $N = 3$.

The responses labeled with "measured" and "simulation" are for filters with indented slots, and they are in good agreement. At least 30 dB of spurious response suppression around $2f_o$ is achieved. The dip of the measured response in the upper stopband for the maximally flat filter with $N = 1$ is below -50 dB, and that for the Chebyshev filter with $N = 3$ is better than -70 dB. Since the attenuation of the fabricated filter in upper stopband is greatly enhanced, the passband response symmetry with respect to the center frequency is also greatly improved.

Also plotted in Fig. 3(a) and (b) is the total power loss of the circuit, which is calculated as P_L (dB) $= 10\log(1 - |S_{11}|^2 - |S_{21}|^2)$. The simulation responses for the classical and indented slot designs have comparative magnitudes. The measured results for the fabricated circuits are 1–2 dB higher than the simulation in the fundamental passband.

IV. CONCLUSION

Corrugated coupled microstrip lines are proposed to form the building blocks for planar microstrip filters with suppression of the spurious passband at the second harmonic. The response symmetry of the filter is also greatly improved. For the particular case studies shown here, a corrugated coupled section is about 10% shorter than that of a flat line section, and the measured results show that a harmonic rejection of at least 30 dB can be achieved.

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