# Parallel-Coupled Microstrip Filters With Over-Coupled End Stages for Suppression of Spurious Responses

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***Abstract*—In a parallel-coupled microstrip filter, end stages with over-coupling are designed to suppress the unwanted responses at twice the passband frequency $(2f_o)$. The inherent transmission zero of an over-coupled input/output stage is shown tunable. It is found that increasing the image impedance of the filter sections can further enhance the suppression. The designed bandpass filters thus have a wide upper stopband and improved passband response symmetry. Measured results of fabricated circuits show that the idea works very well.**

***Index Terms*—Microstrip filter, spurious response.**

## I. Introduction

PARALLEL-COUPLED microstrip filters have been widely used in the RF front end of microwave and wireless communication systems for decades. Major advantages of this type of filter include an easy synthesis procedure [1], good repetition, and a wide range of filter fractional bandwidth [2].

The traditional design of parallel-coupled microstrip filters suffers from the spurious response at twice the passband frequency ($2f_o$) [2], [3], which causes passband response to be asymmetric, reduces the width of the upper stopband, and could greatly limit their applications. It is resulted from the inequality of $\beta_e$ and $\beta_o$, the even- and odd-mode phase constants, respectively, of the coupled lines for each stage. This problem becomes more severe if a dielectric substrate with relative high permittivity is used, since the two eigen-modes will exhibit a considerable difference in $\beta_e$ and $\beta_o$.

Consequently, the ways to tackle this problem fall into two categories [4]: providing different lengths for the even- and odd-modes, and equalizing the modal phase velocities. In [3], [4], an over-coupled resonator is proposed to extend phase length for the odd-mode to compensate difference in the phase velocities. The structures in [5], [6] use capacitors to extend the traveling path of the odd-mode. The corrugated coupled microstrips in [7] are designed for equalization of the modal phase velocities. The stepped impedance resonators (SIRs) in [8], the method in [9] and the wiggly-line coupled stage design in [10] are also effective in improving the rejection characteristics of the filter at $2f_o$.

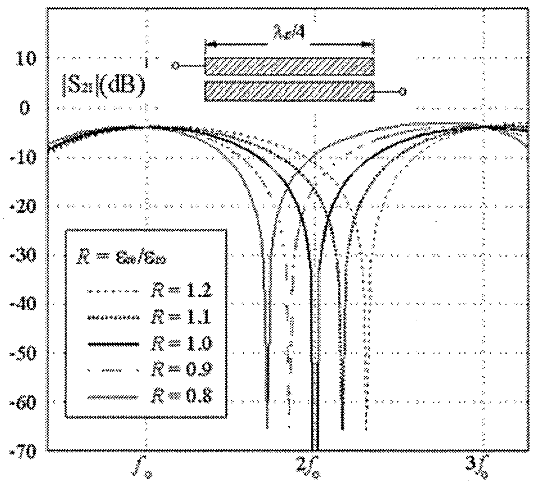


Fig. 1. Dependence of $|S_{21}|$ responses on $R = (\varepsilon_{re}/\varepsilon_{ro})$ for a coupled microstrip stage.

In this letter, two techniques are incorporated into the design of parallel-coupled microstrip filters for suppressing the spurious response at $2f_o$. First, the over-coupling in [4] is used. It is found in this work that applying over-coupling to the end stages, rather than to every coupled stage, is sufficient to improve the filter characteristics in the upper stopband. Then the image impedance is increased to reduce the difference in $\beta_e$ and $\beta_o$ of each coupled stage, so that the suppression of the spurious harmonic can be enhanced. Sections II and III will explain the technical background of these two ideas, and compare the predicted and measured responses. Section IV draws the conclusion.

## II. Transmission Zero of an Over-Coupled Stage

For a microstrip coupled stage, Fig. 1 shows the dependence of $|S_{21}|$ responses on $R = \varepsilon_{re}/\varepsilon_{ro}$, the ratio of the effective permittivity of the even-mode to that of the odd-mode. The results can be easily obtained by deriving the $Z$-parameters of the two-port network, followed by converting to the $S$-parameters [1]. For the ideal case with $R = 1$, the $|S_{21}|$ response has an inherent transmission zero at $2f_o$. When $R$ is increased, the zero moves to higher frequencies, and vice versa. For practical

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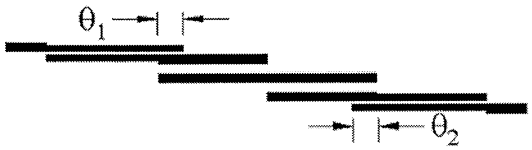


Fig. 2. Layout for a third-order filter. Over-couplings are applied to the end stages.

coupled microstrips, $R$ is greater than unity. The passband responses in the neighborhood of $f_o$, however, do not change significantly when the value of $R$ is changed, since the derivative of the coupling response is zero at $f_o$. Therefore when a stage is over-coupled, i.e. the coupling length is longer than $\lambda_g/4$, the passband response will be almost unchanged, and the inherent zero will move to a frequency lower than $2f_o$. In other words, the effectiveness of increasing the coupling length of a coupled-line stage on the zero is equivalent to that of decreasing $R$, which is also equivalent to increasing $\varepsilon_{ro}$ or decreasing $\varepsilon_{re}$. It implies that from the circuit design point of view, the inherent zero can be tunable, within a certain range, by merely adjusting the length for the over-coupling. Since the position of the zero is close to the band of the spurious responses, it can be used to enhance the filter performance around $2f_o$.

Fig. 2 shows the layout of a third-order Chebyshev bandpass filter, of which both the end stages are over-coupled. Fig. 3 plots the simulation and measured results for a third- and a fifth-order filters. The detailed passband responses are also plotted in the zoomed windows. The filters are designed by the classical synthesis method [1], followed with adding an extra section to the end stages for over-coupling. The lengths of the extra sections are chosen so that the peak of the spurious response is minimized. The IE3D [11] is used for the electromagnetic simulations. The simulation results for filters directly synthesized by the traditional method, i.e. without any over-coupling, are also plotted for comparison. The measured peak rejection levels for the filters with proper over-couplings are no more than $-30$ dB. It can be seen that a suppression of at least 20 dB to the spurious responses is obtained by using the over-coupled stages.

It is noted that the design in Fig. 2 is much simpler than that in [4], where over-coupling is applied to every coupled stage. The tuning in our design involves only two over-couplings at the end stages, while that in [4] involves the coupling coefficients of all the coupled stages, which include three-line sections or angled nonuniform coupled lines. The substrates in both works have a similar dielectric constant, but the thickness of our substrate is more than three times that of the counterpart. Nevertheless, the measured suppression to the spurious passband in Fig. 3(a) and Fig. 3(b) shows a similar level to that of the optimized filter in [4].

## III. Enhancing the Suppression by Increasing the Image Impedance

Suppressing spurious harmonics for parallel-coupled microstrip filters on a substrate with larger $\varepsilon_r$ is more difficult than those on a substrate with smaller $\varepsilon_r$, since the eigen-modes will exhibit more deviation in phase velocities, which is the very

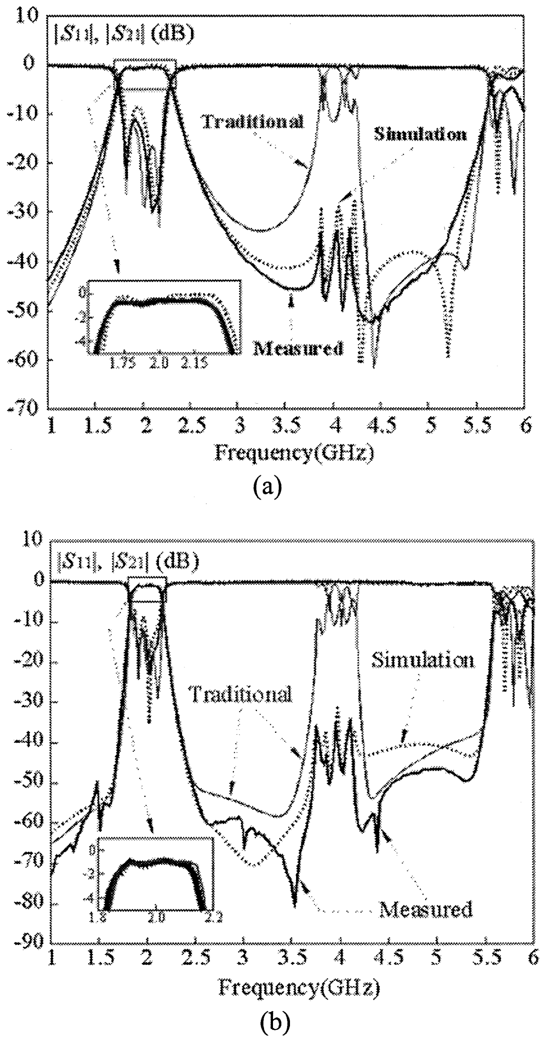


Fig. 3. Simulated and measured responses for Chebyshev bandpass filters. The center frequency $f_o = 2$ GHz and passband ripple $= 0.1$ dB. The substrate has $\varepsilon_r = 10.2$ and thickness $h = 1.27$ mm. (a) Responses of a third-order filter with fractional bandwidth $\Delta = 20\%$. The electrical lengths for over-coupling at the end stages are $\theta_1 = 12.7^\circ$ and $\theta_2 = 17.2^\circ$. (b) Responses of a fifth-order filter with $\Delta = 15\%$, $\theta_1 = 15.1^\circ$ and $\theta_2 = 18.8^\circ$.

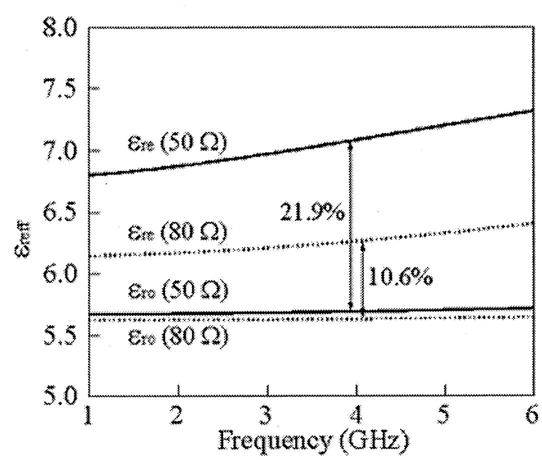


Fig. 4. Comparison of $\varepsilon_{re}$ and $\varepsilon_{ro}$ for two pairs of coupled lines. $Z_i = 50\ \Omega$: $W = 0.590$ mm, $S = 0.220$ mm; $Z_i = 80\ \Omega$: $W = 0.206$ mm, $S = 0.396$ mm.

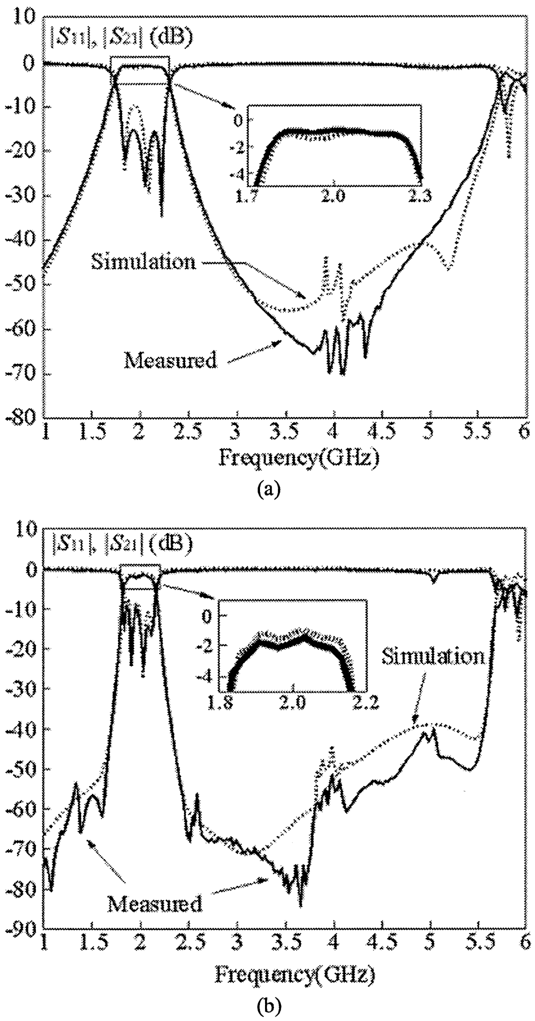


Fig. 5. Simulated and measured responses for filters with image impedance $Z_i = 80\ \Omega$. The design specifications of the filter and the substrate are identical to those in Fig. 3. (a) Responses of a third-order filter with $\Delta = 20\%$, $\theta_1 = 12.5^\circ$ and $\theta_2 = 12.9^\circ$. (b) Responses of a fifth-order filter with $\Delta = 15\%$, $\theta_1 = 14.1^\circ$ and $\theta_2 = 15.6^\circ$.

reason that the spurious response arises. Thus, any technique for reducing the deviation between the modal phase velocities will be helpful in the suppression of unwanted harmonics. It is found that if the image impedance of a coupled stage can be increased, the difference between $\beta_e$ and $\beta_o$ of the coupled lines can be reduced at the same time. For keeping both system reference impedance and the passband response unaltered at the same time, the method in [12] can be invoked to design parallel-coupled filters with an image impedance other than 50 Ω. In this letter, the image impedance $Z_i$ of the filter is changed from 50 Ω to 80 Ω. Fig. 4 compares $\varepsilon_{re}$ and $\varepsilon_{ro}$ of two pairs of coupled microstrips, of which the dimensions are those for the first stages of the filters shown in Fig. 3(a) and Fig. 5(a). The relative deviation between $\varepsilon_{re}$ and $\varepsilon_{ro}$ for the 50 Ω case is reduced from 21.9% to 10.6% for the 80 Ω case. The responses for two filters with $Z_i = 80\ \Omega$ are shown in Fig. 5(a) and Fig. 5(b), of which the specifications are identical to those of Fig. 3(a) and Fig. 3(b), respectively. The over-coupling is also included in the circuit design. As indicated for both filters, the measured attenuation levels at $2f_o$ are better than −50 dB. For the particular case studies shown, the suppression is enhanced by 15 dB by increasing the image impedance of the filter. It is to be noted that the passband responses are close to being unchanged.

## IV. Conclusion

This letter shows an effective example of common parallel-coupled microstrip filter design. Suppression of the spurious response is achieved by introducing over-coupling to the end stages and increasing the image impedance of the filter. The over-coupling is applied to the end stages only. A coupled microstrip stage with higher image impedance is shown to have smaller difference in $\varepsilon_{re}$ and $\varepsilon_{ro}$, and parallel-coupled microstrip filters with higher image impedances also show an improved rejection at $2f_o$.

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