行政院國家科學委員會補助專題研究計畫成果報告

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計畫類別：個別型計畫

計畫編號：NSC89－2213－E－009－193－

執行期間：89 年 08 月 01 日至 90 年 07 月 31 日

計畫主持人：郭仁財教授

共同主持人：

本成果報告包括以下應繳交之附件：

□赴國外出差或研習心得報告一份

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□國際合作研究計畫國外研究報告書一份

執行單位： 交通大學電信工程學系

中　華　民　國　90 年　08 月　15 日

行政院國家科學委員會專題研究計畫成果報告

平行耦合微帶線寬頻濾波器設計

Wideband Bandpass Filter Design with Parallel Coupled Microstrip Line

計畫編號：NSC 89-2213-E-009-193-
執行期限：89 年 08 月 01 日至 90 年 07 月 31 日

主持人：國立交通大學電信工程學系 郭仁財教授

一、中文摘要

我們建立了平行耦合三線微帶線結構的濾波器系統化設計流程。從三線平行耦合微帶線的電路分析開始，到針對指定的介電常數值建立起各種模態的電壓特徵係數及特性阻抗值資料庫。並利用電路合成分析的方式，成功推導出單一級三線耦合微帶線相對應的等效電路參數，進而建立起濾波器的系統設計流程。在寬頻濾波器方面，我們設計出的濾波器有下列兩個重要的特徵: (1) 原先較小的第一級耦合級線距將會被有效的擴大。(2) 提高非工作頻段的截止衰減程度。最後並就兩種不同的介電常數值，分別進行實作與測量。其中理論預估與測量結果相當吻合。

關鍵詞：微波濾波器,寬頻,平行耦合,微帶線

Abstract

A systematic procedure is described for designing bandpass filters based on parallel coupled three-line microstrip structures. It starts with modal analysis of a three-line coupled microstrip circuit. A database of modal eigenvoltage coefficients and modal characteristic impedances for a specified value of substrate ε_r is established. The relation between the circuit parameters of a three-line coupling section and an admittance inverter circuit is derived, so that the filters can be synthesized by standard procedure. As compared with traditional parallel coupled lines, our three-line design has the following two important features in designing wideband filters: (1) the tight line spacings between the input/output lines and the resonators of end stages can be greatly released, and (2) the stopband rejections are significantly improved. Two filters are fabricated on substrates with low and high dielectric constants. The prediction and measurement results are in good agreement.

Keywords: Microwave Filter, Wideband, Parallel coupled, Microstrip

二、Introduction

Parallel coupled-line microstrip filters has been found to be one of the most commonly used microwave filters in many practical wireless systems for several decades [1]-[2]. In addition to the planar structure itself and relatively wide bandwidth, the major advantage of this kind of filters is that its design procedure is relatively simple. Based on the insertion loss method [1], filter functions of maximally flat and Chebyshev function can be easily synthesized. In addition, the filter performance can be improved in a straightforward manner by increasing the order of the filter.

Bandpass filters with relatively wide bandwidths are useful in many applications. When these filters are to be realized by parallel coupled microstrip lines, one of the main limitations can be the small gap sizes of the first and the last coupling stages. The more fractional bandwidth, the smaller gap size is required to increase the coupling. Obviously, shrinking the gap size is not the only way to increase coupling of coupled lines. It is the idea of our work [3] to construct a coupled section with a symmetric three-line microstrip structure shown as in Fig.1. It will be shown quantitatively that a coupled three-line section has larger coupling than a traditional two-line coupled section with the same gap size.

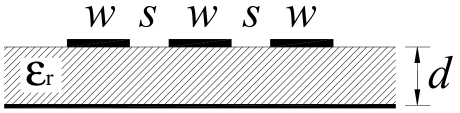

Fig.1 Cross-section view of a parallel coupled three-line microstrip.

三、Methods

The inductance matrix [L] and capacitance matrix [C] per unit length for the structure can be obtained by invoking the spectral domain approach (SDA) [4]-[5]. Each vector of [M_V] is the eigenvoltage vector of the matrix product [L][C].

We follow the approximations used in [6] to establish the equivalence between the coupled section and the admittance inverter circuits. Assume that the three modal phase constants are approximately the same, and let $\beta_i l = \pi/2$ at center frequency. It is to be noted that the approximation may not be suitable for designing filters with fractional bandwidth less than 20%, since it loses the accuracy for three-line structures with loose couplings.

Thus it is meaningful to define the coupling coefficient of a three-line coupled section K for comparing with that of a coupled line C:

$$C = \frac{Z_{oe}/2 - Z_{oo}/2}{Z_{oe}/2 + Z_{oo}/2}$$

$$K = \frac{m_1 Z_{m1} - m_3 Z_{m3}}{m_1 Z_{m1} + m_3 Z_{m3}} \tag{2}$$

It can be proved that both K and C can be expressed as $\{JZ_o + (JZ_o)^{-1}\}^{-1}$, with J being the admittance of the equivalent inverter.

In Fig.2, we compare the coupling coefficients C in (1) with K in (2) for given line widths and line spacings. As expected, the values of C and K decrease as s/d ratio is increased, and that $K > C$ for the same w/d and s/d. Given a specific coupling, the gap spacing for a three-line section is larger than that for a two-line one. This feature makes the three-line approach useful for designing filters or couplers when the line spacing of a coupled microstrip line is smaller than the lower limit of fabrication.

(1)

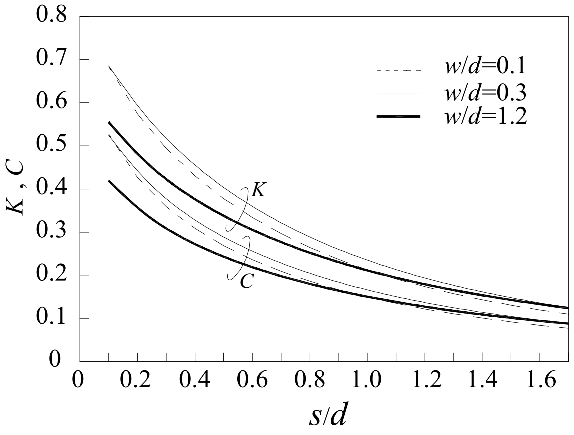

Fig.2 A comparison of coupling coefficients of a three-line and a two-line quarter wave-length microstrip couplers. The substrate $\varepsilon_r = 2.2$.

In Fig.3, the line spacings of the first coupled stage for designing a two-line and a three-line Chebyshev filters with 0.5dB passband ripple are plotted against the fractional bandwidths. The substrate dielectric constant $\varepsilon_r = 2.2$ and the filters are of order three. As compared with a three-line structure, a two-line section requires wider strips and smaller line spacings to meet the demand of fractional bandwidths from 30% to 70%. For the particular case studies shown here, the tight line spacings for the two-line design can be greatly released by six to seven times if a three-line section is used. If the substrate ε_r is changed to 10.2, the line spacing required for a three-line section is around two times those for a two-line section for the same range of fractional bandwidths [7].

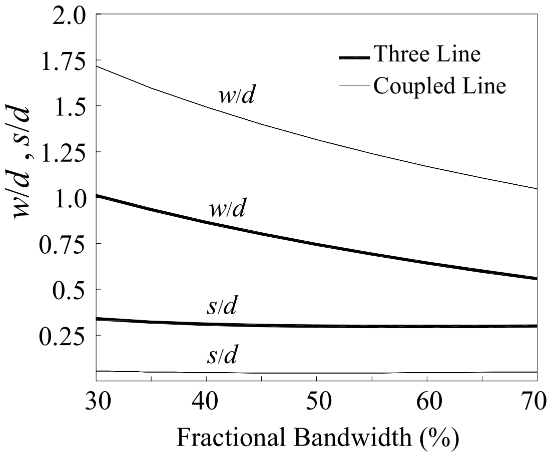

Fig.3 A comparison of the w/d and s/d dimensions required for three-line and two-line designs of bandpass filters with fractional bandwidths from 30% to 70%.

四、Results

Built with the three-line microstrip coupling sections, two filters are fabricated and measured to demonstrate the design procedure for wideband bandpass filters described above. Both of them are of Chebyshev type. Filters A is of order 3, and filters B is of order 2. For filter B, a 180° hybrid junction is required to take care of the sum of output signals on the outer strips. Filters A is fabricated on RT/duroid 6010 substrate with $\varepsilon_r = 10.2$ and thickness $d = 50$ mil (1.27 mm), and designed to have 0.5dB passband ripple. Filters B is fabricated on RT/duroid 5880 with substrate $\varepsilon_r = 2.2$ and thickness $d = 20$ mil (0.508 mm), and designed to have 1 dB passband ripple. The fractional bandwidths, Δ, of both filters A and B are 40%.

In the design procedure, the first step is to calculate the JZ_o value for each coupled section from the element values for the low-pass filter prototypes [2]. The design equations in [7] are used to calculate the values of m_1Z_{m1} and m_3Z_{m3}. Then, the design graphs in Fig.4 for $\varepsilon_r = 10.2$ and $\varepsilon_r = 2.2$ are invoked to determine the w/d and s/d.

Our three-line structure shows its distinctive feature on designing wideband filters on substrate with low dielectric constants. For filters B where the substrate $\varepsilon_r = 2.2$, all the s/d values for the traditional coupled line filters are less than 0.05, which corresponds to a line spacing of 1 mil if a substrate of 20-mil thickness is used. If the three-line design is used, on the other hand, the required line spacings are about 6 mils.

We use the full-wave simulator IE3D to validate our design before the circuit is fabricated. The simulation shows that each filter can meet the specifications once the open-end discontinuity is correctly compensated. Each coupled section is set to be commensurate and its length is determined by the geometric mean of the phase constants of all the coupled sections. The filters are measured using an

HP8720 network analyzer.

In Fig.5, traditional two-line filters is also fabricated and measured for comparing the filter performance with our three-line designs. The simulation and measured results for filter *A* are shown in Fig.5(a) and Fig.5(b), respectively. The $|S_{11}|$ and $|S_{21}|$ responses in Figs.5(a) and 5(b) are well matched. The upper stopband rejection of the three-line filter is better than that of the traditional design by about 6dB. In the modified two-trace coupled line filters [9], the gap spacings between adjacent coupled sections have been reported to be critical to the filter performance. Thus it is believed that if the gap spacings of the fabricated three-line filters can be properly trimmed, the stopband rejection and/or the response symmetry could also be improved.

Fig.6 shows the *S*-parameters of filters *B*, of which the fractional bandwidth is 40%. The simulations and the measurements are in good agreement.

五、Conclusions

It is believed that for the first time a systematic design procedure has been given for synthesizing parallel coupled line wideband filters based on three-line microstrip structure. The equivalence between a coupled three-line section and an admittance inverter circuit is established [7]. As compared with the traditional coupled line design, our three-line filter has two important advantages. The one is that the tight line spacing for designing wideband bandpass filters can be greatly released, and the other is that the stopband characteristics of the filter can be significantly improved.

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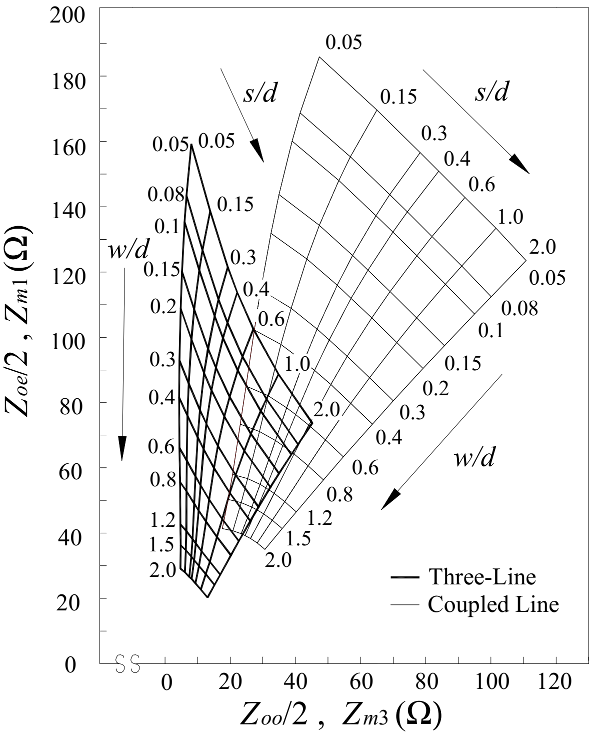
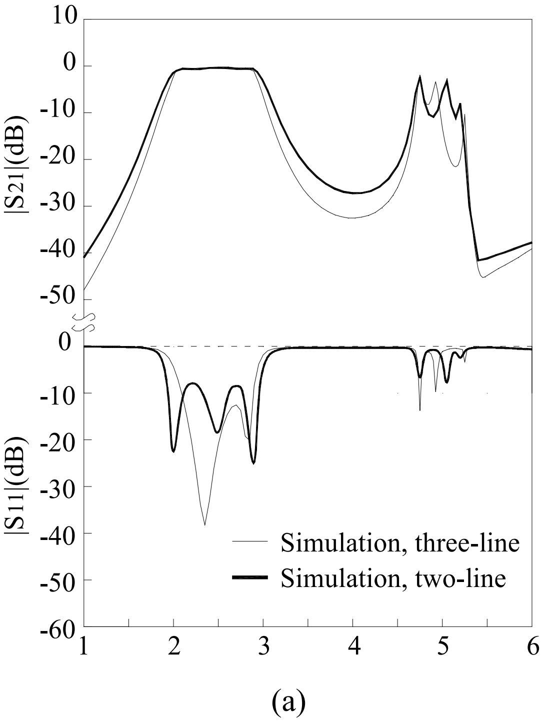
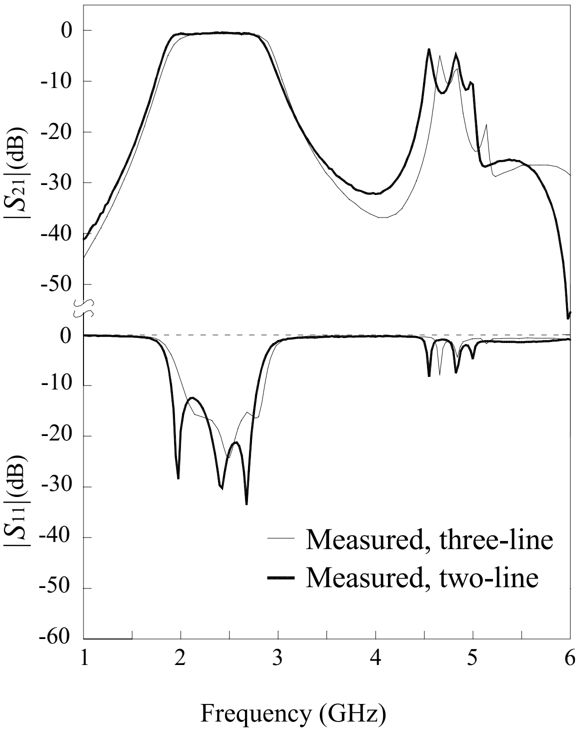


Fig.4 Design graphs for a three-line and a two-line microstrip structures. The substrate dielectric constant ε_r = 2.2.

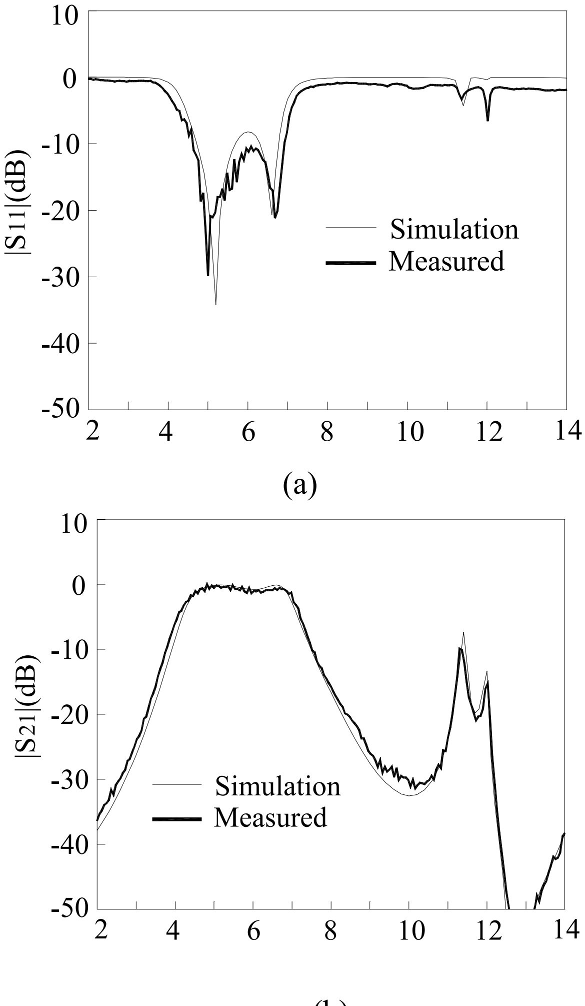


(a)



(b)

Fig.5 Comparing $|S_{21}|$ and $|S_{11}|$ responses of filter *A* with those of a traditional two-line design. (a) Simulation. (b) Measurement.



(a)

(b)

Fig.6 Measured and simulated responses for a three-line filter with f_c = 5.8GHz and Δ = 40%. (a) $|S_{21}|$. (b) $|S_{11}|$.