A Compressed-Length 90°-Bent Offset Broadside-End-Coupled Bandpass Filter

Ching-Kuang C. Tzuang, Yit-Chyun Chiang, and Shyang Su

Abstract—**A 21–22 GHz compressed-length offset broadside-end-coupled three-resonator bandpass filter is presented. The filter length, defined as the distance between the two interface planes governing the input and output ports, is reduced by approximately two-thirds for the particular filter as compared to the conventional colinear realization. The measured response shows less than 1.5 dB insertion loss and greater than 10 dB return loss in the passband. The noncolinear and offset broadside-end-coupled arrangement of such filter makes it flexible to interface with other microwave circuits in a communication system or subsystem design.**

I. Introduction

A TYPICAL layout and the cross-sectional view of the commonly used three-resonator end-coupled bandpass filter realized by the suspended substrate striplines (SSS) are shown in Fig. 1(a). This filter arranges the resonators in a colinear way and has demonstrated its use in millimeter-wave frequencies [1], [2]. Here we will present a different layout technique for designing basically the same end-coupled bandpass filter using the concept of the offset broadside-end-coupling of the adjacent resonators arranged in a noncolinear fashion. The new construction scheme of such filter immediately results in a reduced length of $(l_2 + 2W)$ between the interface planes P1 and P2 for the input and output ports shown in Fig. 1(b) when compared with that of $(l_1 + l_2 + l_3 + g_1 + g_2 + g_3 + g_4)$ for the colinear end-coupled filter shown in Fig. 1(a). Moreover the new filter configuration adds additional degree of flexibility to interface the filter with other microwave components in a microwave subsystem or system module when the colinear realization is undesirable.

II. Description of a Compressed-Length Three-Resonator Bandpass Filter Prototype

A. The New Filter Configuration

The use of SSS and broadside coupling provides many features such as high-Q, typically on the order of 500, low-loss, insensitive to temperature variation, and wider bandwidth [3], [4]. The filter shown in Fig. 1(b) consists of three noncolinear offset broadside-end-coupled SSS resonators. Note that the adjacent resonators on the opposite sides of the suspended substrate are perpendicular to each other, although this may not be necessary. The corresponding three resonators are designated as L_1, L_2, L_3 in Fig. 1(b). The SSS resonators represented by the dashed lines are underneath the suspended substrate and located at $y = h_1$. Fig. 1(c) is the equivalent circuit representation of Fig. 1(b). The J_{01}, J_{12}, J_{23}, and J_{34} in Fig. 1(c) are the admittance inverters, of which the parameters are associated with the discontinuity problem introduced by the noncolinear offset broadside-end-coupling of the adjacent resonators.

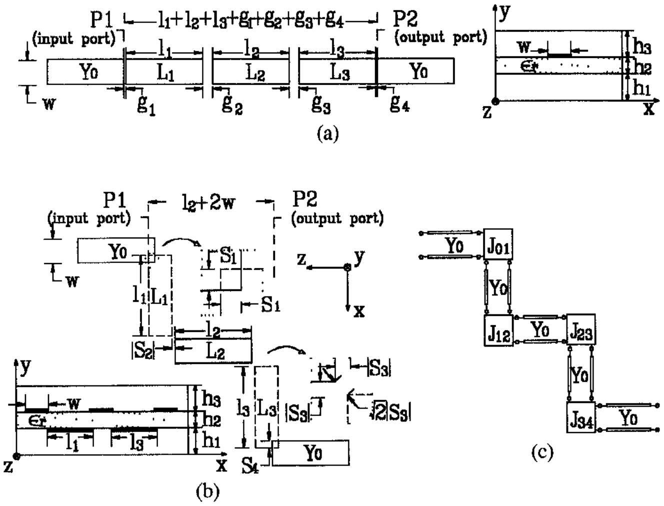

Fig. 1. (a) Typical layout and cross-sectional view of a conventional colinear end-coupled bandpass filter printed on a suspended substrate. (b) Physical layout and cross-sectional view of a compressed-length offset broadside-end-coupled bandpass filter printed on both sides of a suspended substrate. Note that the resonators located at $y = h_1$ and $y = h_1 + h_2$ are plotted by the dashed lines and solid lines, respectively. (c) Equivalent circuit representation of the compressed-length bandpass filter shown in Fig. 1(b).

B. Parameters De-embedding of the Discontinuity Problem

The discontinuity problem can be modeled by the equivalent π-circuit illustrated in Fig. 2. The parameters of the equivalent π-circuit are obtained by the variational technique based on the quasi-TEM three-dimensional SDA (spectral-do-

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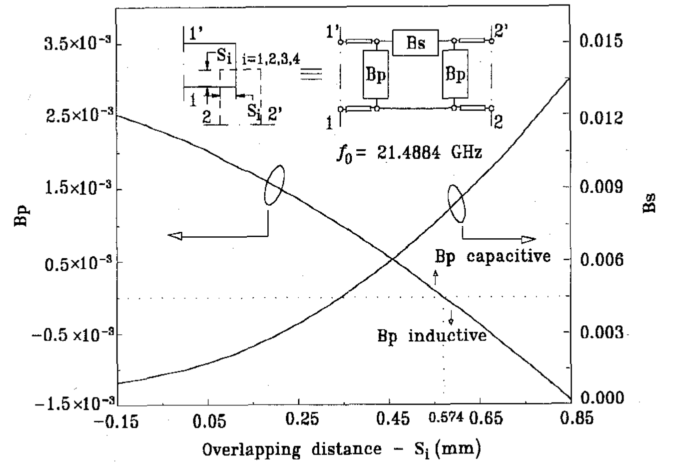

Fig. 2. Parallel susceptance (B_p) and series susceptance (B_s) as functions of the overlapping distance—S_i. The associated physical parameters shown in Fig. 1(b) are $h_1 = h_3 = 0.6$ mm, $h_2 = 0.254$ mm, $\epsilon_r = 2.2$, $W = 1.84$ mm.

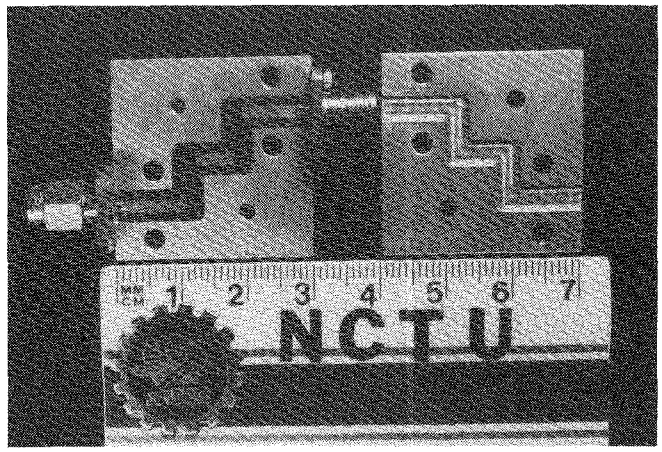

Fig. 3. Photograph of the prototype circuit—a 21–22 GHz compressed-length three-resonator bandpass filter. Structural parameters of the prototype circuit are $h_1 = h_3 = 0.6$ mm, $h_2 = 0.254$ mm, $\epsilon_r = 2.2$, $W = 1.84$ mm, $l_1 = l_3 = 5.45$ mm, $l_2 = 5.70$ mm, $S_1 = S_4 = 0.45$ mm, and $S_2 = S_3 = -0.03$ mm.

main-approach) reported in [4]. For a certain midband frequency f_0 obtained from the filter synthesis theory [5], Fig. 2 plots the values of the parallel susceptance (B_p) and the series susceptance (B_s) against the overlapping distance S_i of the adjacent resonators shown in Fig. 1(b). We assume that the overlapping region between the adjacent resonators is a square in shape. When S_i is positive, the overlapping region is a square with S_i^2 in size. When S_i is negative, there is no overlapping region defined. Instead, the shortest distance of the two adjacent resonators, L_{i-1} and L_i, projected into the $z - x$ plane is $\sqrt{2}\,|S_i|$. Given the dimensions of the discontinuity problem and the midband frequency, the values of B_s/ω_0 and B_p/ω_0 are insensitive to frequency variations [4]. The value of B_s is always positive. This implies a capacitive coupling is between the two resonators. When the value of S_i increases, the value of B_p decreases and changes sign at $S_i = 0.574$ mm. This indicates that the shunt elements are no longer capacitive but inductive, when S_i is greater than 0.574 mm.

Next one may invoke the conventional filter synthesis technique [5] to decide the values of S_i for a given filter specification. A 21–22 GHz three-resonator bandpass filter prototype has been built and tested. Fig. 3 shows the photograph of the prototype printed on a RT-5880 Duroid substrate. The structural parameters of the prototype are also given in Fig. 3. The ideal filter design without considering the conductor loss of the SSS assumes 0.2 dB equal ripple response in the passband.

III. Measured and Theoretic Results

The measured and theoretic filter responses are superimposed in Fig. 4 for return and insertion losses, respectively. The theoretic filter responses are obtained by providing the Touchstone™ microwave circuit simulator with the discontinuity circuit parameters out of Fig. 2, complex propagation constant of the SSS obtained by a rigorous full-wave approach [6], and the electric lengths of the SSS resonators. The attenuation constant of the SSS at f_0 is 5.574×10^{-3} dB/mm. The solid line and the dotted line of Fig. 4 represent the theoretic results for the insertion and return losses considering the conductor loss of the SSS, respectively. The measured insertion and return losses are represented by square (□) and triangle (△) symbols. The theoretic and measured data are in very good agreement. The excess midband insertion loss of 1.2 dB corresponds to an unloaded Q of 280 [5]. This unloaded Q would be increased if the aluminum housing of the prototype were plated with copper or silver.

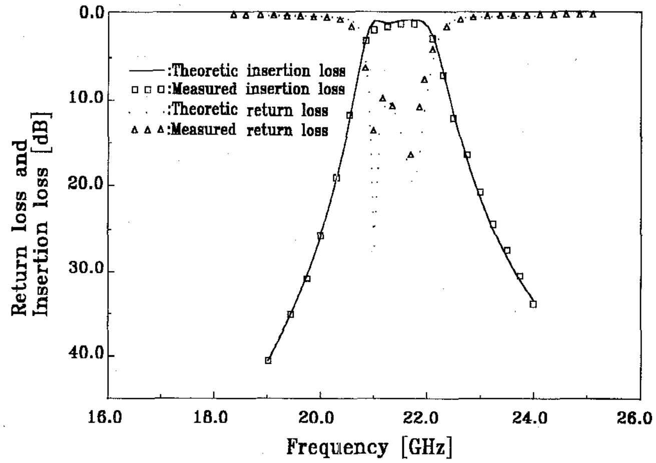

Fig. 4. Measured and theoretic characteristics of a 21–22 GHz compressed-length three-resonator bandpass filter.

IV. Conclusion

A new technique for constructing a compressed-length bandpass filter based on the concept of noncolinear offset broadside-end-coupling of the adjacent resonators is presented. A 21–22 GHz three-resonator bandpass filter prototype is built and tested. The measured filter characteristics agree well with the theoretic ones when the conductor loss of the SSS is considered. When compared with the colinear design, the new compressed-length filter shortens the distance between the interface reference planes for the input and output ports by approximately two-thirds for the particular filter prototype.

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