DESIGN OF A QUASI-PLANAR BROADSIDE END-COUPLED BANDPASS FILTER

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Abstract

This paper presents the design and implementation of a quasi-planar broadside end-coupled bandpass filter. It circumvents the problem of bandwidth limitation imposed on the conventional end-coupled filter realized by coplanar strips. To realize such a complicated filter in shape, an accurate tridimensional deembedding of the filter discontinuity problem based on the quasi-TEM variational spectral-domain approach (SDA) is developed. Then this approach leads to the design of a 30% bandwidth bandpass filter which agrees favorably with the measured performance.

I. Introduction

As the complexity of a microwave integrated circuit (MIC) increases, the filter of low loss, compact size, high productivity, and easy fabrication by conventional photolithography technique is needed. Many works have been devoted into the integrated microwave and millimeter-wave filter designs [1]. The filters reported in [1] may be classified as E-plane or H-plane type. Most of them are restricted to narrowband applications. Considering the case of monolithic integration at the present time, microstrip and (conductor-backed) CPW are highly preferable [2] and are often placed in H-plane. A new way of constructing a broadband filter using quasi-planar broadside end-coupled resonators is illustrated in Fig.1. It is a semi-lumped-element filter with a spurious response not necessarily occurring at integer multiples of the primary response. It is relatively simple to design and construct such a filter in a hybrid MIC or MMIC. The end-coupled filter also provides a DC block between its input and output ports. This can be useful when a DC isolation is required.

By doing so, the coupling between the adjacent resonators increases drastically and exceeds the practical limitation imposed on the conventional filters. The arrangement should find its application in hybrid double-sided MIC or two-layer interconnect MMIC technologies.

As a case study, an approximately 30% bandwidth broadband bandpass filter is designed and tested to verify the design procedure and the physical parameters of the deembedded broadside end-coupled discontinuities obtained by the variational quasi-TEM spectral-domain approach (SDA)[3]. Section II describes how

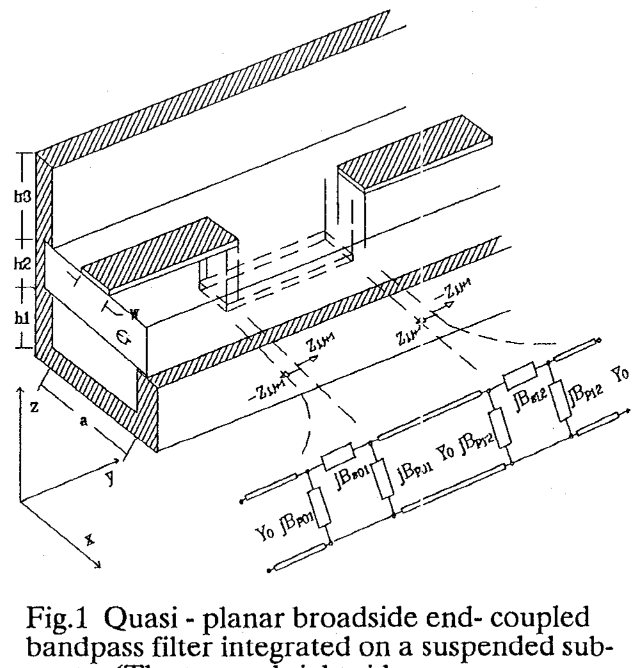


Fig.1 Quasi - planar broadside end- coupled bandpass filter integrated on a suspended substrate. (The top and right side covers are removed.)

to obtain the discontinuity parameters by the field-theoretic approach. The approach is validated first by comparing its results to the available measured and full-wave field-theoretic data. Then it is carried out to complete the new filter design. Section III presents the physical realization of the new filter and compares the calculated response with measured performance.

II. Analysis of Gap Discontinuity Associated with Fig.1

(a) The Quasi-TEM Spectral-Domain-Approach (SDA)

To deembed the gap discontinuity parameters corresponding to the equivalent network of Fig.1, the approach based the quasi-TEM variational spectral-domain approach is adopted [3,4]. For a given cross-sectional geometry, the suspended microstrip line capacitance per unit length C_0 is computed first. This follows the work of [3]. Next the edge capacitance C_e of a resonator with the same cross-sectional geometry is computed by the method described in [4].

In the first two stages, we only need to calculate once. The third step is essentially the extention of [3], i.e. the computational of a 2 by 2 capacitance matrix associated with two adjacent resonators. The Green's function is similar in form to that of [3] due to the fact that the two-dimensional Fourier transform is invoked. The SDA basis functions for the unknown charge distributions on the strip are illustrated in Fig.2.

For certain value of $z_{j,j+1}$ (of Fig.1),

$$Bs = -C_{12} \times \omega_0 \quad \text{and}$$

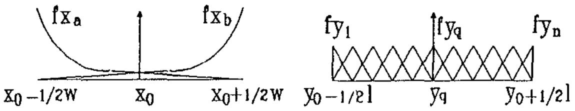
$$Bp/\omega_0 = (C_{11}+C_{12}) - C_0 l_j - C_e$$

where ω_0 is the central angular frequency in the passband $(\omega_0=(\omega_u+\omega_1)/2)$, and C_{12} is negative in value.

Notice that Bs is variational and Bp is not variational.

(b) Validity Check

We will compare two sets of data obtained



$$fx_a = \frac{1}{\sqrt{1+(x-x_0)/(w/2)}}$$

$$fx_b = \frac{1}{\sqrt{1-(x-x_0)/(w/2)}}$$

$$\Delta = l/(n-1)$$
$$y_m = y_0 - l/2$$
$$y_p = y_0 + l/2$$
$$y_q = y_0 + (q-1)\Delta$$
$$fy_1 = 1-(y-y_m)/\Delta$$
$$fy_n = 1+(y-y_p)/\Delta$$
$$fy_q = \begin{cases} 1+(y-y_q)/\Delta & y<y_q \\ 1-(y-y_q)/\Delta & y>y_q \end{cases}$$

$$f(x,y) = fx_p * fy_q \qquad p = a \text{ or } b, \quad q = 1,2,---,n$$

Fig.2 The SDA basis function for unknown charge distribution on the metalization strip.

by the above-mentioned theory with available published results for microstrip open-end [5] and coplanar suspended end-coupled discontinuity problems [6]. In the case of microstrip open-end, the deembedded parameter, namely $2\Delta l$, agree to the measured data reported in Fig.7 of [5] in less than 2% deviation.

Next the case of coplanar suspended end-coupled gap discontinuity is studied [6]. It is encouraging to observe the fact that the quasi-TEM approach of the present theory results in data that agree well with the full-wave SDA approach at 35 GHz. The results are illustrated in Fig.3.

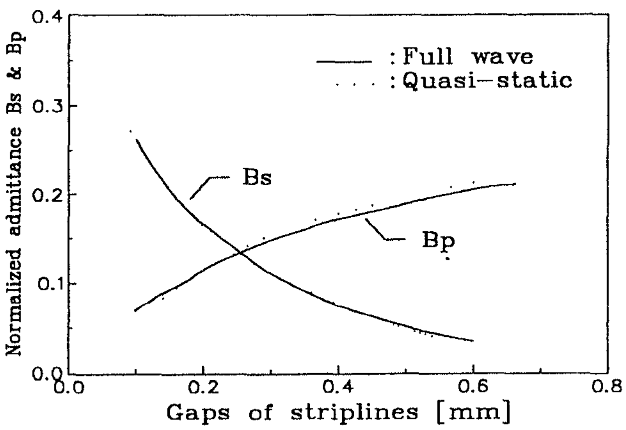


Fig.3 Discontinuity characterized by normalized admittances Bs and Bp versus gap width

(c) Data for $Bs(z_{jj+1})$ and $Bp(z_{jj+1})$ of Fig.1

The previous analyses indicate that the quasi-TEM approach results in very close agreement with the published full-wave theoretical data and measured data. This enables us to proceed to design a broadband broadside end-coupled bandpass filter shown in Fig.1. The unknown parameters which are necessary for carrying out our design procedure are $Bs(z_{jj+1})$ and $Bp(z_{jj+1})$. They are plotted in Fig.4, respectively. When z_{jj+1} is negative in value, the adjacent resonators overlap each other. As z_{jj+1} decreases from positive value to negative value, the coupling susceptance Bs increases while the shunt (parasitic) susceptance decreases and becomes negative. This implies that the shunt elements become inductive as the amount of overlap between two resonators increases.

III. Preliminary Prototype and Its Results

To design a 19 -to- 25 GHz broadside end-coupled bandpass filter of .2dB passband ripple, a prototype, of which the photograph is shown in Fig.5. is built and tested. Due to the mechanical tolerance and fabrication error, the real physical dimensions are measured. Table1 lists ideal and measured structural parameters associates with Fig.1. Fig.6 plots the measured and simulated results. The circuit elements used in simulation are obtained by the SDA approach with the measured structural parameters. The simulated result is plotted under dot line, whereas the measured performance is under solid line. Both agree favorably althrough the idealized filer response is specified from 19 -to- 25 GHz. The low side is shifted from 19 GHz to 17.5 GHz. The effects of the coaxial launchers of Fig.5 are not extracted from the measured data due to the lack of standards at the present time for the suspended microstrip line.

Another source of error between measured and simulated results can be explained as follows. The sum of the square of the magnitude of the elements in a column (or row) of the measured 2-port s-parameters is less than 1. This suggests that some error sources are due to skin effect of the metalized resonators, finite conductivity of the housing, and substrate dielectric loss. We expect tight control on the fabrication stage which includes minimizing the mechanical tolerance, gold plating and good practice on the deembedding of the filter will yield a much better agreement between theory and measurement.

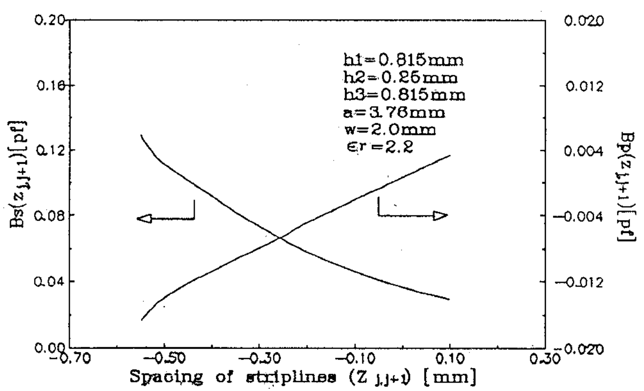


Fig.4 $Bs(z_{jj+1})$ and $Bp(z_{jj+1})$ versus spacing of striplines

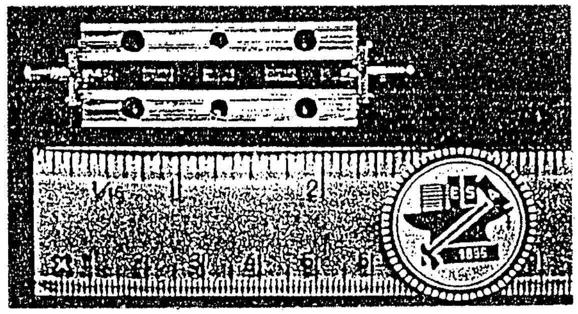


Fig.5 Photograph of the prototype : a broadside end-coupled bandpass filter

Table1 Structural parameters associated with broadside end-coupled bandpass filter

Parameters	Z_{01}	Z_{12}	Z_{23}	Z_{34}	Z_{45}	Z_{56}	Z_{67}	Z_{78}
Ideal	-0.45	-0.15	-0.05	0.00	0.00	-0.05	-0.15	-0.45
Measured	-0.44	-0.08	-0.02	0.06	0.00	0.04	-0.13	-0.31
Parameters	h_1	h_2	h_3	a	w	(unit=mm)		
Ideal	0.815	0.25	0.815	3.76	2.00			
Measured	0.88	0.25	0.88	3.82	1.96			

IV. Conclusions

A broadside end-coupled bandpass filter design technique which allows the increased coupling between adjacent resonators for broadband hybrid MIC or MMIC application has been developed and tested. The preliminary measured result agree favorably with theoretical calculation. A proper set of calibration standards is under development to extract these transition effects from the measured data presented in the paper. The design procedure described here directly fits in the well-known filter synthesis theory [7].

The higher order effects, should change the theoretical filter performance in both passband and stopband. To this end, the synthesized structural parameters of this paper based on the quasi-TEM approximation is a good starting point for knowing the effects of generating higher order modes as well as optimizing filter performance based on more elaborate full-wave field-theoretic approach.

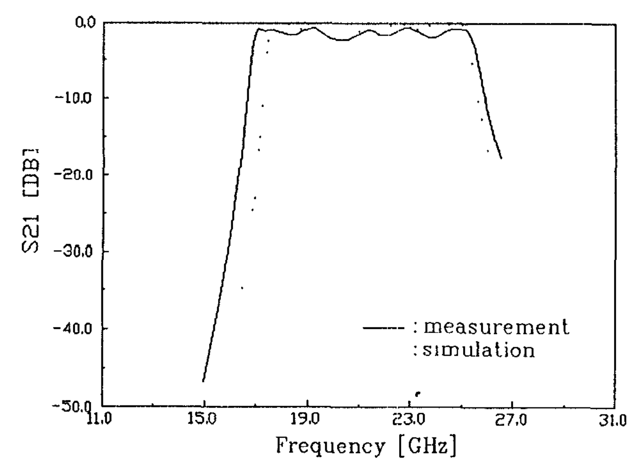


Fig.6 Performance of quasi - planar broadside end-coupled bandpass filter

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