Analysis and Design of 5-Microstrip Line Coupled Bandpass/Bandstop Filter for MIC and MMIC

(MIC와 MMIC를 위한 5-마이크로스트립 선로결합 대역통과/대역소거 여파기의 분석과 설계)

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(Yhl Park, Hyuck Jae Lee and Youn Kang Chin)

要 約

MIC와 MMIC를 위한 광대역 대역통과/대역소거 5-미이크로스트립 선로결합 구조에 대한 분석과 설계를 하고 이를 실현하였다. 전송계수에 대한 주파수 특성의 측정결과는 이론치에 근사하게 일치하고 있다.

Abstract

The analysis and design procedure for 5-coupled microstrip line structure for applications as a wide bandpass/bandstop filter for MIC and MMIC are presented to implement this one. The measured frequency responses for the transmission coefficient are in good agreement with the theoretical results predicted.

I. Introduction

As microwave circuit technology advances, more effective methods for realizing broad-band quadrature hybrids and power dividers/combiners are required for microwave integrated circuits (MIC) and monolithic microwave integrated circuits (MMIC). In MIC, interdigitated couplers, composed of four coupling strip tied together in pairs, are commonly used to meet tight coupling conditions. Several quantitative design procedures[1-5] have been proposed since Lange's first investigation[6] of the interdigitated coupler. Later, an unfolded Lange coupler has been presented by Waugh and LaCombe[7] that only needs two bond wires. A 3-dB interdigitated three line microstrip coupler with two bond wires on alumina substrate (ϵ_r=10) has been developed by Tulaja et al[8]. The immittance parameters for the case of symmetrical coupled three-line microstrip conductors or other inhomogeneous

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six-port structures were derived in terms of the normal modes of the coupled system by Tripathi[9].

The explicit closed expression for an n-line structure was derived by Chin[10] in terms of the normal modes of the coupled system. An effective computational procedure to calculate the quasi-TEM parameters for both symmetrical and nonsymmetrical multiple lines in an inhomogeneous medium has been formulated by Lee[11].

In this paper, the expressions[10], mode parameters[11], and the procedure[12] to determine the optimum terminations for four-port couplers are used to analyze and design the wide bandpass/bandstop filter for MIC and MMIC as microwave communication field.

The conventional bandpass/bandstop filter [13,14] is a type of homogeneous coupled line structures, which consists of two main lines with coupled quarter-wave sections interconnected by a ring resonator. Itanami[15] substituted the dielectric rectangular waveguide for the coupled line and resonator.

II. Immittance Functions

1. Analysis

1) Equivalent Admittance

The expressions for scattering parameters are used to analyze to obtain the frequency characteristics of five-line four-port couplers shown in Fig.1. The scattering parameters are very convenient in the analysis of the coupler performance of a general symmetrical four-port couplers.

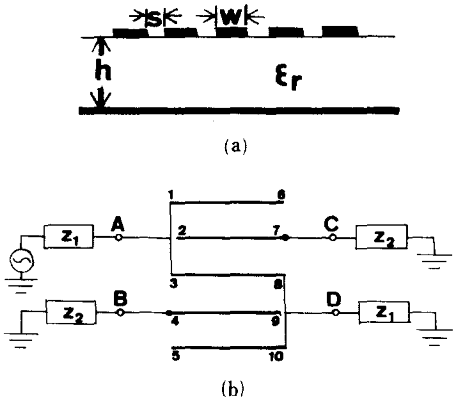

Fig.1. a) Crosssectional view of the symmetrical 5-line microstrip structure.
b) Schematic of the coupled line 4-port.

The general scattering matrix is given by

$$[S]=\{[U]-[Y_n]\}\{[U]+[Y_n]\}^{-1}$$
$$=\{[Z_n]-[U]\}\{[Z_n]+[U]\}^{-1} \qquad (1)$$

where

$[U]$: unit matrix

$$[Y_n]=[Z_o]^{1/2}[Y][Z_o]^{1/2}$$

$$[Z_o]=\begin{bmatrix} Z_1 & 0 & 0 & 0 \\ 0 & Z_2 & 0 & 0 \\ 0 & 0 & Z_2 & 0 \\ 0 & 0 & 0 & Z_1 \end{bmatrix}$$

$$[Y]=\begin{bmatrix} Y'_{11} & Y'_{12} & Y'_{13} & Y'_{14} \\ Y'_{12} & Y'_{22} & Y'_{23} & Y'_{13} \\ Y'_{13} & Y'_{23} & Y'_{22} & Y'_{12} \\ Y'_{14} & Y'_{13} & Y'_{12} & Y'_{11} \end{bmatrix}$$

$$[Z_n]=[Y_n]^{-1}$$

The admittance matrix of an interdigitated five-line four-port, shown in Fig.1. (b) can be found from the following boundary conditions;

$$I_A=I_1+I_3,\ I_B=I_4,\ I_C=I_7,\ I_D=I_8+I_{10},$$
$$I_2=I_5=I_6=I_9=0,$$
$$V_A=V_1=V_3,\ V_B=V_4,\ V_C=V_7,\ V_D=V_8=V_{10}$$

The equivalent admittance matrix for four-port is given by

$$[Y]=[Y_P]-[Y_q]\ [Y_r]^{-1}\ [Y_t] \qquad (2)$$

where

$$[Y_P]=\begin{bmatrix} Y_{11}+Y_{13}+Y_{31}+Y_{33} & Y_{14}+Y_{34} & Y_{17}+Y_{37} & Y_{18}+Y_{110}+Y_{38}+Y_{310} \\ Y_{41}+Y_{43} & Y_{44} & Y_{47} & Y_{48}+Y_{410} \\ Y_{71}+Y_{73} & Y_{74} & Y_{77} & Y_{78}+Y_{710} \\ Y_{81}+Y_{83} & Y_{84} & Y_{87} & Y_{88}+Y_{810}+Y_{108}+Y_{1010} \end{bmatrix}$$

$$[Y_q]=\begin{bmatrix} Y_{12}+Y_{32} & Y_{15}+Y_{35} & Y_{16}+Y_{36} & Y_{19}+Y_{39} \\ Y_{42} & Y_{45} & Y_{46} & Y_{49} \\ Y_{72} & Y_{75} & Y_{76} & Y_{79} \\ Y_{82}+Y_{102} & Y_{85}+Y_{105} & Y_{86}+Y_{106} & Y_{89}+Y_{109} \end{bmatrix}$$

$$[Y_r] = \begin{bmatrix} Y_{21}+Y_{23} & Y_{24} & Y_{27} & Y_{28}+Y_{210} \\ Y_{51}+Y_{53} & Y_{54} & Y_{57} & Y_{58}+Y_{510} \\ Y_{61}+Y_{63} & Y_{64} & Y_{67} & Y_{68}+Y_{610} \\ Y_{91}+Y_{93} & Y_{94} & Y_{97} & Y_{98}+Y_{910} \end{bmatrix}$$

$$[Y_t] = \begin{bmatrix} Y_{22} & Y_{25} & Y_{26} & Y_{29} \\ Y_{52} & Y_{55} & Y_{56} & Y_{59} \\ Y_{62} & Y_{65} & Y_{66} & Y_{69} \\ Y_{92} & Y_{95} & Y_{96} & Y_{99} \end{bmatrix}$$

Where Yij is an element of the coupled line 10-port admittance matrix [10].

2) Input/Output Impedance Matching

For the general case of the coupled system with different mode velocities (For 5-line coupled structure, $Va \neq Vb \neq Vc \neq Vd \neq Ve$. Vi is the mode velocity) in an inhomogeneous medium such as MIC or MMIC, the scattering parameters of the four-port when terminated in non-mode converting impedances as obtained by Cristal's homogeneous medium values[16] gives good isolation but a mismatch of all the ports, depending upon the difference between the normal mode velocities. In order to match the structure and keep the isolation maximum, new terminations, Z_1, and Z_2 can be found by the impedance renormalization procedure[12] as follow.

The desired scattering parameters [S'] and the arbitrary new termination Zi is given by

$$[S'] = \{[Z_d]+[Z_s][S]\}\{[Z_s]+[Z_d][S]\}^{-1} \tag{3}$$

where [Zs] and [Zd] are diagonal matrices with diagonal terms given by

$$Z_{si} \triangleq \sqrt{Z_{io}/Z_i} + \sqrt{Z_i/Z_{io}}$$

$$Z_{di} \triangleq \sqrt{Z_{io}/Z_i} - \sqrt{Z_i/Z_{io}}$$

where Zio: the characteristic impedance on port i

To determine the optimum terminations, the following formulations for $S'_{11}=0$ and $S'_{22}=0$ can be derived from equation (3).

(1) For $S'_{11}=0$

$$Z_1 = Z_{10}\sqrt{(K/2-1)/(K/2+1)} \tag{4}$$

where $K=(S_{14}^2 - S_{11}^2 - 1)/S_{11}$

(2) For $S'_{22}=0$

$$Z_2 = Z_{20}\sqrt{(K/2-1)/(K/2+1)} \tag{5}$$

where $K=(S_{23}^2 - S_{22}^2 - 1)/S_{11}$

2. *Design*

1) Dimensions

The dimensions for the desired bandwiths of bandpass/bandstop filter were found by trial and error method as follow: the quasi-TEM mode parameters for a given relative dielectric constant, $\epsilon_r=2.55$ (teflon) and arbitrarily chosen physical dimensions of the structure was first determined by using the technique[11]. These parameters were substituted into the equivalent admittance parameters. The above procedure has been repeated until one can find the desired bandwidth The length of the coupler is a quarter of the center frequency wave length.

The bandpass/bandstop filter design conditions are as follow.

center frequency : 4 GHz
3-dB bandwidth : 1.5 GHz
teflon substrate

relative dieletric constant (ϵ_r): 2.55
height (h): 1.588mm

The normalized physical dinensions (W/h and S/h), coupled-line length(ℓ) obtained by the above procedure are given as follow.

W/h=0.6
S/h=0.3
ℓ=1.3632cm

In this case, the effective values of the dielectric constant in each mode i (i=a,b,c,d,e) are given as follow.

$\epsilon_{ra}=2.177$, $\epsilon_{rb}=1.813$, $\epsilon_{rc}=1.908$, $\epsilon_{rd}=1.784$, $\epsilon_{re}=1.770$.

2) Input/Output Optimum Impedance

These above parameters are substituted into the explicit expressions for scattering parameters given by equation (1), in which both of Z_1 and Z_2 have been taken as arbitrary values. However, as stated in the analysis, the coupler is not matched. The new termination Z_1 and Z_2 required for the optimum performance are determined by using the impednace renormalization procedure as given by equations (4) and (5) in an iterative manner.

The method to determine the optimum terminations is illustrated in the following example of a symmetrical five-line four-port filter. The scattering parameters for the four-port filter when terminated in Z_1=30 ohm and Z_2=50 ohm are found to be

$\vert S_{11}\vert$	$\vert S_{12}\vert$	$\vert S_{13}\vert$	$\vert S_{14}\vert$
0.1533	0.2840	0.9320	0.1651

The same parameters when terminated in real impedances Z_1=35.2 ohm and Z_2=37.6 ohm, found after three iterations by using the procedure described above are

$\vert S_{11}\vert$	$\vert S_{12}\vert$	$\vert S_{13}\vert$	$\vert S_{14}\vert$
0.0145	0.2563	0.9481	0.1877

where

S_{11} : on port A
S_{12} : between port A–B
S_{13} : between port A–C
S_{14} : between port A–D

The coupling performance, S_{13} ,S_{11} , are improved as shown in the above results, but the bandstop performance, S_{14} , takes a turn for the worse. In order to improve the bandstop characteristic, it is necessary to cause some mismatching on each port.

By varying the load Z_1 with Z_2 fixed, and vice versa, the characteristics observed show that the desirable result is obtained when input impedance with little variance and output impedance with larger than the optimum value are used. This result gives Z_1 of 30 ohm and Z_2 of 90 ohm. With this condition the scattering parameters are found to be

$\vert S_{11}\vert$	$\vert S_{12}\vert$	$\vert S_{13}\vert$	$\vert S_{14}\vert$
0.1752	0.2706	0.9420	0.0933

The coupling performance S_{13} is nearly unaffected, but the stop performance is improved about 6 dB. The transmission coefficient of the filter with the optimum terminations traded is plotted as a function of frequency in Fig.2.

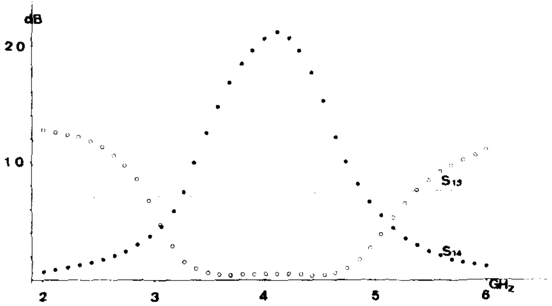

Fig.2. Frequency characteristics of the bandpass/bandstop filter.

III. Experimental Results

This five-line four-port bandpass/bandstop filter was fabricated on teflon (ϵ_r=2.55) with its dimensions obtained. The bandpass/bandstop filter fabricated is shown in Fig.3.

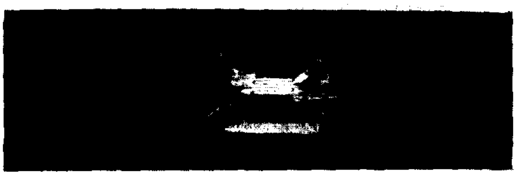

Fig.3. Fabricated bandpass/bandstop filter.

The measured results for the transmission coefficient are shown in Fig. 4, and as seen the experimental results are in good agreement with the theoretical ones in Fig. 2. The minor discrepancy is primarily due to the junction discontinuities, coupling length, conductor and radiation loss.

The bandpass characteristic shows 3-dB bandwith, 1.126 GHz better than the results obtained by Makimoto[17], 0.8 GHz. For the case of 5-dB bandwith 2.37 GHz is measured. The maximum attenuation of the filter is 17.5 dB around 3.4 GHz.

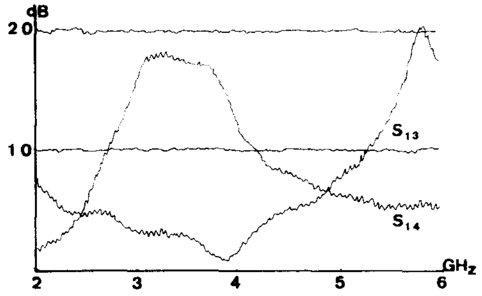

Fig.4. Experimental results for the freq. range over 2-6 GHz.

IV. Conclusion

The measured characteristics of the bandpass/bandstop filter offer satisfactory results which are close to the theoretical results. It is shown that the immittance parameters are in a formular form for finding the scattering parameters of the four-port. The procedure obtained above can be used to design the multiple coupled-line couplers.

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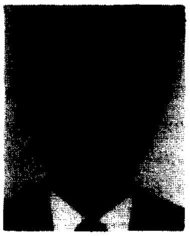

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