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論 文

# 깍지낀 복수 결합 마이크로스트립선 DC블럭

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# The Analysis of Interdigital Multiple Coupled Microstrip Line DC Blocks

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요 약 광대역DC블럭에 응용되는 깍지낀 복수 결합스트립선구조에 관한 해석방법을 소개했다. 결합된 마이크로 스트립선의 준TEM파라미터를 사용해서 계산한 전송계수의 정확한 주파수 응답을 구했다.

*ABSTRACT* The analysis procedure for open-circuited interdigital multiple coupled microstrip-line structures for applications as wideband DC blocks are presented. The exact frequency responses for the transmission coefficient computed by utilizing the quasi-TEM parameters of coupled microstrip lines are shown.

## 1. Introduction

Open circuited interdigial filter[1] has been used for application as DC blocks[2-4] because of its improved performance at higher frequencies as compared to a lumped capacitor. The circuit is physically realizable in microstrip form and can be incorporated in microwave integrated circuits (MIC). These DC blocks were introduced by La Combe and Cohen[2], who, for their analysis, used an approximate equivalent circuit, based on the even- and odd-mode propagation in coupled microstrip. A more general approach was presented by Rizzoli[3], who derived the conditions for both flat and first order Chebyshev frequency response and obtained design formulas for DC blocks with a pair of lines. The circuit is physically realizable in microstrip form and can be incorporated in microwave integrated circuits. The bandwidth of DC blocks depends on the coupling between the two lines and the structure becomes either impratical or unrealizable by conventional MIC technlology for larger bandwidths.

Since, for a larger bandwidth, the lines have to be very tightly coupled, it is more convenient to use more than two lines. The bandwidth for a given coupling, and hence the line width and spacing can be increased significantly by utilizing more than two lines.

The analysis is similar to that of interdigitated couplers[5,6]. However, unlike the interdigitated couplers no bonding wires are required for the DC blocks.

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## 2. Symmetrical two- and Three-coupled Lines

The scattering parameters of a symmetrical two-port terminated in R(Fig. 1) are given by

$$S_{11}=S_{22}=\frac{Z_{11}^2-Z_{12}^2-R^2}{(Z_{11}+R)^2-Z_{12}^2} \quad (1)$$

$$S_{12}=S_{21}=\frac{2RZ_{12}}{(Z_{11}+R)^2-Z_{12}^2} \quad (2)$$

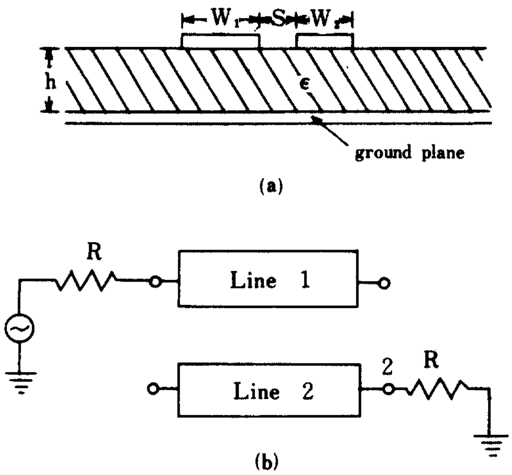


Fig.1 (a) Cross sectional view of the symmetrical two-line microstrip structure.
(b) Schematic of the coupled line two-port.

where $Z_{11}$ and $Z_{12}$ are the elements of the two-port impedance matrix.

$S_{11}$ is simply the reflection coefficients $\rho$ as defined in the following:

$$\rho=\frac{R-Z_0}{R+Z_0}$$

where $Z_0$ is the characteristic impedance of the coupled lines.

The matching conditions for the symmetrical case can be obtained by setting $S_{11}=0$ at the center frequency.

$$R=\sqrt{Z_{11}^2-Z_{12}^2} \quad (3)$$

Fig. 2 shows symmetrical coupled transmision line embedded in an inhomogeneous medium.

The transmission coefficient $S_{12}$ for the symmetrical two-coupled line structure is derived in terms of the equivalent immittance parameters, as follows:

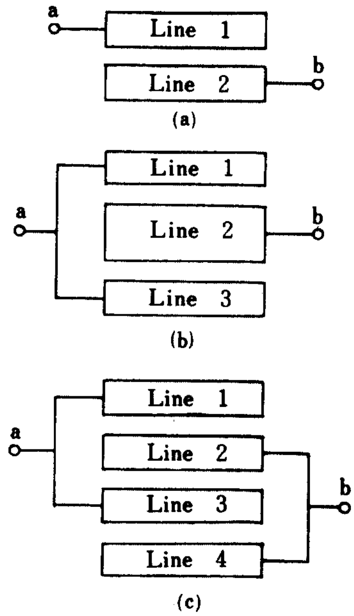


Fig. 2 symmetrical DC blocks configurations.

Using the boundary condition given by $I_2=I_3=0$, the remaining two-ports are described by the following impedance matrix:

$$\begin{bmatrix} Z_{11} & Z_{14} \\ Z_{14} & Z_{11} \end{bmatrix}$$

where the elements of[2] are expressed by Tripathi[11]. For a lossless coupled line structure, they are given as follows:

$$Z_{11}=-j\,(Z_e\cot\theta_e+Z_o\cot\theta_o)\,/\,2 \quad (4a)$$

$$Z_{14}=-j\,(Z_e\csc\theta_e+Z_o\csc\theta_o)\,/\,2 \quad (4a)$$

where $Z_e$ and $Z_o$ are even and odd characteristic impedances respectively. $\theta_e=\beta_e\ell$ and $\theta_o=\beta_o\ell$ (where

$\beta_e$ and $\beta_o$ are even and odd phase constants respectively and $\ell$ is the length of line).

The transmission coefficient $S_{12}$ can be obtained by substituting the above parameters into Eq.(2).

In the symmetrical three-coupled line case, using the boundary conditions given by $I_2=I_4=I_6=0$ and $V_1=V_3$ with $I_a=I_1+I_3=2I_1$, the two-port circuit is described by the following impedance matrix:

$$[Z]=\begin{bmatrix} Z_{22} & Z_{15} \\ Z_{15} & \frac{Z_{11}+Z_{13}}{2} \end{bmatrix}$$

where the elements of [Z] are expressed by Tripathi[7] and for the symmetrical case $Z_{22}$ must be chosen such that it is equal to $(Z_{11}+Z_{13})/2$. They are given as follows:

$$\begin{aligned} Z_{22}&=-j\,(Z_{b}\cot\theta_b+Z_{c2}\cot\theta_c)/2 \\ Z_{15}&=-j\,(Z_{b2}\csc\theta_b-Z_{c2}\csc\theta_c)/2 \end{aligned} \qquad (5)$$

where $Z_{jk}$ is the characteristic impedance of line j for mode k and $\theta_k=\beta_k\ell$ (where $\beta_k$ is the phase constant for mode k).

Similarly, the above parameters are substituted into Eq (2) to find the transmission coefficient.

## 3. Symmetrical Four-coupled Lines

In order to find the exact flat frequency response, one must first derive the equivalent impedance matrix from the boundary conditions given by $I_2=I_4=I_5=I_7=0$

The impedance matrix obtained is

$$\begin{bmatrix} V_1 \\ V_3 \\ V_6 \\ V_8 \end{bmatrix} = \begin{bmatrix} Z_{11} & Z_{13} & Z_{16} & Z_{18} \\ Z_{13} & Z_{22} & Z_{17} & Z_{16} \\ Z_{16} & Z_{27} & Z_{22} & Z_{13} \\ Z_{18} & Z_{16} & Z_{13} & Z_{11} \end{bmatrix} \begin{bmatrix} I_1 \\ I_3 \\ I_6 \\ I_8 \end{bmatrix}$$

where the elements of the impedance matrix are given by Chin[9].

They are given by:

$$\begin{aligned} Z_{11}&=j\,(R_cZ_{a1}\cot\theta_a-R_aZ_{c1}\cot\theta_c \\ &\quad+R_dZ_{b1}\cot\theta_b-R_bZ_{d1}\cot\theta_d)/R_1 \\ Z_{13}&=-j\,[(Z_{a1}\cot\theta_a-Z_{c1}\cot\theta_c)/R_1 \\ &\quad-(Z_{b1}\cot\theta_b-Z_{d1}\cot\theta_d)/R_2] \\ Z_{16}&=j\,[(Z_{a1}\csc\theta_a-Z_{c1}\csc\theta_c)/R_1 \\ &\quad+(Z_{b1}\csc\theta_b-Z_{d1}\csc\theta_d)/R_2] \\ Z_{17}&=j\,[(Z_{a1}\csc\theta_a-Z_{c1}\csc\theta_c)/R_1 \\ &\quad-(Z_{b1}\csc\theta_b-Z_{d1}\csc\theta_d)/R_2] \\ Z_{18}&=-j\,[(R_cZ_{a1}\csc\theta_a-R_aZ_{c1}\csc\theta_c)/R_1 \\ &\quad-(R_dZ_{b1}\csc\theta_b-R_bZ_{d1}\csc\theta_d)/R_2] \\ Z_{22}&=-j\,[(R_aZ_{a2}\cot\theta_a-R_cZ_{c2}\cot\theta_c)/R_1 \\ &\quad+(R_bZ_{b2}\cot\theta_b-R_dZ_{d2}\cot\theta_d)/R_2] \\ Z_{27}&=j\,[(R_aZ_{a2}\csc\theta_a-R_cZ_{c2}\csc\theta_c)/R_1 \\ &\quad-(R_bZ_{b2}\csc\theta_b-R_dZ_{d2}\csc\theta_d)/R_2] \end{aligned} \qquad (6)$$

where $R_k$ is the ratio of voltages on the lines for mode k (k=a, b, c, d). $R_1=2(R_a-R_c)$ and $R_2=2(R_b-R_d)$.

Then, taking the inverse of the above matrix and using the boundary conditions given by $I_a=I_1+I_3$, $I_b=I_6+I_8$, $V_a=V_1=V_3$, and $V_b=V_6=V_8$ the final equivalent admittance matrix of the two-port circuit is found to be:

$$[Y]=\begin{bmatrix} Y_{11} & Y_{12} \\ Y_{12} & Y_{11} \end{bmatrix}$$

where

$$\begin{bmatrix} y_{11} & y_{12} & y_{13} & y_{14} \\ y_{21} & y_{22} & y_{23} & y_{24} \\ y_{31} & y_{32} & y_{33} & y_{34} \\ y_{41} & y_{42} & y_{43} & y_{44} \end{bmatrix} = \begin{bmatrix} Z_{11} & Z_{13} & Z_{16} & Z_{18} \\ Z_{13} & Z_{22} & Z_{17} & Z_{16} \\ Z_{16} & Z_{27} & Z_{22} & Z_{13} \\ Z_{18} & Z_{16} & Z_{13} & Z_{11} \end{bmatrix}^{-1}$$

$$\begin{aligned} Y_{11}&=y_{11}+2\,y_{12}+y_{22} \\ Y_{12}&=y_{13}+y_{14}+y_{24} \end{aligned} \qquad (7)$$

The matching condition for an admittance expression is given by

$$R=\frac{1}{\sqrt{Y_{11}^2-Y_{12}^2}} \tag{8}$$

## 4. Interdigital Multiple Coupled Lines

For an n-line open circuited interdigital structure as shown in Fig. 3, the scattering parameters can be found from the 2n-port impedance matrix with (2n-2) boundary conditions. For example for a even, these conditions are

$$I_A=I_1+I_2+\cdots+I_{n-1};\ I_B=I_{n+1}+I_{n+3}+\cdots+I_{2n-1};\ I_2=I_4=\cdots=I_n=I_{n+2}=\cdots=I_{2n}=0;$$
$$V_A=V_1=V_3=\cdots=V_{n-1} \text{ and}$$
$$V_B=V_{n+1}=V_{n+3}=\cdots=V_{2n-1}.$$

The expressions for the elements of the impedance matrix for a 2n-port are known in a closed form for the symmetrical four-line case [9]. For a larger number of lines it is more convenient to compute the frequency response of the DC block on a digital computer by utilizing the boundary conditions and the general expressions for the immitance matrix of this n-line system.

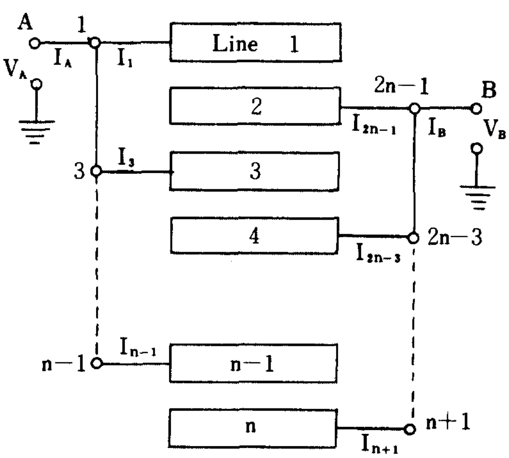


Fig. 3 Schematic of an open-circuited interdigital multiple coupled line two-port.

The scattering parameters for the DC blocks, as is the case of other coupled inhomogeneous line structures, can be formulated by assuming TEM mode of propagation (all normal mode velocities are equal) in terms of the equivalent even- and odd-mode immitances of the n-line strucuture. For the n-line interdigital structure these are found in the same manner as for the case of interdigitated couplers and are given below for even and odd number of lines.

n-even

$$\frac{1}{Z_{en}}=Y_{en}\simeq V_P\left[C_{11}-C_{12}+\left(\frac{n}{2}-1\right)(C_{22}-2C_{12})\right] \tag{9a}$$

$$\frac{1}{Z_{on}}=Y_{on}\simeq V_P\left[C_{11}+C_{12}+\left(\frac{n}{2}-1\right)(C_{22}+2C_{12})\right] \tag{9b}$$

n-odd

$$\frac{1}{Z_{en}^{(A)}}=Y_{en}^{(A)}\simeq V_P\left[2(C_{11}-C_{12})+\left(\frac{n-3}{2}\right)(C_{22}-C_{12})\right] \tag{10a}$$

$$\frac{1}{Z_{on}^{(A)}}=Y_{on}^{(A)}\simeq V_P\left[2(C_{11}+C_{12})+\left(\frac{n-3}{2}\right)(C_{22}+2C_{12})\right] \tag{10b}$$

$$\frac{1}{Z_{en}^{(B)}}=Y_{en}^{(B)}\simeq V_P\left[\left(\frac{n-1}{2}\right)(C_{22}-2C_{12})\right] \tag{10c}$$

$$\frac{1}{Z_{on}^{(B)}}=Y_{on}^{(B)}\simeq V_P\left[\left(\frac{n-1}{2}\right)(C_{22}+2C_{12})\right] \tag{10d}$$

In the above equations $V_P$ is the phase velocity, $C_{11}$ is the self capacitance of lines 1 and n, $C_{22}$ is the self capacitance of lines 2 through n-1, $C_{12}$ is the mutual capacitance between adjacent lines. In addition all the lines are assumed to have equal widths and the coupling between nonadjacent lines is neglected. A structure with odd number of lines is inherently nonsymmetrical and in order to design a symmetrical two-port, the widths of lines 2, 4, -- n-1 must be chosen differently from the width of lines 1, 3, -- n (with $C_{22}$ is Equation 10 c and d changed accordingly) such that $Y_{on}^{(A)} = Y_{on}^{(B)}$ and $Y_{en}^{(A)} = Y_{en}^{(B)}$. In terms of the even- and odd-mode impedances of the n-line structure $Z_{11}$ and $Z_{12}$ for the two port are:

$$Z_{11} = -j\,(Z_{en}+Z_{on})\,\frac{\cot\theta}{2} \text{ and}$$

$$Z_{12} = -j\,(Z_{en}-Z_{on})\,\frac{\csc\theta}{2}, \tag{11}$$

where $\theta = \beta\ell$, is the normalized frequency. Substituting Equation (11) into (1) gives:

$$S_{11} = \frac{-Z_{en}Z_{on}\cot^2\theta + \frac{(Z_{en}-Z_{on})^2}{4} - R^2}{\left[-Z_{en}Z_{on}\cot^2\theta + \frac{(Z_{en}-Z_{on})^2}{4} + R^2\right] - jR(Z_{en}+Z_{on})\cot\theta} \tag{12}$$

This results in a flat frequency response with center frequency at $\theta = \pi/2$ for $R = (Z_{en}-Z_{on})/2$ and a single ripple response for $R < (Z_{en}-Z_{on})/2$ with maximum ripple given by:

$$S_{11}\mid_{at\ \theta=\pi/2} = \frac{(Z_{en}-Z_{on})^2 - 4R^2}{(Z_{en}-Z_{on})^2 + 4R^2} \tag{13}$$

For a specified R and bandwidth $Z_{en}$ and $Z_{on}$ can be determined from Equation[12] for flat frequency response and from Equations (12) and (13) for single ripple response with specified maximum ripple.

The transmission coefficient $|S_{12}|$ can be found by

$$|S_{12}|^2 = 1 - |S_{11}|^2$$

$Z_{en}$ $Z_{on}$

The validity of the above expressions has been tested and the results have been found to be fairly close to the exact ones. The design procedure for the DC blocks can be formulated by using the above parameters.

## 5. The Results

The exact frequency responses for transmission coefficient computed by utilizing the quasi-TEM parameters of coupled microstrip lines for two-, three- and four-line cases shown in Fig. 4 for their comparison. The width of the center line for the three line case was chosen to make the two ports symmetrical[10]

The quasi-TEM parameters (phase constants and line impedances for n modes) were computed by modifying Weiss' procedure[8] for symmetrical two line case to apply to multiple coupled lines. For a pair of coupled microstrip lines with $\epsilon_r = 10$, W/H = 2 S/H = 0.078, $Z_e$ and $Z_o$ are found to be 181.6 Ω and 43.4 Ω respectively.

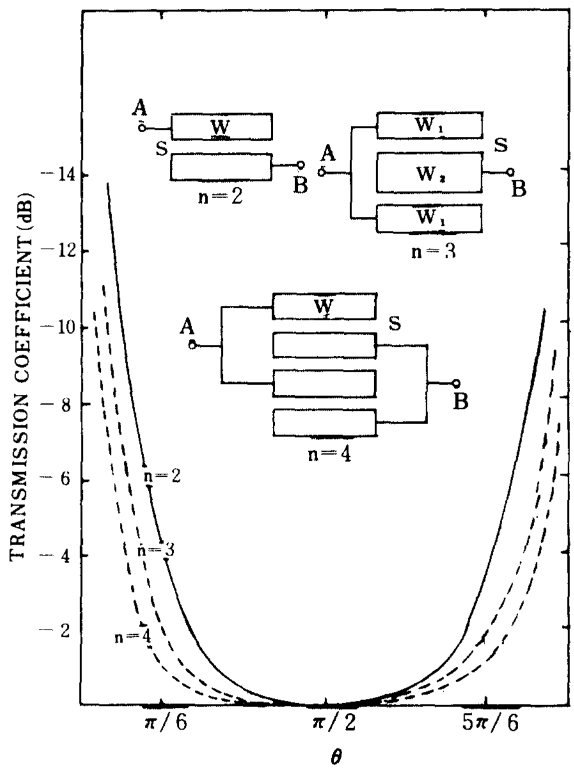


Fig. 4 Transmission coefficient $|S_{12}|$ vs normalized frequency $\theta$ for multiple coupled microstrip line DC block with $\epsilon_r = 10$ (where w/h=2s/h=0.078 and R=69.1 ohms for n=2; $w_1/h = 2s/h = w_2/4h = 0.078$ and R=50.6 ohms for n=3; w/h=2s/h=0.078 and R=67.6 ohms for n=4).

## 6.. Conclusions

Analysis procedure for symmetrical open circuited interdigital multiple coupled microstrip line structures for applications as wideband DC blocks and filters is presented. The general equations for analysis, as is the case of other microstrip structures, are based on a simplified TEM model.

The exact frequency responses for the transmission coefficient computed by utilizing the quasi-TEM parameters of coupled microstrip lines for the two-, three-and four-line cases are presented in terms of their respective equivalent immittance parameters.

Examination of typical cases indicate that increasing the number of lines beyond four may not be remunerative.

The design procedure for DC blocks can be formulated by using the above results.

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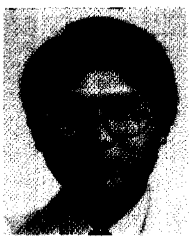


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