ANALYSIS EQUATIONS FOR SHIELDED SUSPENDED SUBSTRATE MICROSTRIP LINE AND BROADSIDE-COUPLED STRIPLINE

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Abstract

Simple and closed-form equations for analysis of shielded suspended substrate microstrip line (SSL) and Broadside-coupled stripline (BSCL) are presented, valid over a practical application range of structural parameters and substrate dielectric constant. Comparing with the values obtained using finite-differential method, the accuracy is found to be within ±2% ($w < a/2$) and ±3% ($a/2 < w < a$) for SSL and within ±4.5% (odd mode) and ±3.5% (even mode) for BSCL.

1. Introduction

The suspended substrate microstrip line is the modified version of microstrip line. Compared with normal microstrip line, it has some attractive features, such as lower attenuation and larger tolerance of fabrication. Therefore, the suspended substrate microstrip line has been extensively used in millimeter-wave integrated circuits, such as millimeter-wave mixer, oscillator, multiplier and so on.

The coupled-line structures are ultilized extensively to form many microwave circuits. Because the flank coupling or gap coupling between strip lines is difficult to be realized at millimeter-wave range due to the critical tolerance of fabrication, the broadside-coupled stripline is preferable for millimeter-wave circuits.

A number of numerical approachs for analysis of such lines have been given(1)-(5), but all of these approachs need complicated mathematical deducing and time-consuming computer programming. Although a set of simple analysis and synthesis equations has been presented recently by Tomar, Pramanick and Bhartia(6)(7), it is suitable only for open SSL. In practice, there exists a strong need to analyze and synthesize such lines with shield in lucid and tractable manner. In this paper, simple and closed-form analysis equations for shielded SSL and BSCL are developed by using least-square curve fitting to numerical results of finite-differential method. The transmission characteristics of such lines can easily be analyzed by the calculator based on these equations. Comparing with the values obtained using finite-differential method (1)(8), the accuracy is found to be within ±2%($w < a/2$) and ±3%($a/2 < w < a$) for SSL and within ±4.5%(odd mode) and ±3.5%(even mode) for BSCL.

A synthesis program can easily be developed with simple iteration technique. It makes the computer aided design of such transmission lines and circuits possible.

2. Analysis Equations

A. Shielded Suspended Substrate Microstrip Line

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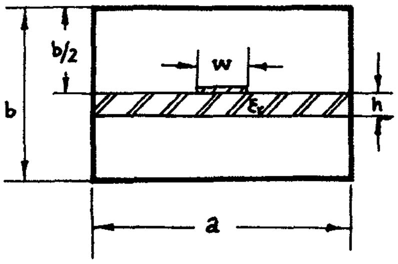

Fig.1 Cross sectional view of SSL

The cross sectional view of SSL is shown in Fig.1. Its characteristic impedance can be expressed as

$$Z=Z_0/\sqrt{\varepsilon_e} \qquad (1)$$

where Z_0 is the characteristic impedance of SSL of identical dimensions and completely filled with air, ε_e is the effective dielectric constant of SSL. Considering general practical application range of structural parameters and substrate constants, all of the developed equations are valid under following conditions

$$1 \leqslant \frac{a}{b} \leqslant 2.5, \quad 1 < \varepsilon_r < 4, \quad 0.1 < \frac{h}{b} < 0.5.$$

1. Effective dielectric constant

$$\sqrt{\varepsilon_e}=\left[1+(E-F\ \ln\frac{w}{b})\ \ln\frac{1}{\sqrt{\varepsilon_r}}\right]^{-1} \qquad (2)$$

where

$$\left.\begin{aligned} E&=0.2077+1.2177\frac{h}{b}-0.08364\frac{a}{b} \\ F&=0.03451-0.1031\frac{h}{b}+0.01742\frac{a}{b} \end{aligned}\right\} \qquad (3)$$

for $0 < w < a/2$, and

$$\left.\begin{aligned} E&=0.4640+0.9647\frac{h}{b}-0.2063\frac{a}{b} \\ F&=-0.1424+0.3017\frac{h}{b}-0.02411\frac{a}{b} \end{aligned}\right\} \qquad (4)$$

for $a/2 < w < a$.

2. Characteristic impedance

When $0 < w < a/2$,

$$Z_0=\frac{\eta_0}{2\pi}\left[V+R\ \ln\left(\frac{6}{w/b}+\sqrt{1+\frac{4}{(w/b)^2}}\right)\right] \qquad (5)$$

where

$$\eta_0=120\,\pi$$

$$\left.\begin{aligned} V&=-1.7866-0.2035\frac{h}{b}+0.4750\frac{a}{b} \\ R&=1.0835+0.1007\frac{h}{b}-0.09457\frac{a}{b} \end{aligned}\right\} \qquad (6)$$

When $a/2 < w < a$,

$$Z_0=\eta_0\left\{V+R\left[\frac{w}{b}+1.3930+0.6670\ \ln\left(\frac{w}{b}+1.444\right)\right]^{-1}\right\} \qquad (7)$$

where

$$\left.\begin{aligned} V&=-0.6301-0.07082\frac{h}{b}+0.2470\frac{a}{b} \\ R&=1.9492+0.1553\frac{h}{b}-0.5123\frac{a}{b} \end{aligned}\right\} \qquad (8)$$

The comparison of the results obtained by using given equations and finite-differential method[1] shows the accuracy within ±2%(for $0 < w < a/2$) and ±3%(for $a/2 < w < a$).

B. Broadside-Coupled Stripline

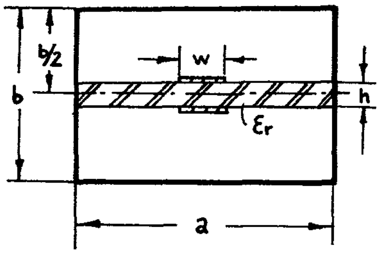

Fig.2 Cross sectional view of BSCL

The cross sectional view of BSCL is shown in Fig.2. The coupling coefficient K and characteristic impedance Z_0, the most important parameters of such line, can easily be obtained from following formulas

$$K=\frac{Z_{oe}-Z_{oo}}{Z_{oe}+Z_{oo}} \qquad (9)$$

$$Z_0=\sqrt{Z_{oe}Z_{oo}} \qquad (10)$$

where Z_{oe} and Z_{oo} are characteristic impedance of even mode and odd mode respectively.

1. Characteristic impedance of odd mode Z_{oo}

Z_{oo} can be expressed as

$$Z_{oo} = Z^o_{oo}/\sqrt{\varepsilon_{oo}} \tag{11}$$

a. Determination of ε_{oo}

$$\frac{1}{\sqrt{\varepsilon_{oo}}}=1+0.5\left[H-P\ \ln\left(\frac{w}{b}+\sqrt{\left(\frac{w}{b}\right)^2+1}\right)\right]\left[\ln\frac{1}{\sqrt{\varepsilon_r}}+\frac{1}{\sqrt{\varepsilon_r}}-1\right] \tag{12}$$

where

$$\left.\begin{aligned} H&=0.7210-0.3568\frac{h}{b}+0.02132\frac{a}{b} \\ P&=-0.3035+0.3743\frac{h}{b}+0.07274\frac{a}{b} \end{aligned}\right\} \tag{13}$$

b. Determination of Z^o_{oo}

$$Z^o_{oo}=\frac{\eta_o}{2}\left[S+T\ \ln\left(\frac{0.2}{w/b}+\sqrt{1+\frac{0.23}{(w/b)^2}}\right)\right] \tag{14}$$

where

$$\left.\begin{aligned} S&=-0.1073+1.67080\frac{h}{b}+0.007484\frac{a}{b} \\ T&=0.4768+2.1295\frac{h}{b}-0.01278\frac{a}{b} \end{aligned}\right\} \tag{15}$$

2. Characteristic impedance of even mode Z_{oe}

Z_{oe} can be expressed as

$$Z_{oe} = Z^o_{oe}/\sqrt{\varepsilon_{oe}} \tag{16}$$

a. Determination of ε_{oe}

$$\frac{1}{\sqrt{\varepsilon_{oe}}}=1+\left(H-P\ \ln\frac{w}{b}\right)\ \ln\frac{1}{\sqrt{\varepsilon_r}} \tag{17}$$

where

$$\left.\begin{aligned} H&=0.2245+0.7192\frac{h}{b}-0.1022\frac{a}{b} \\ P&=0.001356+0.06590\frac{h}{b}+0.01951\frac{a}{b} \end{aligned}\right\} \tag{18}$$

b. Determination of Z^o_{oe}

$$Z^o_{oe}=\frac{\eta_o}{2\pi}\left[S+T\ \ln\left(\frac{12}{w/b}+\sqrt{1+\frac{16}{(w/b)^2}}\right)\right] \tag{19}$$

where

$$\left.\begin{aligned} S&=-2.6528+0.9452\frac{h}{b}+0.4531\frac{a}{b} \\ T&=1.4793-1.1903\frac{h}{b}-0.04511\frac{a}{b} \end{aligned}\right\} \tag{20}$$

Eqns. (12), (14), (17) and (19) are valid under following additional condition

$$0 < w < 0.45a$$

The comparison of the results obtained by using given equations and finite-differential method[8] shows the accuracy within ±4.5%(odd mode) and ±3.5%(even mode).

3. Conclusion

Simple and closed-form analysis equations for suspended substrate microstrip line and broadside-coupled strip line have been presented. The transmission characteristic can easily be analyzed by calculator based on these equations. The synthesis equations of such lines are being developed.

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