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

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Abstract

Simple and explicit equations for synthesis of shielded suspended substrate microstrip line (SSL) and broadside-coupled stripline (BSCL) are presented, valid over a practical application range of structural parameters and dielectric constants of substrate in common use. By comparison of the results obtained using developed synthesis equations with those obtained using SUPER COMPACT (for SSL) and finite-difference method (for BSCL), the accuracy is found to be within ±3% and ±3.5%, respectively.

1. Introduction

The suspended substrate microstrip line is a 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 and gap coupling between striplines 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 approaches for analysis of such lines have been given (1)-(5), but all of these approaches need complicated mathematical deducing and time-consuming computer programming.

Although a set of closed-form analysis equations for SSL and BSCL has been published recently (6), up to now, there are not any equations which can be used to synthesize such lines directly. In this paper, a set of simple and explicit synthesis equations for SSL and BSCL are developed by using least-square curve fitting to obtained numerical results using SUPER COMPACT (for SSL) and finite-difference method (for BSCL), the accuracy is found to be within ±3% and ±3.5%, respectively over the applicable range of structural parameters.

By using these synthesis equations, the CAD of millimeter-wave integrated circuits consisting of such lines can be simplified considerably.

2. Synthesis Equations

A. Shielded Suspended Microstrip Line

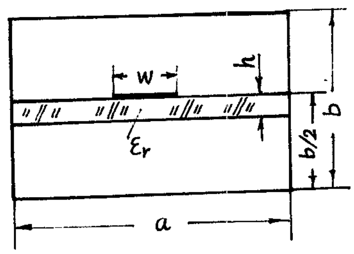

Fig.1 Cross Section of SSL

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The cross sectional view of SSL is shown in Fig. 1.The structural parameters of channel a and b are determined to prevent from the lowest waveguide mode, h is the thickness of chosen substrate. For specified characteristic impedance Z of SSL, the strip width w can be synthesized using following formula:

$$\frac{w}{b}=\left[A\exp\left(1.77245\frac{CZ}{120}\right)+B\exp\left(-1.77245\frac{DZ}{120}\right)\right]^{-1}$$

where A,B,C, and D have different values corresponding to different dielectric constants of substrate.

1. For $\varepsilon_r=2.22$

$$A=0.0854\left(\frac{a}{b}\right)^{-3}+0.2901\left(\frac{h}{b}\right)+0.2342-\left(\frac{h}{2b}\right)^{3}\delta\left(\frac{h}{b}-0.4\right)$$

where $\delta\left(\frac{h}{b}-0.4\right)=\begin{cases}1 & \text{for } h/b\geq 0.4\\ 0 & \text{for } h/b<0.4\end{cases}$

$$B=-1.2083\ln\left(\frac{a}{b}\right)-0.3796\ln\left(\frac{h}{b}\right)+0.1370$$

$C=1.446$

$D=2.010$

2. For $\varepsilon_r=2.80$

$$A=\left[0.0968\ln\left(\frac{h}{b}\right)+0.6130\right]/\left[0.3980\ln\left(\frac{a}{b}\right)+1.0276\right]$$

$$B=1.038\left(\frac{h}{b}\right)-0.754\left(\frac{a}{b}\right)-0.7380\ln\left(\frac{h}{b}\right)-0.4723$$

$C=1.440$

$D=2.005$

3. For $\varepsilon_r=3.80$

$$A=\left[0.1138\ln\left(\frac{h}{b}\right)+0.5775\right]/\left[0.4902\ln\left(\frac{a}{b}\right)+1.0238\right]$$

$$B=-1.6943\ln\left(\frac{h}{b}\right)-1.544-\left(\frac{a}{b}-1\right)/\left(3.5\frac{h}{b}\right)$$

$C=1.685$

$D=2.792$

Considering general practical application range of structural parameters and characteristic impedance, the synthesis equations of SSL are valid over under following conditions:

$$40\Omega\leq Z\leq 150\Omega$$

$$1\leq\frac{a}{b}\leq 2.5$$

$$0.1\leq\frac{h}{b}\leq 0.5$$

For a series of given values of strip width w, the charactristic impedances of SSL are computed by using SUPER COMPACT, and then the values of strip width w can be calculated by using developed synthesis equations. These values are listed in Table 1. The comparison of synthesized values with given values shows that the accuracy is within ±3%.

B. Broadside -Coupled Stripline

The cross sectional view of BSCL is shown in Fig. 2, where a, b, and h are determined as in the case of SSL. The terminating

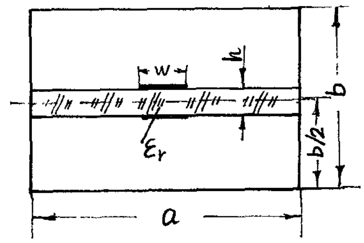

Fig. 2 Cross Section of BSCL

impedance Z for a $\lambda/4$ coupled structure can be expressed as follows

$$Z=\sqrt{Z_{oe}Z_{oo}}$$

Where Z_{oo} and Z_{oe} are characteristic impedances of odd mode and even mode, respectively.

For specified terminating impedances Z, the synthesis formula for calculating strip width w of BSCL takes the form as follows:

$$\frac{w}{b}=\left[A\exp\left(1.77245\frac{CZ}{120}\right)+B\exp\left(-1.77245\frac{DZ}{120}\right)\right]^{-1}$$

where A,B,C and D have different values corresponding to different dielectric constants of substrate also.

1. For $\varepsilon_r=2.22$

$$A=0.12\left(\frac{a}{b}\right)^{2}-0.40\left(\frac{a}{b}\right)+3.40\left(\frac{h}{b}\right)^{2}-2.43\left(\frac{h}{b}\right)+1.17-0.017\delta\left(\frac{h}{b}-0.15\right)$$

$$B=0.2(\frac{a}{b})^2-0.70(\frac{a}{b})-6(\frac{h}{b})^3+0.6\ln(\frac{h}{b})-1.1055\ln(\frac{a}{b})+1.7121$$

$C=1.456$

$D=2.564$

2. For $\varepsilon_r=2.80$

$$A=0.120(\frac{a}{b})^2-0.41(\frac{a}{b})+3.40(\frac{h}{b})^2-2.43(\frac{h}{b})+1.235-0.021\,\delta(\frac{a}{b}-2)\,\delta(\frac{h}{b}-0.15)$$

$$B=-0.12(\frac{a}{b})^2+0.36(\frac{a}{b})-1.18\ln(\frac{a}{b})+0.6\ln(\frac{h}{b})-0.1(\frac{h}{b})+0.733$$

$C=1.510$

$D=2.621$

3. For $\varepsilon_r=3.80$

$$A=0.132(\frac{a}{b})^2-0.46(\frac{a}{b})+3.4(\frac{h}{b})^2-2.43(\frac{h}{b})+1.296-0.021\,\delta(\frac{a}{b}-2)\,\delta(\frac{h}{b}-.15)$$

$$B=-1.072\ln(\frac{a}{b})+0.3597\ln(\frac{h}{b})+0.3256$$

$C=1.641$

$D=2.722$

where $\delta(\frac{h}{b}-0.15)=\begin{cases}1 & \text{for } h/b\geq 0.15\\ 0 & \text{for } h/b<0.15\end{cases}$

$\delta(\frac{a}{b}-2.0)=\begin{cases}1 & \text{for } a/b\geq 2.0\\ 0 & \text{for } a/b<2.0\end{cases}$

The synthesis equations given above are valid under following conditions:

$$Z>40\Omega$$

$$1\leq\frac{a}{b}\leq 2.5$$

$$0.1\leq\frac{h}{b}\leq 0.4$$

For a series of given strip width w/h, terminating impedance Z is computed by using a special program based on finite-difference method(7). Then, the strip width w/h corresponding to Z is calculated by using developed synthesis equations. All of these values are listed in Table 2. The comparison of synthesized values and given values of strip width shows that the accuracy is within ±3.5%.

3. Conclusion

The synthesis equations of SSL and BSCL have been presented. For the practical application range of structural parameters and dielectric constants of substrate in common use, the accuracy of these synthesis equations is acceptable. By using these synthesis equations, the CAD of millimeter-wave integrated circuits consisting of such lines can be simplified considerably.

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Table 1. Comparison of Synthesized and Given Strip Width of SSL

Given w (mm)	εr=2.22, a/b=2.5 h/b=0.1427, b=1.78		εr=2.8, a/b=2 h/b=0.0713, b=1.78		εr=3.8, a/b=1 h/b=0.1427,b=1.78	
	Z (Ω)	Syn. w (mm)	Z (Ω)	Syn. w (mm)	Z (Ω)	Syn. w (mm)
0.3	141.93	0.305	143.18	0.309	114.31	0.297
0.5	118.08	0.509	119.37	0.512	93.24	0.498
0.7	102.13	0.717	103.32	0.721	78.58	0.705
0.9	90.37	0.926	91.34	0.929	66.92	0.913
1.1	81.12	1.134	81.97	1.133	56.86	1.113
1.3	73.64	1.338	74.19	1.335	47.53	1.288
1.5	67.42	1.540	67.21	1.530	/	/
1.7	62.14	1.739	62.18	1.719	/	/
1.9	57.62	1.933	57.34	1.902	/	/
2.1	53.65	2.126	53.03	2.080	/	/
2.3	50.16	2.317	49.10	2.256	/	/
2.5	47.04	2.507	45.42	2.433	/	/
2.7	44.20	2.693	41.88	2.621	/	/
2.9	41.60	2.892	/	/	/	/

Table 2. Comparison of Synthesized and Given Strip Width of BSCL

Given w/h	εr=2.22, a/b=2 h/b=0.1		εr=2.8, a/b=1.0 h/b=0.2		εr=3.8, a/b=1.5 h/b=0.1	
	Z (Ω)	Syn. w/h	Z (Ω)	Syn.w/h	Z (Ω)	Syn. w/h
1	128.227	0.991	95.414	1.001	110.338	0.995
2	94.521	2.056	65.054	1.970	80.966	2.040
3	76.348	3.074	47.768	2.899	65.136	3.033
4	64.448	4.044	/	/	54.750	3.980
5	55.908	4.931	/	/	47.267	4.897
6	49.416	5.900	/	/	41.542	5.803
7	44.291	6.817	/	/	/	/
8	40.110	7.748	/	/	/	/