Line Thickness for Various Characteristic Impedance of Microstrip Line

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Abstract

The aim of this research is studying the thickness of microstrip line and the effective range of impedance. These describe an ingenious and power approximation based on a new conformal mapping.
The impedance in range (26 – 157) ohms and width between (0.15 – 4.5) mm. for different strip thickness had been calculated. The illustrated results show the mistake in finding the value impedance of this thickness which was neglected in previous works; the reported results are very useful for wide strip with thickness in this pepper.

Introduction

Microwave Integrated Circuits (MICs) have been increasingly adopted in many electronic civilian and military systems such as satellite communications, radar, electronic warfare, navigation and guidance systems. Microwave components such as antennas, couplers, filters and the entire device existing as the pattern of metallization on the substrate.

Microstrip is probably the most popular transmission line of choice for MIC. It cannot support a true transverse - electric – magnetic (TEM) wave propagation since the dielectric materials surrounding the strip are inhomogeneous. The main driver for microstrip popularity is credited to simpler fabrication process using conventional processes [1].

Microstrip thus is much less expensive than traditional waveguide technology, as well as being for lighter and more compact.

Microstrip is a type of electrical transmission line which can be fabricated by using Printed Circuit Board (PCB) technology, which used to convey microwave frequency signals. The cross sectional view of a microstrip line is shown in figure (1).

Microstrip transmission lines have received much consideration in the technical in the last 40 years. Most of the efforts were dedicated to the analysis and electrical characterization of single or coupled microstrip lines [2].

Microstrip

Microstrip line consists of a conducting strip separated from a ground plane by a dielectric layer known as the substrate Figure (1). The dielectric material serves as a structural substrate upon which the thin-film metal conductors are deposited. Conductors are usually gold or copper.

On a smaller scale, microstrip transmission line is also built into Monolithic Microwave Integrated Circuits (MMIC)s.

The electromagnetic wave carried by microstrip line exists partly in the dielectric substrate, and partly in the air above it. In general, the dielectric constant of the substrate will be different than that of the air, so that the wave is traveling in an inhomogeneous medium.

Microstrip line, is used extensively in fabrication of Microwave Integrated Circuits (MICs) because of the following particularly useful characteristics [3,4]:

(1) The microstrip lines are easily fabricated with low cost.

(2) The network interconnection and placement of the lumped elements and active devices are easily made on its metal surface.

(3) DC as well as AC signals can be transmitted.

(4) Line wavelength is reduced considerably because of the substrate fields; hence distributed component dimensions are relatively small.

(5) The structure is quite rugged and can withstand moderately high power level.

Microstrip parameters

One of the most challenging problems associated with this configuration arises from the fact that the small strip is not immersed in a single dielectric. On one side there is the board dielectric, and on the top is usually air. The technique that has been developed to handle this challenge uses, as was mentioned above, the concept of effective relative dielectric constant, ε_{eff} .

This value represents some intermediate value between the relative dielectric constant of the board material, ε_r, and that of air (assumed equal to 1) that can be used to compute microstrip parameters and the two most basic parameters that define a transmission line are characteristic impedance, Z_o and the velocity of propagation, v_p .

Characteristic impedance and velocity of propagation are defined in terms of inductance per unit length *L* and capacitance per unit length *C* [5].

$$Z_o = \sqrt{\frac{L}{C}} \qquad \text{…. (1)}$$

$$v_p = \frac{1}{\sqrt{LC}} \qquad \text{…. (2)}$$

the characteristic impedance of the microstrip line can be expressed in the form:

$$Z_o = \frac{1}{v_p C} \qquad \text{…. (3)}$$

and the velocity of propagation is given by:

$$v_p = \frac{c}{\sqrt{\varepsilon_{eff}}} \qquad \text{…. (4)}$$

where *c* is the velocity of light $c = 2.998 \times 10^8$ m/s.

therefore:

$$Z_o = \frac{\sqrt{\varepsilon_{eff}}}{cC} \quad \text{.... (5)}$$

Microstrip Impedance

Any circuit trace on the Printed Circuit Board (PCB) has characteristic impedance (Z_o) associated with it. This impedance is dependent on the width (*W*) of the trace, the thickness (*T*) of the trace, the dielectric constant (ε_r) of the material used, and the height (*H*) between the trace and reference plane.

When designing microstrip components, calculating microstrip impedance is more significant. By using this microstrip impedance calculator, one can compute the opposition to alternating current based on the input values of trace width, thickness, dielectric thickness, and dielectric constant.

The following microstrip impedance equation to calculate the impedance of a microstrip trace layout [6,7,8,9].

For zero thickness or very thin thickness (T/H < 0.005) :

$$Z_o = \frac{\eta}{2\pi\sqrt{\varepsilon_{re}}} \ln\left(\frac{8H}{W} + 0.25\frac{W}{H}\right) \quad \text{for } (W/H) < 1 \quad \text{.... (6)}$$

$$Z_o = \frac{\eta}{\sqrt{\varepsilon_{eff}}} \left\{\frac{W}{H} + 1.393 + 0.667\ln\left(\frac{W}{H} + 1.444\right)\right\}^{-1} \quad \text{for } (W/H) \geq 1 \quad \text{.... (7)}$$

where:

η is the impedance of free-space =376.7 Ω (≈120π).

ε_{eff} is the effective dielectric constant of substrate given by [10,11,12]:

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2} F(W/H) \quad \text{.... (8)}$$

$$F(W/H) = \begin{cases} (1 + 12H/W)^{-1/2} + 0.04(1 - W/H)^2 & for (W/H) < 1 \\ (1 + 12H/W)^{-1/2} & for (W/H) \geq 1 \end{cases} \quad \text{.... (9)}$$

***Effect of strip thickness (T/H ≥ 0.005)* :**

The effect of strip thickness on Z_o and ε_{re} of microstrip lines has been reported by a number of investigators [6,8,9,13]. Simple and accurate formulas for Z_o and ε_{re} with finite strip thickness are:

$$Z_o = \frac{\eta}{2\pi\sqrt{\varepsilon_{re}}} \ln\left(\frac{8H}{W_e} + 0.25\frac{W_e}{H}\right) \quad \text{for } (W/H) < 1 \quad \text{.... (10)}$$

$$Z_o = \frac{\eta}{\sqrt{\varepsilon_{re}}} \left\{\frac{W_e}{H} + 1.393 + 0.667\ln\left(\frac{W_e}{H} + 1.444\right)\right\}^{-1} \quad \text{for } (W/H) \geq 1 \quad \text{.... (11)}$$

where :

W_e is the effective width (actual width) of the strip, the width correction for the fringing fields associated with the finite thickness of the center conductor strip and given by [14,15]:

Narrow strip *{1/(2π) > W/H > 2T/H}:*

$$\frac{W_e}{H} = \frac{W}{H} + \frac{1.25}{\pi}\frac{T}{H}\left(1 + \ln\frac{4\pi W}{T}\right) \quad \text{.... (12)}$$

Wide strip *{W/H > (1/2π) > 2T/H}:*

$$\frac{W_e}{H} = \frac{W}{H} + \frac{1.25}{\pi}\frac{T}{H}\left(1 + \ln\frac{2H}{T}\right) \quad \text{.... (13)}$$

$$\varepsilon_{re} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2} F(W/H) - C \quad \text{.... (14)}$$

in which

$$C = \frac{\varepsilon_r - 1}{4.6} \frac{T/H}{\sqrt{W/H}} \quad \text{.... (15)}$$

These correction are further subject to the restrictions that: $T \leq H$ and $T < W/2$.

Program Description

A Computer program MSTL was created originally to compute the values of the characteristic impedance, line width, strip thickness and dielectric thickness. This program also provide the ability to use other materials and geometries of the microstrip transmission line.

The characteristic impedance of the microstrip line was calculated by using this program and was listed in table (1). The table shows the characteristic impedance of the microstrip line for various geometries and for a given dielectric constant is 4.3 .

The values listed in the table were plotted in figure (2).

The program allow the user to input the relative dielectric constant, thickness of the strip and height of substrate. It will also output the width of the strip and strip impedance.

Even through programmable calculators and Computers are easy to perform microstrip impedance line calculations.

MSTL program was written in Fortran 90 to be more flexible and more organized.

Results and discussion

The numerical methods for the characterization of microstrip line discussed so far, involve extensive computations. Closed form expressions are necessary for optimization and computer aided design of microstrip circuits. A complete set of design equations for microstrip are presented in this paper. These include closed form expressions for the characteristic impedance variation with metal strip thickness.

The characteristic impedance of microstrip displayed in Figure (2), has described an ingenious and powerful approximation based on conformal mapping [13]. Some thickness is accommodated at the expense of some refinements in other respects. The result is a very useful approximation for wide stripe with thickness. To yield this in analytic form is a major achievement.

It is based on a thin strip which are remarkable for including the width and the thickness in formula; the width adjustment for thickness, without the effect of dielectric [7].

The formulas given for the quasi-static characteristic impedance and effective dielectric constant are based on an infinite thin microstrip line thickness *T*=0 [6]. A finite thickness *T* can be compensated by a reduction of width. That means a strip with the width *W* and the finite thickness *T* appears to be a wider strip shown in Figure (2) .

Conclusion

Characteristic impedance Z_o versus *W/H* relation are calculated and shown in Figure (2) as a function of *W/H* with parameter of thickness. It can be seen from Figure (3) the effect of thickness on the characteristic impedance.

The mathematics used represent a good closed form approximation for the line impedances between (26-157) ohms. Table (1) contains a list of microstrip line impedance for (0.15 - 4.5)mm. strip width.

Whenever, thickness increases of strip its impedance decreases which means that when neglecting strip thickness the impedance be as large as it could, but this has a large mistake, Figure (3).

So we have take into consideration the strip thickness when conducting any design for microstrip line. The effect of strip thickness is significant on conductor loss in the microstrip line.

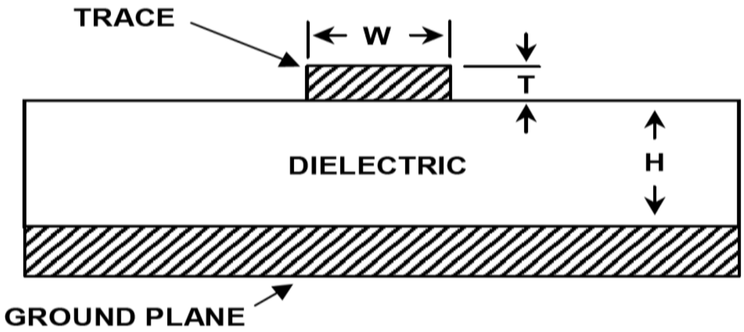
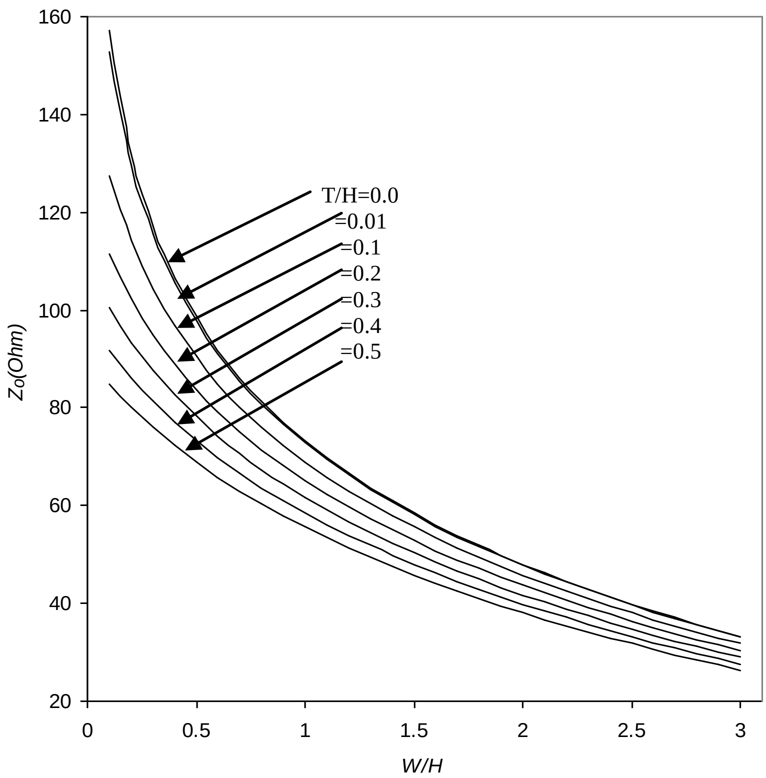


Figure (1): Cross sectional view of a microstrip line.



Figure(2): Characteristic impedance Z_o versus *W/H* at $\varepsilon_r = 4.3$ and *H=1.5* mm.

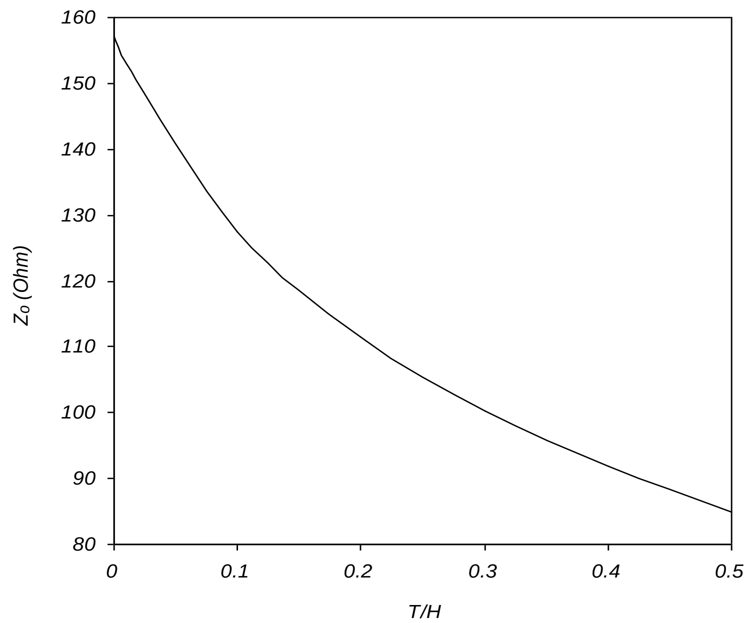


Figure (3): Characteristic impedance Z_o versus *T/H* at $\varepsilon_r = 4.3$, *H=1.5* mm. and *W=0.15* mm.

Table (1): Design data of microstrip line at $\varepsilon_r = 4.3$ and *H=1.5* mm.

T/H=0.5	T/H =0.4	T/H =0.3	T/H =0.2	T/H =0.1	T/H=0.01	T/H =0.0	W/H
Z_o							
84.9461	91.83609	100.3416	111.4601	127.5465	152.7828	157.0711	0.1
80.24171	86.22372	93.38561	102.3101	114.1582	129.6275	131.8348	0.2
76.07622	81.36205	87.5478	95.00403	104.3912	115.5862	117.0724	0.3
72.33875	77.07377	82.51797	88.92187	96.69775	105.4781	106.5984	0.4
68.94948	73.23776	78.09943	83.7118	90.34983	97.5751	98.47412	0.5
65.84901	69.76768	74.15955	79.15481	84.9461	91.08537	91.83609	0.6
62.99199	66.59973	70.60468	75.10526	80.24171	85.5793	86.22371	0.7
60.34295	63.6855	67.36625	71.46139	76.07621	80.79757	81.36205	0.8
57.87363	60.98735	64.39249	68.14925	72.33875	76.57157	77.07376	0.9
55.56121	58.47544	61.64338	65.11346	68.94947	72.78548	73.23775	1
53.38693	56.12569	59.08736	62.31144	65.84901	69.35627	69.76767	1.1
51.33522	53.91845	56.69907	59.70974	62.99199	66.22243	66.59973	1.2
49.39297	51.83741	54.45784	57.28161	60.34294	63.3371	63.6855	1.3
47.54912	49.86891	52.34662	55.00535	57.87363	60.66372	60.98735	1.4
45.79416	48.0014	50.35114	52.86306	55.56121	58.17329	58.47543	1.5
44.11992	46.22503	48.45937	50.83986	53.38693	55.84236	56.12569	1.6
42.51929	44.53131	46.66106	48.92318	51.33521	53.65172	53.91845	1.7
40.98608	42.9129	44.94741	47.10238	49.39297	51.58544	51.83741	1.8
39.51484	41.36337	43.31081	45.36832	47.54912	49.63016	49.8689	1.9
38.10074	39.87711	41.74462	43.71312	45.79416	47.77456	48.0014	2
36.73952	38.44915	40.24303	42.12989	44.11992	46.00896	46.22503	2.1
35.42737	37.07509	38.80093	40.61266	42.51929	44.32504	44.53132	2.2
34.16087	35.751	37.41377	39.15613	40.98608	42.71557	42.9129	2.3
32.93694	34.47338	36.07754	37.75564	39.51484	41.17424	41.36338	2.4
31.75282	33.23909	34.78861	36.40703	38.10075	39.69553	39.87712	2.5
30.60601	32.04527	33.54376	35.10659	36.73953	38.27454	38.44916	2.6
29.49422	30.88935	32.34007	33.85101	35.42738	36.90693	37.0751	2.7
28.41537	29.769	31.17491	32.63729	34.16087	35.58883	35.75101	2.8
27.36758	28.68211	30.04587	31.46272	32.93695	34.3168	34.47339	2.9
26.3491	27.62672	28.9508	30.32487	31.75283	33.08771	33.23909	3

Reference

1. J. A. Seeger (Microwave Theory, Components, and Devices) Prentice- Hall, New Jersey (1986), pp.230- 234.
2. A. Arshad and A. Cheldavi (Simple and Novel Model for Edged Microstrip Line (EMTL) *Progress in Electromagnetics Research, PIER* 65, (2006), pp.247- 259.
3. IPC-2141 (Controlled impedance circuit boards and high-speed logic design) April 1996.
4. B. Kennedy and M. David, Note-1469 (Design and layout guide) April 2008.
5. G. L. Matthaei; L. Young and E. M. T. Jones (Microwave Filters Impedance Matching Networks and Coupling Structures) New York, Artech House (1980) pp. 163-165.
6. H. A. Wheeler (Transmission-line properties of parallel a strip on a dielectric sheet on a plane) *IEEE-Trans. Microwave Theory Techniques*., Vol.MTT-25, No.8, (1977), pp. 631-647.
7. F. E. Gardiol (Design and Layout of Microstrip Structures) *IEE Proceedings,H,* Vol. 135, No.3, (1988), pp.145-157.
8. I. J. Bahl and D. K. Trivedi (A Designer's Guide to Microstrip Line) *Microwaves*, (1977), pp.174-182.
9. B. C. Wadell (Transmission Line Design Handbook) Artech House (1991), pp.93- 97.
16.
10. V. V. Thakare and P. Singhal (Neural Network Based CAD Model for the Design of Rectangular Patch Antennas) *Journal of Engineering and Technology Research* Vol.1 No.7, (2009), pp.129-132.
11. F. Schnieder and W. Heirrich (Model of Thin-Film Microstrip Line for Circuit Design) *IEEE-Trans. Microwave Theory Techniques*, Vol. MTT- 49, No.1, (2001), pp.104- 110.
12. H. Paul (Microstrip Design Laboratory) *IEEE Transactions on Education*, Vol. 34, No. 1, (1991), pp.113- 117.
13. M. V. Schneider (Microstrip Line for Microwave Integrated Circuit) *B. S. T. J*., Vol.48, (1969), pp.1422- 1444.
14. K. K. Joshi; R. D. Pollard and V. Postoyalko (Microstrip with Dielectric Overlay: Variational Analysis and Validation) *IEE Proc. Microwave Antennas Propag..* Vol.141, No.2, (1994), pp.138-140.
15. R. A. Pucel; D. J. Masse and C. P. Hartwig (Losses in Microstrip) *IEEE-Trans. Microwave Theory Techniques*, Vol. MTT- 16, No.6, (1968), pp.342- 350.

سمك الخط إلى مختلف مقاومات شريحة مايكروية

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الملخص

يتناول هذا البحث دراسة مقاومة شريحة مايكروية نوع (Microstrip line) ومدى تأثير سمك هذه الشريحة على مقاومتها ، هذا التأثير يصف بشكل بارع التقريب الأساسي للتصميم الذي يطابق التخطيط العملي لتصميم الشريحة المايكرووية .

تم حساب المقاومة ضمن المدى (26 – 157) آوم وعرض بين (0.15 – 4.5) ملم وبسمك مختلف للشريحة والنتائج الموضحة بالأشكال تبين الخطأ في إيجاد قيمة المقاومة عند إهمال السمك كما في بحوث سابقة وكانت نتائج البحث مفيدة جدا عند عرض وسمك كبير للشريحة.