Impedance of Stripline

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Abstract

This research aims at studying the resistance of the transmission line model for the stripline components description of the algorithm used to calculate the characteristic impedance for the stripline in the different thickness and width of the strip which demonstrates that the new calculation method was valid and useful in applying actual stripline structure.

The impedance in range (25-115) ohms for several thickness and widths of strip had been programmed. The calculations had been compared with exact solution and showed a good closed form approximation.

Keywords: Impedance, Stripline

Introduction

The past few years have seen tremendous progress in solid state devices used for microwave applications and many different materials are used to construct microwave components such design as transmission lines, filters, capacitors, and many others. It is important to know the characteristics of the construction materials at microwave frequencies for proper design, the properties of the materials used in fabricating the circuit are very important as any anomalies result in degradation of electrical performance [1].

Both Stripline and Microstrip configurations are preferred by electric engineers in general. Yet, many favor the stripline configuration, because of the difference performance between the two configurations. Stripline have the same relative dielectric constant (ε_r) on both sides of the trace accordingly it has better ground (reference) as compared to a microstrip configuration [2].

In this paper new calculation method has been applied to actual structure and dispersion characteristic impedance were calculated for various dimensions.

Wave Impedance

The wave impedance of an electromagnetic wave, is the ratio of the transverse components of the electric and magnetic fields. For transverse - electric − magnetic (TEM) plane wave traveling through a homogeneous medium, the wave impedance is everywhere equal to the intrinsic impedance of the medium [3].

The wave impedance is given by:

$$Z = \frac{E_o(x)}{H_o(x)} \quad \text{.... (1)}$$

where $E_o(x)$ is the electric field and $H_o(x)$ is the magnetic field.

Characteristic Impedance

The characteristic impedance of a uniform transmission line, usually written Z_o which is the ratio of the amplitudes of a single pair of voltage and current waves propagating along the line of characteristic impedance.

The characteristic impedance of a lossless transmission line is purely real, that is, there is no imaginary component ($Z_o = /Z_o/ + j$).

The ratio of voltage applied to the current is called the input impedance, the input impedance of the infant line is called the characteristic impedance. The general expression for the characteristic impedance of a transmission line is [4]:

$$Z_o = \sqrt{\frac{R + j\omega L}{G + j\omega C}} \quad \text{.... (2)}$$

where: R is the resistance per unit length, L is the inductance per unit length, G is the conductance of the dielectric per unit length, C is the capacitance per unit length, j is the imaginary unit, and ω is the angular frequency.

For a lossless line, R and G are both zero, so the equation (2) for characteristic impedance reduces to [5]:

$$Z_o = \sqrt{\frac{L}{C}} \quad \text{.... (3)}$$

The imaginary term j has also canceled out, making Z_o a real expression and so is purely resistive with a magnitude of $\sqrt{\frac{L}{C}}$.

For a stripline, where the electric (and magnetic) fields are in a uniform substrate, dielectric constant ε_r, equation (3) becomes:

$$Z_o = \frac{\sqrt{\varepsilon_r}}{cC} \quad \text{.... (4)}$$

where c is the velocity of light in vacuum (or free-space) = $\frac{1}{\sqrt{\mu_o \varepsilon_o}} = 3\times10^8$ m/s.

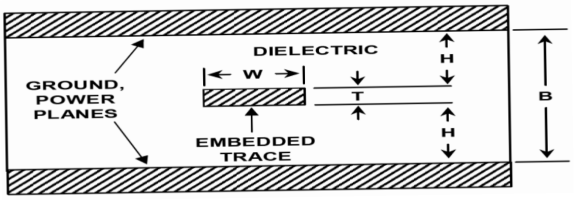
The velocity of pulse travel along the transmission path is :

$$V = \frac{c}{\sqrt{\varepsilon_r}} \quad \text{.... (5)}$$

ε_r is the relative permittivity of the dielectric compare to that of free space.

Stripline

A stripline circuit uses a flat strip of metal which is sandwiched between two parallel grand planes. The insulating material of the substrate forms a dielectric Figure (1). The characteristic impedance is dependent on width (W) of the trace, thickness (T) of the trace, dielectric constant (ε_r) of the material used, and height (*H*) between the trace and reference plane.



Figure(1): Typical stripline cross section

Stripline is an important transmission line for Microwave Integrated Circuit (MIC) system. In order to carry out rigorous analysis and design for stripline circuit, exact characteristic impedance for any strip thickness is strongly needed.

There are many numerical calculation methods for stripline with zero and finite strip thickness. Exact analytical solution for zero thickness was already well-known and given by conformal transformation method [6], but that for finite thickness is not available. So far, relatively exact solution are given by Wadell [7].

Hence, it is important to develop a new method which can give more exact characteristic impedance for any strip thickness including zero. In this paper a new systematic method for the calculation of characteristic impedance.

For an ideal stripline with a zero-thickness perfectly conducting center strip, the characteristic impedance is given exactly by [6]:

$$Z_o = \frac{\eta_o}{4\sqrt{\varepsilon_r}}\frac{K(k\ )}{K(k^{'})} \qquad \text{…. (6)}$$

$$k\ = \operatorname{sec}h\frac{\pi W}{2B} = \left[\cosh\frac{\pi W}{2B}\right]^{-1} \qquad \text{…. (7)}$$

$$k^{,} = \sqrt{1-k^2} = \tanh\frac{\pi W}{2B} \qquad \text{…. (8)}$$

where: η_o is the wave impedance of free space $= \sqrt{\frac{\mu_o}{\varepsilon_o}} \cong 120\pi\ (\Omega)$.

$K(k)$ is the complete elliptical integral of the first kind and modulus k with the complementary modulus $k^{,} = \sqrt{1-k^2}$ [8].

μ_o permeability of free space = $4\pi\times10^{-7}\Omega$.

ε_o permittivity of free space = $\frac{1}{36\pi}\times10^{-9}$ F/m.

W is the center strip width.

B is the dielectric thickness.

K(k) from $K(k=0)=\frac{\pi}{2}$ rises monotonically with *k* to the value $K(k=1)=\infty$.

The definition range is $0\le k\le1$ and $K(k^{,})=K(k)$.

Although this formula is exact, it is not very useful because in reality any center strip will have a finite thickness and a finite conductivity.

One of the most useful approximate formulas is given by [7] :

Wide strip: $\frac{W}{B}\ge0.35$

The characteristic impedance is given by:

$$Z_o = \frac{1}{\sqrt{\varepsilon_r}}\times\frac{94.15}{[(W_e/B)/(1-T/B)]+Z_{k1}/\pi} \qquad \text{.... (9)}$$

where:

$$Z_{k1} = \left[\frac{2}{1-(T/B)}\ln\left(\frac{1}{1-(T/B)}+1\right)-\left(\frac{1}{1-(T/B)}-1\right)\ln\left(\frac{1}{(1-T/B)^2}-1\right)\right] \qquad \text{…. (10)}$$

W_e the effective center strip width, defined by [9]:

$$\frac{W_e}{B} = \frac{W}{B} \qquad \text{….(11)}$$

Narrow strip: $\frac{W}{B} < 0.35$

The fringing fields on each side of the center strip conductor cannot be treated independently, the approximate formulation is that used for slab line.

$$Z_o = \frac{60}{\sqrt{\varepsilon_r}}\ln\left(\frac{4B}{\pi Z_{k2}}\right) \qquad \text{…. (12)}$$

where the strip width W and thickness T is related to a round center of diameter Z_{k2} by:

$$Z_{k2} = \frac{W_e}{2}\left[1+\frac{T}{\pi W_e}\left\{1+\ln\frac{4\pi W_e}{T}+0.51\pi\left(\frac{T}{W_e}\right)^2\right\}\right] \qquad \text{.... (13)}$$

W_e is given by the empirical formula [9]:

$$\frac{W_e}{B} = \frac{W}{B}-\left(0.35-\frac{W}{B}\right)^2 \qquad \text{…. (14)}$$

Both expressions (11), and (14) for W_e were found to be within 1 percent of measured data for $\frac{T}{B}\le0.25$.

A graph of Z_o versus *W/H* for various thickness ratios, *T/H*, is given in Figure (2).The formulas given above are the same as the formulas used by Cohn [6,10], except that Cohn dose not use the empirical correction for the narrow strip case.

Instead, Cohn uses an equivalent round conductor approximation for the narrow strip region of $\frac{W}{B-T} < 0.35$.

This new calculation method is applied to actual stripline structure, dispersion characteristic impedance has been calculated for various dimensions.

The symmetric stripline also has a characteristic capacitance. Which can be calculated in terms of pF/in as show in Equation (15) [11]:

$$C_o(pF/in) = \frac{1.41(\varepsilon_r)}{\ln[3.81H/(0.8W+T)]} \quad \text{.... (15)}$$

The propagation delay φ_{pd} is the time required for a signal to travel from one point to another. Transmission line propagation delay is a function on the dielectric constant of the material [12]:

$$\varphi_{pd}(n_s/ft) = 1.017\sqrt{\varepsilon_r} \quad \text{.... (16)}$$

Program Description

The STP program is originally created to implement the analytical expression and coased-from solution for single stripline transmission line. On the user command STP program can compute the characteristic impedance Z_o with different thickness and different width of the strip. STP program is developed and written in Fortran 90, its flexible and well organized.

Results And Discussion

According to Figure (2), the relation is Z_0 = f(*W, H*), where *W* is the trace width and *H* is the conductor height, greater trace width and strip thickness result in lower values of characteristic impedance.

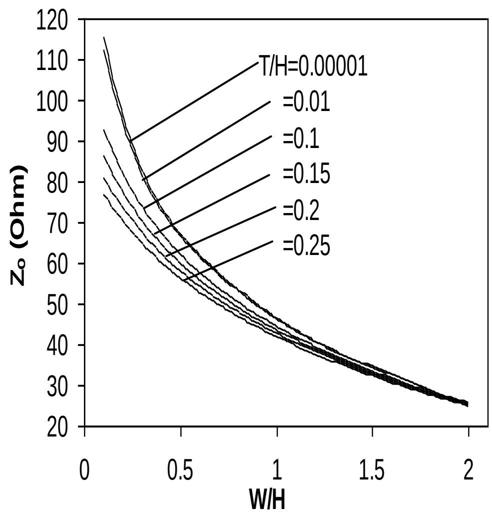


Figure (2): Characteristic Impedance versus *W/H* for $\varepsilon_r = 4.0$

The mathematics equation used present a good closed form approximation for line impedances between 25-115 ohms and will deliver results that fall within 3 percent of Wheeler's, [13] line impedance values.

Table (1) contains a list, printed by using a STP program, of stripline impedance from 25 to 115 ohms for (0.00006 -1.5) mm. trace thickness and for (0.6 – 12.0)mm. trace width.

These calculated results are compared with exact solution of zero thickness or conventional solution with good agreement, which demonstrates that our new method is valid and useful.

Table(1): Design data of stripline at $\varepsilon_r = 4.0$ and *H*=6.0 mm.

Z_o (Ohm)								W/H
T/H= 0.25	*T/H*= 0.2	*T/H*= 0.15	*T/H*= 0.1	*T/H*= 0.01	*T/H*= 0.001	*T/H*= 0.0001	*T/H*= 0.00001	
76.8434	81.0983	86.30993	92.95769	112.438	115.4642	115.7859	115.8183	0.1
70.3315	73.5589	77.35514	81.92594	93.35836	94.85555	95.01023	95.02575	0.2
64.984	67.5388	70.4679	73.87802	81.78849	82.75378	82.85252	82.86242	0.3
60.4471	62.5271	64.87033	67.53875	73.45953	74.15445	74.22518	74.23227	0.4
56.507	58.2341	60.15476	62.30815	66.9476	67.47884	67.53275	67.53815	0.5
53.0249	54.4792	56.08072	57.85555	61.60015	62.02167	62.06436	62.06863	0.6
49.9052	51.1424	52.49436	53.9792	57.06322	57.40606	57.44073	57.4442	0.7
47.0795	48.1399	49.29132	50.54689	53.12314	53.4068	53.43546	53.43832	0.8
44.4973	45.4108	46.39751	47.46726	49.64098	49.87851	49.90248	49.90488	0.9
42.1198	42.9093	43.75845	44.67455	46.52128	46.72185	46.74208	46.74411	1
39.917	40.6005	41.33288	42.11981	43.69567	43.86595	43.88312	43.88484	1.1
37.8649	38.4567	39.08885	39.76567	41.11343	41.25845	41.27306	41.27452	1.2
35.9443	36.456	37.00105	37.58289	38.73595	38.85957	38.87202	38.87327	1.3
34.1392	34.5804	35.04914	35.54821	36.53312	36.63839	36.64899	36.65005	1.4
32.4366	32.8152	33.21651	33.6428	34.48104	34.57038	34.57938	34.58028	1.5
30.8255	31.1481	31.48941	31.85123	32.56039	32.63579	32.64338	32.64414	1.6
29.2965	29.5688	29.85636	30.16064	30.75533	30.81843	30.82478	30.82541	1.7
27.8417	28.0684	28.30762	28.56026	29.05275	29.1049	29.11015	29.11067	1.8
26.4541	26.6396	26.83494	27.04095	27.44162	27.48398	27.48824	27.48867	1.9
25.128	25.2757	25.43117	25.59488	25.91263	25.94617	25.94954	25.94988	2

Conclusion

The impedance depends on the trace width and distance to ground. If the trace is wide and closer to ground it has lower impedance.

If the trace is narrow and the spacing from the ground plane is larger, the trace has a higher impedance.

Controlled impedance boards in which all the impedance match within several ohms usually have a characteristic impedance in the 25 ohm to 115 ohm range. This is due to manufacturing constraints such as maximum dielectric thickness and minimum trace widths, in which we can see :

1-Increasing *W* decreases Z_o .

2-Increasing *H* Increasing Z_o .

3-Increasing *T* decreases Z_o .

References

1. Ahmed M. El-Bakly (Optimization Study of the Stripline Resonator Technique for Dielectric Characterization) Blacksburg, Virginia (1999), pp.1-2.
2. C. Robinson; T. Piwtorok; B. Souid, Project 1 (Synthesis and Analysis of Microstrip and Stripline Transmission Line Structures) Syracuse University (10/18/2011).
3. M. Matsunage, *PIER*, Vol.42, (2003), pp.219-232.
4. G. L. Matthaei,; L.Young; E. M. T. Jones, (Microwave Filters, Impedance -Matching Networks, and Coupling Structures) New York, Artech House, (1980), pp.163-165.
5. P. Rashmi (Characterizing Losses in Microstrip Transmission Line) University of Wisconsin (2005) Madison, pp.6-8.
6. S.B. Cohn, *IRE Trans. MTT*-Vol., (1954), No. 2, pp.52-57.
7. B. C. Wadell, (Transmission Line Design) Handbook Artech House. (1991), pp.125-130.
8. V. Milanovic,; M. Ozgur,; D.C. DeGroot,; J.A. Jargon; M. Gaitan,; M.E. Zaghloul, *IEEE Trans. MTT*-Vol.46, (1998),No.5, pp.632-640.
9. I.J. Bahl,; G. Ramesh , *Microwaves*, (1978), pp.90 -96,
10. S.B. Cohn, *IRE Trans., MTT*-Vol.3, (1955), No.2, pp.119-126.
11. IPC-2141 (Controlled Impedance Circuit Boards and High Speed Logic Design) *The Institute for Interconnecting and Packaging Electronic Circuits*, (1996).
12. T. K. Sarker (History of wireless) Jon Wiley and Sons, (2006), pp.556-559.
13. H. A. Wheeler, *IEEE Trans., MTT* –Vol.13, (1965), No. 3, pp.172-185.

مقاومة شريحة مايكروويية نوع Stripline

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الملخص

يهدف هذا البحث إلى دراسة مقاومة احد خطوط نقل موجات المايكروويف نوع (Stripline) وحساب قيمة هذه المقاومة عند سمك وعرض مختلفين للشريحة بتطبيق طريقة جديدة لحساب التصميم الحقيقي للشريحة.

تم حساب المقاومة ضمن المدى (25–115) آوم بسمك وعرض مختلفين للشريحة وقورنت هذه المقاومة مع حلول دقيقة وتبين أنها جيدة وقريبة جدا من تلك الحلول.