Determination of Even / Odd TE & TM- Like Modes Propagation Of Dielectric Waveguide Structures

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Abstract
The symmetrical condensed node (SCN) transmission line modeling (TLM) method is applied to dielectric waveguides structures (i.e. two identical strip dielectric waveguides and two identical insulanted image waveguide, respectively) for the determination of the propagation TE and TM – like modes. The properties of the even and odd modes are also presented .In this paper; the calculated numerical results are verified by results available from other methods.

Introduction
The application of dielectric waveguides (DW) in millimeter wave integrated circuits depnde critically on the propagation characteristics of these waveguides. For this reason, there has been enduring interest in methods of determining these characteristics for paractical dielectric waveguide (DW) structures [1] **.**

Several methods for the analysis of dielectic waveguides (i.e. two identicat strip dielectric and two identical image waveguides, respectively) in Fig. 1 have been the subject of many papers[2-11]. Among them, the Effective Dielectric Constant (EDC) method [2] , the Transverse Resonance Method (TRM)[3], and Mode- Matching Techniques (MMT) [4]which can't provide complete information on the field distributions. The Vectorical Finite Method (VFM) formulation interims of longitudinal electic (E_z) and magnetic (H_Z) fields components enable one to compute accurately the mode spectrum of a waveguide with arbitrary cross section, is widely used [5] .

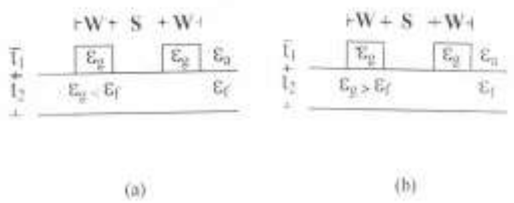

Fig. 1 : cross sections : (a) two identical strip dielectric waveguide structure , (b) two identical insulated image waveguide structure .

The more general developed another (VFM) method interme of all three components of the electric and / or magnetic fields can be found in the literature[6]. In this procedure, spurious solution don't appear, but needless zero eigen values are produced. The kernel of the domain integral equation (DIE) method is the Green's function of an electric line source (i.e. the DIE method has been developed to compute both propagation constant and corresponding electromagnetic field distribution of guided waves in integral optical guides). For the derivation of the Green's function, the method presented by [7,8] has been modified and extended , thus loading to a numerically stable calculation scheme . Cut off conditions for all modes in three-layer cylindrical dielectric waveguides with arbitrarily discrete refractive index profiles have been derived by [9] The Finite Element Method (FEM)and the Finite Difference Method (FDM) [10],[11] have been also to solve for the dispersion characteristics of the DW . However, the leakage effect was not investigated.

In this paper , it will be demonstrated how the model methed is powerful approach for the analysis of (DW) structures (the characterization of the effective refractive index and the imaginary part (log (η_i / k_0)) of propagation constant of the TE-and –TM-like modes (i.e. E^X_{11}, E^X_{12}, and E^z_{11} - modes) see in Fig . 1.

TLM Method Analysis
The transmission-line modeling (TLM) method has been successfully applied during the last twenty years for the solution of electromagnetic-wave-propagation(EMWP)problems. Details, application and advantages of the method are readily availabke in the literature [12],[13],[14] . As in any numerical method which is based on space segmentation by point grid and time segmentation by a discrete sampling , an unavoidable inconvenience of TLM method is the resulting numerical dispersion, which makes the phase and group velocities depending on the frequency even in cases where the numerical method attempts to simulate non-dispersive media as shown in Fig.2

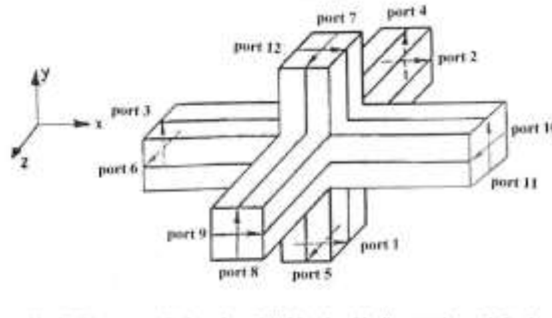

Fig. 2 : The symmetrical condensed TLM node with all port voltages defined .

The general dispersion relation for TLM nodes is given as[15].

$$\det (PS-e^{jK0d} I) = 0 \quad …… (1)$$

where k_0 is the propagation constant along the transmission lines . d is the node spacing . S is the

scattering matrix. and I is identity matrix (i.e. the fact that energy is conserved is that the scattering matrix is unitary , $[S^T][S]$= I, this condition was fundamental to John's original derivation [16]) , while P is a connection matrix .
The row and columns of the SCN scattering matrix gives [17]:

$$S = \begin{bmatrix} 0 & S_0 \\ S_0^T & 0 \end{bmatrix} \quad \ldots\ldots (2)$$

where

$$S_o = \begin{bmatrix} \begin{bmatrix} 0 & 1/2 & 1/2 \\ 1/2 & 0 & 1/2 \\ 1/2 & 1/2 & 0 \end{bmatrix} & \begin{bmatrix} 0 & -1/2 & 1/2 \\ 1/2 & 0 & -1/2 \\ -1/2 & 1/2 & 0 \end{bmatrix} \\ \begin{bmatrix} 0 & -1/2 & 1/2 \\ 1/2 & 0 & -1/2 \\ -1/2 & 1/2 & 0 \end{bmatrix} & \begin{bmatrix} 0 & 1/2 & 1/2 \\ 1/2 & 0 & 1/2 \\ 1/2 & 1/2 & 0 \end{bmatrix} \end{bmatrix} \ldots 3$$

For the now agreement of node ports, matrix P can be written in the form

$$p = \begin{bmatrix} \begin{bmatrix} 0 & p_1 \\ p_1^* & 0 \end{bmatrix} & \begin{bmatrix} 0 & 0 \\ 0 & 0 \end{bmatrix} \\ \begin{bmatrix} 0 & 0 \\ 0 & 0 \end{bmatrix} & \begin{bmatrix} 0 & p_1 \\ p_1^* & 0 \end{bmatrix} \end{bmatrix} \quad \ldots\ldots 4$$

with

$$p1 = \begin{bmatrix} e^{jk_x d} & 0 & 0 \\ 0 & e^{jk_y d} & 0 \\ 0 & 0 & e^{jk_z d} \end{bmatrix} \quad \ldots\ldots 5$$

where p_1^* stands for the Hermitian transpose of p_1 and k_x, k_Y, k_Z are the components of mesh propagation vectors , (i.e. the propagation vector $|k|$ = $(k_X^2 + K_Y^2 + K_Z^2)^{1/2}$).
Equation (1) can be solved as an eigen value problem , because the left-hand side of Eq.(1) represents the characteristics polynomial of the matrix PS in terms of $\Psi = e^{jKod}$. By obtaining the coefficient C_i , i = 1,2,…, N of this Nth order polynomial , we can get as

$$p^N(\Psi) = \Psi^N + \sum_{i=1}^{N} C_i \Psi^{N-1} = 0 \ldots\ldots(6)$$

where N is equal to the number of node ports .
The dispersion relation for propagation modes (i.e. the dispersion relation for the SCN) can be get in form

$$\cos^2(k_0 d) = 0.5(C_1 + 1) \ldots\ldots(7)$$

where

$$C_1 = 0.5\left[\sum_{K_p,K_q} \cos(kpd)\cos(k_q d) - 1\right]$$

and $\{(k_p, k_q) \in \{(k_x, k_y), (k_y, k_z), (k_z, k_x)\}\}$
The dispersion in eq. (7) is an implicit function of k_x, k_y, k_z and k_0 which have solve numerically.

Results and Discussion

In this section we apply TLM method to study the propagation constant for the (DW) structures . The wave modes of DW are hybrid modes by nature. In our notation , they are called E^x_{pq} modes (TE-like) when the TE_Z portion is larger than the TM_Z portion and are called E^z_{pq} modes (TM-like) when TE_Z portion is less than the TM_Z portion as was observed in [7] .This mean , when the TE – TM coupling at the sides of the dielectric waveguide is taken into account, the hybrid modes now become more complex, possessing six field components instead of five . Although these modes can no longer be characterized according to whether they possess ,in the vertical direction, only a magnetic field component, or only an electric field component, the amount of the other vertical field component is usually small because the TE-TM coupling itself is usually small . It becomes convenient then to characterize these hybrid modes as TE-like or TM - like , depending on which surface wave that bounces back and forth between the sides has the predominant field energy[18].
The new physical effects which result from TE-TM coupling at the sides of the guiding structures are leakage, which changes a guided mode into a leaky mode, and a resonance or cancellation effect, which prevents leakage at specific parameter values and which may also influence the value of $(\eta = \beta)$ of the guiding mode [18] .
The guiding structures consists of three different dielectric media , for convenience , the media are the designated as : the dielectric air of dielectric constant $(\in_a = \in_0)$, the guiding strip of dielectric constant $(\in_g)$, the dielectric film of the dielectric constant $(\in_f)$ located on the ground plane , and
W: the width of the guiding strip (i.e. the guiding strip placed on the dielectric film).
The first proposal structure test is that of two identical strip dielectric guide, usually $\in_f > \in_g$ $.Fig.3$ represents the effective refraction index n_{eff} ($n_{eff} = \eta_r / k_0$, where η_r is the real part of the propagation constant η ; and k_0 is a wave number in free space) for the E^Z_{11} modes (i.e. the E^Z_{11}- mode consists of the even and odd-modes) as a function of separation S with fixed f=38.67 GHz, $\in_f = 2.6 \in_0, and \in_g = 2.55 \in_0$. The guide parameters are $t_1 = 0.32cm, t_2 = 0.5cm, W = 0.56cm, and \in_a = \in_0$.

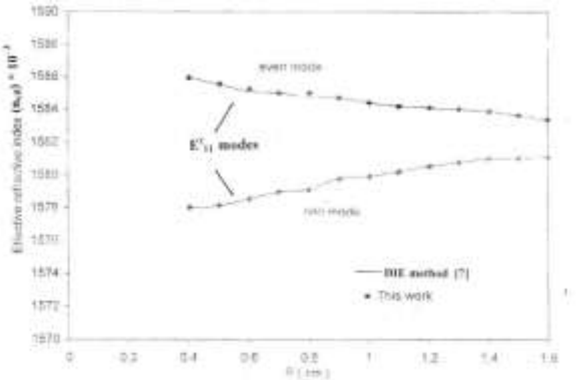

Fig. 3: The effective refractive index (n_{eff}) for the E^x_{11} modes as a function of S for the two identical strip dielectric guides at f = 38.67 GHz .

In the above figure , the n_{eff} for the E^Z_{11} modes shows a growing tendency toward being degenerated whenever the separation S become great (i.e. the even and odd modes tend to be degenerate when the separation S is increased . The E^Z_{11} modes are no leakage mode (the electric fields decay away from the center region) as the corresponding E^z_{11} on the single insulated image guide) . From Fig.4 (a &b) we observed the n_{eff} and the imaginary part (log($\eta_{i/}$ k_0) for the E^x_{11} - mode (i.e. .E^x_{11} - modes contation the even – and- odd modes) as a function of s with fixed f=40 GHz , respectively. The structure has dimensions a by t_1 =0.32cm, t_2 = 0.5cm, W=0.65cm, $\in_g$ = 2.55 $\in_0$, $\in_f = 2.62 \in_0$, and $\in_a = \in_0$. These figures shows that the n_{eff} for the E^x_{11} -

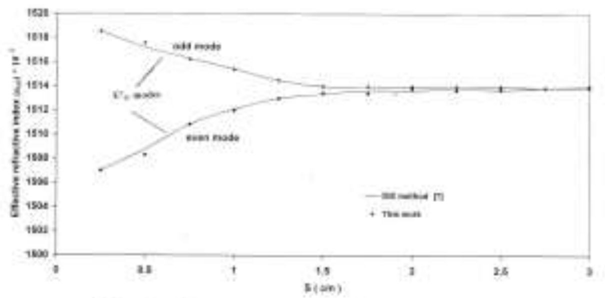

Fig. 4a : The effective refractive index (n_{eff}) for the E^x_{11} modes as a function of S for the two identical strip dielectric guides at f = 40 GHz .

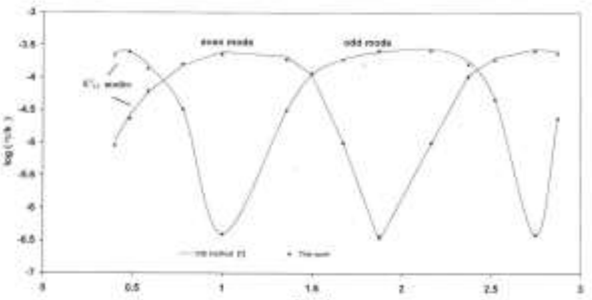

Fig. 4b: The imaginary part of the propagation constant (log (η_i / k_0) for the E^x_{11} modes as a function of S for the two identical strip dielectric guides at f = 40 GHz .

modes of the odd mode and the even mode shows a growing tendency toward being degenerated with separation S increase . Nevertheless, when the separation S is larger, a small oscillatory behavior is consequently viewed . Moreover, the imaginary part of the propagation constant of both the even and the odd modes maximum and minimum behavior respectively . At cartain separation S when the even mode has a maximum leakage , it implies that surface wave modes exited by each waveguide add in phase . For the mode at the same separation S , these surface wave modes add out of phase due to the definition of even and odd modes; hance the cancellation effect is observed as a nall in the imaginary part of propagation constant and also if the odd mode has a maximum leakage at a cantina separation S , the even mode shows a cancellation effect [18], Fig.5(a & b), the propagation constant of the E^x_{12} mode is presented (the nE^Z_{11} and the imaginary part (log(η / k_0) of both the even mode and odd mode , respectively) with fixed f = 38.67 GHz . As seen in figs., the n_{eff} for the E^x_{12} modes minimum and maximum behavior alternatively , but the log (η_i / k_0) for these modes the even mode is maximum behavior and the odd mode is minimum behavior alternatively

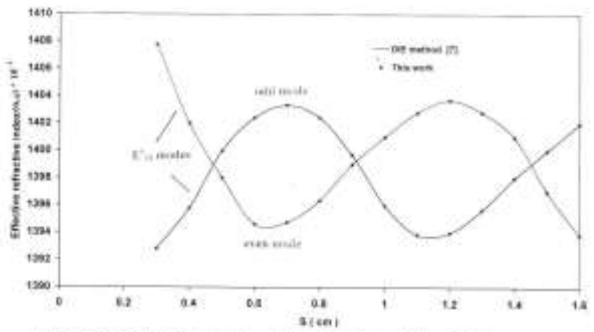

Fig. 5a : The affective refractive index (n_{eff}) for the E^x_{12} modes as afuction of S for the two identical strip dielectric guides at f = 38.67 GHz .

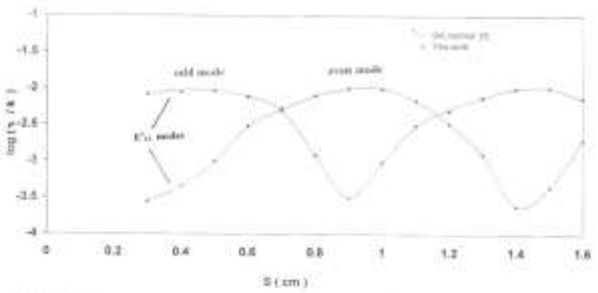

Fig. 5b : The imaginary part of the propagation constant (log (η_i / k)) for the E^x_{12} modes as afunction of S for the two identical strip dielectric guide at f = 38.67 GHz .

The second proposal structure test considered is about two identical insulated image guide for millimeter- wave integrated circuits as shown in Fig. Ib , usually $\in_g > \in_f$ (i.e. because the dielectric constant $\in_f$ is lower than $\in_g$, the structure can be designed so that the fields decay exponentially in the vertical direction in the regin $\in_f$, and the currents in the ground plane become greatly reduced) .

In Fig.6 , we show that the n_{eff} for the E^z_{11} modes $\big(E^Z_{11}$ modes represented the even –and – odd modes $\big)$ versus S for f = 30.23 GHz In this figure, the even – and –odd modes

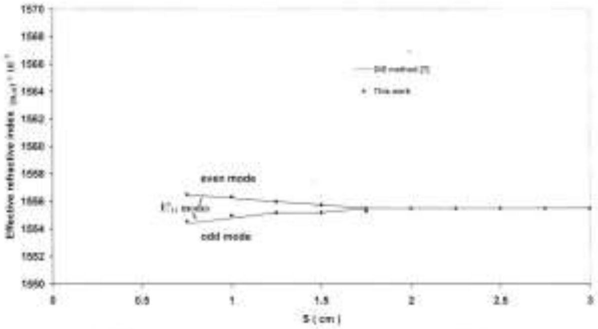

Fig. 6 : The effective refractive index (n_{eff}) for the E^x_{11} modes as a function of S for the two insulated image guides at f = 38.23 GHz

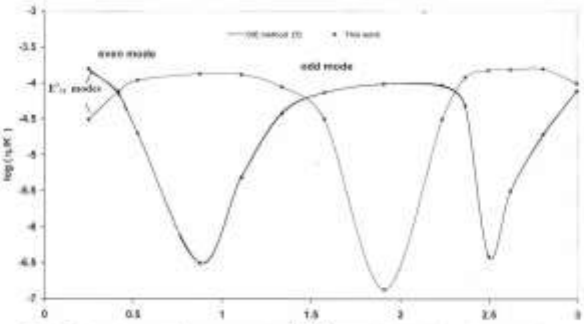

Fig. 7b: The imaginary part of the propagagtion constant (log (η_i/k_0) for the E^x_{11} modes versus S for the two identical insalated image guides at f = 40 GHz

tend to be degenerate when the separation S larger . The results of the n_{eff} and log $\left(\eta_i / k_0\right)$ of the E^x_{11}- mode vesus S with f = 40 GHz is lotted in Fig.7 (a & b) respectively. The guide parameters are the same above the first guide dimensions expect the parameters $\in_g = 2.62 \in_0$ *and* $\in_f = 2.25 \in_0$. In these graph , the n_{eff} for the E^x_{11}- modes tend to be degenerate (i.e. the odd and even modes tend to be decay), and the imaginary part of the propagation constant displays maximum and minimum alternatively . As we can see, the numerical results in this work are in good agreement with our data [7] .

Conclusion:

The effective refractive index n_{eff} and the imaginary part of the propagation constant (log $\left(\eta_i/k_0\right)$) for the TE and TM – like modes proportion of DW structures have been investigated . The numerical analysis was preformed using SCN- TLM method. Results for the properties of the even – and odd modes have been calculated for various dimensions of the structures and have been found to be in good agreement with periously calculated results. Our results are shown to agree with those originally given by demain integral equation technique (DIF) [7] .

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حساب الأنماط الزوجية والفردية ذات TE & TM المنتشرة
في تراكيب دليل الموجة العازلة

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الخلاصة :
تطبيق طريقة شبكية خطوط النقل من نوع (symmetrical condensed node)على تراكيب دليل الموجة العازلة (دليل الموجة العازل ذي الشريطين المتماثلين ودليل الموجة العازل الصوري المتماثلين على التوالي) لحساب انتشار أنماط (TM & TE) وإيجاد خواص الأنماط الفردية والزوجية لتلك التراكيب. النتائج العددية المحسوبة في هذا البحث أعطت نتائج مقبولة مع طرق عددية أخرى .