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RESEARCH ARTICLE

DISPERSION CHARACTERISTICS OF TRAPPED INVERTED MICROSTRIP LINES.

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Abstract

Trapped Inverted microstrip lines are studied for their dispersion characteristics using Galerkin's Technique in Spectral Domain. Basis functions for the unknown strip current are chosen according to the structure of the line. For theoretical analysis, Fourier transform of the basis functions from space domain to spectral domain are considered. The line is analyzed for dispersion characteristics in the X-band corresponding to different values of the side and top wall separations so that limits for separation of the shielding walls may be determined beyond which no effect of shielding is discernable. Again the effect of strip width on the dispersion characteristics is also studied for different values of relative permittivity of the substrate.

Introduction:-

Simple microstrip lines have been analyzed by many authors using Spectral Domain Approach. We have performed earlier detailed analysis for microstrip variants like Inverted microstrip line[1] and Suspended microstrip line[2,5]. Here a detailed investigation is done for Trapped inverted microstrip line, a new variant of microstrip by using SDA (Spectral Domain Approach) and Galerkin's Technique[6]. The main feature of the structure is that the strip conductor is trapped in a narrow rectangular channel, which is cut into the ground plane. The fields are largely confined to the channel region, thereby considerably reducing the coupling to free space above the substrate. The channel serves as a shield and also provides for suppression of any higher order mode, which might otherwise propagate if generated at the discontinuities. This is a very useful structure with low propagation loss and has wide application in modern communication systems. Here mainly effect of shielding, effect of strip width and dispersion characteristics[5] for the given structure are studied.

THEORY:-

The geometry of the structure under investigation is shown in Fig.1.

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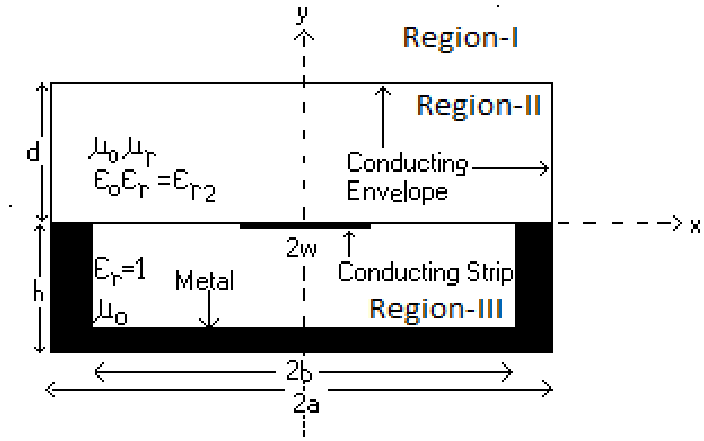

Fig. 1:-

Let us expand the unknown strip currents $J_x(x)$ and $J_z(x)$ in spatial domain in terms of properly chosen basis functions (which must vanish outside the strip) as,

$$J_x(x) = \sum_{n=1}^{M} c_n J_{xn}(x)$$

and

$$J_z(x) = \sum_{n=1}^{N} d_n J_{zn}(x)$$

In spectral domain these are given as,

$$\tilde{J}_x(\hat{k}_n) = \sum_{n=1}^{M} c_n \tilde{J}_{xn}(\hat{k}_n)$$

and

$$\tilde{J}_z(\hat{k}_n) = \sum_{n=1}^{N} d_n \tilde{J}_{zn}(\hat{k}_n)$$

with the Fourier transform defined as

$$\tilde{\phi}(\alpha) = \int_{-\infty}^{\infty} \phi(x) e^{j\alpha x} dx$$

Where, functions $\phi(x)$ and $\tilde{\phi}(\alpha)$ are in space domain and in transform (frequency) domain respectively.

The basis functions considering edge correction chosen by us are,

$$Jxn(x) = \begin{cases} (\mathrm{Sin} 2\pi n x / w) \Big/ \sqrt{(w/2)^2 - x^2}, & |x| \langle w/2 \\ 0 & , \text{otherwise} \end{cases}$$

$$Jzn(x) = \begin{cases} \mathrm{Cos}[2\pi(n-1)x / w] \Big/ \sqrt{(w/2)^2 - x^2}, & |x| \langle w/2 \\ 0 & , \text{otherwise} \end{cases}$$

whose Fourier transforms are obtained as

$$\tilde{J}xn(\hat{k}_n) = \frac{\pi}{2j}[J_0(\hat{k}_n\, w/2 + n\pi) - J_0(\hat{k}_n\, w/2 - n\pi)]$$

$$\tilde{J}zn(\hat{k}_n) = \frac{\pi}{2}[J_0\{\hat{k}_n\, w/2 + (n-1)\pi\} + J_0\{\hat{k}_n\, w/2 - (n-1)\pi\}]$$

With a proper choice of electric and magnetic field expressions in different regions, we use the boundary conditions on the tangential components of electric and magnetic fields at y=h and y=h+d to get all field amplitudes in terms of a single excitation constant.

Then we consider the continuity of the normal components of electric and magnetic fields at y=h and take the inner product of both sides of the resulting equations with respect to $\tilde{J}_{zm}$ and $\tilde{J}_{xm}$ respectively for all values of m (m=1, 2,……….. , N), to get a set of linear equations through application of Parseval's Theorem, as

$$\sum_{n=1}^{M} K_{mn}^{(1,1)} c_n + \sum_{n=1}^{N} K_{mn}^{(1,2)} d_n = 0; m = 1,2,\ldots,N ----(1)$$

$$\sum_{n=1}^{M} K_{mn}^{(2,1)} c_n + \sum_{n=1}^{N} K_{mn}^{(2,2)} d_n = 0; m = 1,2,\ldots,M ----(2)$$

where c_n and d_n are the unknown amplitude coefficients for the n-th current basis functions. These are to be evaluated for complete knowledge of the strip currents and hence to solve for the fields. Since equations (1) and (2) are linearly independent, so for a nontrivial solution set, the determinant of the coefficient matrix should be set equal to zero i.e.

$$\Delta = \begin{vmatrix} \sum_{n=1}^{M} K_{mn}^{(1,1)} & \sum_{n=1}^{N} K_{mn}^{(1,2)} \\ \sum_{n=1}^{M} K_{mn}^{(2,1)} & \sum_{n=1}^{N} K_{mn}^{(2,2)} \end{vmatrix} = 0 --- (3)$$

where

$$K_{mn}^{(1,1)} = \sum_{\hat{k}_n=-\infty}^{+\infty} \tilde{J}_{zm}(\hat{k}_n)\tilde{G}_{11}(\hat{k}_n,\beta)\tilde{J}_{xn}(\hat{k}_n) \quad \text{------------------- (4a)}$$

$$K_{mn}^{(1,2)} = \sum_{\hat{k}_n=-\infty}^{+\infty} \tilde{J}_{zm}(\hat{k}_n)\tilde{G}_{12}(\hat{k}_n,\beta)\tilde{J}_{zn}(\hat{k}_n) \quad \text{------------------- (4b)}$$

$$K_{mn}^{(2,1)} = \sum_{\hat{k}_n=-\infty}^{+\infty} \tilde{J}_{xm}(\hat{k}_n)\tilde{G}_{21}(\hat{k}_n,\beta)\tilde{J}_{xn}(\hat{k}_n) \quad \text{------------------- (4c)}$$

$$K_{mn}^{(2,2)} = \sum_{\hat{k}_n=-\infty}^{+\infty} \tilde{J}_{xm}(\hat{k}_n)\tilde{G}_{22}(\hat{k}_n,\beta)\tilde{J}_{zn}(\hat{k}_n) \quad \text{------------------- (4d)}$$

and $\tilde{G}_{11}(\hat{k}_n,\beta)$, $\tilde{G}_{12}(\hat{k}_n,\beta)$, $\tilde{G}_{21}(\hat{k}_n,\beta)$, $\tilde{G}_{22}(\hat{k}_n,\beta)$ are corresponding spectral domain Green's functions.

Equation (3) forms the characteristic equation for the system solving which we get the propagation constant[4] and there from the unknown current and fields. Variations in effective dielectric constant with frequency over the X-band are studied for different values of substrate permittivity. Results indicate a saturating trend with frequency after an initial rise for all cases. We also studied the dependence of effective permittivity with strip thickness for a particular dielectric substrate.

Results:-

Computations are performed based on the above analysis for values of w=3.17mm, d=3.04mm, b=a/2.
Initially the variations of effective permittivity as function of a/w with constant 'h' and again as function of h/w with constant 'a' are studied as presented hereafter.

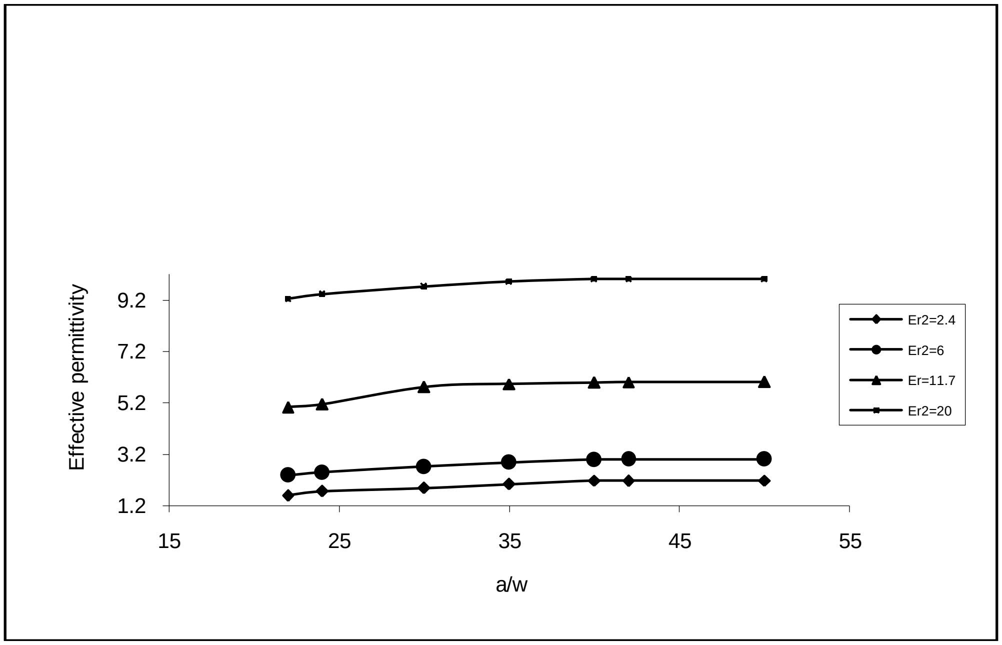

Fig. 2:- Variation of effective permittivity as a function of a/w for h=7.12mm at 10GHz.

It can be seen that for a/w ~ 40 or above effective permittivity is invariant with a/w for a set of values of relative permittivity of the substrate over the range 2.4 through 20.

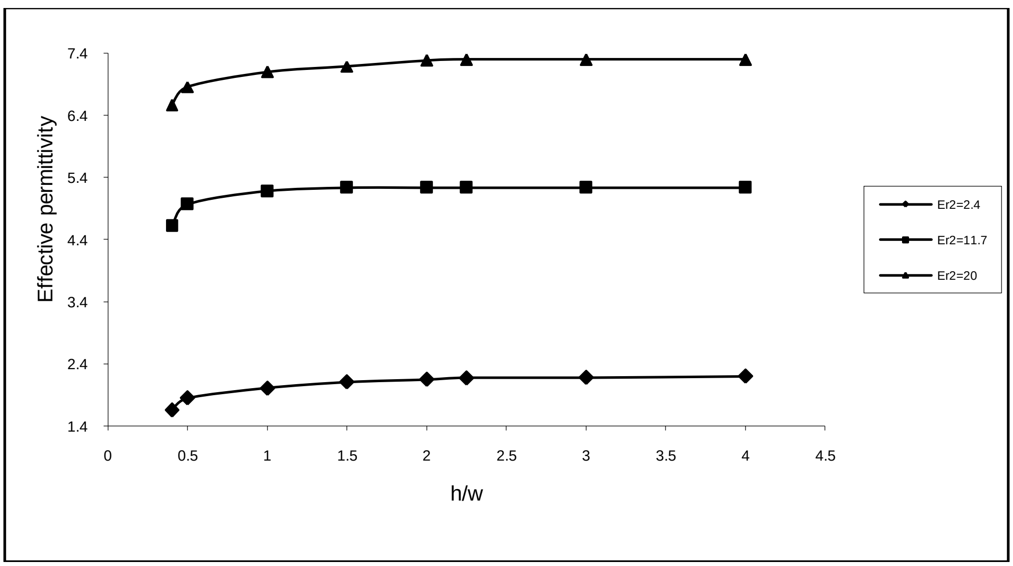

Fig. 3:- Variation of effective permittivity as a function of h/w for a/w =40 at 10GHz.

It is observed that the effective permittivity is almost invariant with h/w for the same set of dielectrics considered. Saturation is obtained for h/w $\geq$ 2 for all curves shown in Fig.3.

Results for dispersion characteristics are given below for different relative permittivity values of the substrate and for different strip width with a=40w, b=a/2, h=2.25w, substrate thickness d=3.04mm.

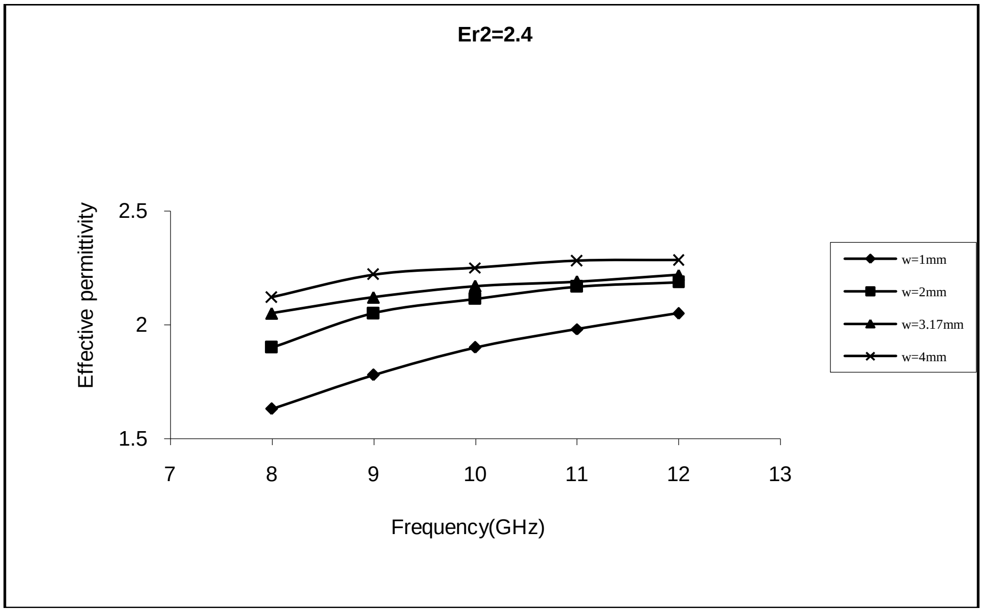

Fig. 4:- Variation of effective permittivity as a function of frequency for different strip width for relative permittivity ε_{r2}=2.4.

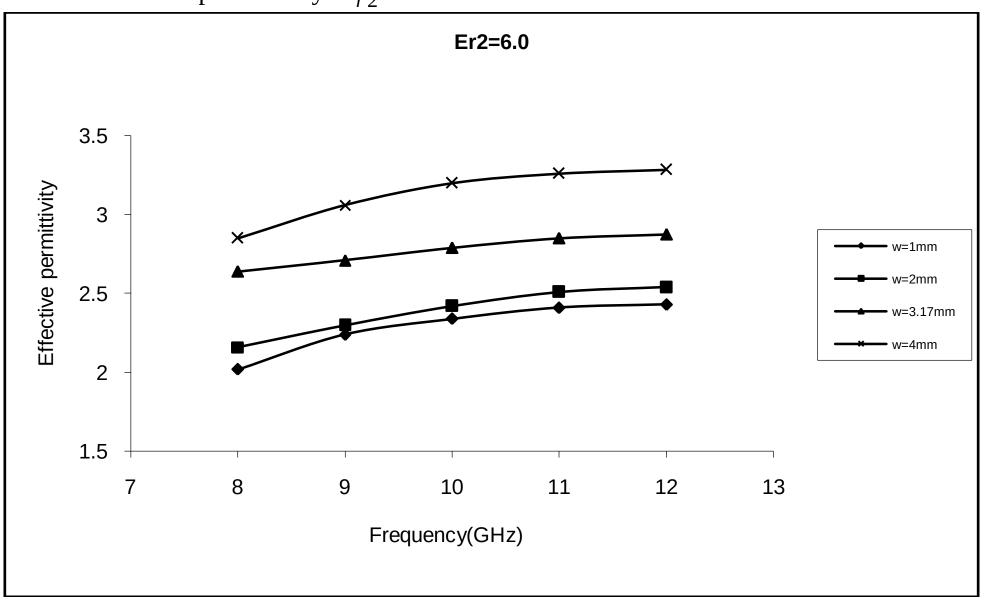

Fig. 5:- Variation of effective permittivity as a function of frequency for different strip width for relative permittivity ε_{r2}=6.0.

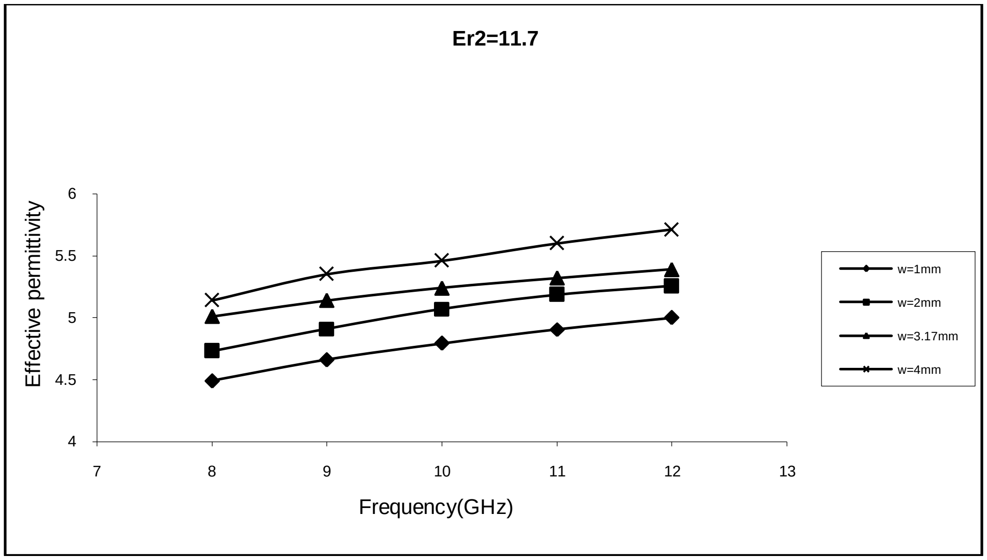

Fig.6

Fig.6 : Variation of effective permittivity as a function of frequency for different strip width for relative permittivity ε_{r2} =11.7.

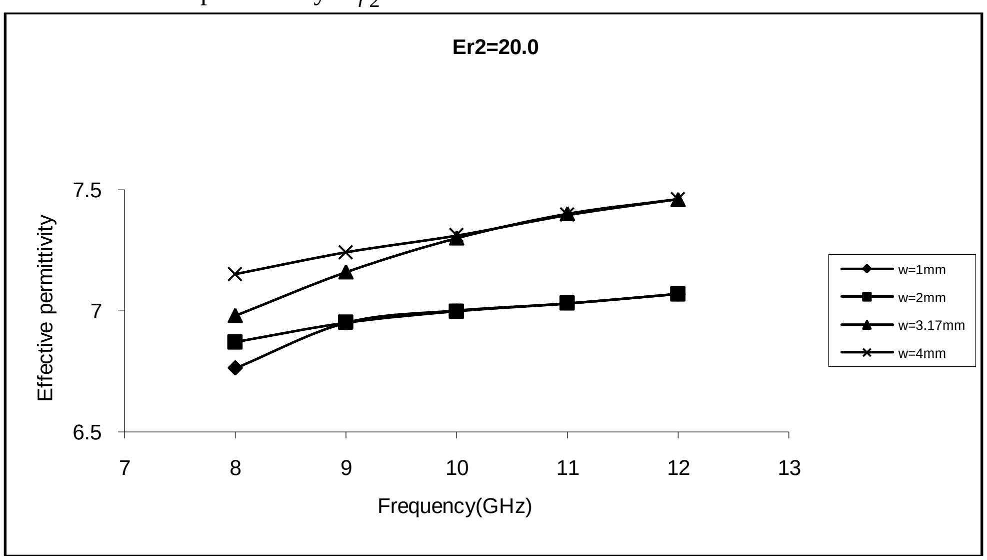

Fig.7

Fig. 7:- Variation of effective permittivity as a function of frequency for different strip width for relative permittivity ε_{r2} =20.0.

Each of the above figures shows similar saturating tendency of the dispersion characteristics.

Conclusion:-

It may be concluded from the results that for a wide range of values of relative permittivity (2.4 to 20.0) of the substrate, the dispersion characteristics for trapped inverted microstrip line show the same tendency of convergence for different values of line width with same dimensions of the structure. For each case it is also observed that the dispersion characteristics are almost saturated after 10GHz.

Such detailed dispersion analysis for this structure has not been reported before as per our knowledge. From that point of view this is a unique work. Results obtained are significant in respect of radar and communication systems since trapped inverted microstrip lines form a very useful category of transmission structures from mid microwave to the millimeter wave region of spectrum. Especially in view of the low losses and good EMI rejection since the structure is well protected by metal enclosure, these lines should find widespread application. Their dispersion analysis, as presented in this paper, should thus be very helpful to microwave engineers who would like to make use of the trapped inverted microstrip transmission lines.

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