RIGOROUS ANALYSIS OF A LONGITUDINAL STRIP ON THE SURFACE OF INSET DIELECTRIC GUIDE.

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ABSTRACT.

This contribution rigorously determines the equivalent circuits of longitudinal strips of finite width on the air-dielectric interface of an Inset Dielectric Guide,(I.D.G.).

These are used to design an array of dipoles forming a longitudinally polarised linear antenna,that is theoretically consistent with the properties of microstrip-loaded I.D.G.

1:INTRODUCTION.

The Inset Dielectric Guide, (I.D.G.), possesses all the manufacturing advantages of dielectric waveguides at frequencies above 40GHz, whilst retaining excellent confinement of the E.M. fields. In addition, the air-dielectric interface provides an ideal location for the introduction of radiating discontinuities, allowing the formation of leaky wave antennas.These leaky wave antennas promise the development of electrically steerable linear and planer arrays, that are, lightweight, compact and exhibit good beamwidths and polarisation. The propagation characteristics of the I.D.G. have been analysed ,[1], demonstrating that the fields closely approximate to L.S.E.,when the slot is deep, and to L.S.M. polarisation when the slot is shallow. Transverse metallic strips have been sucessfully used, [2], as the radiating elements for the L.S.E. polarised I.D.G. With the L.S.M. polarised I.D.G., longitudinal metallic strips produce longitudinally polarised antennas.See fig. 1.

Utilising an analysis of the 'microstrip loaded' I.D.G., (M.L.I.D.G.), an antenna array of discrete longitudinal strips has previously been considered as a cascade of sections of I.D.G. and M.L.I.D.G., [3]. This analysis highlights the compatibility of this structure with a simple microstrip feed network.

The present contribution rigorously analyses a discrete longitudinal strip using a variational approach.This is an improvement upon the previous work as it includes the effects of the ends of the strip, and does not assume monomode propagation.The analysis determines the equivalent π network, S-parameters and far field characteristics of a discrete strip which has subsequently been used for the accurate design of antenna arrays.

2: METHOD OF ANALYSIS.

Following the approach of Schwinger, [4], the structure is considered under odd and even surface mode excitation seperately, yielding the odd and even reflection coefficients from which the Y- and S-parameters of the network may be derived.

A Green's function approach has been adopted, based upon the complete mode spectrum of the L.S.M. polarised I.D.G.. This allows the formulation, on the metal of the I.D.G. and on the strip, of the following integral equation;

$$\hat{n}(\underline{r})\times\bar{E}_i(\underline{r}) + \hat{n}(\underline{r})\times\bar{E}_s(\underline{r}) = 0 \tag{1}$$

This integral equation has been solved by two methods;

i) The Rayleigh-Ritz method, using a single term expansion that intrinsically models the expected current in terms of edge behaviour and phase distribution, for each of the strip and the metal-air interface, (M.A.I.), currents.

ii) The Galerkin's method using a simple multiple term current expansion with a basis set that allows the analytical evaluation of the final expressions to be carried futher, without attempting to completely model the the edge behaviour and phase distribution.

2.1:Rayleigh-Ritz Method.

Consider even excitation of the form $\Phi_1(x,y)2cos(\beta_1 z)$, where $\Phi_1(x,y)$ and β_1 are the transverse mode vector and the phase constant of the incident surface mode. Application of the Rayleigh-Ritz method to the integral equation allows the following variational expression for R_{even} to be derived, where only the dominant current, J_z, and electric field, E_z, have been considered. Note that J_{zs} and J_{zm} represent the currents on the strip and the M.A.I. of the I.D.G.. respectively.

$$R_{even}\, e^{+j\beta_1 L} = \tag{2}$$

$$1 - \frac{1}{4\beta_1}\left(\frac{< \Phi_{1z}(x,y)\, 2cos(\beta_1 z), J_{zs}(\underline{r}) >^2}{< J_{zs}(\underline{r}), G_e^{zz}(\underline{r} \mid \underline{r}'), J_{zs}(\underline{r}') > - \dfrac{< J_{zm}(\underline{r}), G_e^{zz}(\underline{r} \mid \underline{r}'), J_{zs}(\underline{r}') >^2}{< J_{zm}(\underline{r}), G_e^{zz}(\underline{r} \mid \underline{r}'), J_{zm}(\underline{r}') >}} \right)$$

An appropriate expression for the strip current that models the expected edge behaviour of the current, J_{zs}, whilst maintaining the square integrability required by the Rayleigh-Ritz method, is;

$$J_{zs}(\underline{r}) = \left(1 - (\frac{2z}{L})^2\right)^{\frac{2}{3}} \left(1 - (\frac{2x}{w})^2\right)^{-\frac{1}{3}} \delta(y)\, cos(\beta_1 z) \tag{3}$$

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The amplitude terms have been taken from reference [5]. The $\cos(\beta_1 z)$ term models the phase distribution along the strip, where the surface mode phase constant of both the I.D.G. and the M.L.I.D.G. have been tried for β_1. It is found in practice that the overall results are very insensitive to the distribution assumed for the M.A.I. current, and hence, the following has been used;

$$J_{zm}(\underline{r})_{even} = \delta(y)\left(1-\left(\frac{2z}{L}\right)^2\right)^{\frac{2}{3}}\left(\left(|x|-\frac{a}{2}\right)^{-\frac{1}{3}}\cos(\beta_1 z)\right) \qquad (4)$$

This approximation is computationally advantageous as it does not require a further messy numerical integration to be evaluated.

The numerical complexity of the single term Rayleigh-Ritz approach suggests that a simple multiple term Galerkin's analysis may prove more successful, and indeed this is the case.

2.2:Galerkin's method.

The conventional application of Galerkin's method to equation (1) allows J_z to be determined and hence R(even). The z-dependence is now expanded by simple sine and cosine terms, as follows;

$$J_{zs} = \sum_{n=1,3,5..}^{N} A_n \left(1-\left(\frac{2x}{w}\right)^2\right)^{-\frac{1}{3}} \delta(y)\cos\left(\frac{n\pi z}{L}\right) \qquad (5)$$

Similarly the M.A.I. current has been expanded as ;

$$J_{zm} = \sum_{n=1,3,5...}^{N} B_n \left(|x|-\frac{a}{2}\right)^{-\frac{1}{3}} \delta(y)\cos\left(\frac{n\pi z}{2.3L}\right) \qquad (6)$$

where the z-dependence has been truncated to a finite length, (2.3L), an approximation vindicated by the current distributions that are finally obtained.

3:FAR FIELD ANALYSIS.

The accurate current distributions derived from the Galerkin's analysis allows the far field characteristics to be determined using saddle point integration techniques.

4:RESULTS.

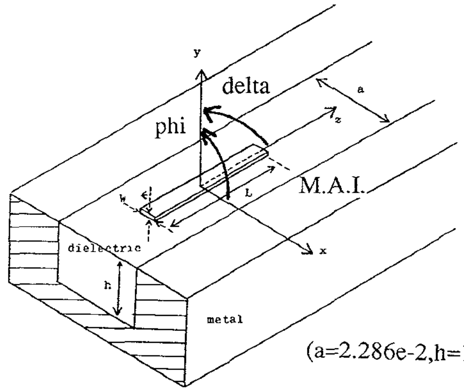
The graphs, figs [2-10] below, show the theoretical parameters that have been derived for a single longitudinal strip using both of the above methods. Both the width and the length of the strip have been varied, as has the phase constant used in the Rayleigh-Ritz current expansion. The polar plots show the dominant electric field component in the far field for a theoretical 20 element linear array.

Figs. [2-8] show the variation with strip length of the Y- and S-parameters, for a 2mm wide strip, using the Galerkin's method and the Rayleigh-Ritz method with both approximations for the current phase.

It is clear,from the periodic nature of |S11|, fig. [6], that as the length of the strip increases the Galerkin's method has been more successful than the single term Rayleigh-Ritz method. As expected the use of the M.L.I.D.G phase constant for the Rayleigh-Ritz current approximation gives some improvement.Considering the more accurate results of the Galerkin's analysis,the following is observed.

i) The phase shift of S21,fig. [7], is 2π radians when the strip is 20.5mm long. As expected,due to the capacitive nature of the ends of the strip, this is slightly shorter than the fundamental wavelength of the M.L.I.D.G.(22.0mm).

1. Radiating Strip on an L.S.M polarised I.D.G.



(a=2.286e-2,h=1.016e-2,

relative permitivity=2.08,

Figure 2. Y11 (real) vrs L/mm

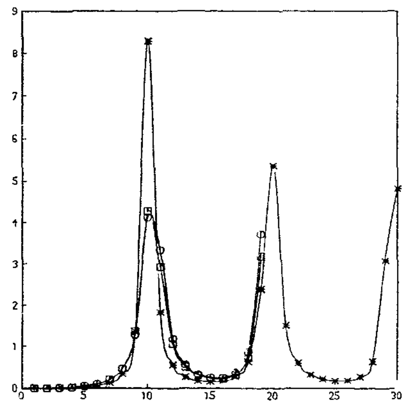
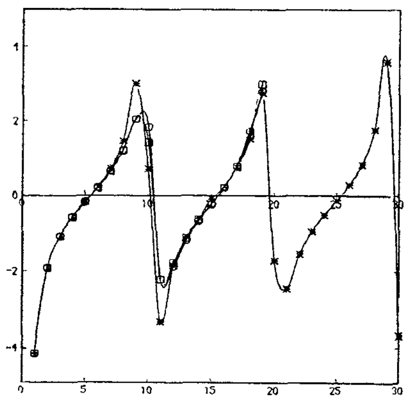


Figure 3. Y11 (imag) vrs L/mm



Galerkin's.

Rayleigh-Ritz(current phase constant=beta1 of I.D.G.)

Rayleigh-Ritz(current phase constant=beta1 of M.L.I.D.G.)

ii) Fig. [8] shows that as the strip length increases the radiated power levels off and starts decreasing,consistent with the non radiating nature of the surface modes of the M.L.I.D.G. and coupling of the continuum modes back into the surface modes.

iii) It is found that,whilst small w.r.t the width of the I.D.G., the width of the strip has a relatively minor effect on the circuit parameters.

iv) The accurate current distributions obtained from the Galerkin's analysis confirm the inaccuracy of the Rayleigh-Ritz current approximations as the strip length increases.The relative amplitudes of the strip and M.A.I. currents confirm the minor role of the latter and its decay with distance from the end of the strip.

v) The radiation patterns demonstrate the good beamwidths of the dominant radiated electric field, E (delta).

Experimental confirmation of these results is now being undertaken.

5:ARRAY DESIGN.

The parameters derived above have initially been used to design a simple linear array. Strips of length 12.0mm are chosen to minimise the array reflection coefficient,spaced by 15.2mm of I.D.G. to give an electrical displacement of 2π radians.Neglecting higher order mode interaction, a 20 element array theoretically radiates 96% of the power with a reflection coefficient of -15.4dB.The radiation pattern, figs (15,16),has a sidelobe 13.2dB down on the main lobe. This array is presently under construction.

6:CONCLUSION.

It has been demonstrated that the longitudinal strip may be successfully analysed using the Galerkin's method, yielding both the circuit parameters and radiation characteristics essential for the accurate synthesis of antenna arrays.

7:REFERENCES.

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2) T.Rozzi, R.De leo, L.Ma and A.Morini , "Equivalent network of transverse dipoles on Inset Dielectric Guide:Application to linear arrays." , To appear in IEEE Trans. Antennas and Propagation , 1989.

3) T.Rozzi, R.De Leo and A.Morini , "Analysis of the 'Microstrip-Loaded Inset Dielectric Waveguide' " , IEEE MTT-S digest 1989, pp923-26.

4) J.Schwinger and Saxon , "Discontinuities in Waveguides" , Gordon and Breach , 1968.

5) R.E. Collin "Field Theory of guided Waves" , McGraw-Hill , New York , 1964.

Figure 4. Y12 (real) vrs L/mm

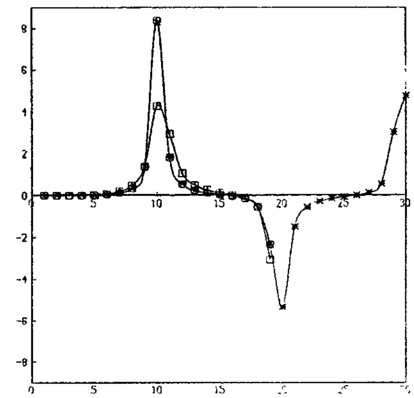


Figure 5. Y12 (imag) vrs L/mm

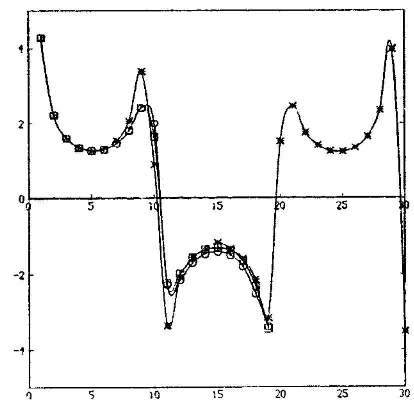


Figure 6. |S11| vrs L/mm

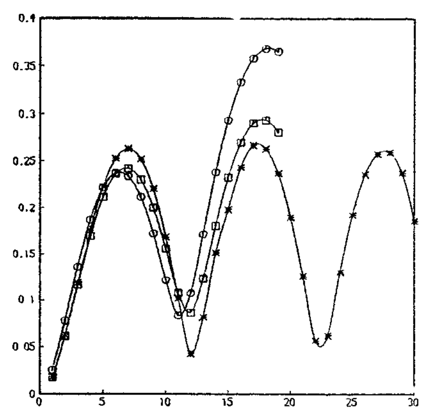


Figure 7. arg S21 vrs L/mm

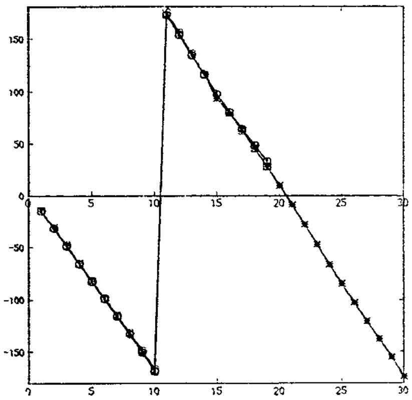


Figure 8. Power loss vrs L/mm

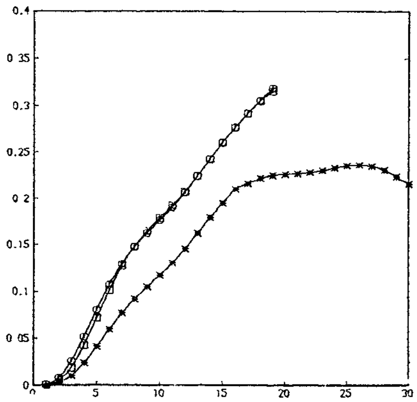
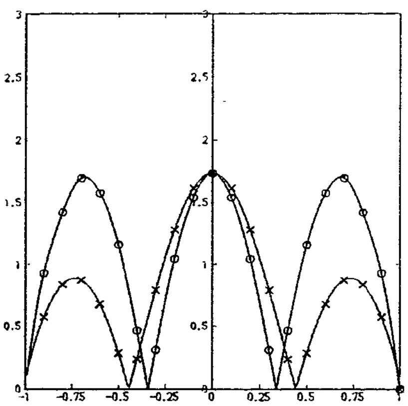
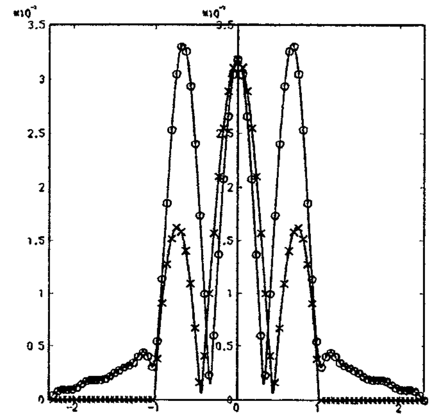


Figure 9. |Jzs(z)| even,L=30mm



Length,norm'ed to strip length.

Figure 10. |Jzm(z)| even,L=30mm



Length,norm'ed to strip length.

Figure 11. E(delta) vrs phi

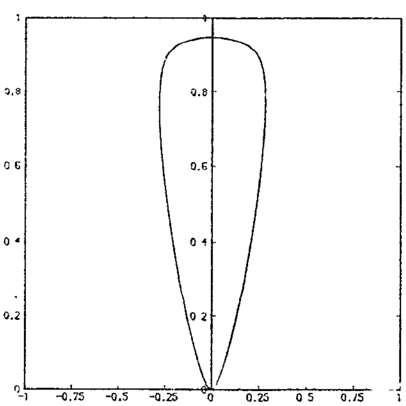


Figure 12. E(delta) vrs delta