AN EFFICIENT MODE LAUNCHER FOR ARRAYS OF LONGITUDINAL DIPOLES IN IDG

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ABSTRACT

IDG (Inset Dielectric Guide) has proved an excellent antenna medium featuring pure polarization, broadband matching and high efficiency. Antenna characteristics, however, are affected by the feeding system. We present a new effective feed arrangement suitable for application to multiple arrays in IDG.

INTRODUCTION

Increasing attention has been paid to developing new classes of low profile substrate-based planar antennas that can be flush-mounted on vehicles and missiles and can possibly allow some degree of circuit integration together with additional means of electronic scanning by semiconductor implant or frequency sweeping.

Efforts are being made to devise new fabrication methods leading to further miniaturization, integration and cost saving.

Recently, some elaborate approaches employing dielectric guide configurations loaded by metal disks or strips were reported for millimeter wave applications (1)-(2).

IDG, an alternative of image line, is just a rectangular groove filled with dielectric as shown in Fig.1. As a transmission line. it has demonstrated some excellent advantages, namely ease of manufacture, low cost, lightweight and low loss. Standard grooves are easy to cast on a metal sheet or they can be realized in a plastic mould, that can be subsequently spray-metallized. Low melting point dielectric can be poured in the groove in liquid form, which is sufficient for many applications. The measured loss of the HE_{01} mode supporting guide is 0.353 dB/m at 10 GHz and Q-factor is 2929.4 (3).

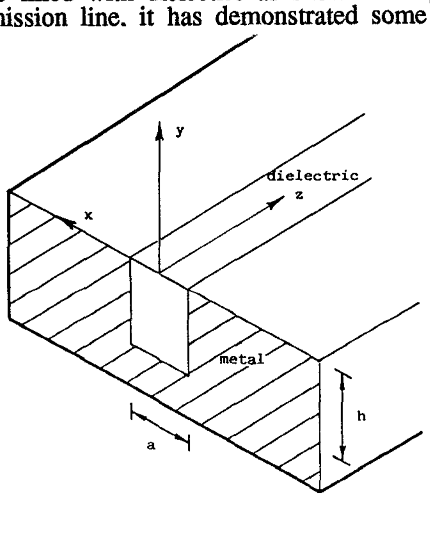

Fig.1 Cross-section of IDG.

It is easy to lay thin metal strips on the air dielectric interface that act as dipole radiators to form integrated leaky wave arrays. Theoretical analysis and experimental results have shown that IDG seems to offer particular promise for antenna applications, featuring pure polarization, high efficiency, low mutual coupling and physical compatibility with conventional waveguide or coaxial feeds (4)-(6).

FEEDING ARRANGEMENT

There are two useful manners of single mode operation in IDG. The first one is to operate in the H_{01} mode in a relatively deep slot. The second manner is in the E_{11} mode in a shallow, broad slot. As electric field lines must begin and terminate perpendicularly to metallic walls, the presence of the 90^o-edges in the inset guide implies that the modes are essentially hybrid, i.e. with six field components. Normally, however, either a narrow slot or a broad slot configuration is used. It is then quite accurate to use just the LSE and LSM families with only five components, as shown in Fig.2. The field distribution for the deep slot (H_{01} mode) and shallow slot (LSM mode) are plotted as the magnitude over the transverse guide cross section in Figs.3 and 4. Corresponding to these two modes, there are two kinds of arrays can be realized on IDG. The array composed of transverse strips on the top of a deep slot offers a vertically polarized pattern (6). In a shallow slot the main component of the electric field is z-directed and its maximum is at the center of the interface, where the electric field in the transverse direction vanishes. Therefore, when a longitudinal strip is located at the center of the guide, it acts as a z-directed dipole radiator, so that a horizontally polarized array can be formed by a series of strips, as shown in Fig.5. This kind of arrays are particularly desirable for marine radar antennas.

A commonly existing problem with the arrays formed on open structures is that the radiation from the mode launcher affects the far field pattern in varying degrees. Therefore, finding an efficient way to excite the guide becomes a very important factor in the realization of a practical array. In a deep slot the field distribution is very similar to that in one half of a conventional

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rectangular waveguide, operating in its lowest H_{10} mode. Therefore a waveguide with a dielectric taper can be used to feed the line directly. But in a shallow slot the fundamental mode is neither TE nor TM. If it is connected directly with a rectangular waveguide the discontinuity introduced by the junction will be strong and cause radiation which affects the radiation pattern seriously. For a linear array a coaxial line-IDG transducer has proven an excellent efficient mode launcher (5). But for two-dimensional arrays, coaxial line power dividers could be complicated electrically and structurally. The mode launcher presented in this paper is very suitable for multiple arrays. It is very simple, but turns out to be excellent. The IDG is fed by a rectangular waveguide, crossing the IDG at 90° below the plane of the slot. A circular hole, of diameter d, is opened at the interface. At the center of the hole a pin is located, whose length is l. The pin projects into the IDG and the waveguide in order to tune the hole and enhance the coupling, as shown in Fig.6. By varying d, l and p, the amount of the coupling can be controlled easily and effectively.

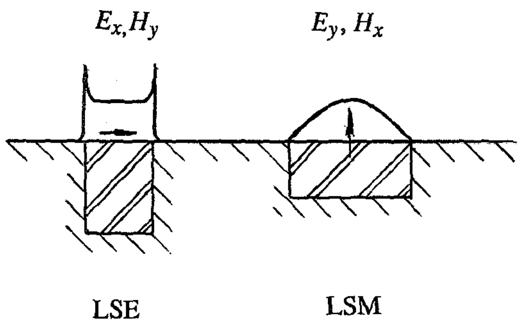

Fig.2 Two families of modes for narrow and broad slots.

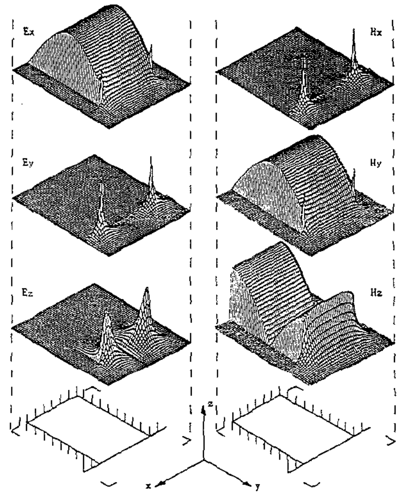

Fig.3 Field distribution of the fundamental HE_{01} mode.

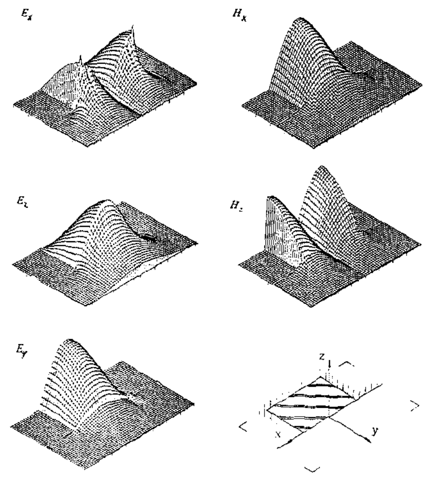

Fig.4 Field distribution of the fundamental LSM mode.

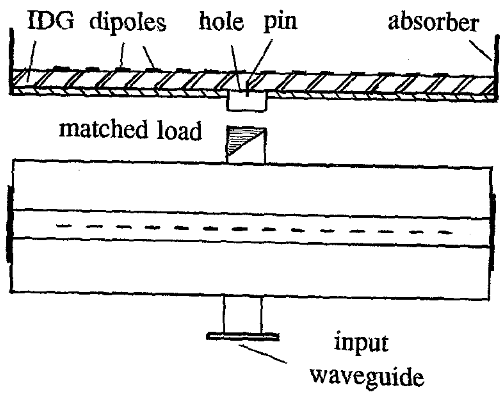

Fig.5 Geometry of a 14-element linear array on IDG.

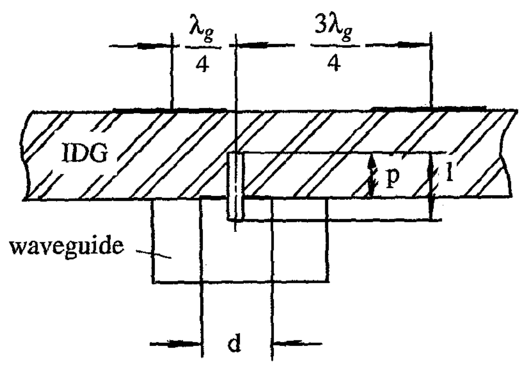

Fig.6 Cross section of the mode launcher.

COUPLING MECHANISM

In any wave-guiding structure, the field must be generated or excited by a suitable source. In a cylindrical guide the field is generally excited by means of an antenna (probe or loop type), which in turn is driven by a generator. Coupling of fields from one guide to another may be accomplished by means of small antennas, but is also achieved by means of small radiating apertures located at appropriate positions in the common wall separating the two guides. The criterion in choosing the type of the coupler, the position and the dimension of the probe or aperture is that the excited field satisfying the boundary condition be similar to the field of the fundamental mode. In our case a probe and an aperture are combined. According to Love's field equivalence principle, the total field in the IDG may be found from an equivalent magnetic current

$$J_m = -n \times E_a$$

located in the aperture of the hole s_a and an equivalent electric current

$$J = n \times H_p$$

located on the surface of the probe s_p, where E_a and H_p are the total tangential fields in the aperture and probe. Unfortunately, these fields are unknown, but if the the hole is small and the pin does not project too deeply into the waveguide, we may assume that the higher-order waveguide modes which are excited are negligible. The fields will then be associated with the incident and reflected H_{10} modes in the rectangular waveguide. The scattered electric field E_s from the hole may be expanded in terms of the normal IDG modes as

$$E_s = \sum_n c_n \, e_n$$

while each normal mode function e_n is a solution of the source free equations. By applying the Lorents reciprocity principle (or Bethe's small aperture approximation) we find the expansion coefficients

$$c_n = \frac{1}{P_n} \iint_{s_a} h_n \cdot J_m \, ds = \frac{d^3}{3} \frac{\omega \mu_0}{\beta} \cdot \sin \frac{\pi x}{a} \cdot h_n^{IDG}(x') \qquad (1)$$

where x denotes the x coordinate in the waveguide system, x' that in the IDG system. Similarly, the scattered field from the probe is

$$E_s = \sum_n c_n \cdot e_n$$

where

$$c_n = -\frac{1}{P_n} \iint_{s_p} e_n \cdot J \, ds = \frac{4\,l}{\pi} \frac{\omega \mu_0}{\beta} \cdot e_n^{IDG}(x') \cdot e_n^{wg}(x) \qquad (2)$$

under the assumption $J \propto \sin \frac{\pi y}{l}$. Eqs.(1) and (2) show that for a fixed frequency, the coupling is proportional to d^3 and l as well as being influenced by the position of the hole.

LINEAR ARRAY: EXPERIMENTAL RESULTS

A 14-element linear array (11 λ_0 long) was built and tested at X-band to verify the performance of the launcher. The feed point was set at the center of the array, which reduced the full length of the array and made the current distribution and the structure symmetrical. The diameter of the hole and the length of the pin were both chosen as 7mm, with the pin projecting by 5mm into the IDG. To get a stronger coupling the distances between the pin and its adjacent elements were set to be $\lambda_g/4$ and $3\lambda_g/4$, respectively. In order to compensate for the phase shift of each strip, the length of the strips was chosen to be 11 mm, and the spacing between two adjacent elements was 13 mm, i.e. half a guided wavelength. The ends of the array were loaded with absorbing material. Far field measurements were carried out in a full-size chamber. The pattern shown in Fig.7 indicates that the performance of this antenna is excellent. Even with such a small array the beamwidth is only of 6 degrees and the sidelobe level is -17.5 dB lower than the main lobe. Reflection coefficient was measured by means of a Hewlett Packard network analyzer. The match is very good over the whole X-band as shown in Fig.8.

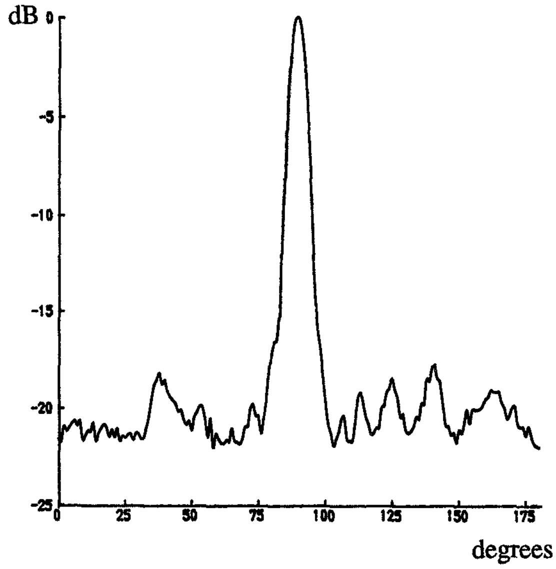

Fig.7 Far field pattern of the array of Fig.5.

S_{11} Log Mag

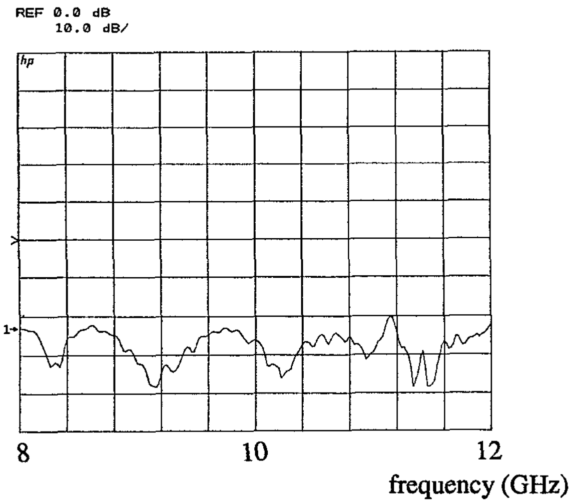

Fig.8 S_{11} of the array of Fig.5.

TWO DIMENSIONAL ARRAYS

An important feature of the *IDG* antenna is the virtual decoupling of the near field between parallel arrays. Coupling via surface waves on the substrate, which is a real problem in microstrip and image line antennas, is prevented here by the metal sidewalls of the guide. Therefore the *IDG* configuration with our new feeding system is ideally suited to the realization of two-dimensional arrays. The parallel arrays can be excited by a series of holes and pins as shown in Fig.4. There are different ways of realizing a tapered distribution. We can either feed the waveguide at its center and use the same size of holes and pins for all the lines or feed the guide from one end and vary the sizes of the holes and the pins. A K_a-band two-dimensional array has been designed and further work is in progress.

In conclusion, owing to the natural transition of the field from the waveguide to the IDG, the mode launcher introduced in this paper radiates very little power into space directly, which ensures that the radiation pattern almost entirely depends on the distribution of the elements. The simplicity of the arrangement and its flexibility in the control of the coupling makes this new feeding system very suitable for application to two-dimensional arrays.

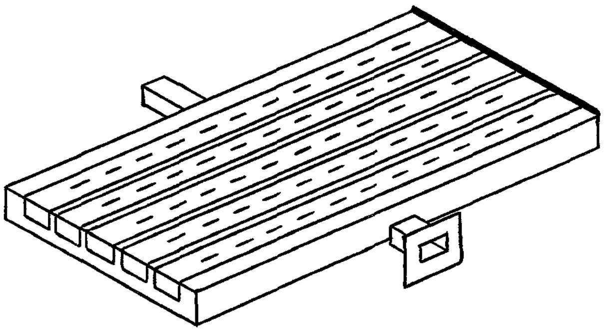

Fig.9 Geometry of a two-dimensional array and its feeding system.

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