STUDY OF A NOVEL PLANAR TRANSMISSION LINE

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ABSTRACT

A new type of monolithic planar transmission line is proposed. This line can operate without the need for via-holes or the use of air-bridges for ground equalization. Furthermore, it has shown the tendency to radiate less than the conventional microstrip or coplanar waveguide (CPW) and can provide a wide range of impedances due to the many available parameters for design. The space domain integral equation method is used to analyze four different discontinuities of the proposed type. A comparison to conventional CPW with respect to radiation shows very good performance.

1 INTRODUCTION

The first planar transmission line, the stripline, was introduced almost forty years ago and created the basis of a new and revolutionary hybrid technology. Since then, the hybrid technology has evolved to the monolithic one drastically increasing operating frequencies and consequently reducing weight and volume. In conventional planar transmission lines the power is propagated by creating an RF voltage difference between two planar conductors printed on the same (coplanar waveguides, coplanar strips) or opposite surfaces (stripline, microstrip, coupled strips) of a dielectric slab structure. In most cases, the geometry of the conventional lines permitted great design flexibility, tremendous reduction of the space occupied by the circuit, and realization of very large scale, very high frequency applications.

The planarization of the conductors in the above transmission lines provided the capability of integration but also generated fringing in the electromagnetic fields, led to unwanted mechanisms such as radiation and dispersion, and enhanced ohmic losses and electromagnetic coupling. These mechanisms are frequency dependent and impose serious limitations as we approach the submillimeter frequency range. The ability to find new geometries [1-4] which reduce or eliminate the above loss or coupling mechanisms but do not affect the monolithic character of the line will extend the operating frequencies long into the Terahertz region and will improve circuit performance in existing applications.

As a common practice, elimination of radiation losses and reduction of electromagnetic coupling has been achieved by enclosing the planar circuits in shielding cavities. In most cases, the cavities have to be placed away from the circuit to avoid proximity effects, thus introducing cavity resonances which interfere with the circuits electrical performance. While shielding is possible in many circuit applications, in monolithic arrays where the enviroment has to remain open, radiation from the feeding structure and parasitic coupling to the radiating elements has been a major issue.

This paper presents the **microshield line** (Fig.1), a new type of monolithic line appropriate for circuit or array applications. These lines may be considered as an evolution of the conventional microstrip or coplanar structure and are characterized by reduced radiation loss and electromagnetic interference. In this configuration, the ground plane has been deformed from its original planar form to totally or partially surround the inner conductor which still has the form of a printed strip. Such a structure can be made monolithically using etching and metal deposition techniques. Furthermore, the inner conductor can be suspended in air (see Figs.1a,1b) by using membrane technology [5]. This eliminates dielectric losses which could be high at millimeter-wave frequencies. Membranes have been effectively employed to provide high-efficiency monolithic antennas and arrays operating at frequencies as high as 2.5 THz [6]. The optimization of membrane technology on silicon substrates has been completed. At the present time we are working towards achieving the same goals with GaAs compounds.

One of the advantages of the microshield line, in comparison with the more conventional ones such as the microstrip or the coplanar waveguide, is the ability to operate without the need for via-holes or the use of air-bridges for ground equalization. Furthermore, due to the many available parameters in design, a wide range of impedances may be achieved. Specifically, by varying the size of the shielding waveguide (see Fig.1) the per unit length capacitance of the line can increase or decrease from the value of the corresponding microstrip or coplanar waveguide resulting in lower or higher values of the characteristic impedance.

In the line of Fig.1b the ground plane totally surrounds the circuits and prevents radiation in any form. In addition, the electrically small separation between the two conductors, widens considerably the single mode frequency band and assures dispersionless characteristics and no electromagnetic coupling over that frequency range. The lines of Figs.1a and 1c are partially shielded by the ground plane and, thus, could radiate in the upper half space. However, the excited mode is similar to the coplanar mode in conventional coplanar waveguides and as it has been found in [7, 8], appropriate design can reduce radiation to very low levels. One loss mechanism still pertaining in this novel structure is conductor loss. Due to the geometry of the ground plane,

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the level of the conductor losses is expected to be slightly higher than microstrip losses and lower than conventional CPW losses.

To provide an indication of the tendency of the microshield line to radiate less, several three-dimensional discontinuities are analyzed and their response is compared to the same discontinuity geometries in conventional coplanar waveguide form. Specifically, a microshield open-end, short-end, and coupled open- and short-ends are studied. In all cases, the microshield discontinuities show much lower radiation than the conventional CPW ones. A similar study will be presented on series and shunt stubs and the electrical response of the stubs will be compared to conventional CPW stubs with and without air-bridges. Furthermore, the study will be completed with propagation constant and characteristic impedance evaluations. Even if the applied theoretical method has been widely verified by experiments performed on conventional microstrip and CPW discontinuities [7-11], experiments will be performed to test the effects of the low radiation loss characteristics of the microshield line on the Q of a bandpass filter.

2 THEORY

The theoretical method is based on a space domain integral equation (SDIE) which is solved using the method of moments. The SDIE approach has been previously applied to study several microstrip and coplanar waveguide (CPW) discontinuities and has shown very good accuracy, efficiency and versatility in terms of the geometries it can solve [7-11]. The original boundary problem is split into two simpler ones by introducing an equivalent magnetic current $\bar{M}_s$ on the slot aperture. This surface magnetic current radiates an electromagnetic field in the two regions, above and below the slots, so that the continuity of the tangential electric field on the surface of the slots is satisfied. The remaining boundary condition to be applied is the continuity of the tangential magnetic field on the surface of the slot apertures which leads to the following integral equation

$$\hat{n} \times \int_S\int [\bar{\bar{G}}_0^h(\vec{r}/\vec{r}') + \bar{\bar{G}}_1^h(\vec{r}/\vec{r}')] \cdot \bar{M}_s(\bar{r'})\, ds' = \bar{J}_s, \quad (1)$$

where $\bar{\bar{G}}_{0,1}^h$ are the magnetic field dyadic Green's functions in the two regions and $\bar{J}_s$ denotes the assumed ideal current source feeding the microshield line, (gap generator model). The free space Green's functions are computed as Sommerfeld integrals in space domain [8, 9] while those in the shielding waveguide consist of double summations over the waveguide's eigenvalues. Since the cavity dimensions are very small, higher order microshield modes are not excited in the frequency range of interest.

The integral equation (1) is solved using the method of moments where the unknown magnetic current is expanded in terms of rooftop basis functions. Then, Galerkin's method is applied to reduce the above equation to a linear system of equations

$$\begin{pmatrix} Y_{yy} & Y_{yz} \\ Y_{zy} & Y_{zz} \end{pmatrix} \begin{pmatrix} V_y \\ V_z \end{pmatrix} = \begin{pmatrix} I_z \\ I_y \end{pmatrix} \quad (2)$$

where $Y_{ij}(i = y, z; j = y, z)$ represent blocks of the admittance matrix, V_i is the vector of unknown y and z magnetic current amplitudes, and I_j is the excitation vector which is identically zero everywhere except at the position of the sources. Finally, the equivalent magnetic current distribution and consequently the electric field in the slots are obtained by matrix inversion. Away from the discontinuity, the slot fields form standing waves of the fundamental propagating mode. Using the derived electric field, an ideal transmission line method is applied to determine the scattering parameters of the discontinuity. From the scattering parameters, radiation loss can be evaluated as a function of the frequency and other geometrical parameters.

3 NUMERICAL RESULTS

In the numerical results shown here, the microshield lines and the conventional coplanar waveguides have an inner conductor width of 500 μm and slot widths of 250 μm. The substrate used in the dielectric microshield and in the coplanar waveguide is 635 μm thick and has a dielectric constant $\epsilon_r = 2.1$. The waveguide size (height and width) is specified in the figures' captions. It is expected that reducing the waveguide size up to the point where the sidewalls touch the slot edges will improve field confinement. This waveguide size does not present an optimum design and the results presented here, by no means, provide a complete study of the electrical performance of the microshield line. These specific dimensions were merely used as examples to demonstrate the capability of the proposed microshield line to radiate considerably less than the corresponding coplanar waveguides.

As mentioned earlier, four different microshield discontinuities are treated in this paper: an open end, a short end, two coupled open ends and two coupled short ends. Even if there are other discontinuities which radiate more, the above geometries are the building blocks for creating a variety of circuit elements. Furthermore, their performance can give a very good indication of what should be expected from other more complex planar structures such as stubs, bends and T-junctions.

- **Short-end.** As shown in Fig.2, the membrane microshield lines tend to give lower normalized inductive end-reactance than the conventional coplanar waveguide and the dielectric microshield. This tendency is consistent over the whole frequency range. In addition, it has been found numerically that the wavelength of the dielectric microshield is slightly larger than the wavelength of the conventional CPW (depending on the waveguide size), while that of the membrane microshield is essentially the free space wavelength. This is very important at higher frequencies where circuit dimensions need to be larger in order to ease fabrication tolerance.

- **Open-end.** Fig.3a shows the normalized capacitive reactance of an open-end as a function of the gap width for the three types of the proposed microshield line and is compared to the coplanar waveguide open end. In addition, the radiation loss factor, $10\log(1-|\Gamma|^2)$, for the same discontinuity is shown in Fig.3b. As it can be noticed from the above figures, the membrane microshield lines have an open-end reactance almost 40% higher than the dielectric microshield line and the conventional CPW. At the same time, the dielectric microshield open-end has the lowest radiation loss which is approximately half of that encountered in the conventional CPW open-end . Low radiation results from the good confinement of the fields in the slots which is due to the presence of the dielectric substrate and the shielding cavity.

- **Coupled Short-Ends.** Fig.4 shows the loss factor, $10 \log(1 - |S_{11}|^2 - S_{12}|^2)$, for two coupled shorted ends as a function of frequency. Again, the dielectric microshield has smaller radiation loss factor than the membrane microshield and the conventional CPW. Despite these differences, in all cases, the radiation loss is very small due to the type of the planar discontinuity.
- **Coupled Open-Ends.** Fig.5 shows the magnitude of S_{12} and the loss factor for this discontinuity as a function of frequency. Here the cavity size is chosen such that the sidewalls touch the slot edges and with height equal to one slot width. The membrane microshield of Fig.1b is not included in Fig.5a since it has shown very small coupling (Mag(S_{12}) less than 70 dB) because of the very small shielding cavity. Fig.5b shows that radiation in the coupled microshield open-ends is approximately one third the radiation from coupled open-ends made of conventional CPW. In addition, it can be seen that the dielectric microshield coupled open-ends radiate more than the membrane microshield in contrast to the coupled short-end discontinuity (Fig.4). This is due to the excitation of the surface waves from the open ends along the direction of propagation.

This study will be extended to other structures and results will be presented for series and shunt stubs. The theoretical results will be compared to experimental data for further justification of the low radiation loss properties of the microshield lines.

4 CONCLUSIONS

A new type of monolithic planar transmission line, Microshield line, has been proposed. This line has the following advantages:

- There is no need for via-holes or air-bridges for ground equalization.
- A wide range of impedances can be obtained.
- Wavelength is closer to the free space wavelength (or equal to it in the case of membrane microshield) which results in larger circuit dimensions.
- Radiates much less than the conventional CPW.

Numerical results for four different discontinuities, namely, an open end, a short end, two coupled open ends and two coupled short ends, have been shown and compared with similar discontinuities in conventional CPW. It has been found that the substrate microshield line has the lowest radiation (unless surface waves are excited along the line) which is approximately half of that encountered in the conventional CPW.

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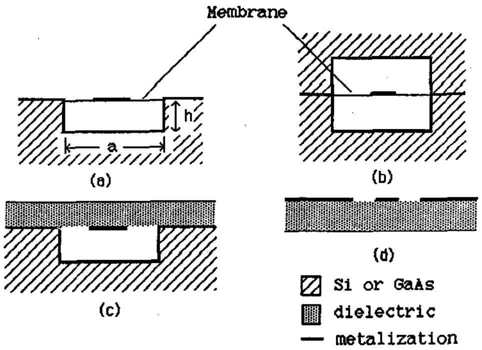

Figure 1: (a),(b) Membrane microshield transmission lines. (c) Dielectric microshield transmission line. (d) Conventional coplanar waveguide.

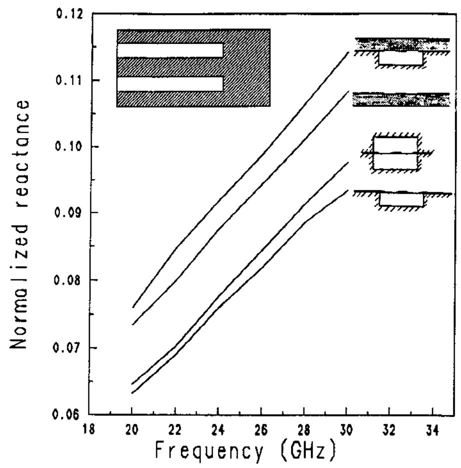

Figure 2: Normalized inductive end-reactance of a shorted line. (h=3 mm, a=1.5 mm)

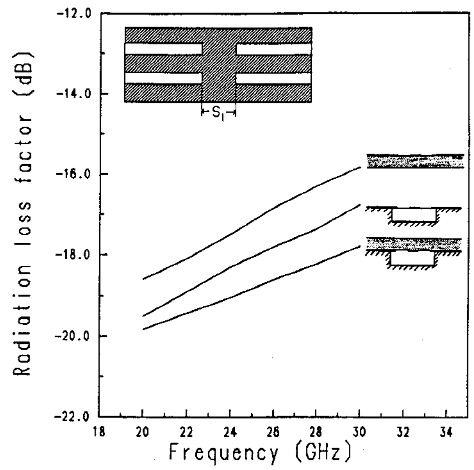

Figure 4: Radiation loss factor for two coupled short-ends. (h=3 mm, a=3 mm, S_1=0.25 mm)

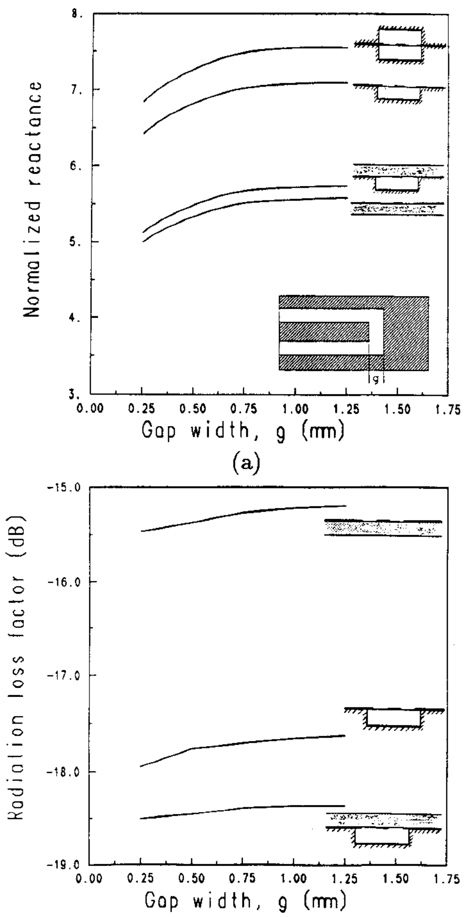

Figure 3: (a) Normalized capacitive end-reactance of an open-end line. (h=3 mm, a=3 mm, f=24 GHz) (b) Radiation loss factor for the same discontinuity.

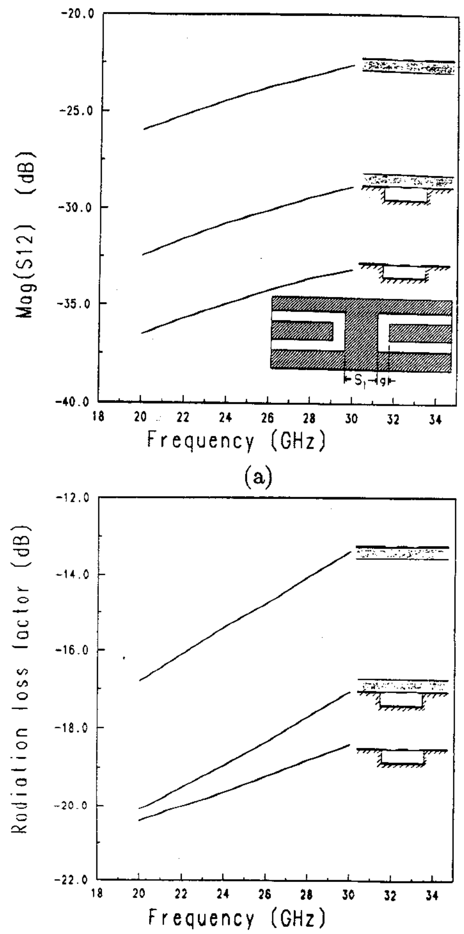

Figure 5: (a) Mag(S_{12}) for two coupled open-ends. (h=0.25 mm, a=1 mm, S_1=0.5 mm, g=0.25 mm) (b) Radiation loss factor for the same discontinuity.